THE INFLUENCE OF SURFACE RESIDUE ON SOIL LOSS AND RUNOFF

BY

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DECLARATION

This thesis is my original work and has not been submitted for a degree in any other University

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Abstract

The study was conducted on sixteen runoff plots installed at the erosion control research station, Department of Agricultural Engineering, at the Kabete Campus of the University of Nairobi, on a 16.4% slope of a humic nitosol, to assess the effect of surface scattered maize residue on soil loss and runoff. Four treatments, a control without residue cover and three different rates (0.5, 1, and 2.25 t/ha) of maize residue were tested under natural rainfall (two seasons) and a 65 mm/hr intensity simulated rainfall. The levels selected were based on an estimated average residue production of 3 t/ha associated with grain yield of approximately 1.5 t/ha by most small holder farmers under tropical conditions. Percent ground cover provided by the different residue rates was determined using the photographic method.

Results showed that treatment effects were highly significant ($P \leq 0.05$) in reducing soil and runoff losses under all conditions of natural and simulated rainfall tests. Under all natural and simulated rainfall studies, consistent reduction in both soil and runoff losses were obtained with increased application of residue as surface cover.

Total soil loss from the control plots during the 1988 short rains, 1989 January rains and 1989 long rains was 407

t/ha, while it was 357, 323, and 299 t/ha from plots with 0.5, 1, and 2.25 t/ha residue treatments respectively. Total runoff from the control plots during the same periods was 240 mm, while it was 214, 201 and 194 mm, from plots with 0.5, 1, and 2.25 t/ha residue treatments respectively.

Total soil loss for the three simulation runs from the control plot was 63 t/ha, while it was 51, 40, and 25 t/ha from plots with 0.5, 1, and 2.25 t/ha residue treatments respectively. Total runoff for the three simulation runs from the control plots was 33 mm, while it was 30, 28, and 20 mm from plots with 0.5, 1, and 2.25 t/ha residue treatments respectively.

In general surface scattered crop residues were found to be more effective in reducing soil and water losses from low intensity rains than from high intensity rains and during the early part of a rainy season when soils are relatively dry (even if high intensity rains occur) than later in the season when soils are already saturated with antecedent rainfall.

Equations relating air dry residue weight to percent surface cover, as well as percent surface cover to soil and runoff losses were derived. Residue cover was exponentially related to both soil and runoff losses, with coefficient of determination (r^2) of 0.997 for soil loss and 0.970 for runoff.

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Subfactor values of the C factor for surface scattered crop residue were derived from the natural rainfall data. These values were estimated to be 0.74, 0.52, and 0.45 for the 0.5, 1, and 2.25 t/ha residue treatments, when values obtained during the three rainfall periods were averaged. To give an indication of the availability of crop residue for erosion control and asses the current utilization of crop residue under the small holder farming condition in Eastern Africa regions, a small field survey was carried out in the Muranga District of Central Kenya. On the average an availability of 2 tonnes of residue per tonne of grain was indicated*. The main type of residue utilization was found to be, feed and bedding material for animals.

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*for example a crop yielding 1.5 tonnes of grain/ha could be expected to have 3 tonnes of residue/ha.

1. INTRODUCTION

Soil erosion is a great menace to the development of agriculture in most developing countries. It has become a common phenomenon to see agricultural fields dissected into a number of segments by rills and gullies formed during the rainy season. Deposition of large amounts of soil behind bushes, dense vegetation or any other physical object capable of reducing the velocity of runoff down a slope has become a usual scene after a storm. Sedimentation of valley bottoms, channels and dams has become more frequent. Most rivers carry large volumes of muddy water during the rainy seasons and little or no water during the dry seasons.

Each year billions of tons of fertile soil is washed away from agricultural fields and deposited in areas where it is not accessible for use. According to Barber(1983) for five sub catchments of the upper Tana river(Kenya) sediment yields from cultivated areas ranged from 507-3036 tons/ km^2/year and 786-4707 tons/km^2/year for two periods of flow data. When these values are converted into equivalent average reduction in soil depth assuming a soil bulk density of one the highest values are 3 and 4.7 mm/year both for Mathioya catchment.

In 1970, Ware-Austin, advisor to the Ethiopian Government on Soil and water conservation, estimated that Ethiopia losses one billion tons of soil every year from erosion (Gowns, 1975). If the above statement holds true this loss is equivalent to a soil depth of one meter covering an area of 100,000 hectares (assuming a soil bulk density of one) every year.

The social and environmental implications of such a huge annual loss may be very serious. Hurni, (1989) also reported the total soil loss of the country to be almost 1.5 billion metric tons per year (an average of 12 t/ha /yr), while the soil loss from crop land was estimated at 42 t/ha/yr.

Currently, much effort is under way to conserve the soil by means of different physical and biological conservation measures. However, most of the physical measures have received limited popularity among farmers because of their high labour requirement and cost of construction and maintenance, their requirement of trained personnel for layout, and their variable effectiveness in controlling soil loss and runoff. Where incentives have been used results have often been disappointing because the work done has not been maintained. They are thus not a complete solution to the problem.

For the farmer in the humid tropics to invest in terraces whose effectiveness is uncertain but, whose cost is rather high may be uneconomic. In addition to the maintenance problem, a considerable area of land may also go out of production (Lal, 1981). These structural measures need to be combined, and where applicable replaced with conservation measures which are less costly, less labour and skill requiring and which can easily be adopted by the small holder farmers who form the majority of the farming population in the developing countries. One such measure may be the increased use of surface residue.

The physical effect of surface residue in reducing soil loss and runoff by absorbing the kinetic energy of falling raindrops, resisting the shear force offered by surface runoff and increasing infiltration is reported

by different experimenters. Soil erosion is a work function involving detachment of soil particles from aggregates and transportation of the detached particles to another place. The energy to perform this work is provided by raindrop impact and the stress exerted by concentrated runoff. The stress increases with slope steepness and runoff velocity. Effective control of erosion therefore lies in reducing the direct impact of raindrops, maintaining maximum soil infiltrability and decreasing the quantity, the velocity and transport capacity of runoff water.
These control measures can be achieved through residue mulches on the soil surface (Lal,1976).
Crop residues are much cheaper and often more accessible to small holder farmers than most of the currently practised conservation measures.

Tillage and planting systems which leave a protective cover of crop residue on the soil surface have been shown to reduce soil losses and are among the least costly erosion control practices (Dickey et al, 1985). More over, their use in the control of erosion requires no special training, except awareness of their beneficial effect which further facilitates the dissemination of the technology quite easily among small scale farmers. In the USA crop residues have been shown to play a major role in erosion control. In countries like Kenya and Ethiopia there has been little study with regard to the effect of residues in reducing soil loss and runoff. Though soil erosion is widely recognized as being a critical problem in the developing countries little work has been done either to measure or model erosion under the conditions prevailing in the tropics (Brown and Wolf, 1984, Blaike, 1984, quoted by Barnard and Kirstoferson, 1985). As a result there is no adequate data base on which to predict the role of residue in soil and water conservation. Thus there is a need for research on the performance of crop residue in reducing soil loss and runoff under the conditions prevailing in the tropics aimed at assessing their potential use with respect to the different climatic conditions, soil types and slopes. Research in the tropics needs to be directed to studying the basic processes of soil erosion and developing techniques for soil conservation that are technically viable and socially acceptable to the small land holders in the tropics (Lal, 1984).

The objectives of this study were therefore :

1. To determine the effect of crop residue on soil loss and runoff on a sloping land.
2. To determine subfactor values of the C factor(cover factor) of the universal soil loss equation (USLE) for surface crop residues, which can be used in the planning and design of soil conservation measures.
3. To determine the current utilization of crop residue under typical small holder farming in central Kenya and the availability of residues for erosion control purposes.

This thesis describes an investigation into the effect of crop residues on runoff and soil loss. It was carried out on runoff plots at Kabete field station under natural and simulated rainfall. A small field survey was carried out to assess the availability of residues to farmers in Muranga district. The next chapter gives a survey of literature on the role of residues in erosion control. It is followed by chapters giving details of the methodology used and the results obtained. A discussion of the results is presented and the thesis ends with conclusions and recommendations for future work.

2. LITERATURE REVIEW

This chapter presents a survey of literature in four sections. A review of earlier studies on the role of crop residue in erosion control under simulated and natural rainfall conditions is presented in section 2.1. Section 2.2 presents a survey of literature on the availability and utilization of crop residues in Eastern Africa regions. The different approaches to determine the Cover and Management Factor (C), of the Universal Soil Loss Equation by previous works are reviewed in section 2.3, while section 2.4 presents a brief review on the design principles and operation mechanisms of rainfall simulators used in erosion, runoff and infiltration studies with emphasis on field rainfall simulators as per their suitability to this study.

2.1.1 Crop residue in erosion control

The effect of surface residue on runoff and soil loss has been studied by different investigators during the recent years mainly in the United states of America, where crop residues are widely used in combination with different tillage practices for the control of erosion.

Each of the trillions of raindrops that annually bombard a hectare of land has the potential to detach soil from the soil mass, splash it to other locations and seal the soil surface if it strikes exposed soil (Meyer, 1981). A portion of the soil surface is protected from rain drop impact by residue cover, thus reducing soil detachment (Mannering and Meyer, 1963). Runoff that is flowing across land surfaces can detach soil particles once its shear stress is greater than the soil critical shear stress (Meyer, 1981). Small runoff velocities caused by residues can decrease the transport capacity of flow and reduced sediment concentration can result from the reduced detachment and the small runoff velocity (Gilley et al, 1986).

During rainfall simulation studies, it has been observed that corn stalk residues act as small dams creating ponds behind them. This ponding allows deposition of sediment within a few feet of where it was eroded (Brenneman and Laflen,1982). Even though the volume of water stored in individual ponds may be small, the cumulative effect caused by a large number of ponds can be substantial. Therefore reduction in runoff and sediment concentration caused by crop residue may serve to decrease soil loss (Gilley et al, 1986).

Residue mulches intercept falling raindrops so near the surface that the drops regain no fall velocity and they also obstruct runoff flow and thereby reduce its velocity and transport capacity (Wischmeier and Smith, 1978).

Runoff plot studies under simulated rainfall of 28 mm/hr intensity and uniform soil conditions on a 5.2% average slope gradient (Gilley et al., 1986 a & b) showed that, there was a consistent reduction in runoff sediment concentration, and soil loss from the application of varying rates of unanchored corn residue (corn residue scattered on the soil surface). It was also reported that, on a 6.73 t/ha residue treatment runoff occurred only during the very wet simulation run, while a residue treatment of 13.45 t/ha prevented runoff for all three simulation events.

Reduced runoff, sediment concentration and soil loss from increased application of unanchored sorghum and soybeans residues at rates ranging from 0.00 to 13.45 t/ha on an average slope of 6.4% under simulated rainfall and uniform soil conditions was also reported by Finker et al (1986). They have also shown that, no runoff occurred on the plots with 13.45 t/ha of sorghum or soybean residue.

Comparing soil losses from tillage and planting systems used in residue from soybeans on 5% and 10% slopes (Jasa et al., 1986 b) reported that, for tillage and planting treatments ranging from a mouldboard plough system to no-till planting, no-till planting left the most residue on the soil surface and had the least soil loss.

Shelton et al., (1986), on a slope of 10% and under simulated rain fall conditions compared soil losses from various tillage and planting systems used in soybean residue, which had been grown in wide (76 cm) and narrow (25 cm) spaced rows the previous season, and reported that, soil erosion averaged across tillage treatments was reduced by more than 50% in residue from soybeans which had been grown in narrow rows compared to residue from the wide rows. One reason for this could be more plant population and hence more residue mass from soybeans grown in narrow rows.

Evaluating soil loss from different tillage systems used on silty clay loam having a 5% slope and a silty loam soil having a 10% slope using rainfall simulation techniques (Dickey et al., 1984) reported that for both 5% and 10% slopes tillage systems leaving 20% or more of the soil surface covered with residues reduced soil loss by at least 50% of that which occurred from cleanly tilled residue free condition. Comparing soil losses from various tillage systems used in soybean and corn residue on 5% and 10% slopes (Dickey et al., 1985) found that the soil loss for equivalent tillage treatments was always greater following soybeans than following corn. One reason given for this was because equivalent tillage treatments had about 40% less surface cover in soybeans residue than in corn residue.

The erosion reducing effectiveness of six rates wheat straw mulch on slopes averaging 15% was tested by Meyer et al., (1970). Mulch rates of 0.56 and 1.12 t/ha reduced the soil loss, from 127 mm of rain applied at an intensity of 63.5 mm/hr, to less than one third of that where no mulch was applied.The treatment with 2.24 t/ha of mulch rate lost less than 20% as much soil as the unmulched treatment, and the 4.48 and 8.96 t/ha mulch rates reduced erosion by more than 95% . A reduction in runoff velocity by the 0.56 t/ha rate to one half of that from no mulch application was also reported.

The effect of several mulch treatments in reducing soil erosion was also studied under laboratory conditions by Jannings and Jarrette(1985), where the application of a ten minute rainfall, at a constant 135 mm/hr intensity, was reported to have resulted in decreased runoff, sediment concentration and erosion rates from the plots receiving the different mulch treatments compared with the plots receiving no mulch treatment.

Studying soil loss and runoff under simulated rainfall conditions on a grazing land at Iiuni in Kenya, (Barber and Thomas, 1979) found that erosion losses were greatly reduced with an increase in grass cover from 0 to 20%.

While, most of the above works were conducted under simulated rainfall conditions, similarly valuable results have also been obtained from studies under natural rainfall conditions.

Lal (1976) compared runoff and soil losses from plots mulched with 0, 2, 4, and 6 t/ha of rice straw, with losses from no tillage plots on slopes ranging from 1% to 15%. In addition to the tillage treatments 120 kg of N as urea and 30 kg of both P and K were applied to all plots. The results of this experiment conducted at IITA (Nigeria) during the 1974, 1st and 2nd seasons were reported as follows ;

Mean runoff losses (for the slopes 1 to 15 %) during the first season were 286, 40, 14 and 8 mm for the plots with 0, 2, 4, and 6 t/ha of straw mulch respectively. The same losses during the second season were, 108, 41, 16 and 5 mm from plots with 0, 2, 4, and 6 t/ha of mulch respectively.

The mean runoff losses from the no tillage plots were 11.2 and 7 mm during the first and second seasons respectively.

Maximum soil losses observed during the first season were, 110, 3.5, 0.5, and 0.3 t/ha from the plots mulched with 0, 2, 4 and 6 t/ha of rice straw respectively. The maximum soil loss from the no tillage plots was 0.6 t/ha. Similar results were reported for the second season. Analysis of nutrient contents of the runoff water and eroded soil showed that total nutrient losses in the runoff water decreased logarithmically with increase in mulch rate although the mean annual nutrient losses were minimal. On the other hand the nutrient losses in the eroded sediment were quite high. For example losses of organic carbon during the first season only, varied from 200 kg/ha (1% slope) to 1000 kg/ha (15% slope) from the unmulched plots, from 16 kg/ha (1% slope) to 100 kg/ha (15%

slope) from plots mulched at the rate of 2 t/ha and from 10 kg/ha to 15 kg/ha from plots with 4 t/ha straw mulch; whereas no nutrient loss was reported from the plots with 6 t/ha of mulch rate and the no tillage treatments. During the same season, N losses ranged from 27 kg/ha (1% slope) to 126 kg/ha (15% slope) from the unmulched plots and from 2 kg/ha (1% slope) to 12 kg/ha (15% slope) from the plots mulched at the rate of 2 t/ha of rice straw. Exponential relationships between runoff and mulch rate and soil loss and mulch rate were also reported.

Soil erosion reducing potential of different cultural practices was assessed in northern Ghana (Bonsu, 1981), where it was reported that, application of millet straw mulch at the rate of 4 t/ha on land with 2% slope reduced soil loss to 5.47% of that from the control plot in 1977 and to 4.9% of that from the control plot in 1978. It was also reported that the highest yield next to the ridging treatment was obtained from the plot with mulch treatment.

Pathak et al (1985), also reported that the use of organic matter as surface mulch and incorporation into the soil in subsequent years has been useful for achieving favourable rainfall infiltration, reducing soil erosion and promoting structural stability.
According to their report, at ICRISAT (Hydrabad, India) this system is found to be very effective in reducing runoff and soil loss and increasing crop yields. Since 1981-82 was the first year of experiments, the effects seen in that year were of surface mulching alone. However, in 1983-84 the effects shown were due to combination of surface mulching and improvement in soil structure. During 1981-82, the mulch rate of 10 t/ha reduced the seasonal run-off by 74% and the soil loss by 80%

compared with no mulch. In the same year this rate increased the sorghum yield by 90% and the pigeon pea by 35% above the no mulch treatments.

A study conducted at Katumani National Dryland Farming Research Station in a semi-arid region of Kenya, (Kilewe, 1987) evaluated the effect of various cover crops and management techniques on erosion and crop yield. The study was conducted using runoff plots established on slopes ranging from 7.4% to 10.4%. Evaluation of treatments (maize with minimum tillage, maize with 3 t/ha of maize residue and bare fallow) during the 1983 long and short rains showed that the maize with 3 t/ha maize residue treatment was the most effective in controlling erosion and reduced the soil loss to 6% and 36% during the 1983 long and short rains respectively, compared with the soil lost from the control plots.
The high soil loss reduction by this treatment was attributed to the effect of maize residue that provided over 50% ground cover right from the beginning of the season when the frequency of erosive storms was high.

The same treatment also produced higher maize residue and grain yields than the maize with minimum tillage treatment during both seasons. During the 1983 long rains the maize with minimum tillage treatment gave 0.26 and 0.55 t/ha of maize grain and residue yields respectively, while the maize with 3 t/ha of maize residue treatment gave 0.35 and 0.64 t/ha of maize grain and residue yields respectively.
Although, there was small difference in both grain and residue yields between the two treatments during this season, the maize with three t/ha residue treatment gave grain and residue yields which were three times of those obtained from the maize with minimum tillage treatment during

the 1983 short rains. While the very low grain and residue yields during the long rains were attributed to the occurrence of draught in that season, the high grain and residue yields obtained from the maize with three t/ha of residue treatment during the 1983 short rains were attributed to the effect of mulch in decreasing runoff and surface evaporation whose net effect was an increase in the plant available water.

Standard size runoff plots studies under natural rainfall conditions at Dehradun (Khybri, 1989) in the Himalayan region of India indicated that mulch applied at rates of 2 and 4 t/ha were effective in reducing soil and water losses from maize fields on 8% slope. In the experiment the effect of the mulch treatments was studied on plots planted to maize and the mulch was kept for two durations; from sowing to the middle of August and from sowing till the harvest of crops. Results of this study, conducted for three years (1982-1984) showed that, for an average rainfall of 943 mm recorded during the study period, runoff as percent of rainfall for the mulch treatment applied at the rate of 2 t/ha, was 17.9% upto mid August and 17.3% during crop period, while the soil loss was 6.9 t/ha during both periods.

Similarly, from the 4 t/ha mulch treatment average runoff as percent of rainfall was 14.2% upto mid august and 14.5% during crop period and the average soil loss was 5.3 t/ha upto mid august and 5 t/ha during crop period. On the otherhand, the runoff loss from the control plot was reported to be 60.7% and the soil loss 67.9 t/ha. The measurement of similar values of runoff and soil losses for the two durations of mulch application was attributed to the development of enough cover by the crop by mid August which was as effective as the mulch material. It was also reported that mulching had no adverse effect on crop yield.

A study which compared the effect of four management practices on erosion was also made at Kericho (Kenya) (Otieno, 1978). The study was conducted on a field of young tea using runoff plots on land having 10% slope. The soil management treatments evaluated were tillage, no tillage, oats planted between rows of tea and soil surface covered with straw mulch. Results of soil loss measurement during the three years period revealed that, the heavy rate of grass mulch applied at annual rate of 15 t/ha (split into two equal applications) was the most effective treatment in controlling erosion, having a total soil loss of only 0.68 t/ha. The soil losses for the tillage, non tillage and oats planted between the rows of tea treatments were 211 t/ha, 255 t/ha and 40 t/ha respectively.

From this review of earlier work it is clear that residues can play a very significant role in reducing soil loss and runoff. But, the critical question for the Eastern Africa regions is to what extent residue may be available at the kind of rates which have proved effective. Are residues at rates of 6, 10 or 13 t/ha accessible to the small scale farmer in Eastern Africa regions ? A further question is whether residues are as effective on steep slopes as they appear to be on the relatively low slopes used in most experiments.

2.2 Availability and current utilization of crop residue

With most agricultural crops, the quantity of residue produced in a year easily exceeds the production of the crop itself. Most cereals grown under tropical conditions give between one and three tonnes of straw per tonne of grain (Barnard & Kristoferson, 1985).

In East Africa the millions of tonnes of crop residue produced every year are used as fuel, fodder, building materials or are burned in situ. For example, in Kenya it is estimated that crop residue provide 3% of the national energy use (Okeefe et al., 1984). In Tanzania, they also provide an estimated 3% of the total energy needs (Openshaw, 1984). In Ethiopia approximately 5.1 million tonnes of crop residue are used as fuel each year (Barnard and Kirstoferson, 1985).

There is very little information on current utilization and availability of crop residues. This makes it difficult to estimate the amounts which might be available for erosion control purposes under smallholder farming. If the amounts commonly available are known it might be possible to predict erosion losses and/or plan erosion control measures using the Universal Soil Loss Equation.

2.3 The cover and management factor, C

The Universal Soil Loss Equation (USLE) is an erosion model designed to predict the long time average soil losses in runoff from specified areas in specified cropping and management systems (Wischmeier and Smith, 1978).

The equation is presented in the form ;

$$A = R * K * L * S * C * P \quad \text{..................(2.1)}$$

Where, A is the computed soil loss, R is a rainfall erosivity factor, K is a soil erodibility factor, while L, S, C, and P are soil loss ratio factors representing the effects of slope length, slope steepness, cover and management systems and support practices respectively. Units of measurement in the SI system are t/ha, MJ.mm/ha.hr and t.ha.hr/ha.MJ.mm for A, R and K respectively.

Factor, C, in the Universal Soil Loss Equation (USLE) accounts for the combined effect of previous land use, tillage induced roughness, residue management, canopy cover, and their interaction.
It has been defined by Wischmeier and Smith, (1978), as the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean tilled continuous fallow plot for the same soil, slope and rainfall.

Wischmeier, (1975) introduced a sub factor approach to estimate, C, values for undisturbed areas. As the numerical value of C is influenced by the combined effect of various types and qualities of cover and management, this combined effect was separated into three distinct types of effects and each type was evaluated as a sub factor. For example, sub factor type 1, measures the effect of canopy cover, sub factor type 2, estimates the effect of mulch or close growing vegetation in direct contact with the soil surface, and type 3, estimates effects of tillage and residual effects of land use. Numerical values for each sub factor were obtained from figures relating each sub factor to the corresponding cover or management and the multiplication together of the so obtained subfactor values gives the value of the C factor.

Wischmeier and Smith, (1978), gave a detailed explanation of the factors which determine values of C and demonstrated a procedure for deriving appropriate values for use in the universal soil loss equation. The value of C on a particular field was considered to be determined by many variables. Major variables that can be influenced by management decisions include crop canopy, residue mulch, incorporated residue, tillage and land use residuals. Each of these effects may be treated as a sub factor, whose numerical value is the ratio of soil loss with the effect to the corresponding loss with out it. The value of C then is the product of all the pertinent sub factors.

Deriving the appropriate C values requires knowledge of how the erosive rainfall in a given locality is likely to be distributed through the twelve months of the year, and how much erosion control protection the growing plants crop residues and selected management practices will provide at the time when erosive rains are most likely to occur. To enable practical evaluation they therefore, divided the year into six crop stage periods, defined so that cover and management effects may be considered approximately uniform within each period. These crop stage periods were, period F (rough fallow), period SB (seed bed), period 1 (establishment), period 2 (development), period 3 (maturing crop) and period 4 (residue or stubble). Soil loss ratios for the individual crop stage periods were then, combined with the erosion index distribution data for the period to obtain the crop stage period C values. Sum of C values for different crop stage periods gave C value for the crop year.

In India, (Singh, et al., 1981, Verma, 1984), similar procedure was used to determine C values for different areas, where crop stage C value was estimated by the product of percent annual erosivity index , R, and percent soil loss ratio for that period divided by 10^4.

Percent R, was taken from an R distribution curve and percent soil loss from runoff plots. However, unlike the US conditions crop stage periods were divided into four (Verma,1984) for Indian conditions where the growing season is much shorter.

In the absence of crop stage period data, average value of C of a crop has been determined based on the total seasonal soil loss data, (Verma, et al., 1981). The same procedure was also suggested by Hudson, (1981) as appropriate in countries where there is lack of crop stage period soil loss ratio and EI distribution data.

A number of studies conducted on natural and simulated rainfall plots have also determined C values as the ratio of soil loss under a given cover and management conditions to the corresponding loss without it.

Lal, (1976), using data obtained from natural rainfall plots reported mulch factors for soil and runoff losses (the ratio of each type of loss with mulch to the corresponding loss with no mulch) which were decreasing logarithmically with increasing mulch rates. Similarly derived mulch factors for soil loss and runoff using data obtained from simulated rainfall plots were also reported by Gilley et al., (1986).

Kilewe (1987) also, calculated C values for different cropping and management systems from natural rainfall plots as the ratio of soil loss from each cropping and management system to the corresponding loss from plots without them. Bonsu, (1981) also reported similarly derived values for the C factor.

Mutchler et al., (1982) proposed a system of sub factors which are multipliers that represent the effect of land use residual, incorporated residue, tillage intensity and recency, macro roughness and canopy and ground cover for computing the C factor for cotton.

The value for the effect of land use residual (c_1) for the cotton plant which has a tap root system was estimated to be between 0.85 and 0.90. The effect of incorporated residue (c_2) was estimated from,

$$c_2 = 1 - @t, \ @t<1, \ ....(2.2)$$

where, t is incorporated residue in t/ha and @ depends on the distribution of residue in the tilled layer. The effect of tillage intensity and recency (c_3), was estimated using the relation,

$$c_3 = 1 + \# \ (0.1x + 0.05y + 0.02z) \ .....(2.3)$$

where, x is the number of excess tillage near the beginning of the current crop stage, y is the number of excess tillage near the beginning of the previous crop stage, z is the number of excess tillage near the beginning of the crop stage preceding the previous one, and # represents the intensity of tillage produced by tillage tools. A standard tillage sequence was specified to enable determination of the number of excess tillage which may either be negative (less than the standard) or positive (more than the standard). Macro roughness (c_4) which accounts for the effect of ridging or bedding tillage was estimated from the linear relation,

$$c_4 = 0.9 + 8h \ ....(2.4).$$

where, h is bed height,

where as values for canopy and cover effects (c_5) were obtained from figures 6 and 7 of Agricultural hand book 537. These sub factor values (c_1 through c_5) were multiplied together to determine a soil loss ratio for each individual crop stage period. C factor values were then computed by weighing the individual values by the distribution of EI among the crop stage periods. Further detail is given in Mutchler et al., (1982).

An equation that directly computes the C factor of the universal soil loss equation has also been developed by Laflen et al., (1983). Sub factor values (prior land use sub factor, crop canopy sub factor, residue cover sub factor, and surface roughness sub factor) were quantified using a series of equations including those established by previous work. Multiplying the sub factor values then gives the value for factor C that can be used to estimate individual storm soil losses.

In general, although basically related, different approaches have been used by previous studies to estimate values for the cover and management factor of the Universal soil loss equation. These approaches can be classified into three categories;

1. The subfactor approach by Wischmeier and Smith, (1978), which makes use of detailed charts and tables;

2. The subfactor approach by Mutchler et al., (1982) and Laflen et al., (1983) which makes use of a series of equations relating subfactors to variables important in the erosion process;

3. The estimation of subfactor and /or C factor values as a ratio of average annual values by various research workers.

Obviously, the first two approaches allow the estimation of C values with greater mathematical precision. Each subfactor can be evaluated and quantified for its effect on the value of C either using tables and figures or experimentally established mathematical relations. These mathematical relations allow greater precision in the prediction of erosion losses and provide better flexibility in the planning of erosion control measures. Unlike in the first case the second approach also avoids the need for development of a large tabulation of ratios and incorporates more new information on roughness and residue impacts on soil erosion.

But, the critical issue here is, whether these complicated procedures are appropriate for the smallholder farming situation in Eastern Africa regions.

In the USA the wealth of data on the effect of various cover and management practices allowed the development of these subsequent approaches. Data from extensive rainfall simulator experiments substantially aided natural rainfall experiments. Evaluation of various cover and tillage treatments under different conditions was possible within a short period of time with the aid of rainfall simulators.

On the other hand under the smallholder farming conditions in Eastern Africa regions, very little is known about the effect of various cover and management systems that determine values of the C factor. Data on crop-stage soil loss ratios for the different crops grown in the region and on the periodic distribution of erosivity index values are almost none existent. Effects of the different tillage systems, cover materials and landuse practices on erosion losses as used in the different agroclimatic zones are little studied.

Given the high soil loss rates and the urgent need for conservation in these regions, estimation of values for various cover and management practices using average values as in the third approach, is then the appropriate procedure currently available.

2.4 Rainfall simulators

Rainfall simulation, the technique of applying water to plots in a manner similar to natural rainfall, is a tool that has been used for many years in studies of erosion, infiltration, and runoff. All rainfall simulators for field uses have certain common features. They are portable; have a supply source so that water is available when and where needed; have defined field plots that are treated or maintained according to the study objectives; have sprinkling mechanisms with which varying degrees of control can be exercised over water application rates and amounts; and there are devices and procedures for measuring the output from the plots (Neff, 1979).

For rainfall simulation studies to produce reliable indications of natural rainfall effects, Meyer, (1965) outlined some of the more important characteristics of a rainfall simulating equipment as follows;

1. Drop size distribution and fall velocities near those of natural rainfall at comparable intensities,
2. Intensities in the range of storms producing medium to high rates of runoff and erosion,
3. application area of sufficient size for satisfactory representation of treatments and erosion conditions,
4. uniformity of intensity and drop characteristics through out the study area,
5. Rainfall application nearly continuous through out the study area,
6. Angle of impact not greatly different from vertical for most drops,
7. Accurate reproduction of storms,
8. Satisfactory operation in winds of appreciable velocity (field research equipment only),
9. Complete portability (field research equipment only), further

detail is given in Meyer (1965).

Meyer and McCunne, (1958) developed a portable rainfall simulator that produced artificial storms of approximately the kinetic energy of high intensity natural rainfall using the flat pattern 80100 veejet nozzles. Operating the nozzles in the direction perpendicular to the long dimension of the spray pattern provided great area coverage. Intensity distribution (uniformity) was improved by overlapping adjacent nozzle (spray) patterns and intensity was regulated by having the nozzles spraying intermittently. For a design pressure of 0.42 bar (6 psi) at the nozzle suspended 2.44 m above the soil surface and spraying down ward perpendicularly drop size distribution and fall velocities similar to those produced by natural rainfall were reported. At an intensity of 62.5 mm/hr this rainfall simulator produced greater than 75% of the kinetic energy of natural rainfall of the same intensity.

Representative rainfall simulators used in soil erosion research were reviewed by Mutchler and Hermsmeier, (1965) with emphasis on the description of the design principles. Rainfall simulators were classified as Hanging yarn, Tubing tip and nozzle type based on the drop forming method which forms the heart of rainfall simulators.

Hanging yarn and tubing tip type rainfall simulators were shown to have the same (similar) limitations. Impact velocity of the drops is determined by the height of the drop formers above the surface. For attaining at least 95% terminal velocity this height varies from 5 meters for a drop of 2 mm in diameter to about 7.8 meters for a drop of 4 mm in diameter. Because of the inherent requirement of a large number of drop formers per unit area, these simulators have been built to cover only small plots and have delivered a single uniform drop size. The primary use of these simulators in erosion control research is in small scale laboratory investigations.

To produce a drop distribution that includes a large range of drop sizes (as occurs in natural rainfall) they argued the use of nozzles to be the only method available. Although a nozzle with a uniform spray pattern and desirable drop size distribution is not available, they concluded that the 80100 Veejet commercial nozzle which was tested and used by Meyer and McCune (1958) in the rainfall simulator called the Rainulator as the most suitable.

Modern rainulators are highly sophisticated computerised machines which are very expensive and not really appropriate for field use in developing countries such as Kenya. There has been a lot of work on them since 1958.

A simple portable and inexpensive rainfall simulator was also constructed by Dunne et al., (1980). This rainfall simulator consisted of a wooden frame 3 m high, 2m wide and 5.3 m in length supporting a metal track in which a wheeled trolley with a vertically mounted single spray nozzle is rapidly pulled by hand back and forth along the plot. The nozzles used were the type SQ series Delvan nozzles which produce a square spray pattern at moderate pressure and a circular spray pattern at low pressure. Drops with a median diameter of about 80% and kinetic energy 60 - 70% of the same intensity natural rainfall were reported. Christiansen's coefficient of rainfall uniformity was reported to be above 80% in two thirds of 70 field experiments conducted and exceeded 75% percent in the rest except in two experiments when strong winds complicated the distribution. A potential limitation of this equipment is the uniformity of the simulated rain storm as the technique of pulling the nozzle back and forth over a plot creates intermittent rainfall on any section of the plot.

A further attempt to modify the Dunne et al.,(op.cit) type rainfall simulator with the aim of more closely reproducing the kinetic energy of tropical rain storms and improving the uniformity of water application was that of Abury and Wahome (1983) . This modified rainfall simulator consisted of a wooden frame 4.9 m high supporting two parallel metal rails along which wheeled trolleys with vertically mounted two spray nozzles are rapidly moved back and forth over the plots irrigating an area 6 m long and 2.5 m wide. The nozzles used were the 80100 and 80150 Veejet nozzles of the spraying systems company, the same used by Meyer and McCune (op.cit.). The kinetic energy of rain storms obtained was reported to exceed 90% of those in natural tropical rain storms for the intensities employed while the median drop size falls in the lower range of those in natural rainstorms.

Because of the drop distribution that includes a large range of drop sizes as occurs in natural rainfall, production of kinetic energy closer to that produced by the same intensity natural rainfall at a nozzle pressure of 0.42 bar suspended at a height of 2.44 m from the soil surface and the reasonable uniformity of area coverage at 1.5 m nozzle spacing, the 80100 veejet nozzle was selected for this study .

To simulate the erosion process under field conditions during natural rainfall (to measure the erosion occurring by surface flow as well as rain drop splash) the simulator was constructed to cover a 5 m distance in length. longer distance coverage was desirable , but this will make the frame work more cumbersome and will also increase the material cost.

Although, this review of literature of earlier studies has shown crop residues to be very effective in reducing erosion losses under most conditions of natural and simulated rainfall experiments made sofar, it is still important to evaluate their effect under the various soil, slope and climatic conditions. It is also vital to test if residue alone can provide sufficient erosion control throughout a season.

3. MATERIALS AND METHODS

3.1 Site

The study was carried out at the erosion control research station, Department of Agricultural Engineering, at the Kabete campus of the University of Nairobi. Kabete lies $1^0$15'S and $36^0$44'E at an altitude of 1940 m above sea level, approximately 12 kilometres from the Nairobi city centre.

3.1.1 Climate

The area has a bimodal distribution of rainfall, with the long rains occurring from early March to late May and the short rains from late October to late December. The mean annual rainfall (based on 19 years data) is approximately 1030 mm, with 50.7% and 27.5% of the rain occurring during the long and short rainy seasons respectively, and the dry months contributing 21.8% . It has an estimated mean annual temperature of 17.6^{0}C, a potential evaporation of 1727 mm and an estimated evapotranspiration of 1152 mm, (Gachene,1989). The climate of the area is classified as semi-humid, (Sombroek et al.,1982), based on the Kenya soil survey agro climatic zonation methodology (average annual rainfall/average annual potential evaporation, $r/E_0 = 0.6$).

3.1.2 Soils

The soils* at the site are derived from the Nairobi trachytic lava and are classified as humic nitosols, (Gachene,1989). They are very deep, well drained, dark red, friable clay soils showing an ABC sequence of horizon differentiation with clear and smooth boundaries. The top soil which is relatively high in organic matter content* overlies an argillic B horizon which is characterised by shiny clay cutans.

These soils are common on the foot ridges of mount Kenya and the Nyandarua mountains of central Kenya and in the western part of the rift valley in parts of Kericho, Kisii, Nandi and the foot slopes of Mount Elgon. They are also common in parts of Ethiopia such as Gojam.

3.2 plots

Sixteen Djorovic (1977) type simple runoff plots were laid in a randomized complete block design on a natural slope averaging 16.4 % (figure 3.1).

Each plot was 2 meters wide and 10 meters long bounded by galvanized plain iron sheet, 0.25 m wide with 0.15 m driven into the ground. Buffer zones of one and three meters width were provided between plots and blocks respectively. Main components of each runoff plot were, an End plate, a Collecting trough, a Conveyance pipe and a Storage tank, (fig 3.2).

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*OM content of top soil = 3.432%

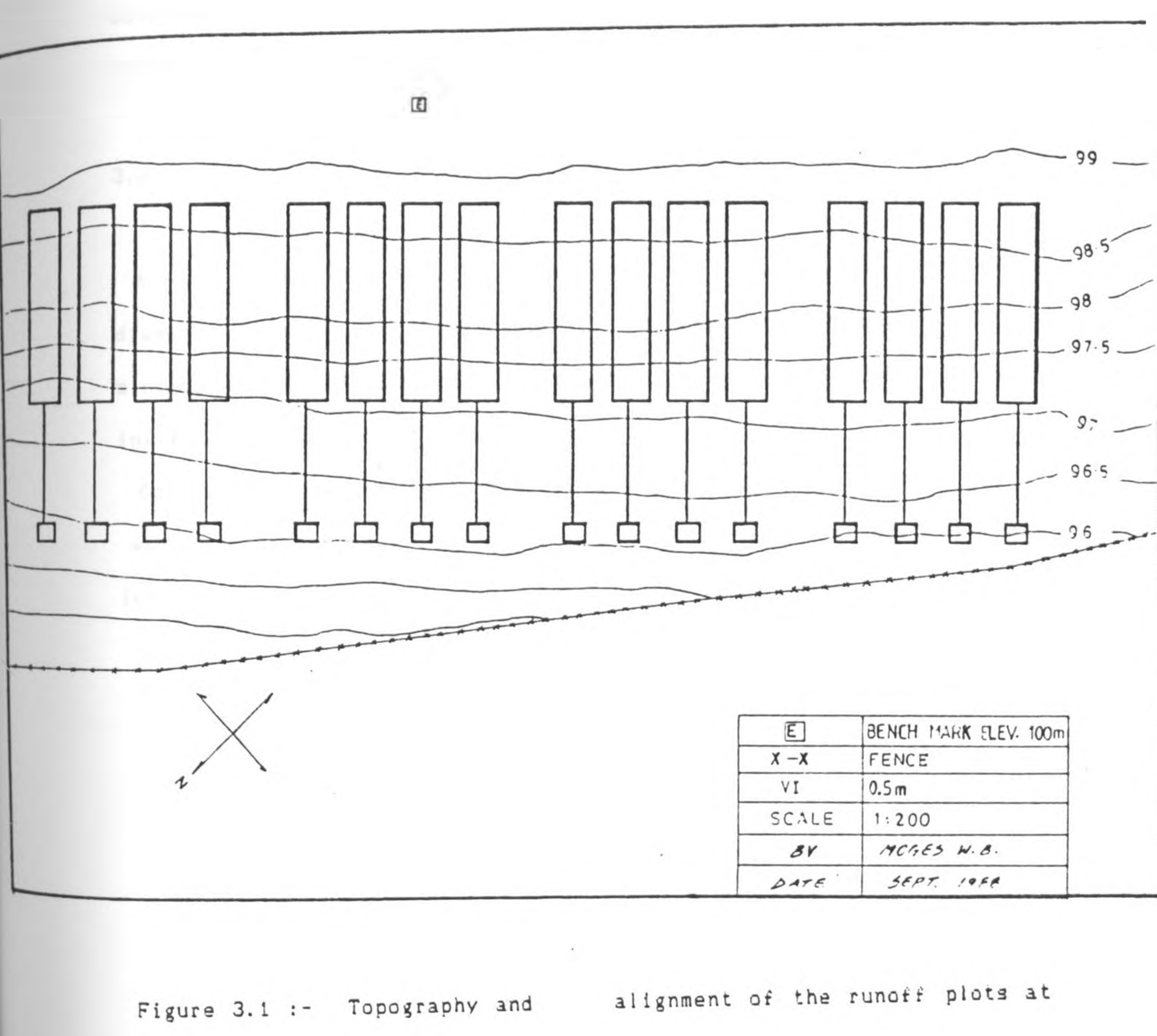


Figure 3.1 :- Topography and alignment of the runoff plots at Kabete

3.2.1 End plate and collecting trough

An End plate made of a 1 mm thick black steel was used to provide a firm seal and smooth connection between the ground surface and the Collecting trough. Runoff from the plots was then concentrated in a Collecting trough made of 24 gauge galvanized iron sheet and passed through a Conveyance pipe which channels it to a Storage tank.

3.2.2 Conveyance

A 7.5 cm diameter PVC pipe compared with the calculated minimum diameter of 6.25 cm and a slope of 16.3 % compared with the calculated minimum slope of 8.12 % were used to convey the runoff to a storage tank installed at the bottom of each plot.

Conveyance size and slope were calculated according to Mutchler (1963) who recommended that 100% of the hundred year five minute, rainfall intensity should be used when estimating the runoff rate.

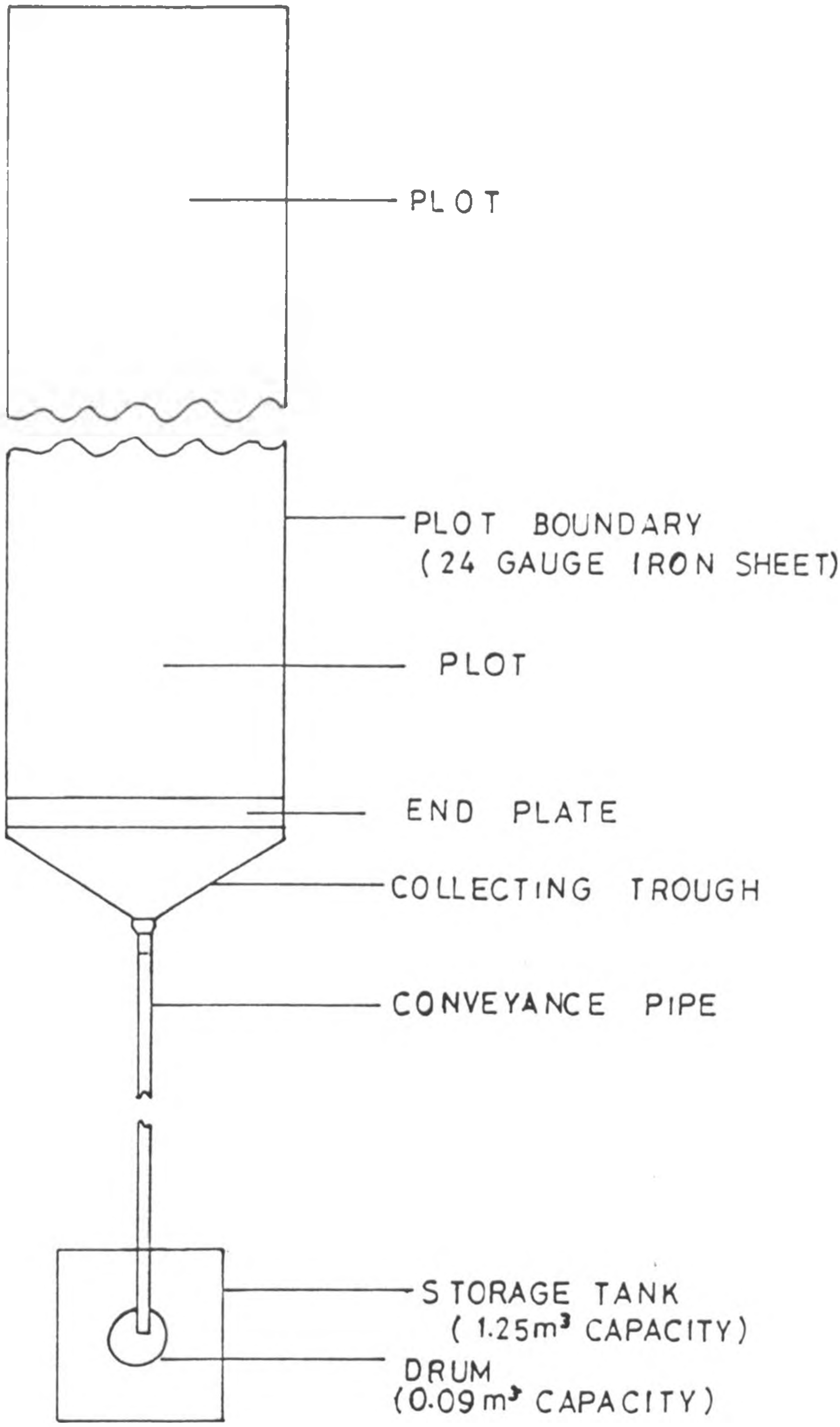


Figure 3.2 :- Plan view of the runoff plot equipment installed at Kabete

However, because of lack of such a record, design was based on 100% of the hundred year ten minute rainfall intensity of 220 mm/hr, (MoWD,1978). The exaggerated size and slope of conveyance is assumed to bridge the gap between Mutchler's recommendation and the value used in the design.

3.2.3 Storage tank

All the runoff and soil loss occurring from a plot in twenty four hours time was collected and stored, using a 1.25 m^3 capacity tank, till measurement and sampling was done. Storage capacity was determined using a runoff coefficient of 0.5, a soil loss estimate of 267.3 gm/m^2, a soil bulk density of 0.57 gm/cm^3 (for the top 20cm), (Barber and Thomas, 1979) and an eighteen year 24 hr. duration storm of 128.3 mm, (Kabete Meteorological Station, 1988).

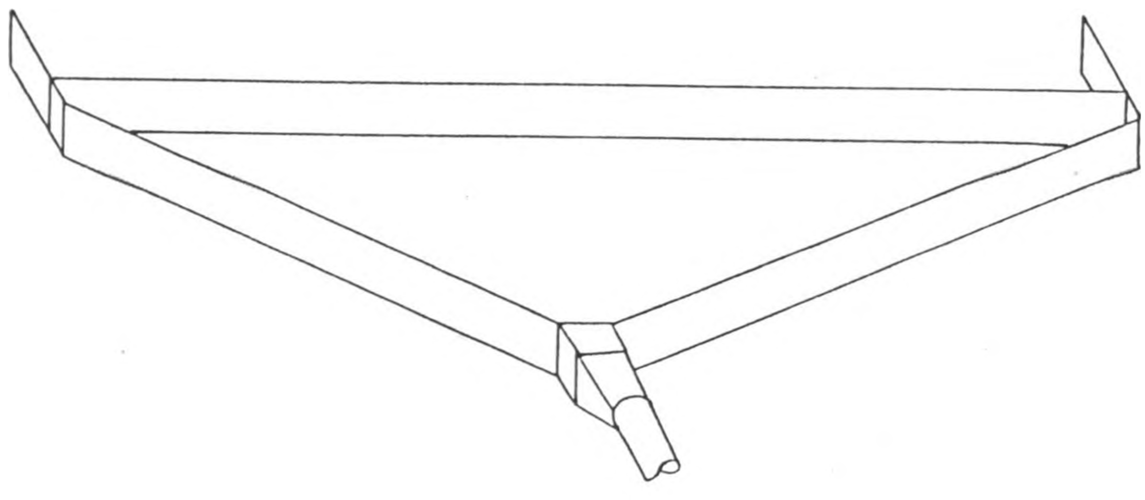
Different design storms were used to estimate the capacity of the conveyance channel and the storage tank. This was necessary, as short duration intensities are highest and the conveyance should have a capacity to channel all the runoff produced including those occurring at such short periods but with high intensities which are likely to occur during most storms even when the total amount of runoff produced by the storm may be small in volume. On the other hand storage capacity is influenced by the total amount of runoff (rather than the rate) that is likely to be produced by a storm of a given recurrence period considered in the design.

A small drum of 0.09 m^3 capacity placed inside the storage tank directly under the outlet of the conveyance pipe facilitated measurement and sampling after small storms and contained most of the sludge during medium runoff events, even though an overflow to the main tank occurred.

3.2.4 Drainage

Two ditches, each laid on a 0.5% channel slope were provided above and below the runoff plots.The upper ditch served to intercept the runoff produced on the area above the plots and prevent it from entering the runoff plots site, while the lower ditch was used to safely dispose off the runoff produced in the runoff plots site and the runoff disposed after measurement and sampling.

a. The End-plate



b. The Collector Trough

Figure 3.3 :- A sketch of the runoff concentrating unit

3.2.5 Raingauges

Rainfall amount and intensity were measured using the tilting siphon recording rain gauge and a 5" standard non recording check gauge. However, for the calculation of erosivity indices rainfall intensity values were taken from the Kabete Meteorological station, which is about 1 km from the runoff plots site, as the recording gauge installed at the site did not function correctly at all times. Paired t-test for the daily rainfall records of the two sites (Fissiha, (1983) showed no significant difference at 0.5% level.

3.3 Treatments

Four levels of maize stover, scattered on the soil surface, were used as treatments. The levels selected were based on an estimate of Barnard and Kirstoferson, (1985) for the average residue production of 3 t/ha associated with grain production of approximately 1.5 t/ha by most small holder farmers under tropical conditions. An assumption was made about the minimum and maximum conditions of availability at the start of the next crop season. For example leaving as little as 15% of the residue produced by a small holder farmer as surface cover was considered minimum and taken as the low rate, while leaving 30% and 75% of the residue produced as surface cover were considered as the medium and high rates of availability respectively. Based on the above assumptions residue rates of 0, 0.5, 1 and 2.25 t/ha were then randomly assigned to the plots. The residue was placed in a random orientation, taking into account the fact that a residue will fall in any given direction during harvest and even while ploughing unless purposely given a certain orientation. This also represents the situation which requires no other input from a farmer, except sacrificing partially the other uses he has for residue in form of erosion control.

Plate 3.1 :- The runoff plot site at Kabete. note: the ladder which was used to take photographs from a nearly vertical angle for percent surface cover determination

Percent surface cover provided by residue was then determined using the photographic method (Laflen et al., 1981). During each season, before the onset of the rains, the plots were prepared according to the conventional tillage practice in the area (hand digging with a jembe) prior to the placement of the surface cover.

3.4 Sampling

During all runoff events the following procedure was used.

1. Before measurement and sampling was done, the end plate and the collecting trough were inspected for deposited soil. If deposition had occurred the soil was scooped and put in the respective tank to which it should belong. The end plate and the collecting trough were then cleaned and flushed using water taken from the respective storage tanks.
2. All measurements made in the field were recorded in a field data sheet prepared for a storm event that produces runoff and all samples were taken with labelled bottles.
3. After taking measurements and sampling was done the storage tank and the drum were cleaned and made ready for the next runoff event.

3.4.1 Small runoff events

These were runoff events when all the runoff was contained in the small drums and had not exceeded approximately 0.03 m^3. The runoff was stirred until all the sediment came into suspension while in the drum. It was then taken out and the volume measured using a graduated bucket. It was again stirred thoroughly while in the bucket and a one litre sample was taken with a graduated plastic cylinder. If two such samples were taken, they were usually combined and a one litre sample taken after stirring the mixture.

3.4.2 Medium runoff events

These were runoff events when the runoff has occupied a volume larger than 0.03 m^3 and smaller than approximately three quarters of the storage tank volume.

The runoff water overlying the sludge was taken out and measured with a graduated bucket of 0.02 m^3 capacity. A sample of approximately one litre was taken from each bucket, after stirring the contents of each bucket to get all the sediment in suspension, and put aside. Five to ten such samples were then combined and exactly one litre sample was taken after stirring the mixture. The remaining deposited sediment both in the drum and storage tank (most of it usually in the drum) was scooped in a bucket and weighed using a spring balance suspended on a tripod to the nearest 0.05 kg. The sludge was then stirred thoroughly while in the bucket till it formed a uniform consistency and one sample was taken from each bucket. Five such samples were then combined and one sample taken after stirring the mixture to a uniform consistency.

Plate 3.2 :- Runoff awaiting sampling (a medium runoff event)

3.4.3 Heavy runoff events

These were runoff events that filled more than three quarters of the storage tank volume. Only two such storms were observed during the entire period of the experiment. The runoff water overlying the sludge was measured and sampled using the procedure described in 3.4.2. The sludge in the drum was emptied into the storage tank after the water had been removed. It was stirred thoroughly while in the storage tank, till it became sufficiently fluid for self levelling, and left for some time to settle. Depth measurements of the settled sludge were then made at the four corners and the centre of the sludge tank. The sludge was stirred again thoroughly till it formed a uniform consistency and three one litre samples were taken from each tank. Volume of the sludge was later calculated using the average of the measured depths and the known dimensions of the storage tank.

3.4.4 Laboratory analysis

All samples collected after a runoff event were taken to the laboratory and the soil and the water masses separated using the evaporation method, (Dendy et al.,1979).

Samples were transferred into labelled bowls of known weight and weighed on an electric balance to the nearest 0.01 gm. Approximately 0.6 ml of a 0.2 molar solution of aluminium potassium sulphate ($AlK(SO4)_2 \cdot 12H_2O$) flocculant was added to each sample and the samples were allowed to flocculate for more than twelve hours. Clear water was then decanted and the remaining soil - water mixture oven dried to constant weight at 105^0C for 24 hours.

The proportions of sediment and water in a sample were then determined using the relations shown below.

1. For a sample representing soil - water mixture in suspension ;

$$Ms = (Msb - Mb)/10^3 \text{ --------------------(3.1)}$$

Where, Ms is mass of oven dry soil, kg, Msb is mass of oven dry soil and bowl, gm, and Mb is the mass of bowl, gm.

$$Vw = (Mws - Ms)(1/p) \text{ ----------------------(3.2)}$$

Where, Vw is volume of water, lit, Mws is mass of wet sample, kg, Ms is as before and p is density of water in Kg/lit.

2. For a sample representing soil - water mixture in the sludge ;

Sc = (Msb - Mb)/Mws ----------------------(3.3)

Where, Sc , is the sediment concentration in a sample , and Msb, Mb, and Mws are as before but all having the same unit of measurement. Equation 3.2 was used to determine the proportion of water in a sample in this case also.

3.5. Construction of a rainfall simulator

The little data obtained during the 1988 short rains and the uncertainty in the timely occurrence of the long rains made the use of an artificial rainfall in the experiment a necessity. This led to the construction of a Dunne et al (1980) type simple rainfall simulator (plate, 3.3). Although, the frame work, materials used and method of water application in this simulator are borrowed from Dunne et al.,(1980); main design parameters as nozzle pressure, height of nozzle from the soil surface, nozzle spacing, direction of a nozzle's movement relative to its spray pattern and the type of nozzles used are all taken from Meyer and McCune (1958). This permitted calibrating the simulator against a simulator of known performance.

3.5.1 The rainfall simulator

The rainfall simulator consists of a bolted wooden frame 2.8 m high, 2.5 m wide, and 5 m in length supporting two 5.4 m long parallel metal rails along which inverted U shaped wheeled trolleys with vertically mounted spray nozzles at one end and a water supply line at the other are rapidly moved back and forth irrigating an area 5.4 m long and 3 m wide. The inverted U shaped wheeled trolleys are 0.4 m in length.

The nozzles used were the 80100 Veejet commercial nozzles produced by the Spraying Systems Company of Bellwood, Illinois, U.S.A., first tested and used by Meyer and McCune (1958) in the rainfall simulator called the rainulator.

The two nozzles spaced 1.52 m apart and spraying down ward from a height of 2.44 m at a nozzle pressure of 0.42 bar are moved in a direction perpendicular to the long dimension of their spray pattern. Two gauges were permanently attached to the water supply lines at a distance of 2.5 m from the nozzles to enable consistent check on nozzle pressure. Two gate valves on the water supply lines together with a return line enabled the maintenance of constant pressure during an experiment.

Water was supplied to the nozzles from three 2.25 m^3 capacity tanks with a small kerosene driven 4.6 horse power pump. Christiansen's coefficient of rainfall uniformity for 12 one hour experiments ranged from 75% to 90% out of which 75% were above 80% and for 24 half hour experiments it ranged from 69% to 89% out of which 46% were above 80%.

The rainfall simulator when dismantled was easily carried by a crew of

Plate 3.3 :- The rainfall simulator

Note: The water supply tanks and pump and the sampling bottles used to measure soil loss and runoff rates

Plate 3.4:- Block D after the three simulation runs

Note the plastic sheet used to cover the plots not more than five people to an area inaccessible for motor vehicles and when assembled it was moved from plot to plot by four people without any problem.

3.5.2 Rainfall simulation

To evaluate the performance of surface crop residues under heavy storms, a simulated rainfall test of a one hour storm at 65 mm/hr intensity with a return period of 10-20 years (MoWD,1978) was run on 12 plots. Plots were prepared and treatments assigned as described in 3.3. Following tillage and prior to rainfall simulation the plots were covered with plastic sheets to maintain similar initial soil moisture conditions.Three simulation runs were then made on each of the twelve plots. The initial simulated storms (dry-runs) lasted for one hour. Two thirty minutes runs (wet and v.wet runs) separated by 20 minutes were then made after 24 hours. Runoff and soil loss were collected in the storage tanks installed at the bottom of the plots. Rates of runoff and soil loss were measured by sampling the discharge at five minute intervals and noting the time taken to fill the sampling bottles. Infiltration rate was determined as the difference between the constant rate of rainfall application and the measured runoff rate.
Amount of rainfall applied and uniformity of rainfall application during each simulation event were measured by an array of nine catch cans placed directly under the spray.

The data were adjusted for slight deviations from the design application intensity of 65 mm/hr using the method reported by Meyer et al., (1970).

Runoff values were increased or decreased by the amount the actual application differed from 65 mm for the dry runs and from 32.5 mm for the wet and very wet runs. Soil losses were adjusted by the ratio of $(65)^2$ to the square of the actual intensity. For all runs made the time for the commencement of runoff and the approximate time for the commencement of the formation of rills was measured.

3.6 Field investigation

To give an indication of the availability and utilization of crop residue on small holder farms and be able to compare experimental findings with the actual field conditions a field survey was carried out in the Tea, Coffee and Cotton zones of Central Kenya (Muranga District). The field survey involved interviewing farmers, field visits (observation and evaluation of the conservation activity) and measuring the weight of grain and maize stover harvested from one meter square areas.
Three such samples were collected from each field visited to enable assessment of the availability of crop residue.

3.7 Difficulties encountered and proposed solutions

The methods used proved to be generally satisfactory although the following difficulties were noted.

1. The sampling procedure used was very tedious and time consuming, especially after medium and heavy runoff events as it involved measurements of volumes and weights very many times from each plot.
2. Manual operation of the rainfall simulator to apply water on the plots was not an efficient method especially when an experiment has to be done over a period of 1 hour.
3. Sealing of the trash protecting screens during a storm event in January, leading to a deposition of soil upto 20 kg weight in some collecting troughs. Some suggestions for the improvement of procedures are given below.

1. The collecting trough used was quiet satisfactory in concentrating the runoff produced on the plots and channelling it to the conveyance pipe. It was also very convenient for cleaning when deposition has occurred as it had quite sufficient space. But, because its slope depended on the ground slope, (as it was manufactured level) this slope was subject to variations depending on such conditions as how precisely the ground was shaped and changes due to soil settlement through time. For future research therefore, provision of up to 10% slope and the use of an eighteen gauge iron sheet to make the collecting trough, rather than the 24 gauge used during this experiment, is envisaged to further improve its efficiency.

2. Providing extensions of about 15 cm size of the same material at both ènds the end plate on the upslope direction will enable better sealing of joints between the end plate and the plot boundary sheet metals.

3. The use of a larger capacity weighing balance, which allows at least upto 50 kg weight to be weighed at a time will greatly reduce the tedious measuring and sampling procedure used during this experiment. What has to be considered is not only the difficulty when doing the job, but the chance of committing errors will also increase when the same procedure has to be repeated very many times and even through out the whole day as the case has been during some runoff events.

4. A 10 mm * 10 mm, mesh screen installed at the point where runoff from the collecting trough enters the conveyance channel, (to protect the entrance of residue and small stones into the conduit and avoid possible clogging) was sealed by residue during one storm event in January, which caused a heavy deposition of sediment in the collecting troughs of most plots.

However, after the removal of these trash screens neither such heavy deposition nor clogging of conveyance pipes was encountered, even during the heaviest runoff events,although some residue leaves were usually found in the storage tanks. Possibly the large size of conveyance facilitated this condition.

5. The method of water application (pulling back and forth by hand) by the rainfall simulator is not a very efficient method especially when a simulation run has to be done over a one hour period . It is difficult to maintain a constant speed during the back and forth pulling process

where two different people are operating it from opposite direction. As a result some points in the plot will receive more rain than others. This and other tasks such as calibrating its performance against some important characteristics of tropical storms need to be given priority in future research as it is a very important research tool.

6. Although, not significant but important to be considered is the condition of laboratory facilities. Because of the presence of one oven for drying samples and the relatively higher number of users (some times upto six students) samples some times have to stay upto a week, before oven dried. The same problem exists with regard to weighing balances, drying bowls and places for keeping samples. This condition need to receive serious considerations if more than one student have to simultaneously use the existing facilities for future research.

4. RESULTS

Soil loss is the product of runoff times sediment concentration. While sediment concentration is mainly due to detachment by rain drop impact and concentrated runoff flow, runoff itself is the difference between what has rained and what has infiltrated (neglecting evaporation). On the other hand detachment, runoff, sediment concentration and infiltration may be significantly influenced by surface cover. Therefore, surface cover, runoff, and soil loss as measured under natural and simulated rainfall conditions will be discussed separately in this chapter.

4.1 Surface cover

Residue rates of 0, 0.5, 1.0, and 2.25 t/ha gave actual ground cover of 0, 13, 23, and 40% respectively (figure 4.1). The data presented in figure 4.1 was used to develop the regression equation shown below.

$$\text{percent surface cover} = 100(1-e^{-0.224W}) \quad \text{--------}(4.1)$$

Where, e, is the base of the natural logarithm and W, is weight of residue in t/ha. The coefficient of determination, r^2, of the above equation is 0.994. Given maize residue rate in t/ha equation 4.1 allows estimation of the resulting percent surface cover.

4.2 Natural rainfall

The total rainfall during the 1988 short rainy season was 261 mm. Most of the rains occurred as very light showers and over a long period of duration. During this season only four storms produced runoff and soil loss whose amount was very little. During the 1989 long rains a total of 827.6 mm of rainfall occurred. Unlike the 1988 short rains, these were high intensity rains. For example a 75 mm rainfall occurred in one hour (appendix 2b) and a total amount of 182 mm rainfall was recorded in a period of less than five hours.

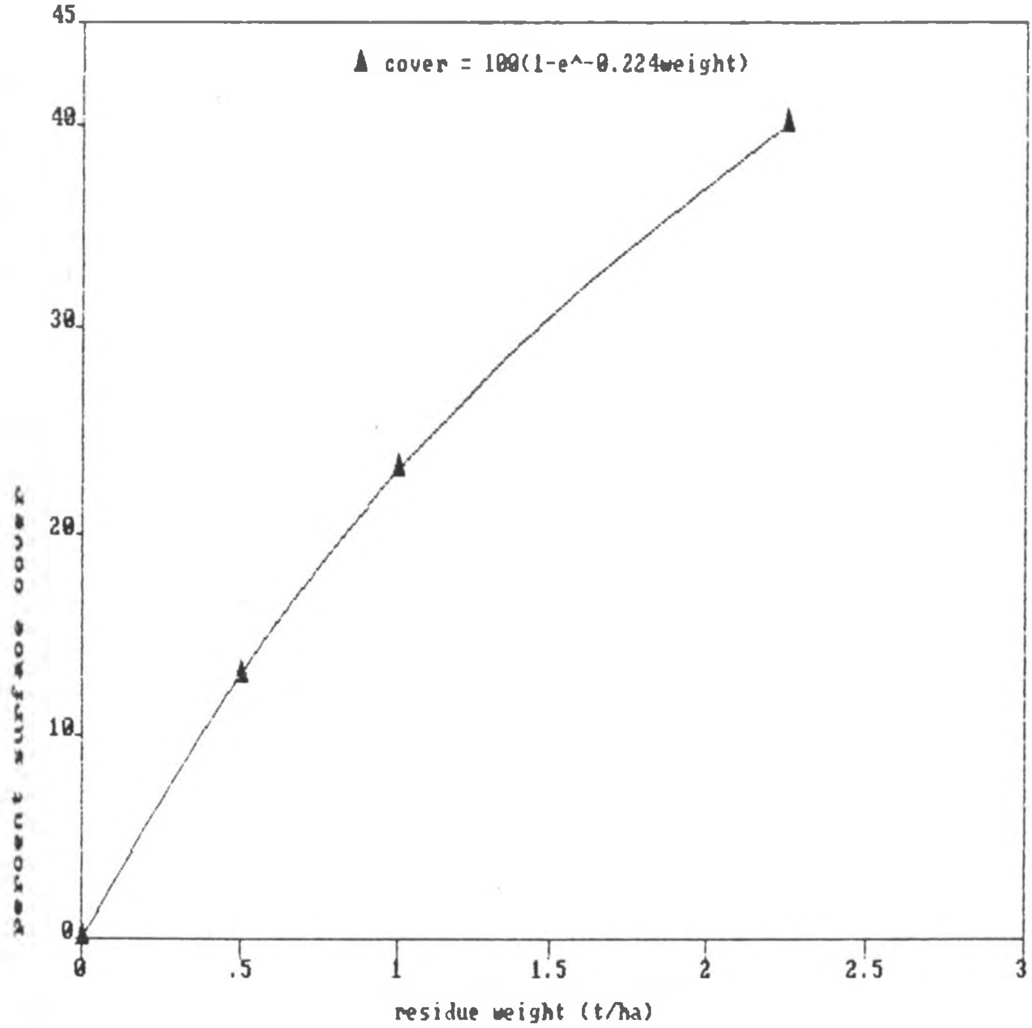


Figure 4.1 percent surface cover residue weight relations

4.2.1 Runoff

Total runoff (mm/season) for each of the maize residue treatment during the 1988 Short rains, 1989 January rains and 1989 Long rains is given in table 4.1

Table 4.3 shows percentage run off losses for each treatment during the same periods and figures 4.2 and 4.3 show total runoff in m^3/ha for the respective percent surface cover provided by the different residue rates during the 1988 short rains and the 1989 long rains respectively. During all seasons application of surface cover resulted in significant ($P = 0.01$) reduction in run off. For all seasons the reduction in runoff loss was consistent with increased application of maize residue as surface cover.

During the 1988 Short rains run off losses were reduced to 66, 35, and 29% from plots receiving 0.5, 1, and 2.25 t/ha maize residue treatments respectively when compared with the losses from plots receiving no residue treatments. The reduction in run off loss from plots with 1 and 2.25 t/ha residue rate was significant ($P = 0.05$) compared with the loss from the plots receiving 0.5 t/ha residue treatment while the difference in the reduction of runoff between the 1 and 2.25 t/ha residue treatments was not significant ($P = 0.05$) during both the short and the January rains. However, during the 1989 long rains although the reduction in runoff loss from plots receiving residue treatments was significant ($P<0.01$) compared with the loss from the plots without residue treatments, the difference in runoff loss between plots with the different residue rates was not significant at $P = 0.05$ level.

Total runoff losses were reduced to 67, 51 and 44% during the 1989

January rain and to 92, 88 and 85% during the 1989 long rains from plots with 0.5, 1, and 2.25 t/ha maize residue treatments respectively compared with the runoff losses from plots without residue treatments.

Table 4.1 :- Runoff (mm/season) for the four maize residue treatments during the 1988 Short rains, 1989 January rains and 1989 Long rains;

Season	No. of storms	Rf. (mm)	Residue cover (t/ha) 0.00	0.50	1.00	2.25
1988 SR	4	110.6	3.6a	2.4B	1.3Bc	1.1Bc
1989 JR	1	48.0	21.7a	14.6B	11.1BC	9.6BC
1989 LR	15	749.6	215.0a	197.4B	189.0B	183.5B
Total	20	908.2	240.3	214.4	201.4	194.2

SR = Short rains

JR = January rains

LR = Long rains

Means of a season labelled with the same letter(s) are not significantly different at 5% level; capital letters indicate significant difference at 1% level.

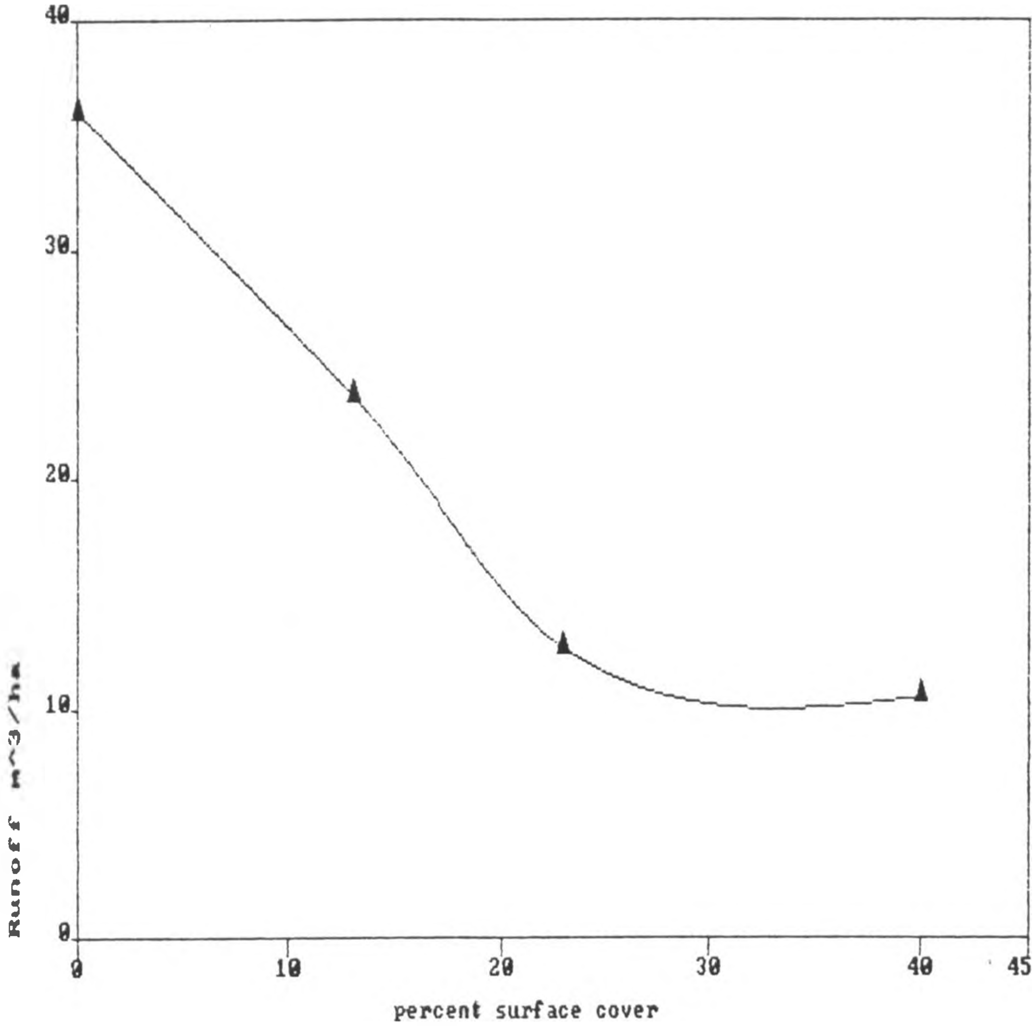


Figure 4.2:- Effect of surface cover on runoff during the 1988 short rains

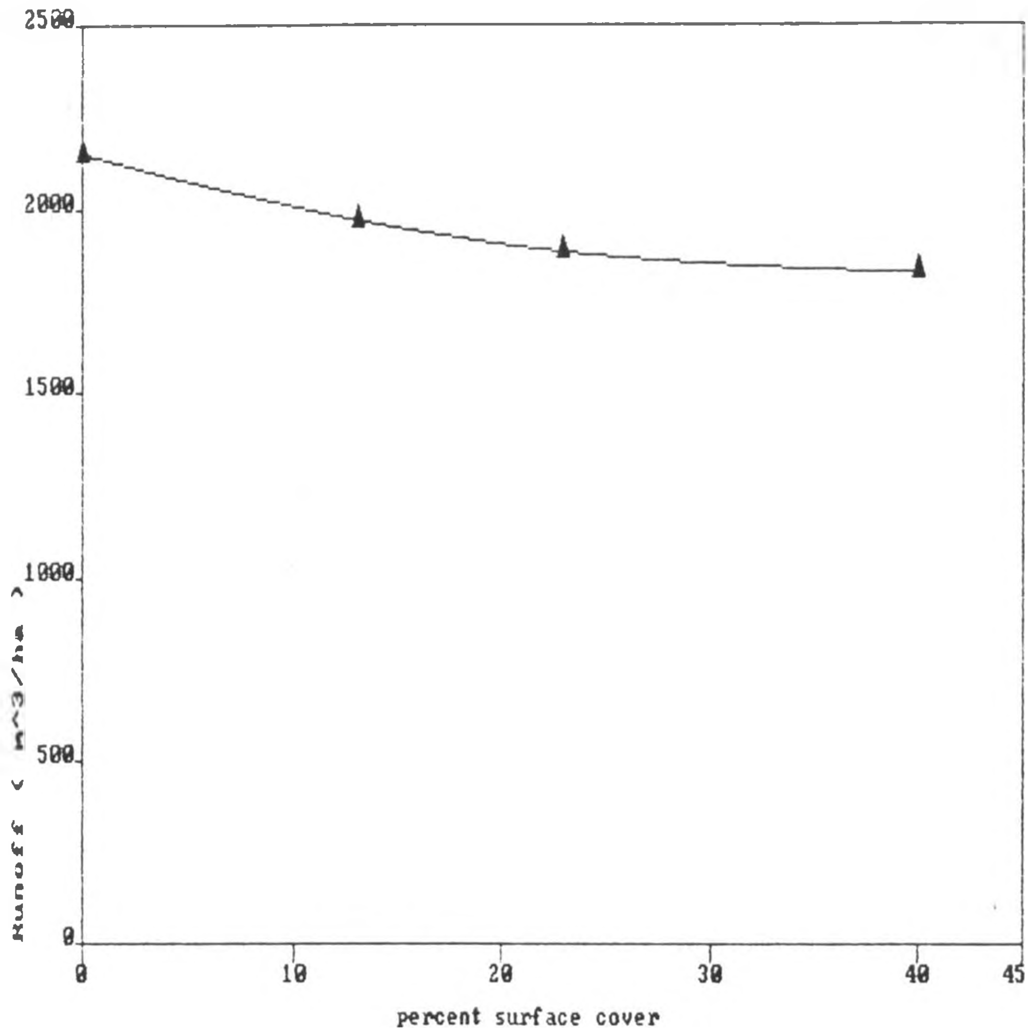


Figure 4.3:- Effect of surface cover on runoff during the 1989 long rains

Table 4.2 :- Soil loss (t/ha/ season) for the four maize residue treatments, during the 1988 Short rains, 1989 January rains and 1989 Long rains;

Season	No. of storms	Rf. (mm)	Residue cover (t/ha)			
			0.00	0.50	1.00	2.25
1988 SR	4	110.6	6.0a	3.6B	1.0Bc	0.73Bc
1989 JR	1	48	46.2a	32.8B	25.5B	20.6B
1989 LR	15	749.6	355.0a	320.6B	297.0Bc	277.5Bc
Total	20	908.2	407.2	357	323.5	298.8

Table 4.3 :- Percentage soil loss and runoff for the four maize residue treatments during the 1988 Short rains, 1989 January rains and 1989 long rains ;

Season	Soil loss				Runoff			
	0.00	0.50	1.00	2.25	0.00	0.50	1.00	2.25
1988 SR	100	60.0	16.6	12.1	100	65.6	35.2	29.3
1989 JR	100	71.1	55.2	44.6	100	66.9	51.2	44.0
1989 LR	100	90.3	83.7	78.2	100	91.8	87.9	85.4
Weighted Mean*	100	69.6	64.3	60	100	74.0	70.8	68.7

*Weighted according to total soil loss/runoff in season

Table 4.4 :- Soil loss and runoff for the four maize residue treatments during the heavy storms of 7/5/89 and 18/5/89 and the other storms of 1989 long rains;

Event	Rf.(mm)	No.of storms	Soil loss (t/ha) 0.00	0.5	1.00	2.25	Runoff (mm) 0.00	0.50	1.00	2.25
1.	294.0	2	186	173	168	164	107	98	101	98
2.	455.6	13	169	147	129	114	108	97	88	86
3.	749.6	15	355	320	297	278	215	195	189	183
4.	39.2	-	52	54	57	59	50	50	53	53

1 = Total for the two heavy storms of 1989 long rains

2 = Total for the other storms of 1989 long rains

3 = Total for 1989 long rains

4 = Percentage soil and runoff losses caused by the two heavy storms

The potential of the various residue treatments in reducing runoff was in the order Short rains > January rains > long rains. The decreased performance during the long rains is partly due to the unusual high intensity storms and prolonged duration of the long rains. For example, out of the total amount of runoff observed during this season (215, 195, 189, and 183 mm from plots with 0, 0.5, 1, and 2.25 t/ha residue rate respectively) approximately more than half was due to two storms that occurred on 7/5/89 (112 mm) and on 18/5/89 (182 mm), (table 4.4), the balance of runoff cause from thirteen separate rainfall events. With these high intensity and long duration rains the volume of runoff produced was big enough to easily overtop and break through the "small dams" created by residue.

The coincidence of the occurrence of these heavy storms with a period of depleted surface cover due to termite activity and decay also contributed to the high run off losses. For example, weight measurement at the end of this rainy season showed reductions to 47.5, 35, and 32% of the originally placed residue at the rates of 0.5, 1, and 2.25 t/ha respectively.

4.2.2 Soil loss

Total soil loss (t/ha) for the different maize residue treatments during the 1988 short rains, 1989 January rains and 1989 long rains is given in table 4.2.

Table 4.3 presents percentage soil loss observed during the same period, while figures 4.4 and 4.5 show soil loss in t/ha during the 1988 short and 1989 long rains from the respective surface covers provided by the different residue treatments.

During the short rainy season leaving only 15% of the residue produced under average production condition gave 13% surface cover and reduced the soil loss to 60%. It was possible to reduce the same loss to 17 and 12% by leaving 30% and 75% of the residue produced under average production conditions respectively compared with the soil loss from the plots where no surface cover was left.

Application of surface cover resulted in significant (P=0.01) reduction in soil loss during all seasons. The reduction in soil loss from plots with 1 and 2.25 t/ha residue covers was also significantly different (P=0.05) from the soil loss observed from plots with 0.5 t/ha maize residue cover while there was no significant (P=0.05) difference in soil loss reduction between the rates of 1 and 2.25 t/ha either during the short or the long rainy seasons. However, during the January rains, although , application of surface cover produced a significant (P=0.01) reduction in soil loss, there was no significant (P=0.05) difference in soil loss reduction between the varying residue rates.

Consistent reduction in mean soil loss resulted from increased application of maize residue as surface cover during all seasons. During the January rains, total soil was reduced to 71, 55, and 45% from plots with 0.5, 1 and 2.25 t/ha residue rates respectively compared with the soil loss from plots without surface cover. During the 1989 long rains the same losses were reduced to 90, 84 and 78% from plots with 0.5, 1, and 2.25 t/ha residue treatments respectively compared with the loss from plots where no surface cover was applied.

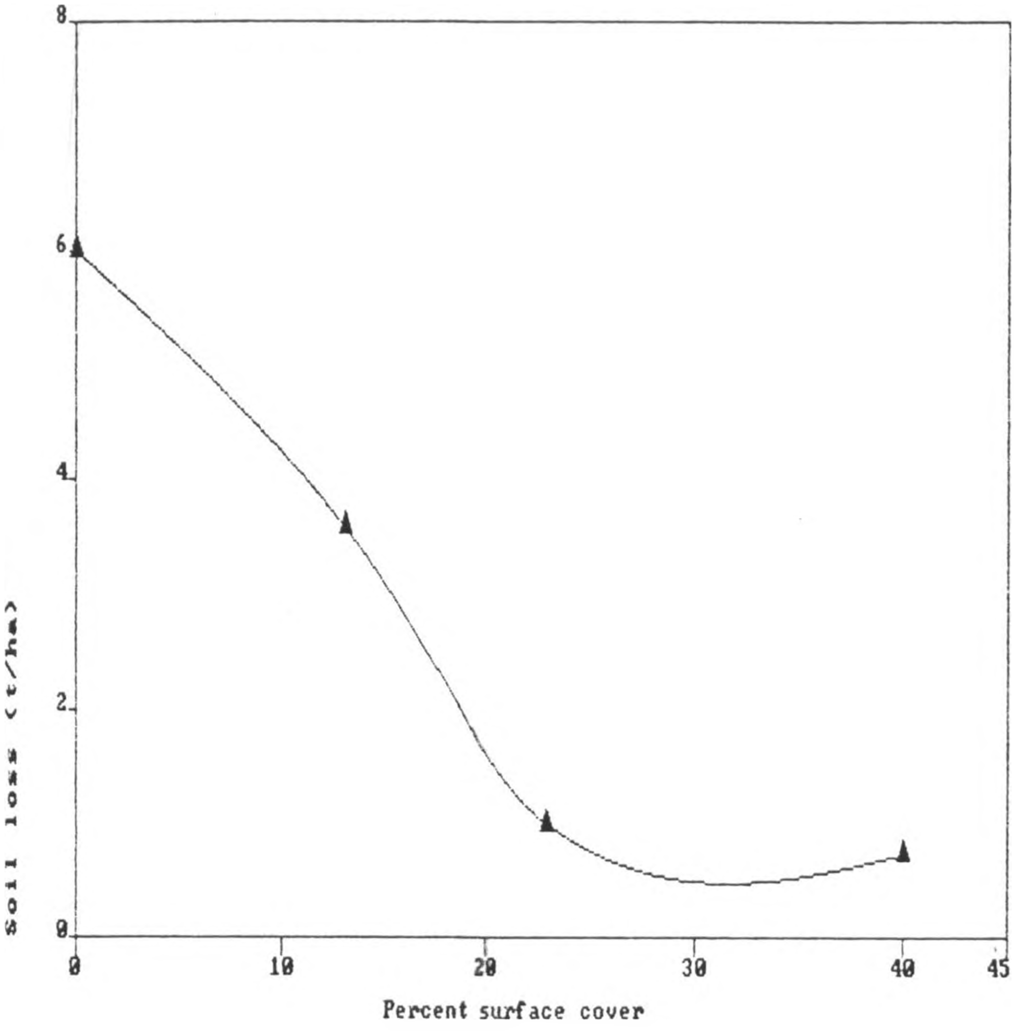


Figure 4.4:- Effect of surface cover on soil loss during the 1988 short rains

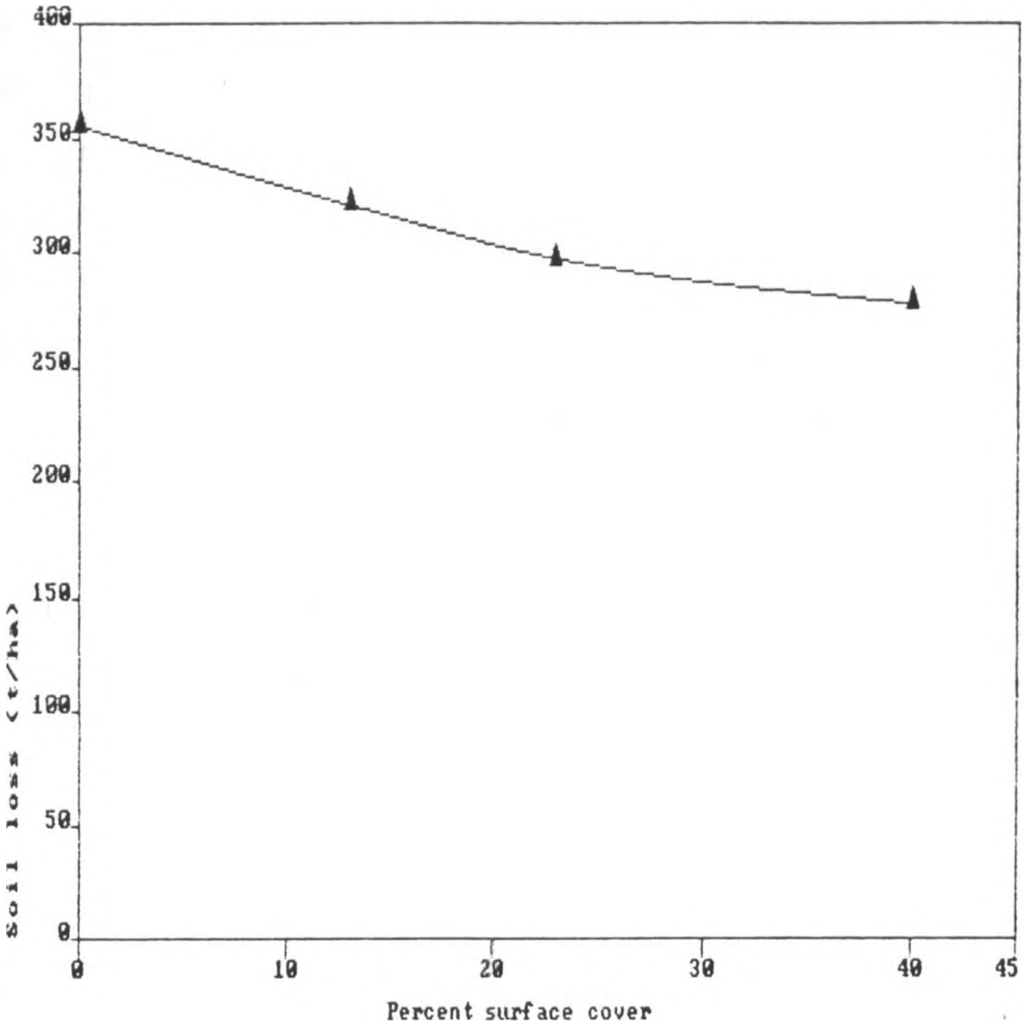


Figure 4.5:- Effect of surface cover on soil loss during the 1989 long rains

The performance of the residue treatments in reducing soil loss was in the order, Short rains > January rains > Long rains. Here also the effectiveness in soil loss reduction by the various residue rates was relatively lower with increase in intensity and amount of the rains and the length of the rainy period as stated earlier. For example, during the 1989 Long rains two heavy storms that occurred on 7/5/89 (112 mm) and on 18/5/89 (182 mm) having a return period of more than twenty five and about fifty years respectively produced soil losses of 185.7, 173.3, 168.3, and 163.7 t/ha respectively (table 4.4) from plots receiving 0, 0.5, 1, and 2.25 t/ha maize residue as surface cover.

The other thirteen storms that occurred in the season produced only 48, 46, 43, and 41% of the seasonal soil loss from the plots with 0, 0.5, 1, and 2.25 t/ha surface cover respectively.

The occurrence of these heavy storms coincided with a period of depleted surface cover due to termites and decay and the availability of loose soil previously deposited behind decaying residue. Each of these factors contributed to high soil loss measurement from plots receiving residue treatments during this time of the season.

4.3 Simulated rainfall

4.3.1 Runoff

Mean runoff(mm) for the four maize residue treatments during the dry, wet and very wet runs and for all runs is given in table 4.5.

Application of surface cover resulted in a significant (P=0.01) reduction in runoff during the dry run. However, there was no significant (P=0.05) difference in runoff as a result of application of varying residue rates. Similarly during the wet and very wet runs, application of surface cover produced a significant (P=0.05) reduction in runoff loss compared with plots where no surface cover was applied.

However, during these two runs increased application of surface cover produced a significant (P=0.05) reduction in runoff loss.

Percentage runoff for the four maize residue treatments during the dry, wet and very wet runs is shown in table 4.6. During the dry run, runoff losses were reduced to 63, 61, and 48% from plots with maize residue applied at rates of 0.5, 1, and 2.25 t/ha as surface cover respectively compared with the loss from plots with no application of surface cover. However, runoff losses were reduced to only 96, 78, and 52% during the wet run and to 98, 97, and 72% during the very wet run from plots with maize stover applied at rates of 0.5, 1, and 2.25 t/ha respectively.

Cumulative runoff-cumulative rainfall relationships for the different cover rates is shown in figure 4.6. Fig 4.7, shows runoff mulch factor percent surface over relationships. A runoff mulch factor for each residue rate was obtained by dividing the runoff from plots with a given cover rate by the runoff from plots with out cover for each simulation run and averaging over the three simulation runs. An equation relating runoff mulch factor to percent surface cover is given below,

$$\text{Runoff mulch factor} = e^{-0.014RC} \text{ ------------------(4.2)}$$

Where, e is the base of natural logarithm, and RC is percent residue cover. The coefficient of determination, r^2, for the above equation is 0.970. Given surface residue in percent the above equation allows prediction of the resulting reduction in runoff relative to the loss from plots without surface cover, for the given experimental conditions.

Table 4.5 :- Soil loss and runoff for the four maize residue treatments under three simulation runs of a 65 mm/hr intensity storm;

(Figures are the mean of three replications)

Residue Cover	Soil loss (t/ha)				Runoff (mm)			
(t/ha)	dry	wet	v.wet	all	dry	wet	v.wet	all
0.00	7.9a	24.9a	30.6a	63.4	5.3a	13a	14.8a	33.1
0.50	4.2B	22.5B	24.2B	50.9	3.4B	12.6b	14.4b	30.4
1.00	3.0B	16.2BC	20.9Bc	40.1	3.3B	10.2bc	14.3bc	27.8
2.25	1.9B	8 BCD	14.6Bc	24.5	2.6B	6.7bcd	10.7bcD	20

Treatment means followed by the same letter(s) are not significantly different at 5% level; and capital letters indicate significant difference at 1% level.

Table 4.6:- Percentage soil loss and runoff for the four maize residue treatments under three simulation runs of a 65 mm/hr intensity storm;

Residue Cover	Soil loss			Runoff		
(t/ha)	dry	wet	v.wet	dry	wet	v.wet
0.00	100	100	100	100	100	100
0.50	52.5	90.6	79.1	63.4	96.4	97.6
1.00	38.1	65.3	68.3	61.3	78	96.9
2.25	24.5	32.3	47.7	48.1	51.7	72.3

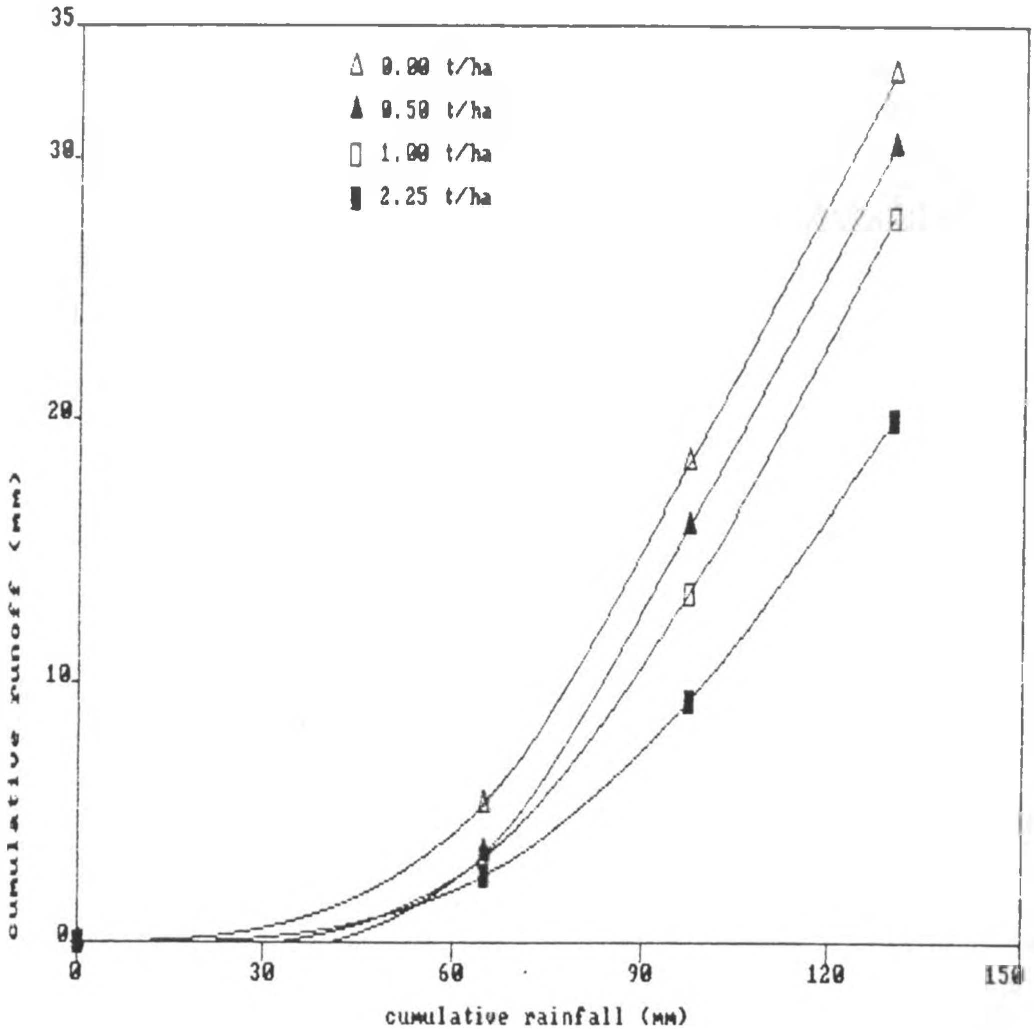


Figure 4.6:- Cumulative rainfall—cumulative runoff relations

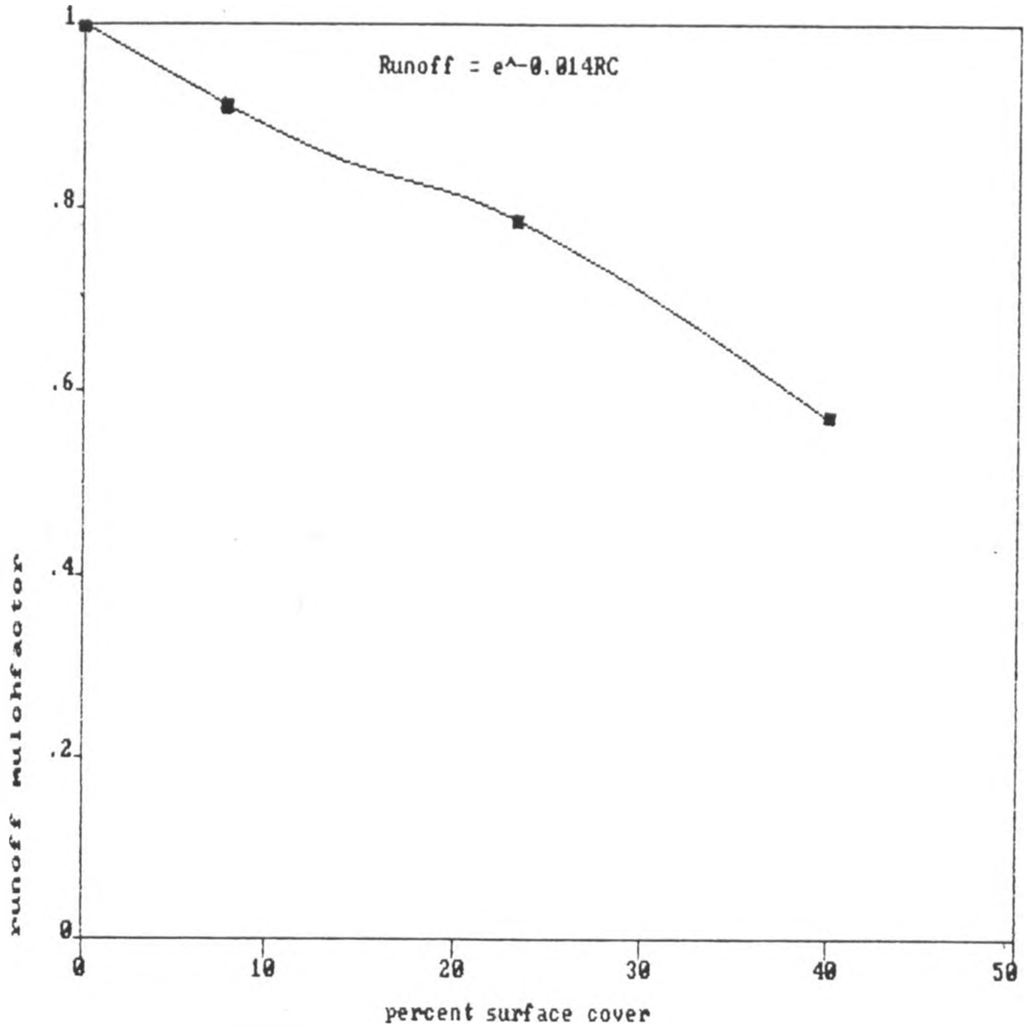


Figure 4.7:- Percent surface cover runoff mulch factor relations

In all cases the reduction in mean runoff was consistent with increased application of maize stover as surface cover. The maize residue rate of 0.5 t/ha reduced the runoff to 86% from a cumulative rainfall of 130 mm, applied at an intensity of 65 mm/hr while the same losses were reduced to 79 and 57% from plots with 1 and 2.25 t/ha residue cover respectively compared with the plots where no residue as surface cover was applied (figure 4.7).

The performance of the different residue covers in reducing the runoff was in the order dry run > wet run > very wet run.

4.3.2 Runoff rates

Runoff rates for the different maize residue treatments during the dry, wet and very wet simulation runs are shown in figures 4.8, 4.9, and 4.10, respectively. During the dry run runoff started after 10, 18, 21 and 27 minutes from the start of rainfall application from plots with 0, 0.5, 1 and 2.25 t/ha respectively. Generally there was a gradual increase in runoff rate during this run except for the last 15 minutes, when there was a rapid increase from plots with 0 and 0.5 t/ha residue treatments. However, during the wet and very wet runs runoff started within a relatively short period from the start of rainfall application and reached peak rate after a short time. The very wet run produced runoff rates which were much higher than those observed during the dry runs. Increased reduction in runoff rates from increased residue application resulted during all runs and this reduction rate was more pronounced during the wet run than either during the dry or very wet runs.

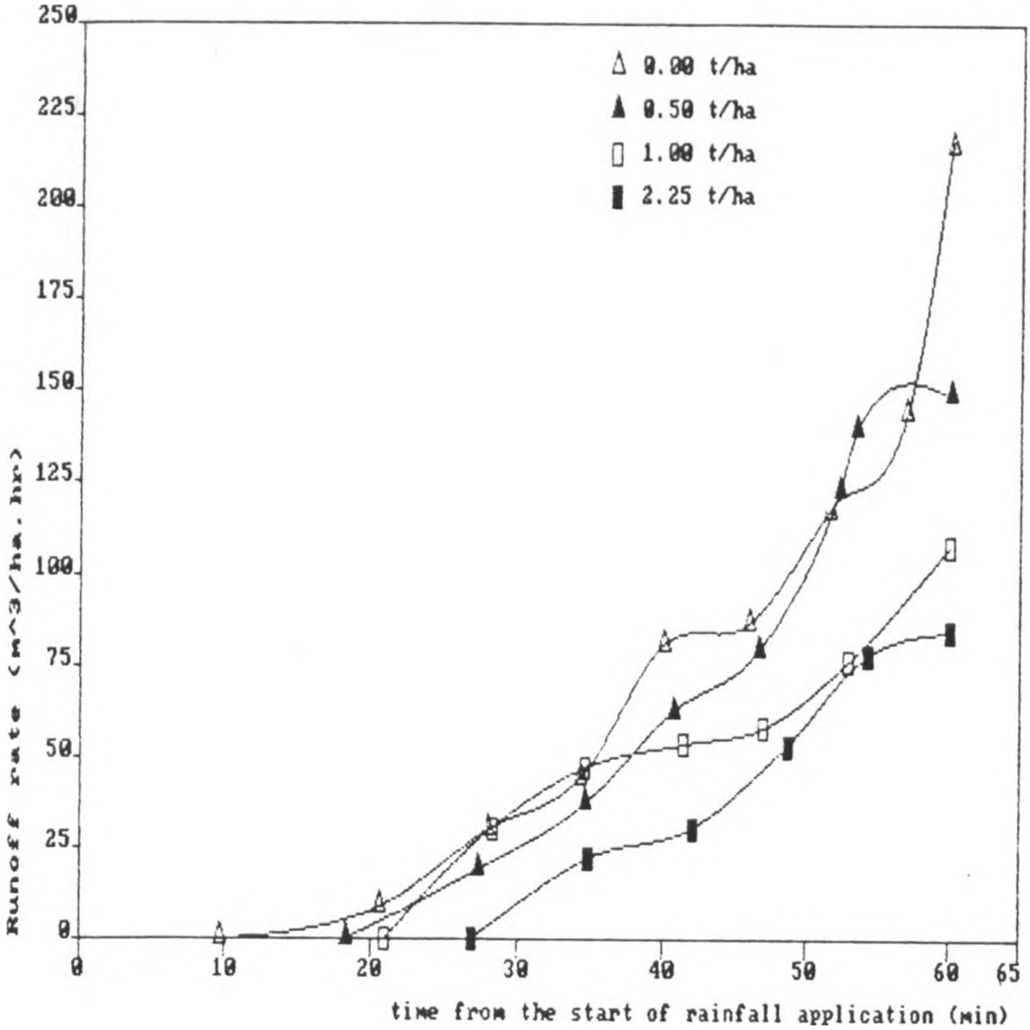


Figure 4.8:- Dry run runoff rates

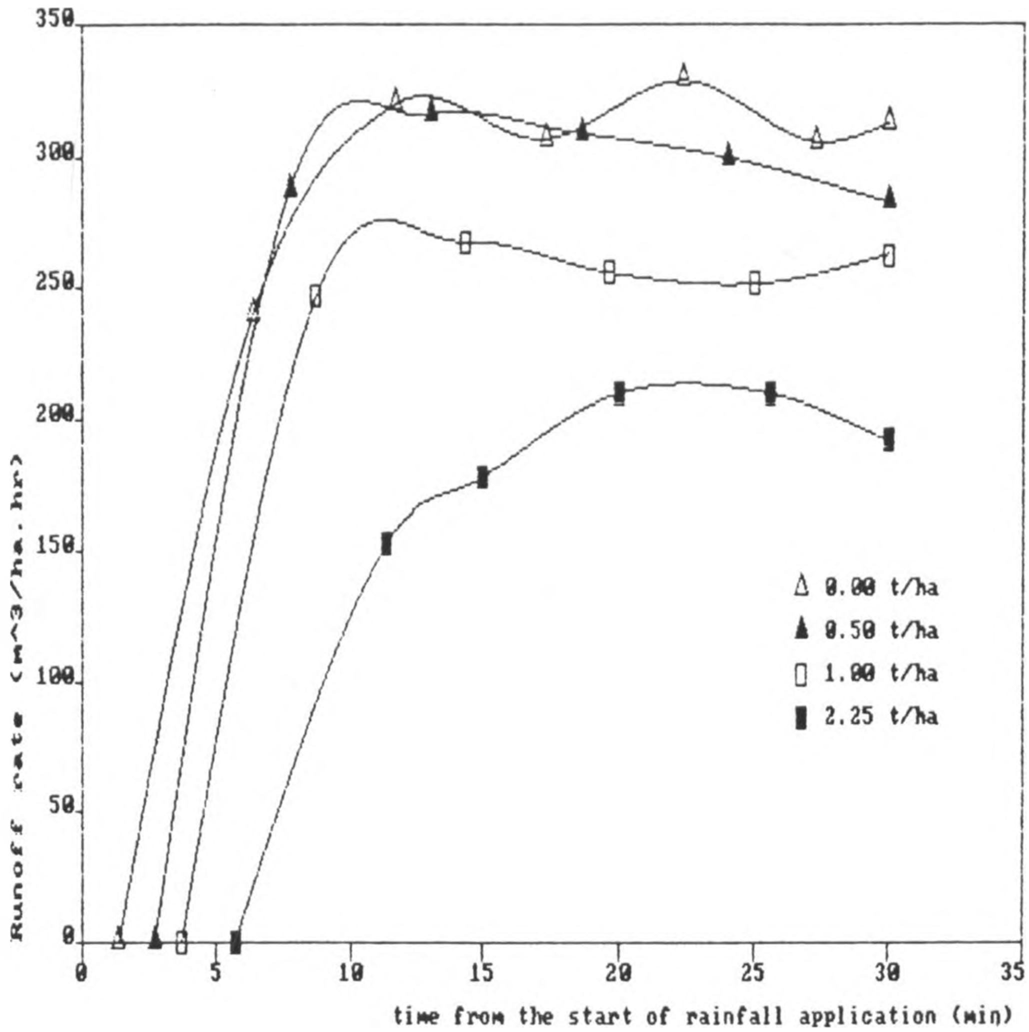


Figure 4.9:- Wet run runoff rates

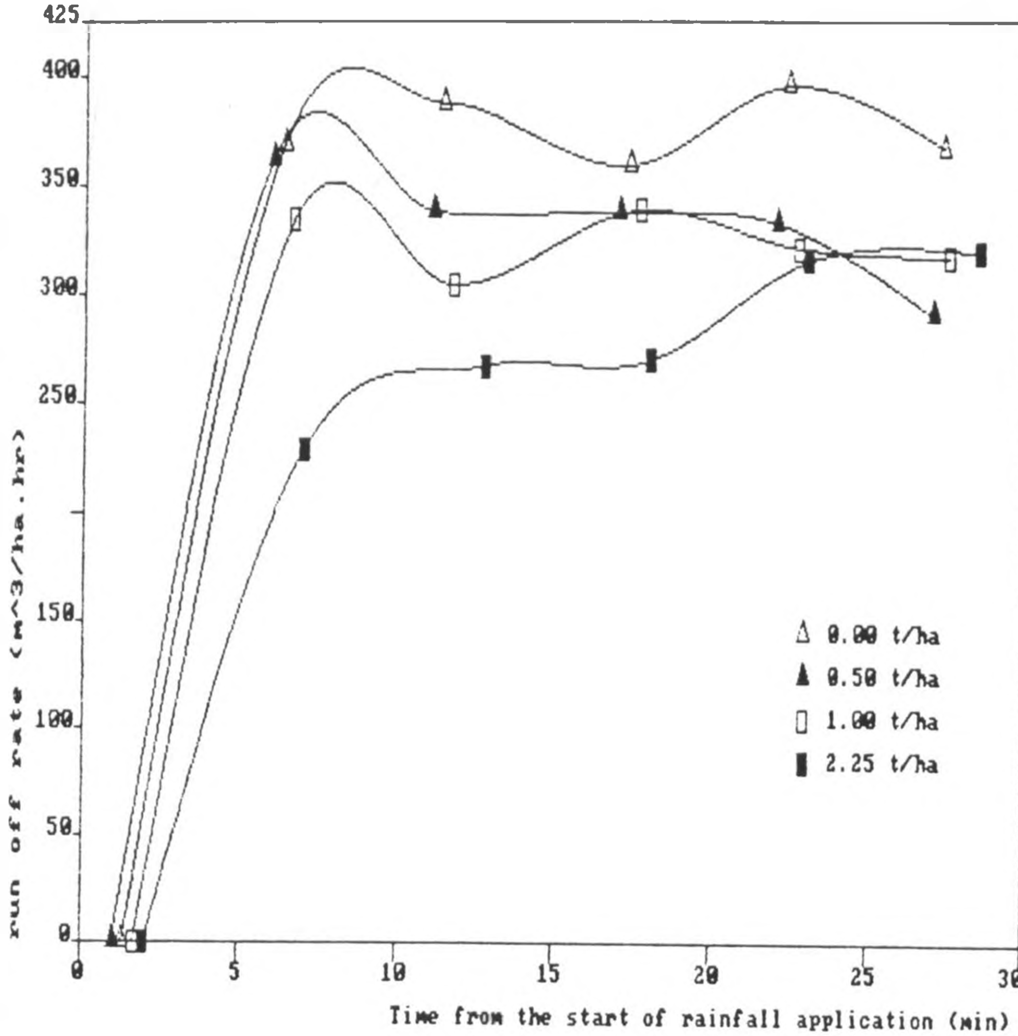


Figure 4.10:- Very wet run runoff rates

4.3.3 Infiltration rates

Figures, 4.11, 4.12, and 4.13 show infiltration rates during the dry, wet and very wet runs of rainfall simulation. Generally increased infiltration rate resulted with increasing surface cover. High infiltration rates were observed for all treatments during the dry runs. the lowest infiltration rate occurred during the very wet run and on plots receiving no surface cover. Here also relatively higher difference in infiltration rate as a result of increased surface cover was observed during the wet run.

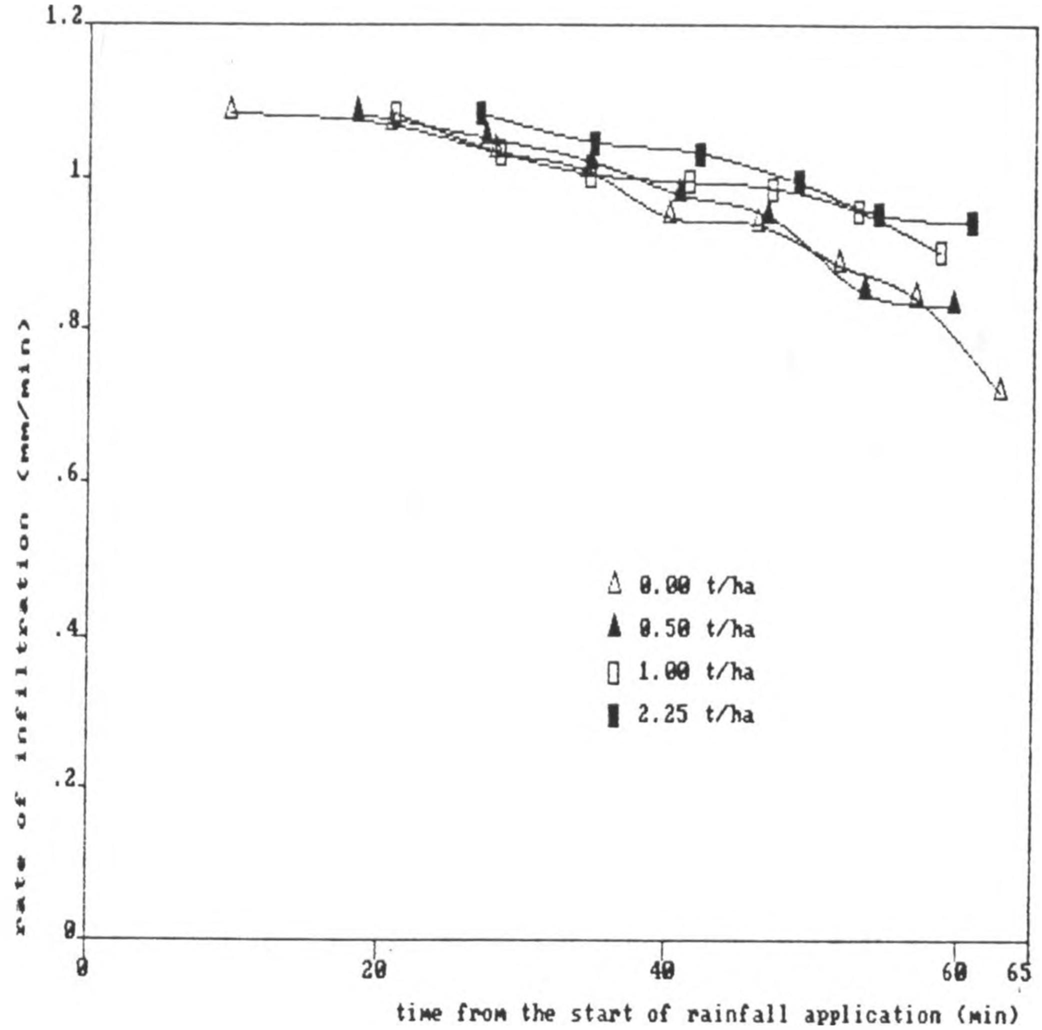


Figure 4.11:- Dry run infiltration rates

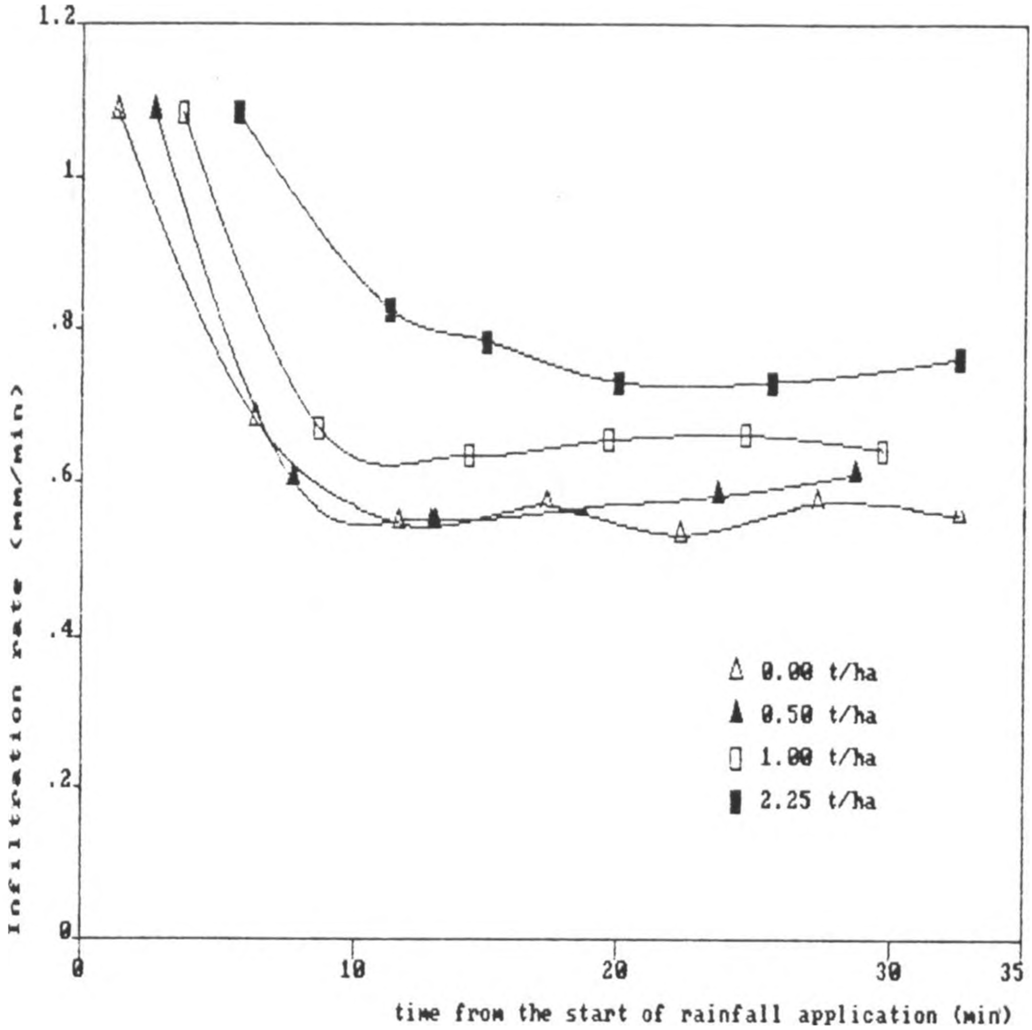


Figure 4.12:- Wet run infiltration rates

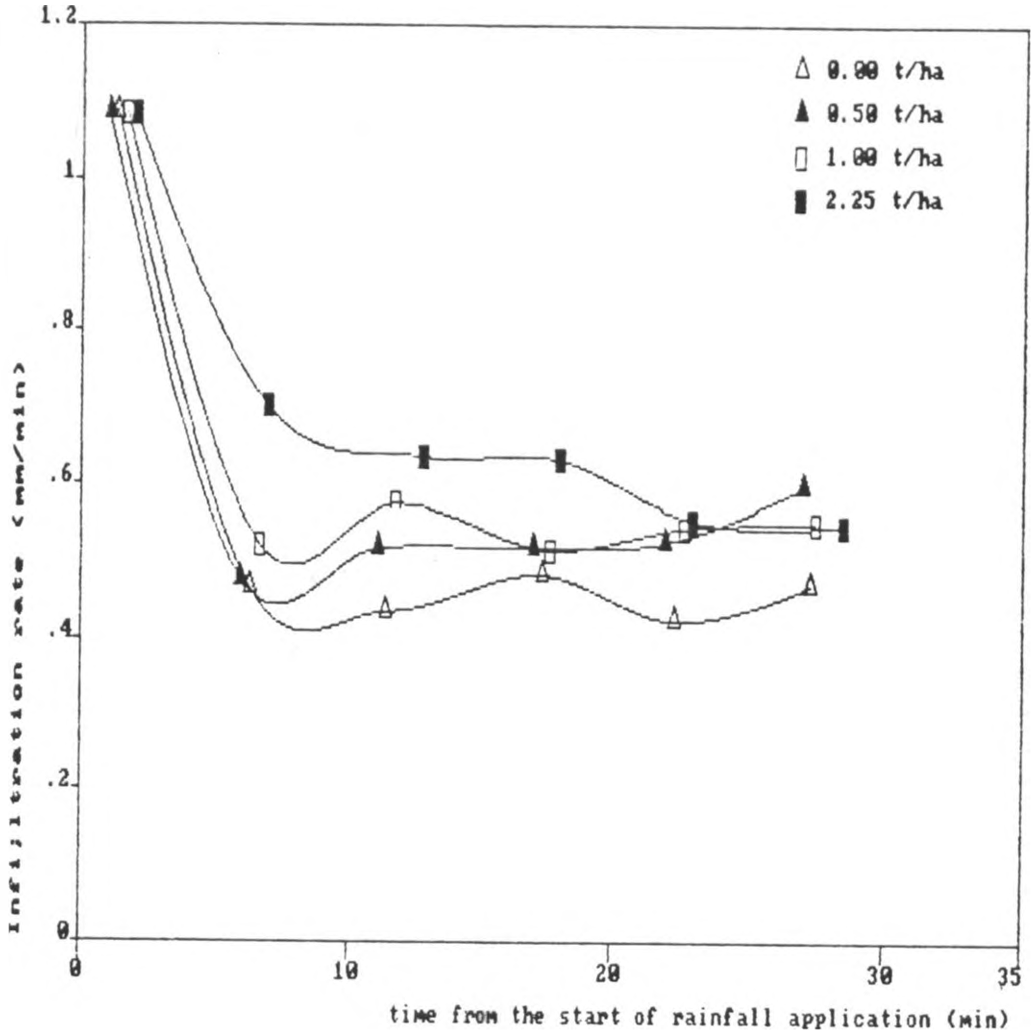


Figure 4.13 :- V. wet run infiltration rates

4.3.4 Soil loss

Soil Loss for the different maize residue treatments during the dry, wet and very wet runs and for all runs is given in table 4.5. Figure 4.14, shows cumulative rainfall - cumulative soil loss relations. Application of surface cover produced a significant (P=0.01) reduction in soil loss during all runs. During the dry run there was no significant (P=0.05) difference in soil loss reduction between the varying residue rates. However, during the wet run there was a significant difference (P=0.01) between the losses from plots with 0.5 t/ha and 1 t/ha residue rate as well as between the 1 t/ha and the 2.25 t/ha residue rate. Also, during the very wet run the 1 t/ha residue rate produced a reduction in soil loss which was significant (P=0.05) compared with the 0.5 t/ha treatment, while there was no significant (P=0.05) difference in soil loss reduction between the 1 t/ha and 2.25 t/ha residue treatments.

Percentage soil loss for the four maize residue treatments is presented in table 4.6 . During the dry run, the residue cover of 0.5 t/ha reduced the soil loss from a storm applied at an intensity of 65 mm/hr to 53% of the soil lost from plots without cover, while the same losses were reduced to 38% and 25% from plots with 1 and 2.25 t/ha residue covers respectively.

During the wet run mean soil loss was reduced to 91, 65 and 32% from plots with 0.5, 1 and 2.25 t/ha maize residue cover respectively compared with the losses from plots where no cover was applied. Similar reductions in mean soil loss were obtained during the very wet run also (table 4.6.)

Soil loss mulch factor - percent surface cover relationships is shown in figure 4.15 . A soil loss mulch factor was obtained by dividing the soil loss observed under a given residue treatment by the soil loss observed from plots without residue treatment for each run and averaging over the three runs.

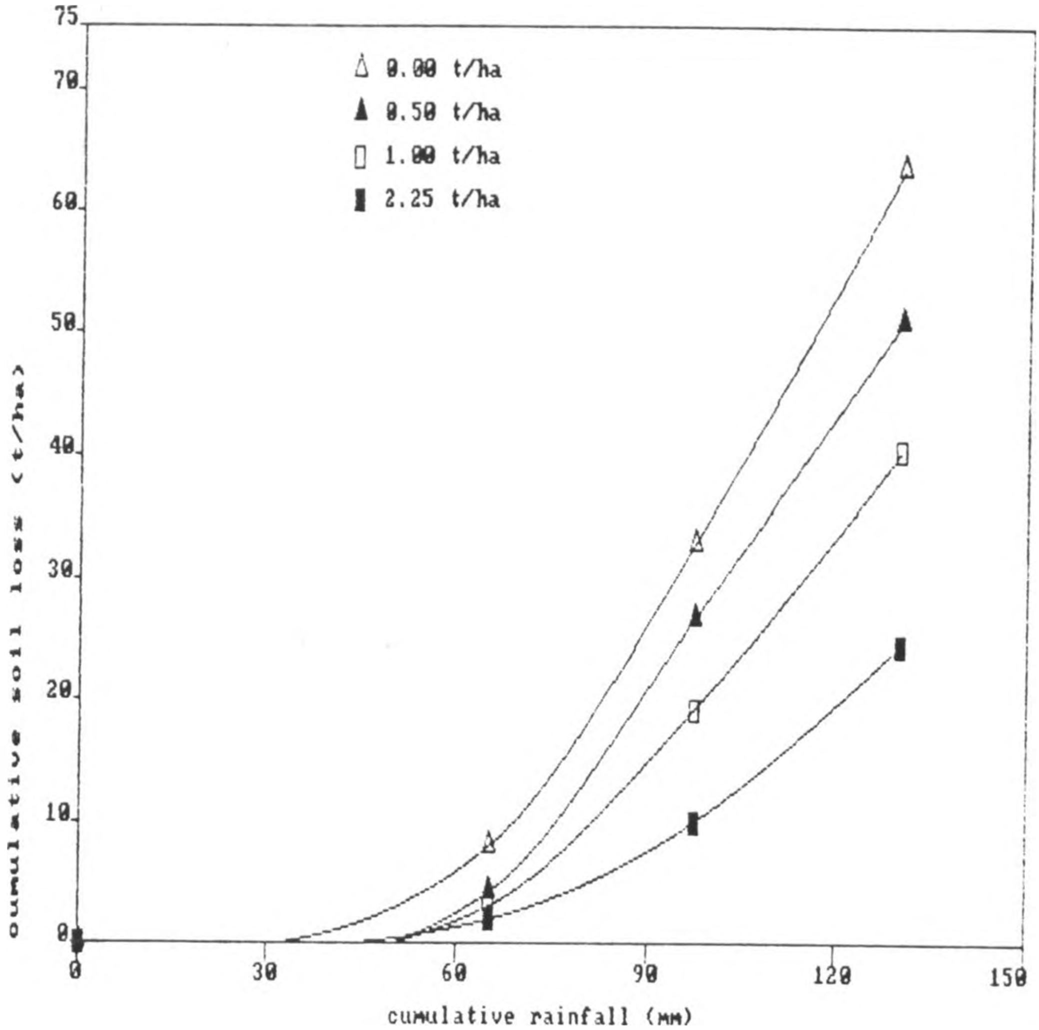


Figure 4.14:- Cumulative rainfall - Cumulative soil loss relations

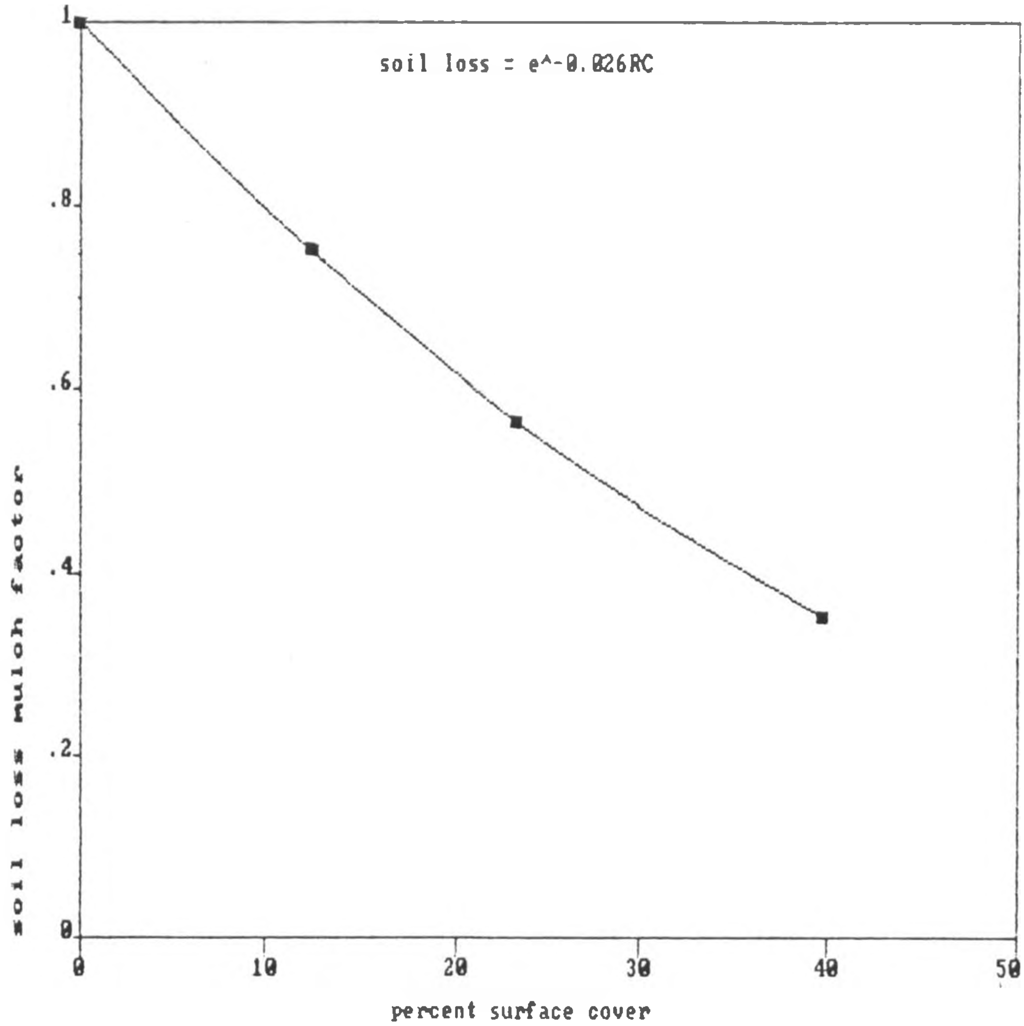


Figure 4.15:- Percent surface cover soil loss mulch factor relations

An equation relating soil loss mulch factor to percent ground cover is given below;

$$\text{soil loss mulch factor} = e^{-0.026RC} \text{ ----------------------------(4.3)}$$

Where e and RC are as defined in equation (4.2).

The coefficient of determination, r^2, for the above equation is 0.997 Given residue cover in percent equation (4.3) can be used to estimate the resulting reduction in soil loss relative to the soil loss that would occur if no surface cover was applied, for soil, rainfall and slope conditions similar to those in this experiment.

Application of surface cover at the rate of 0.5 t/ha reduced the average soil loss from a cumulative rainfall of 130 mm applied at an intensity of 65 mm/hr to 74% of the soil loss measured from plots where no surface cover was applied, while the same losses were reduced to 57 and 35% by the application of surface cover at the rate of 1 and 2.25 t/ha respectively (figure 4.15).

The effectiveness of the residue treatments in reducing soil loss was in the order Dry run > wet run > very wet run.

4.3.5 Soil loss rates

Soil loss rates during the dry, wet and very wet simulation runs are given in figures, 4.16, 4.17, and 4.18 respectively. During the dry run the increase in soil loss rate was gradual from all plots, although there was a sharp increase in soil loss rate during the last minutes of the run from the plots receiving no residue treatment. However, during the wet and very wet runs soil loss reached peak rates for each treatment within a relatively short period from the start of rainfall application, except from the plots with 2.25 t/ha residue application during the wet run. The soil loss rates during the wet runs were more than twice of the rates observed during the dry runs.

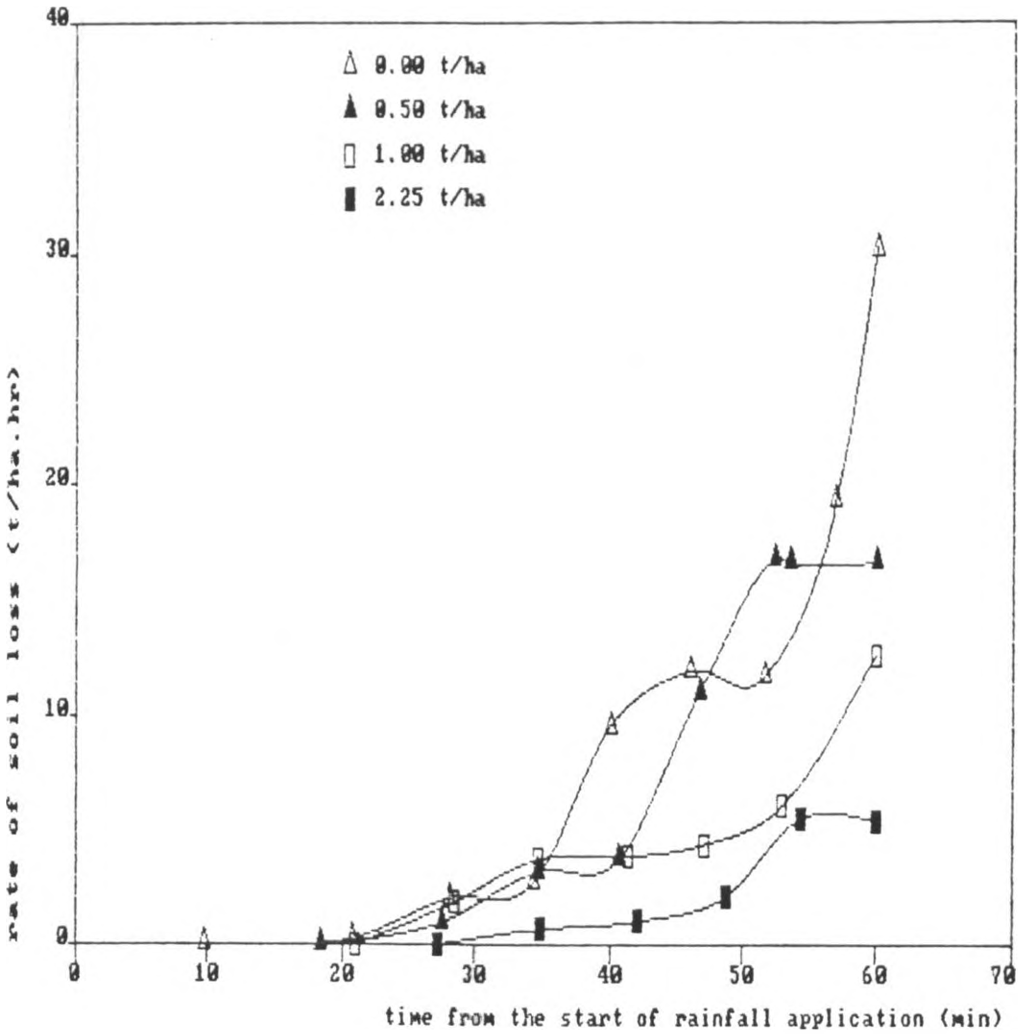


Figure 4.16:- Dry run soil loss rates

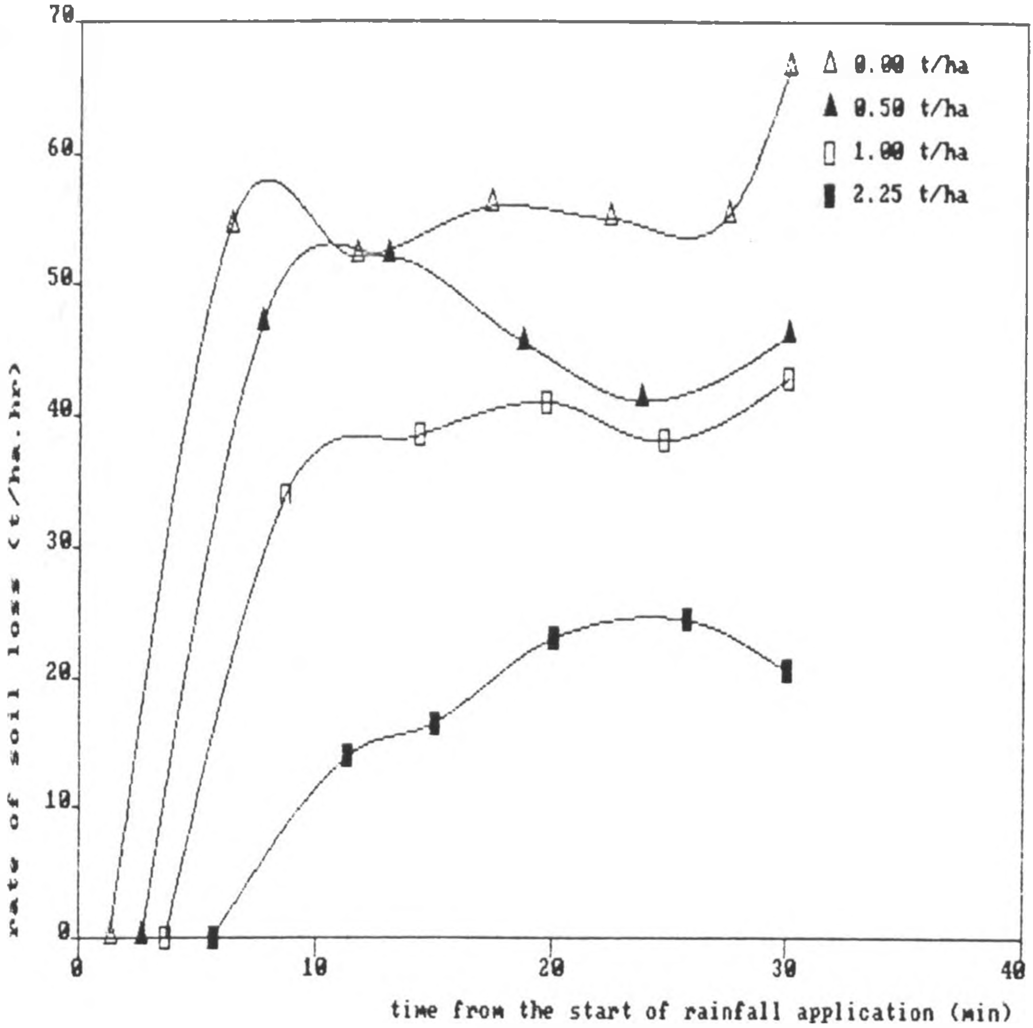


Figure 4.17:- Wet run soil loss rates

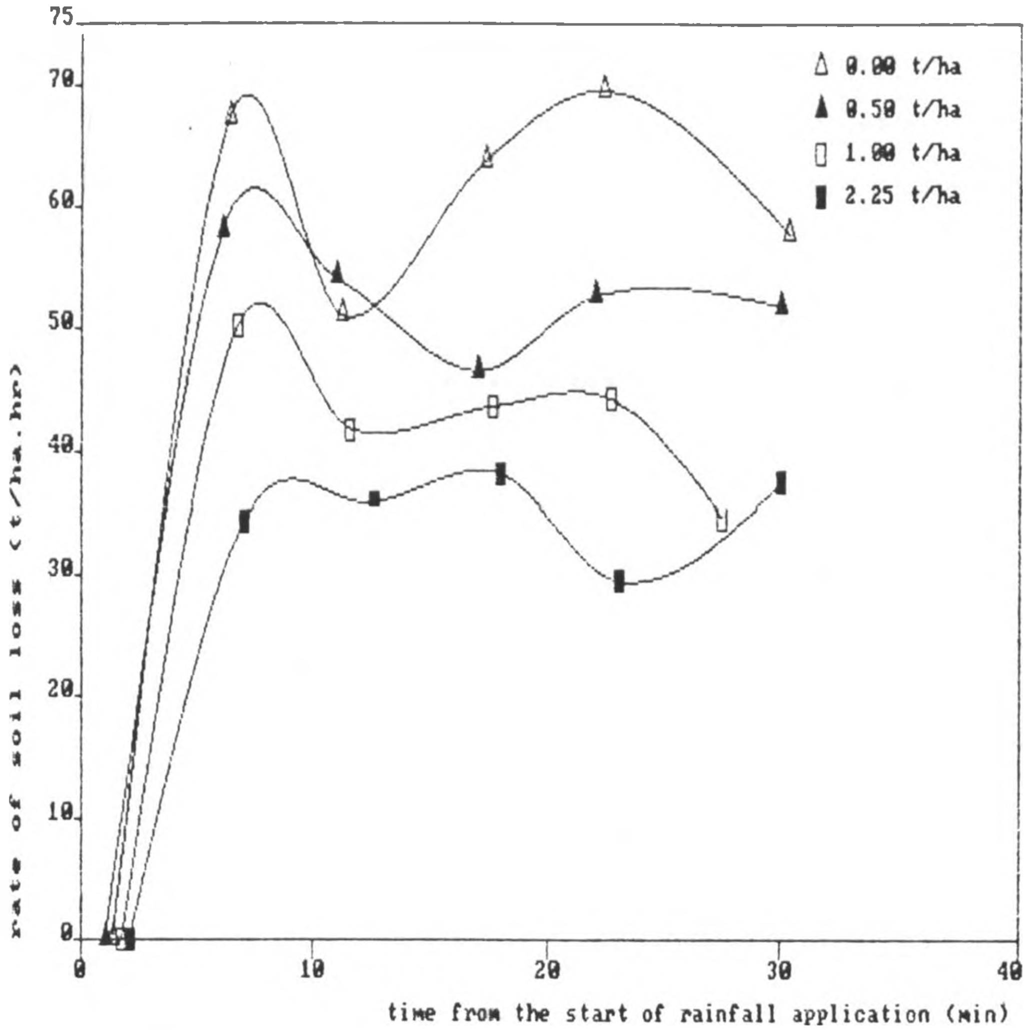


Figure 4.18:- V.wet run soil loss rates

4.4 Sub factor values of the C factor for surface scattered crop residue

Sub factor values for the c factor of the universal soil loss equation (USLE) obtained from the 1988 short rains, 1989 January rains and 1989 long rains, for the different maize residue treatments scattered on the soil surface are given in table 7. These sub factor values were obtained by dividing the soil loss from plots with a given rate of maize residue treatment by the corresponding loss from plots with out residue treatments. The lowest sub factor value was obtained during the 1988 SR and from plots with 2.25 t/ha maize residue application which was the highest rate in the experiment. Sub factor values decreased with increased residue application during all seasons. Lower values were obtained during the 1988 short rains than during the 1989 January rains and during the 1989 January rains than during the 1989 long rains.

Comparison of soil loss mulch factors derived for the simulation runs and averaged for the three runs (figure 4.15) and the mean sub factor values derived for each season and averaged for the three periods (table 4.7) show almost similar values for the respective treatments.

Table 4.7:- sub factor values of the C factor for surface scattered maize residue;

Season	Maize Residue rate in t/ha		
	0.50	1.00	2.25
1988 SR	0.60	0.17	0.12
1989 JR	0.71	0.55	0.45
1989 LR	0.90	0.84	0.78
Mean	0.74	0.52	0.45

SR = short rains

JR = January rains

LR = long rains

4.5 Field survey on the availability and utilization of maize residue

The survey was conducted in the tea, coffee, and cotton zones (The area denoted as cotton zone here, corresponds to the agroecological zones referred as UM3 and UM4 in the farm management hand book of Kenya volume II/B) of Muranga district in Central Kenya. The altitude ranges from 1600 - 2000 m in the tea zone, 1500 - 1600 m in the coffee zone and between 1400 and 1500 m in the cotton zone. The average annual rainfall ranges from 1700 - 2400 mm in the tea zone, 1180 - 1620 mm in the coffee zone and 800 - 1350 mm in the cotton zone(Jaetzold and Schmidt,1983). The survey included a total of 45 maize fields composed of 12, 18 and 15 farms from the tea, coffee and cotton zones respectively. All farms in the tea zone , 61% and 73% of the farms in the coffee and cotton zones respectively were one hectare and below in size, while 28% and 27% of the farms in the coffee and cotton zones respectively were between 1 and 2 hectares. 75%, 83%, and 73% of the farms in the tea coffee and cotton zones respectively were on general slopes ranging from 11 - 30%, while 25% and 11% of the farms in the tea and coffee zones respectively were having more than 30% general slopes. Maize is grown twice a year in all zones except in the upper tea zone where the growing period is much longer.

Table 8, shows the availability of maize residue in tonnes per tonne of grain for each zone. Measurement of the grain and residue harvested from a 1 m^2 sample area indicated a 1 : 2 ratio for grain to residue yields as minimum in the tea zone and a 1 : 1 ratio of grain to residue yields for the coffee and cotton zones. As high as 1 : 5 grain to residue yield ratios were measured on some fields in the tea and cotton zones while the maximum grain to residue yield ratio in the coffee zone was 1 : 3.

On the average an availability of 2 tonnes of residue per tonne of grain was indicated for all zones.

Table 4.8:- Availability of maize residue in tonnes per tonne of grain by zone;

zone	minimum	maximum	mean
Tea	2	5	3
Coffee	1	3	2
Cotton	1	5	2
Mean	1	4	2

Table 4.9, shows maize residue utilization on different farms in the three zones. On all farms in the tea zone, on 94 and 73% of the farms in the coffee and cotton zones respectively maize residue is used as feed and bedding material for animals. One farmer in the coffee zone and three farmers in cotton zone use to sell residue because they do not own animals. Other minor uses mentioned were mulching for potatoes, and for lighting fire although burning in situ was witnessed on two farms in the cotton zone during the survey. Some farmers said they use maize residue for erosion control in the form of trash lines, but, such use was observed only on one farm in the cotton zone.

Table 4.9:- Crop residue utilization by number of farms by zone;

zone	Type of residue utilization			
	animal feed	source of income	erosion control	tot. no. farmers
Tea	12	-	-	12
Coffee	17	1	-	18
Cotton	11	3	1	15
Total	40	4	1	45

Plate 4.1:- Residue being loaded on a lorry for animal feeding (near Maragua)

Plate 4.2:- Bundles of residue, ready for sale, along the main road from Nairobi to Muranga

5. DISCUSSION

The findings of this experiment were presented under different subheadings in the previous chapter to demonstrate better the influence of treatments on the different variables affecting the erosion process under the different experimental conditions. However, as treatment effect on one variable will also influence others, they are discussed under generalised headings in this chapter in order to avoid repetition of concepts.

5.1 The mechanism of surface residue in reducing soil erosion

Under all conditions of natural and simulated rainfall reduced runoff and soil loss resulted from increased application of maize stover as surface cover. Even the smallest residue rate of 0.5 t/ha which any farmer may easily afford to leave on his farm reduced the soil loss by 40% and 48% during the 1988 short rains and during the dry simulation run of a 65 mm/hr storm respectively, relative to the soil loss from the control plots .

This reduction in soil erosion due to the application of residue as surface cover is attributed to, the absorption of the impact energy of falling rain drops by the surface cover, reduction in runoff velocity by obstructing concentrated flow and increased surface roughness, the creation of physical barriers acting as "small dams" which facilitated deposition and provided time for infiltration and biological activities which may enhance soil infiltrability.

5.1.1 Absorption of the impact energy of falling rain drops

Wischmeier, (1975) assumed a 2.5 mm drop diameter to be representative of erosion producing rains and used it for analysis of the influence of changes in fall height on the effective erosivity index. A 2.5 mm drop starting from zero velocity will reach a terminal velocity of 7.41 m/sec in a fall of 20 meters or more, 6.34 m/sec in a fall of 4 meters, 4 meter/sec in a fall of 1 meter and 3 meter/sec in a fall of 0.5 meters (appendix 3).

The kinetic energy of a given mass is directly proportional to the square of its velocity. For example a 2.5 mm drop falling from a height of 0.5 m will have only 16% of the kinetic energy of a free falling rain drop of equal size, $3^2/(7.4)^2$.

For a cover material placed directly on the soil surface the impact energy of a falling rain drop then is essentially eliminated as there is no fall height remaining after being intercepted. The erosion index (EI), which is a measure of the erosivity of a given storm will also have no value in such cases as its value is the product of Energy and Intensity. Because an all most infinite number of rain drops fall during a storm event, not all the energy of a rain falling on a given area is expended before reaching the soil surface. Just how much of this energy will be used in detaching soil particles from aggregates depends on the amount of soil surface exposed to this energy. The more the area of surface covered, the less the number of drops striking the soil surface and hence the less the amount of soil detachment. Therefore,the reduction in soil loss as a result of residue application and with increasing surface cover is partly due to the effect of the maize residue treatments in reducing soil detachment by rain drop impact energy and in proportion to the amount of surface cover each treatment provided.

The relatively higher efficiency in reducing soil loss than the corresponding runoff values during the 1988 short rains (table 4.3) and the higher percentage runoff values than the corresponding soil loss values during all rainfall simulation runs (table 4.6) also suggest that the reduction in erosion during these periods was mainly due to the reduced soil detachment by the different cover rates.

5.1.2 Reduction in runoff velocity

As previously reported (Meyer et al., 1970, Gilley et al., 1986 b) during the rainfall simulation experiments runoff was observed following very tortuous paths on plots receiving cover treatments, a condition which decreases the effective slope steepness. In addition residue lying on the soil surface inhibited flow concentration and increased the surface roughness. Runoff velocity is therefore essentially decreased because of these influences.

5.1.3 Creation of physical barriers

Concentrated flow was observed either tending to pond or dispersing into smaller flows which are less eroding as it passes a residue lying along its path. The whole process may be described as follows ;

When runoff that concentrates on areas of no surface cover approaches a residue lying on the soil surface its speed decreases and it tends to pond. Consequently as it builds in depth it is either caused to follow the whole length of the residue if the residue is in close contact with the soil surface, until it is further obstructed by several other pieces and the process repeated several times or it finds its way down slope. Simultaneously part of the flow may get its way beneath the residue in the form of several tiny flows. In the process deposition of the previously picked sediment takes place. At times part of this sediment fills the space between the residue and the soil surface in which case further ponding and hence more deposition may result. This deposition is more favourably accomplished if a residue happens to lie across slope. There were cases where sediment ponds behind residue stretched upto 40 cm up slope behind residues lying across slope.

This whole process occurs several times and throughout the whole area of the plots, depending on the amount of residue cover on the soil surface and terminates at the outlet, when the runoff finally gets its way into the collecting trough. The net effect of this process was, delay in the commencement of runoff, reduced runoff and soil loss rates (figures, 4.8, 4.9, 4.10, 4.16, 4.17, 4.18) and increased infiltration (figures 4.11, 4.12, 4.13) with increasing surface cover. These factors in turn determined the total soil and water losses from plots with residue treatments.

5.2 The influence of rainfall intensity and antecedent soil moisture content on the effectiveness of surface residue in controlling erosion

A total of 261 mm of rainfall during the 1988 short rains, 134 mm of rainfall during the 1989 January rains and 828 mm during the 1989 long rains occurred during this study period. However, the seasonal soil and water losses were little influenced by the total amount of the seasonal rainfall. For example during the 1988 short rains a total of 111 mm of rainfall produced runoff causing a total soil loss of 6 t/ha and a seasonal runoff loss of only 4 mm from the control plots (tables 4.2 and 4.1). The effective erosivity index (EI30) value during this period was 396 MJ.mm/ha.hr.

On the other hand during the January rains, 48 mm rainfall of 1.6 hours duration produced a soil loss of 46 t/ha and a runoff loss of 22 mm from the control plots (tables 4.2 and 4.1). The erosivity index (EI30) for this storm was 407 MJ.mm/ha.hr. In other words this single storm having less than half the amount of rainfall of the 1988 short rains produced soil losses 8 times as great, and water losses 5.5 times as great as those produced by the short rains and had an EI30 value greater than the effective EI30 value for the whole short rainy season. Despite the relatively higher intensity of this storm antecedent soil moisture was almost similar during both periods.

Infact the short rains occurred as low intensity storms, it took longer time to fill the depressions created by tillage, for the soil to saturate and its intake rate to be exceeded. But, this January rain apart a 35 mm storm the previous day was also preceded by five dry days, infact very hot as January normally is in Nairobi.

The soil and water losses caused by the 1989 long rains were much greater. These rains started from late March and extended to early June. 15 storms with a total rainfall of 750 mm caused a soil loss of 355 t/ha and a runoff loss of 215 mm from the control plots(tables 4.2 and 4.1) during this season. Here also, one storm caused 25% of the soil loss, 28% of the runoff loss and had 47% of the effective EI for the season. Two storms caused 52% of the soil loss, 50% of the runoff loss and had 63% of the effective EI for the season, while three storms had 73% of the effective EI, although soil and runoff losses were little affected by the third storm.

Hudson,(1981) discussed similar findings in different countries. He quoted cases where a single storm caused 50% of the total erosion in 5 years, in Missouri and an event in Zimbabwe where three quarters of the yearly soil loss took place in a period of ten minutes.

The high erosivity index values of these high intensity rains indicates their ability to disintegrate soil aggregates and cause damage to some important properties of the surface soil. The depth of runoff produced by these high intensity rains was also big enough to overtop and break through the residue barriers. This led to the concentration of runoff along weak points and increased the velocity of flow. Deeper and wider rills extending throughout the length of the plots were formed as a result unlike the condition during the low intensity rains of the 1988 short rainy season.

Plate:- 5.1

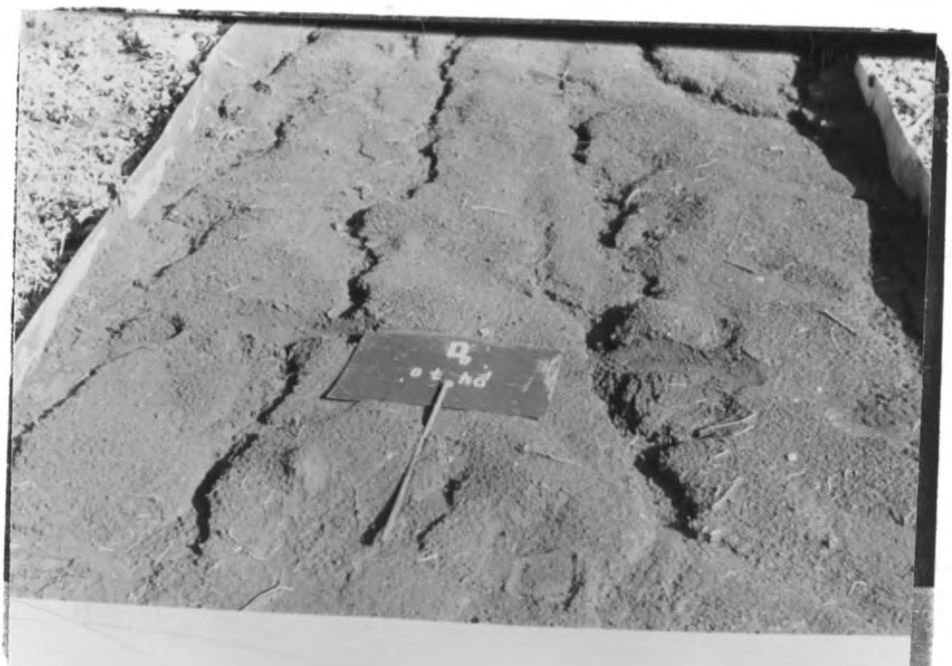


Plate:- 5.2

Plate 5.1 and 5.2 :- Condition of the control plots near the end of the 1989 long rains

With the formation of these rills then both detachment and transportation of soil particles by concentrated flow will be much higher than that which occurred in the case of the scattered small flows of the short rainy season. Higher antecedent soil moisture content almost throughout this season also should affect the rate of infiltration and contribute to increased runoff losses right from the beginning of a storm as demonstrated by the wet simulation runs (figures 4.8 to 4.13). With increase in runoff soil loss also increases. Therefore,unlike during the 1988 short rainy season, the reduced efficiency in reducing soil and runoff losses by the different cover treatments during the 1989 long rains is mainly attributable to the prevalence of rill erosion in almost all the plots and the high antecedent soil moisture content which favoured the commencement of runoff within a few minutes during a storm event, and its subsequent building up of depth to over top and break through the residue barriers.

The closeness of the percentage runoff and the corresponding percentage soil loss values for the different residue treatments during this season (table 4.3) further suggest that most of the soil loss was as a result of rill erosion rather than due to detachment from the uncovered soil surface.

Although, this condition mainly accounts for the very high soil and water losses during this season, there were also other factors which influenced the relative effectiveness of the various cover rates. The two heavy storms discussed earlier, that caused more than half of the soil and water losses, occurred at a time of depleted surface cover due to decay and termite activity and the presence of previously deposited loose soil behind decaying residue which was easily transportable.

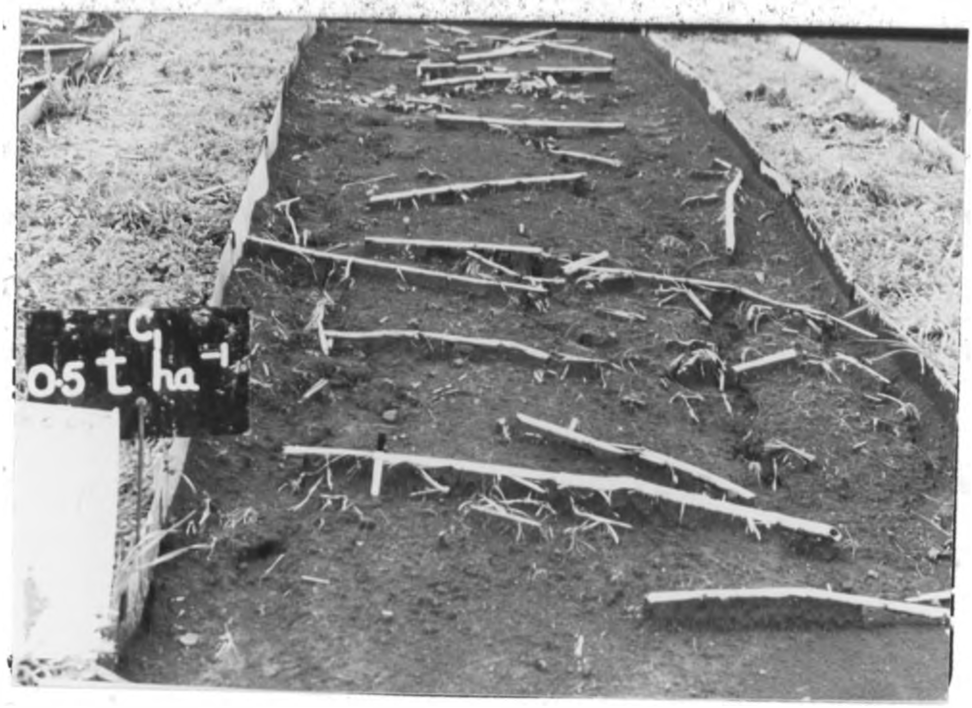


Plate 5.3:- A plot with 0.5 t/ha residue treatment near the end of the 1989 long rains

Plate 5.4:- Closer view of a plot with 0.5 t/ha residue treatment near the end of the 1989 long rains

The concentration of runoff along the plot boundaries which resulted in the formation of rills in almost all plots with residue cover also made its contribution to the high soil and water losses during this season, although, this would not occur under field conditions as agricultural fields are not commonly bounded as are runoff plots.

The possible effect of the strong winds associated with the rains during this season (although it was difficult to identify if a residue has been displaced after a heavy storm)in displacing and /or piling together of different pieces may not be neglected aswell, as such a condition would affect the portion of soil surface covered with residue and would eliminate the ponding effect achieved during previous storms. A considerable increase in soil erosion when rains are wind driven has also been reported by Lyles et al., (1969). They reported cases where a 56 mm/hr intensity simulated rain driven by a simulated wind having a velocity of 13.4 m/sec had disintegrated 95% to 97% of a heap of clods having sizes of 2.6 - 6.4 mm diameter within 5 minutes. It was also reported that, upto 66% more soil detachment occurred at 13.4 m/sec wind velocity than for no wind at the same rainfall intensity, duration and clod size.

Although the high rates of soil and water losses were partly due to the high intensity and highly erosive rains but also to the fact that , there was no crop growing and apart from residues there was no ground cover. If such heavy rains then occur near the beginning of the rainy season when crops are barely established , the potential for damaging erosion is clearly very high. for example, the coincidence of the occurrence of heavy storms with the planting period in the Andit tid area of Ethiopia

(Yohannes, 1989), where most of the residue from the previous season is used to feed animals was found to be one of the main reasons for the high annual erosion losses, which ranged from 78 t/ha - 218 t/ha as indicated by four years of test plot study.

On the other hand if such rains occur when crop cover is well established as it normally would be in Kabete by the end of May, then the potential for damage is much less. For example, the two heavy storms discussed earlier, occurred during a period when the growing crops have already developed approximately upto 40% canopy cover as observed from the surrounding fields planted to maize. This will help in further reduction of erosion losses. However, this condition should be considered with care, as it will be misleading to assume one season's rainfall pattern to represent the general rainfall pattern of an area.

But one thing is very clear here, the fact that such intense rains can occur, and the fact that they may occur before crop cover has developed emphasizes the need for effective erosion control measures.

This experiment has indicated the very important role that residues can play incontrolling erosion especially from light storms. They are also effective in controlling erosion losses from medium and high intensity rains if they occur at the beginning of a rainy season when soils are dry, as indicated by the dry and wet runs of a 65 mm/hr intensity rainfall simulation events. But, they are generally less effective when high intensity rains occur at high antecedent soil moisture content.

The potential reduction in seasonal soil losses of upto 78 t/ha indicates that much more attention should be given to the utilization of residues for erosion control. Although, we do not know the tolerable soil loss value for these nitosols, we do know that the losses which did occur during the experiment were much higher than the maximum figure of about 12 t/ha which is commonly used in USA.

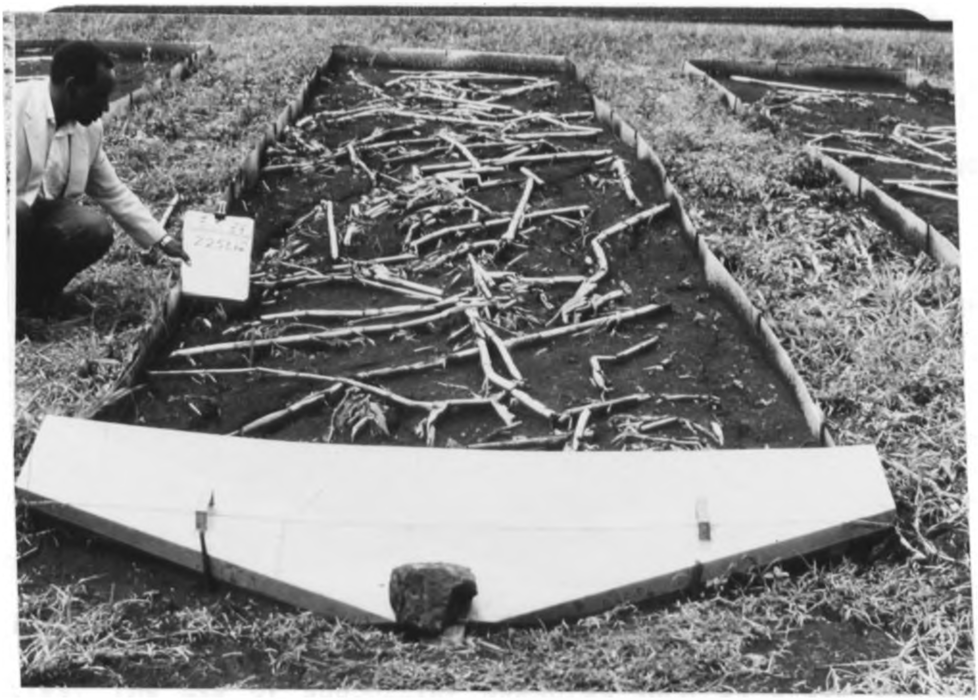


Plate 5.5:- a plot with 2.25 t/ha residue treatment near the end of the longrains

Plate 5.6:- Closer view of a plot with 2.25 t/ha residue treatment near the end of the 1989 long rains

Although, nitosols are considered to be much less erodible than some other soils in Kenya, such as luvisols, (eg. Barber et al., 1979), it is clear that very high losses can occur if there are heavy rains when the soil has neither plant nor residue cover and when the ground is already saturated by antecedent rainfall.

Although this study has showed that residue cover can play an important role in erosion control and its capability of erosion reduction was found to increase consistently with increase in residue cover, there are situations however, where residues are not available in sufficient quantities. The use of supporting measures such as grass strips and terraces is therefore essential, particularly on the higher slopes. But it should be remembered that, despite shortening of the slope length and the gradual effect in the reduction of the slope angle, grass strips or terraces don't prevent soil moving in the spaces between the grass strips or terraces. Residues which provide some degree of cover over the whole surface have the potential to reduce both soil detachment and transport at the place where these processes begin.

This experiment has also showed that a few intense storms occurring for a short period can cause most of the erosion during a season, than the more frequent low intensity storms. This condition emphasises the fact that, an efficient design of soil conservation measures for the area needs to be based on the condition under which the most erosion losses are likely to occur. Such a measure will then take care of these infrequent but highly significant events as well as the more frequent but less erosive storms.

5.3 Field observation and a possible alternative on the utilization of crop residues

More than 75% of the farms included in this survey in all the tea, coffee and cotton zones are on slopes ranging above 11% (appendix 5b) . Comparison of the average annual rainfall for the three zones with that of Kabete (the site for this experiment) also shows much higher values for the tea and coffee zones, while the area denoted as the cotton zone receives similar average annual rainfall as Kabete. These conditions suggest that the potential for erosion on fields where annual crops are grown is likely to be very high especially at the beginning or a rainy season when vegetation is barely established. This is evident from the signs of severe erosion which are clearly visible on 43% of the farms in the tea zone, 46% of the farms in the coffee zone and on 67% of the farms in the cotton zone (appendix 5e), eventhough, 67%, 66%, and 33% of the farms in the tea, coffee and cotton zones respectively receive some type of soil conservation measures.

On farms where soil conservation measures are applied, terraces alone are used, on all farms in the tea zone, and on 67% and 80% of the farms in the coffee and cotton zones respectively. One or two retention ditches constructed per farm constitute the remaining 33% of the conserved farm in the coffee zone and less than 20% in the cotton zone.

In all zones most of the farmers using terraces and retention ditches for conservation expressed their preference for these conservation measures, although, 33% of the farmers in the tea zone and 61% in the coffee zone complained of the high labour requirement for construction where as 25% in the tea zone and 11% in the Coffee zone mentioned the lack of skilled labour for layout.

No farmers, apart from one in the tea zone, complained about the requirement of regular maintenance after construction, even though most of the terraces lack maintenance, and paths of concentrated flow on terrace banks and the area below the banks were frequent on most terraced fields. In general this positive attitude of farmers towards these conservation structures is quite encouraging. But, it should also be remembered that inadequate maintenance of a conservation structure will inevitably lead to the failure of the structure and this at times is likely to cause more damage than that which could have resulted if no conservation structure was used.

During this survey it was also observed that, on almost all farms in each zone very little residue is left after harvest and in most cases it is either thrown in a heap or carried off during field preparation for seeding. Both conditions leave the ground without cover, at the start of the rainy season, when heavy rains are expected. Consequently high erosion losses are likely to occur.

In contrast the findings of this experiment have showed crop residue to be very helpful in reducing erosion losses if left as surface cover. The fact that residue cover was found to be exponentially related to both soil and runoff losses emphasizes that even small amounts of residue are worth retaining as surface cover. In view of this it is further envisaged that the introduction of similar use of crop residue in the smallholder farming systems of the Eastern Africa regions, to be of much help in reducing erosion losses.

For example, the fact that residue is mainly used to supplement grass for feeding animals, the availability of fodder grass during most parts of the year,and the awareness of farmers to the damaging effect of erosion losses, in this survey area are favourable conditions which facilitate the introduction of such a practice.

During this field survey it was also found that some farmers already have developed a positive attitude on the use of crop residue for erosion control, although in the form of trash lines. For example, when asked if they consider crop residue to have any effect in erosion control 47% of the farmers replied positively out of which 52% said they have used crop residue for erosion control in the form of trash lines at one time or another, though not regularly.

Wenner, (1980) also has reported that, temporary or some times permanent trash lines, which were 6 m apart, to have been used in Kenya for generations, on slopes of upto 12% . He also recommended trash lines as a first measure to develop bench terraces, a process which will be accomplished through the growth of local grasses along and through the trash lines starting after 1-2 years of being laid. Although, further experimental evidences may be required to substantiate if this alleged goal could possibly be achieved, presumably trash lines will have some effect in reducing seasonal erosion losses.

This effect will essentially be similar to that of grass strips. But unlike grass strips trash lines will not have firm anchorage to the soil. This may be one limitation that reduces the capability to withstand the trust of runoff and sediment expected to be accumulated behind the trash lines. It is also difficult to assume uniform growth of natural grass along the entire line, as it is possible to have even no grass growth at some points. Without a relatively uniform strip of grass along the entire line then, the damage from concentrated flow along weak points may even be worse. It is also clear that trash lines will not stop soil moving in the spaces between the trash lines as is the case with grass strips and terraces. The fact that residues may not be available in sufficient quantities is also another limiting factor as trash lines themselves being barriers will not be readily combined with other barriers such as grass strips or terraces.

On the other hand, the fact that even small amounts of residue are helpful in reducing erosion losses if used as surface cover and the higher chances of being used incombination with other supporting measures make the use of crop residue as surface cover preferable to the use in the form of trash lines.

6. Conclusions

1. Surface scattered maize residue was found to be helpful in reducing soil and water losses on a 16.4% ground slope. Total soil loss for three periods of measurement was 407 t/ha from the control plot , while it was 357, 323 and 298 t/ha from plots receiving maize residue treatments at rates of 0.5, 1, and 2.25 t/ha respectively. When soil loss ratios (soil loss from plots with a given amount of residue cover divided by the soil loss from the control plots)
for the three periods were averaged, subfactor values for the C factor of the universal soil loss equation for surface scattered maize residue were estimated to be 0.74, 0.52, and 0.45 for the 0.5, 1, and 2.25 t/ha maize residue treatments respectively. Averaging soil loss ratios obtained during a dry, wet and very wet rainfall simulation runs of a 65 mm/hr intensity storm, also gave similar values of 0.74, 0.57 and 0.35 for the 0.5, 1, and 2.25 t/ha residue treatments respectively.

Total runoff measured from the control plots during the three rainfall periods was 240 mm, while it was 214, 201 and 194 mm from the 0.5, 1, and 2.25 t/ha residue treatments respectively.

2. Surface scattered crop residues were found to be more effective in reducing soil and water losses from low intensity rains than from high intensity rains and during the early part of a rainy season when soils are relatively dry (even if a high intensity rain occurs) than later in the season when soils are already saturated with antecedent rainfall. The fact that residue cover was found to be exponentially related to runoff and soil losses further suggests that even low rates of residues are

worth retaining as surface cover.

3. Surface scattered maize residues were more effective in controlling inter rill erosion, when most of the soil loss occurs due to detachment by rain drop impact and shallow overland flow than from rill erosion by concentrated flow in small but well defined channels.

4. The results of this study have also shown that, given the rates at which crop residues are commonly available under the smallholder farming conditions in the Eastern Africa regions, the kind of slopes commonly used to grow annual crops and the nature of the high intensity rains in these regions, crop residues alone however, could not provide sufficient erosion control to keep the annual soil losses within acceptable limits. For efficient erosion protection, they need to be combined with other erosion control measures such as grass strips and terraces.

7. Recommendations

1. The use of surface scattered crop residue even at rates as low as 0.5 t/ha was found to have a considerable effect in reducing erosion losses.

Introducing this form of residue utilization be it alone or in combination with other supporting practices, to the small holder farming system in the Eastern Africa regions will have an important role in reducing the high annual erosion losses in these areas. While residue rates of more than 2 t/ha will presumably have very significant role on slopes below 10% , however, it will be more beneficial to combine this and lower residue rates with other supporting measures such as grass strips or terraces on steeper slopes. Encouraging farmers to pay more attention to growing fodder grasses for their animals on contour strips and/or terrace banks, will have a vital roll to play in this respect.

2. Further study to evaluate the performance of surface scattered crop residue under conditions where runoff plots are planted to crops and in combination with grass strips should be carried out. Information on the range of slopes and quantity of residues (based on the commonly available rates) where surface residue alone may provide erosion control to acceptable rates is also very vital to obtain.

3. Information on the condition of erosion under the different cropping and tillage systems in the Eastern Africa regions is very important. Knowledge of crop stage soil loss values and seasonal distribution of erosivity indices for the different localities is also very vital. Such information for example will allow determination of the cover and

management factor of the universal soil loss equation with better precisions. This inturn provides the chance to make better use of the erosion model for better prediction and planning of soil conservation measures.

4. Although runoff plot studies under natural rainfall are useful, rainfall simulation experiments are also important to get a better understanding of the basic erosion processes involved. They are very helpful for obtaining much of the information required within a short period incontrast to natural rainfall experiments which take quite a long time. This requires developing a rainfall simulating equipment, which is simple and economically appropriate to these regions. Such equipment should also be able to approximately reproduce the most important characteristics of tropical rain storms. This might require further studies to determine such important characteristics as drop size distribution, median dropsize, fall velocities etc. of these tropical storms. However, it needs to be done, if this challenge of soil erosion to the development of agriculture in these regions has to be minimized.

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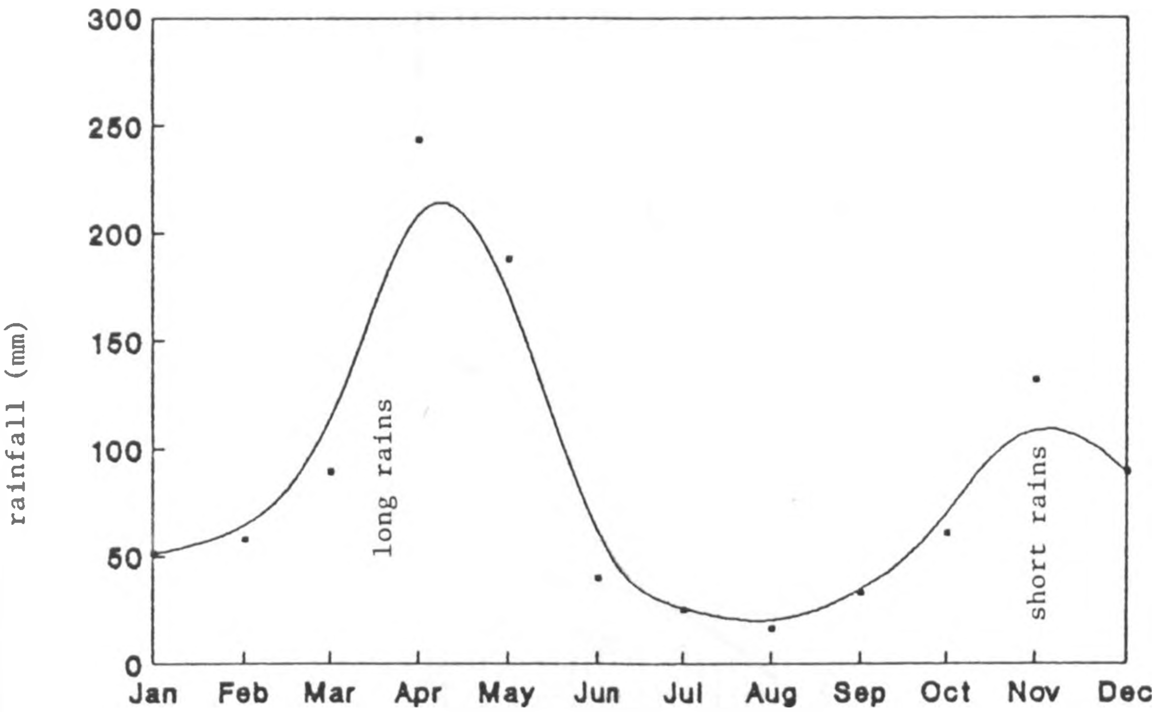
9. APPENDICES

Appendix 1.

Individual storm, soil and runoff losses during the 1989 long rains,

		Soil Loss (t/ha)				Runoff (mm)			
Date	RF. (mm)	0.00	0.50	1.00	2.25	0.00	0.50	1.00	2.25
21/3/89	32.4	5.55	3.46	1.95	1.11	2.18	1.45	0.81	0.59
7/4/89	45.1	1.56	0.51	0.31	0.32	0.67	0.37	0.21	0.16
9/4/89	22.8	2.92	1.61	0.92	0.38	1.1	0.71	0.4	0.26
24/4/89	35.4	28.78	22.81	15.28	12.72	9.26	7.51	5.46	4.59
25/4/89	36.7	21.3	19.51	17.09	15.83	6.64	5.85	5.57	5.28
27/4/89	22.9	7.52	7.4	6.12	5.84	3.56	2.83	2.68	2.43
7/5/89	112.4	95.48	87.9	81.04	79.91	46.89	39.35	40.31	39.74
8/5/89	18.2	1.6	1.43	1.09	1.04	1.73	1.59	1.29	1.37
9/5/89	50	13.89	13.09	12.56	11.29	16.92	15.85	14.55	13.73
11/5/89	49.7	9.4	8.57	8.11	7.04	11.1	9.86	9.17	8.99
12/5/89	56	28.43	24.41	22.59	20.54	26.79	25.92	23.17	2.34
14/5/89	32.8	9.36	8.07	8.1	7.14	6.23	6.18	6.1	5.26
17/5/89	26	7.35	6.57	6.78	5.29	3.98	3.93	3.94	3.78
18/5/89	182.5	90.31	85.49	87.35	83.82	60	58.57	60.31	58.2
3/6/89	26.7	31.62	29.81	27.79	25.19	17.93	17.43	15.1	15.71

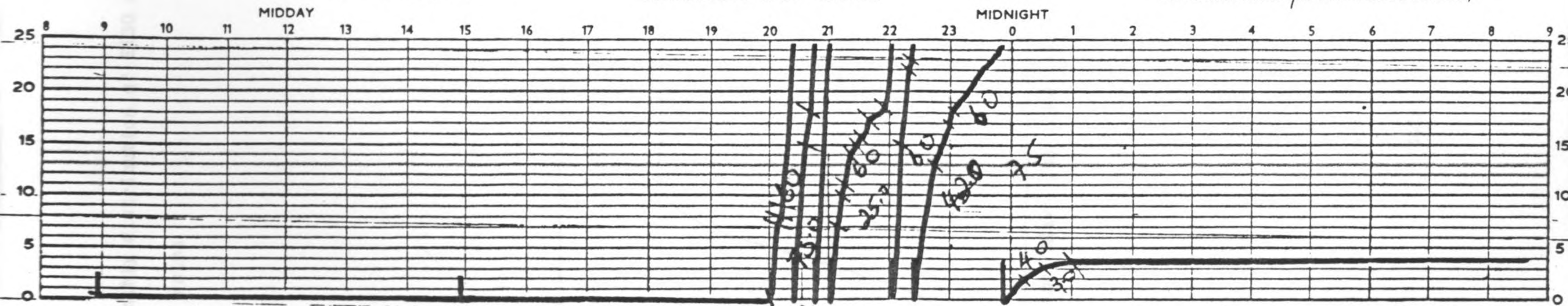
Appendix 2a :- Rainfall pattern at Kabete (based on 19 years record)



KABETE

DINES' TROPICAL
RECORDING RAIN GAUGE.

Date 18/05 1989

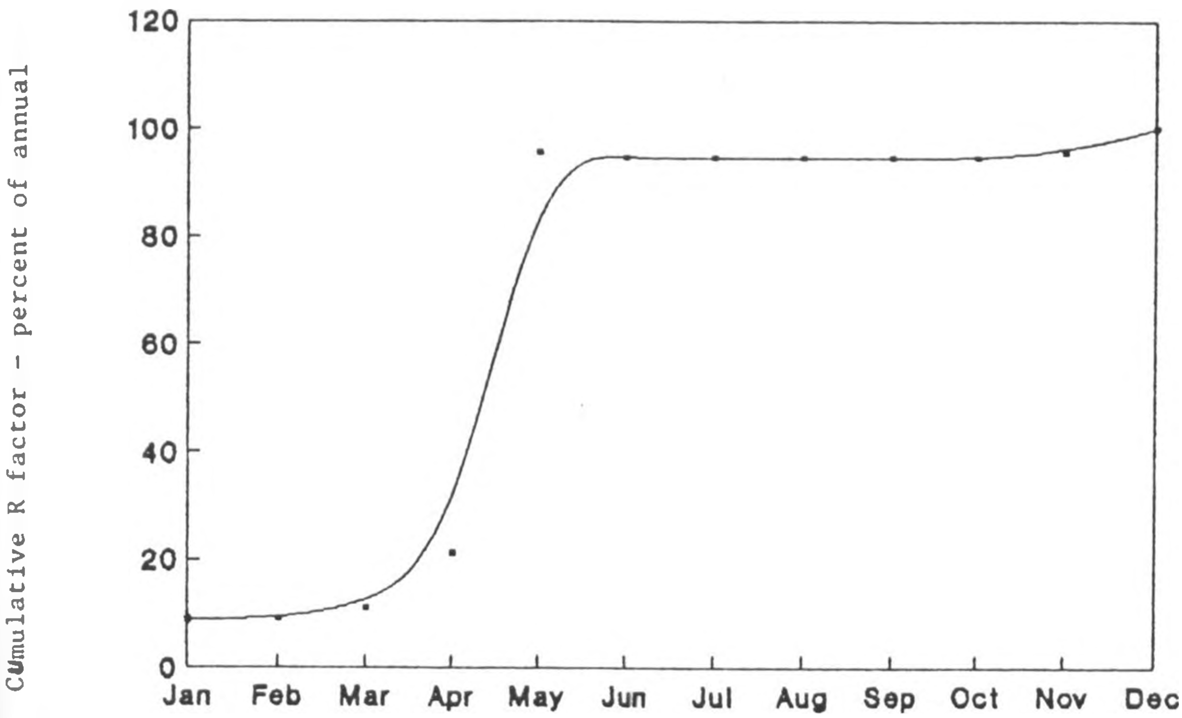


DURATION of RAINFALL 4.7 hrs TOTAL by RAIN RECORDER 153.5 mm TOTAL by CHECK GAUGE 9h to 9h 158.2 mm

Scales:—25mm of rain = 50mm 1 hr. = 11·4 mm. CHART No 2727/D/X/MM

THE BRITISH ROTOTHERM Co. Ltd., PORT TALBOT, SOUTH WALES

Appendix 2c :- Monthly distribution of EI30 at Kabete during the 1988 short and 1989 long rains



Appendix 3. Velocities, in meters per second, of falling water drops of different sizes after various heights of fall in still air**

(after Wischmeier, 1975)

Rain intensity (in mm/hr)	Median drop diam. (mm)	Drop fall height (meters) 0.5	1.0	2.0	3.0	4.0	6.0	20.0*
12.5	2.00	2.89	3.83	4.92	5.55	5.91	6.30	6.58
25	2.25	2.93	3.91	5.07	5.74	6.14	6.83	7.02
50	2.50	2.96	3.98	5.19	5.89	6.34	6.92	7.41
100	3.00	3.00	4.09	5.37	6.14	6.68	7.37	8.06

** From Laws, J.O. 1941. Measurements of the fall velocity of water drops and rain drops. Transactions of the Geophysical Union 22 : 709 - 721.

* Values in the last column are considered terminal velocities.

Appendix 4a. Anova table :- 1988 Short rains - Soil loss

Source	df	ss	mss	F calc	F table	
					0.05	0.01
Treatments	3	73.235	24.41	9.61**	3.86	6.99
Blocks	3	23.831	7.94	3.13ns		
Error	9	22.883	2.54			
Total	15	119.949				

Appendix 4b. Anova table :- 1988 Short rains - runoff

Source	df	ss	mss	F calc.	F table	
					0.05	0.01
Treatments	3	1647.651	549.22	9.88**	3.86	6.99
Blocks	3	718.018	239.34	4.31*		
Error	9	500.27	55.59			
Total	15	2865.939				

** - Significant at 1% level

* - significant at 5% level

ns - not significant

Appendix 4c. Anova table :- 1989 January rains - Soil loss

Source	df	ss	mss	F calc.	F table	
					0.05	0.01
Treatments	3	1485.693	495.231	9.79**	3.86	6.99
Blocks	3	720.717	240.239	4.75*		
Error	9	455.192	50.577			
Total	15	2661.602				

Appendix 4d. Anova table : - 1989 January rains - runoff

Source	df	ss	mss	F calc.	F table	
					0.05	0.01
Treatments	3	35063.355	11687.785	33.2**	3.86	6.99
Blocks	3	13559.863	4519.954	12.84**		
Error	9	3167.904	351.989			
Total	15	51791. 122				

** - significant at 1% level

* - significant at 5% level

ns - not significant

Appendix 4e. Anova table :- 1989 Long rains - soil loss

Source	df	ss	mss	F calc.	F table 0.05	F table 0.01
Treatments	3	15453.893	5151.298	8.27**	3.86	6.99
Blocks	3	11569.154	3856.385	6.19*		
Error	9	5607.923	623.103			
Total	12	32630.97				

Appendix 4f. Anova table : - 1989 Long rains - runoff

Source	df	ss	mss	F calc.	F table 0.05	F table 0.01
Treatments	3	217304.331	72434.777	12.67**	3.86	6.99
Blocks	3	48591.06	16197.02	2.83ns		
Error	9	51449.05	5716.56			
Total	15	317344.441				

** - Significant at 1% level

* - Significant at 5% level

ns - not significant

Appendix 4g. Anova table :- ' Dry run' - Soil loss

Source	df	ss	mss	F calc.	F table	
					0.05	0.01
Treatments	3	61.578	20.526	17.79**	4.76	9.78
Blocks	2	2.533	1.267	1.09ns	5.14	10.92
Error	6	6.912	1.154			
Total	11	71.033				

Appendix 4h. Anova table :- 'Dry run' - runoff

Source	df	ss	mss	F calc.	F table	
					0.05	0.01
Treatments	3	1227.357	409.12	9.67*	4.76	9.78
Blocks	2	68.779	34.39	0.81ns	5.14	10.92
Error	6	253.812	42.30			
Total	11	1549.948				

** - Significant at 1% level

* - Significant at 5% level

ns - not significant

Appendix 4i. Anova table : - Wet run - Soil loss

Source	df	ss	mss	F calc.	F table	
					0.05	0.01
Treatments	3	512.012	170.67	42.77**	4.76	9.78
Blocks	2	20.525	10.263	2.57ns	5.14	10.92
Error	6	23.94	3.99			
Total	11	556.477				

Appendix 4j. Anova table : - Wet run - runoff

Source	df	ss	mss	F calc.	F table	
					0.05	0.01
Treatments	3	7528.996	2509.665	9.81**	4.76	9.78
Blocks	2	272.928	136.464	0.53ns	5.14	10.92
Error	6	1534.715	255.786			
Total	11	9336.639				

** - Significant at 1% level

* - Significant at 5% level

ns - not significant

Appendix 4k. Anova table : - V. wet run - soil loss

Source	df	ss	mss	F calc.	F table 0.05	F table 0.01
Treatments	3	393.136	131.045	11.01**	4.76	9.78
Blocks	2	63.175	31.588	2.65ns	5.14	10.92
Error	6	71.413	11.902			
Total	11	527.724				

Appendix 4l. Anova table : - V. wet run - runoff

Source	df	ss	mss	F calc.	F table 0.05	F table 0.01
Treatments	3	3306.884	1102.295	12.09**	4.76	9.78
Blocks	2	3075.211	1537.606	16.86**	5.14	10.92
Error	6	547.234	91.206			
Total	11	6929.329				

** - Significant at 1% level

ns - not significant

Appendix 5 :- Field Investigation

Appendix 5a :- Farm size in ha (by No. of farms)

zone	1ha and below	1 - 2ha	2 - 4ha	total
Tea	12	-	-	12
Coffee	11	5	2	18
Cotton	11	4	-	15
Total	34	9	2	45

Appendix 5b :- general slope of the farms in the survey area

zone	(No. of farms in the different slope ranges)					
	0 - 5%	6 - 10%	11 - 20%	21 - 30%	> 30%	total
Tea	-	-	4	5	3	12
Coffee	-	1	11	4	2	18
Cotton	2	2	8	3	-	15
Total	2	3	23	12	5	45

Appendix 5c :- Amount of residue left on field after harvest (by No. of farms)

zone	percentage residue					
	0 - 20%	21 - 40%	41 - 60%	61 - 80%	81 - 100%	total
Tea	12	-	-	-	-	12
Coffee	16	2	-	-	-	18
Cotton	9	2	3	1	-	15
Total	37	4	3	1		45

Appendix 5d :- Problems anticipated if residue are left on field after harvest (by No. of farmers)

zone	farming operation	harbour insects and animals	prohibit plant growth	none	total
Tea	-	-	-	12	12
Coffee	-	1	-	17	18
Cotton	-	4	-	11	15
Total	-	5	-	40	45

Appendix 5e :- Severity of soil erosion (by No. of farms)

zone	v.little	little	moderate	high	v.high	total
Tea	-	2	4	5	1	12
Coffee	-	-	8	8	2	18
Cotton	2	1	2	6	4	15
Total	2	3	14	19	7	45

Appendix 5f :- Type of soil conservation measures applied (by No. of farms)

zone	Terraces	Others*	None	Total
Tea	8	-	4	12
Coffee	8	4	6	18
Cotton	2	3	10	15
Total	18	7	20	45

* - either retention ditches or temporary use of trash lines

Appendix 5g :- Portion of farm in percent receiving soil conservation measures (by No. of farms)

zone	< 25%	25 - 50%	50 - 75%	> 75%	total
Tea	5	5	-	2	12
Coffee	11	3	2	2	18
Cotton	12	3	-	-	15
Total	28	11	2	4	45

Appendix 5h :- Preference of the soil conservation measures by farmers (No. of farmers)

zone	v.little	little	preferred	well preferred	no response
Tea	-	4	4	-	4
Coffee	-	5	8	-	5
Cotton	-	1	4	-	10
Total	-	10	16	-	19

Appendix 5i :- Problems associated with the soil conservation measures applied (No. of farmers)

zone	lack of technical know-how	high labour req. for construction	the need for regular maintenance	none*
Tea	3	4	1	4
Coffee	2	10	-	6
Cotton		3	-	12
Total	5	17	1	22

* None - either the farmers do not use soil conservation measures or farmers said they had no problem with the type of soil conservation measure they use.

Appendix 5j :- Do you consider crop residue to have any effect in erosion control ? (No.of farmers)

zone	Yes	No	Total
Tea	4	8	12
Coffee	9	9	18
Cotton	8	7	15
Total	21	24	45

Appendix 5k :- Is there a time when crop residue was used for erosion control (No. of farmers)

zone	Yes	No	Total
Tea	-	12	12
Coffee	5	13	18
Cotton	6	9	15
Total	11	34	45

Appendix 5l :- Form of crop residue utilization in erosion control (No. of farms)

zone	as trash lines	any other form	none	Total
Tea	-	-	12	12
Coffee	5	-	13	18
Cotton	6	-	9	15
Total	11	-	34	45