EFFECTS OF RESIDUE MULCH RATE AND PLACEMENT ON INFILTRATION, RUNOFF AND SOIL LOSS OF A NITISOL.

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This thesis is dedicated to my mother, Flora Njuguna for her unwavering support in so many ways.

DECLARATION

I hereby declare that this thesis is my original work and has not been presented in any other University. All quotations have been distinguished by quotation marks and all sources of information specifically acknowledged.

Signed.................. Date. 21/6/94 ....

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

Signed.................. Date. 22-6-94 ....

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LIST OF ABBREVIATIONS AND SYMBOLS

SAREC. - Swedish Agency for Research Cooperation with Developing countries.

ILRAD. - International Laboratories for Research on Animal Diseases.

°C - Degrees centigrade.

et al. - And others.

Fcal. - Value obtained in an analysis of variance test to determine the significance level of two or more variables.

Fig. - Figure.

g - Gram.

h - Hours.

J - Joules.

kg - Kilograms.

E - Rainfall kinetic energy.

I - Rainfall intensity.

EI - The product of rainfall kinetic energy and intensity.

m - Metres.

mm - Millimetres.

cm - Centimetres.

% - Per cent.

Anova - Analysis of variance.

t/ha - Ton per hectare.

Σ - Sum.

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ABSTRACT

The effects of residue mulch rate and placement on infiltration, runoff and soil loss was studied under natural rainfall on a 16% slope of humic nitisol at Kabete, Nairobi, Kenya.

The study had five treatments which were replicated three times. The treatments were, distributed mulch at a rate of 1.5 t/ha, distributed mulch at a rate of 3 t/ha, lined (trashlined) mulch at a rate of 1.5 t/ha, lined (trashlined) mulch at a rate of 3 t/ha, and control with no mulch. In total, there were 15 plots, each of 2 m by 10 m. Maize crop residues were used. Two way analysis of variance (ANOVA) and Duncan's multiple range test were used in comparing the treatment effect on infiltration, runoff and soil loss. The experiment was cropped with beans during the short rains 1992. Maize planted during the long rains 1993 failed due to drought.

Results showed that:

The mulch treatment effect was significant in increasing infiltration and reducing runoff and soil losses. Distributed mulch at 3 t/ha, lined mulch at 3 t/ha, distributed mulch at 1.5 t/ha and lined mulch at 1.5 t/ha reduced soil loss by 78 %, 74 %, 60 % and 50 % of that from the unmulched (control) plot respectively. Further, lined mulch at 3 t/ha, distributed mulch at 3 t/ha, distributed mulch at 1.5 t/ha and lined mulch at 1.5 t/ha reduced runoff volume by 69 %, 67 %, 54 % and 44 % of the control's runoff respectively. Infiltration depth was deepest in lined mulch at 3 t/ha followed by distributed mulch at 3 t/ha, distributed mulch at 1.5 t/ha, lined mulch at 1.5 t/ha and control respectively. Analysis of variance (ANOVA) showed that there were significant differences in runoff and soil loss among the treatments at P=1%. Comparison of the treatments using Duncan's method showed that only the control treatment was significantly different from the mulch treatments at P = 0.05. However, there was no significance difference in infiltration depth among the treatments. The mulch treatments significantly increased crop yield. Comparison of the treatments using Duncan's method showed that yield from the control was significantly less than that obtained from treated plots at P = 0.05.

It was concluded that use of low cost soil and water conservation methods, like use of crop residues, should be encouraged. Where crop residue is scarce, low rates should still be used as they will be better than nothing. Where crop residue is abundant, high rates would have a beneficial effect. Depending on the availability of crop residue, labour, and type of farm operations which take place, a farmer could be advised to use either distributed or lined mulch at 1.5 t/ha or 3 t/ha. However, where only very small quantities of mulch are available, the farmer could be advised to use it together with other conservation methods as it has been shown that small quantities of mulch will not be adequate to control soil and water losses during heavy storms. All these would

enable the resource poor farmer to control soil and water losses and eventually increase crop yield.

1. INTRODUCTION

1.1 Background and objectives

Increases in agricultural production are possible through modern methods, but these advances in science will be useless unless there's enough good land for farming. "If the soil on which all agriculture and human life depends is wasted away then the battle to free mankind from want cannot be won" (Dudal,1980). To win the battle, we have to reclaim and protect our land from major degradation processes and in particular soil erosion.

Soil erosion by water still remains the major process through which top soil is lost and soil degraded. Reduction in soil fertility is caused by soil and nutrient losses through leaching and runoff (Chisci , 1981). Further, the removal of top soil reduces water holding capacity and causes permanent damage to the land. The damage may be far worse in the developing countries where there is little awareness of the erosion hazard, low level of know-how and limited allocation of resources to combat the problem. There is therefore a need for adequate research on appropriate soil and water conservation techniques which are not only cheap but also acceptable to farmers.

The conservation of soil and water is essential for maintaining or increasing food production. However,the selection of a desirable conservation system is difficult because it must satisfy several requirements, which include (a) providing an economic level of crop production, (b) controlling soil erosion, (c) controlling runoff and (d) limiting movement of nutrients from agricultural land. Most of the conservation systems which are used are very expensive and require frequent maintenance. The tough austerity measures taken by the Kenya government and the World Bank have resulted in a higher cost of living which will hinder many small scale farmers from using these expensive conservation systems. It is therefore, imperative that we find other cheaper soil and water conservation techniques which could easily be adopted by our farmers and also meet most of the above requirements.

In Kenya, soil erosion is a pressing agricultural problem. It presents a major threat to all aspects of land productivity. Each year thousands of hectares undergo land-use changes. Forests and grasslands are continuously being converted to agricultural uses, and rural lands are becoming urbanized. Each change that alters the ground cover is a potential catalyst for erosion. These changing lands are the sources of large quantities of sediment that pollute streams and fill reservoirs when it rains.

Excessive soil erosion by water is a by-product of today's intensive agriculture. It results also from road and building construction and cultivation in the fragile eco-systems (steep-land and semi-arid areas) due to increased population. Continued excessive soil erosion has serious implications for the quality of life in Kenya. If unchecked, it threatens the basic element of life by decreasing the ability of Kenya's land resources to produce the food supply that Kenyans need and by degrading the quality of water. The economic and social costs of soil erosion are enormous and widespread. With the continuation of present management, these costs may be expected to be compounded progressively. Lower agricultural productivity resulting from soil misuse will lead to scarcity of cheap food. This will lead to further misuse of already cultivated land and cultivation of other lands that is even more vulnerable to erosion.

The erosion problem and related solutions are multifaceted and multi-displinary. In addition, there are strong linkages between soil erosion and land-use management and practices. Hence a number of government ministries,agencies, parastatals, and donor organizations are working actively to combat soil and water losses in Kenya. However, inspite of all these activities, the problem of soil erosion is still a threat, particularly on steep slopes and in semi-arid areas. This is probably due to lack of adequate research to find out cheaper soil and water conservation methods which could be used together with other conservation structures, and that are acceptable and affordable to peasant farmers.

The trend of soil and water conservation in Kenya has been to place more emphasis on physical measures than cultural ones. Physical measures, despite their immediate effectiveness right after installation, are potentially dangerous, for they concentrate surface water into channels which can cause serious damage if they fail and they need adequate maintenance and repair at suitable intervals (Hudson, 1971). The high installation and maintenance cost of conservation structures has discouraged many small scale peasant farmers from using them to curb soil loss. Therefore, to reduce soil erosion to a very low level, we need research on cheaper methods which are likely to be adopted by the farmers. One such method is the use of crop residues. A study was therefore carried out using crop residues. The crop residues were either placed in trashlines (lined) or scattered on the surface. Rates of 0 t/ha, 1.5 t/ha and 3 t/ha of crop residues were used. In total, there were five treatments which were replicated three times. The study had the following objectives:

(a) Overall objective

i) To establish the effects of lined and spread residue mulch at different application rates on runoff and soil loss of a nitisol.

(b) Specific objectives

i) To measure surface runoff and soil loss of a nitisol.

ii) To compare the effects of residue placement on infiltration, runoff and soil loss.

iii) To evaluate the effectiveness of mulch application at rates of 0 t/ha, 1.5 t/ha and 3.0 t/ha in reducing runoff and soil loss.

iv) To determine the use of maize residue on selected farms in Makuyu division, Murang'a district.

v) To compare crop yield at different mulch rates and placement methods.

1.2 Research study area

The research was carried out at the S.A.R.E.C. site in the Kabete campus field station, at the University of Nairobi. The area covered by the S.A.R.E.C. site is about 4 hectares. The research site was started with the following objectives:

(i) To provide facilities for postgraduate students and staff to carry out research into problems of conservation, especially on steep slopes.

(ii) To demonstrate both structural and agronomic approaches to conservation of steep slopes and to provide opportunities for learning by observation.

Kabete lies 1°15'S and 36°44'E at an altitude of 1930 m above sea level,in an agro-climatic zone referred to as semi-humid (Sombroek et al. 1980). The area has a bimodal distribution of rainfall with long rains occurring from early March to late May and short rains from October to December. The mean annual rainfall is about 925 mm. The annual evaporation is estimated at 1727 mm. Temperature ranges from a maximum of 26°C in February to a minimum of 13°C in July. Extensive cloud cover is common during the months of July and August when there is often a slight drizzle and evaporation rates are low.

The soils of Kabete are humic nitosols (Sombroek et al. 1980) which are called Rhodic paleudult in the U.S.A. Taxonomic system.

1.3 Significance of study

The soil erosion problem will continue to be of major concern as Kenya's population keeps on increasing. The population growth rate has been at 4 per cent per year (1979 National population census). The total area of Kenya is 583,000 km^2. Eighty percent of the land has a limited agricultural potential on account of low and unreliable rainfall. As the population increases, more and more people will move and open up more fragile ecosystems, particularly the steep and semi-arid areas. These areas require appropriate conservation measures capable of protecting the soils from being washed away during high rainfall events. Further, the measures should be acceptable to the local farmers.

Adequate soil conservation measures are therefore essential if we have to overcome the soil erosion menace. This calls for the development - through relevant basic and adaptive research and extension services - of cheap and acceptable soil and water conservation techniques. Such techniques includes use of crop residues in soil and water conservation.

This study therefore attempts to monitor, evaluate and compare effect of various residue mulch rates and placement methods on infiltration, runoff and soil loss. These should not only conserve soil and water but should also reduce surface runoff. Thus the soil conserved should sustain high soil productivity.

2. LITERATURE REVIEW

2.1 Crop Residue Mulch

2.1.1 Definition

Mulch is defined as any material at the surface of the soil which can reduce moisture losses through evaporation, keep weed growth down, increase infiltrability of the soil profile, enhance mineral nutrients availability and increase organic matter in the soil (Gicheru, 1990). Mulch can also be defined as protective covering (e.g. straw, rotting leaves or plastic sheeting) spread over the roots of trees and bushes to retain moisture, kill weeds, etc (Cowie 1989).

2.1.2 Effect of crop residue on runoff and soil loss

Russell (1973) defined mulching as the practice of applying a layer of dead vegetable waste material, such as straw, hay or old grass, compost or farm yard manure, to the surface of the soil. Further, mulching can be defined as the covering of the soil with crop residues such as straw, maize stalks, palm fronds or standing stubble. The mulch cover protects the soil from raindrop impact and reduces the velocity of runoff and wind (Morgan, 1986). Mulch simulates the effect of a plant cover. Mulching can be organic or inorganic, natural or man-made, soil-enriching or inert (Darrel et al. 1986). Mulching increases soil moisture, prevents soil erosion, moderates soil temperature, and increases seedling establishment. Mulches intercept raindrops and absorb the kinetic energy, and reduce the puddling and splashing they create when they hit the soil surface. Mulches also reduce water erosion by slowing runoff, reducing the scouring effect of the runoff, and allowing more time for the water to infiltrate the soil (Gardner and Woolhiser, 1978). The effect of mulching on the soil and water conservation has been reviewed by Jacks et al. (1955) and McCalla and Witfield (1962). Lal (1975) advocated using mulch and residue on the soil surface to reduce runoff and control wind erosion on fallow land in arid climates. Extensive experiments on use of mulches in soil and water conservation were also done by various researchers. Lal (1975) quotes Duley and Kelly (1939) who found that covering the soil surface with straw increased infiltration and prevented the formation of a thin, compacted, slowly permeable layer caused by raindrop impact on bare soil. Also, Moges (1989) quotes Borst and Woodburn (1942 a and b) who attributed the effect of mulching in reducing runoff and soil loss to increased surface detention and decreased rate of runoff. Gilley et al. (1986) found that small soil loss resulted from increased residue application. Small amounts of surface cover produced substantial reduction in erosion. Taylor and Hays (1960) found in USA that a heavy mulch of corn stalks and manure provides excellent erosion control on corn followed by corn on Fayette siltloam on a 16% slope. Similarly, Khan et al. (1988) found that runoff was significantly reduced by increased mulch cover but was unaffected by canopy cover or canopy height. However, soil loss was significantly reduced by increased mulch cover and also by canopy cover when cover was less than one metre above the soil surface. Foster and Meyer (1975) found that residue cover has a strong effect on soil erosion by water. Runoff and soil loss decreased greatly with an increase in residue cover or surface roughness. Further, Whitaker et al. (1961) reported that a large amount of plant residue greatly reduced serious soil and water losses from sloping clay soils. Experiments done by Finkner et al. (1986) showed that maize residue produced substantial reduction in runoff rate, runoff velocity, sediment concentration and soil loss rate along the entire slope length. Mulch reduced detachment of soil by rainfall.

Large and small amounts of crop residues reduce runoff and water losses. Work done by some researchers has shown that small amounts of crop residues reduce soil loss to some extent. Finney (1984) found that small portions of cover reduces soil erosion, though not to a very great extent. Berg (1984) found that small amounts of straw placed uniformly in steep sloping portions of irrigation furrows reduced soil erosion and sedimentation. Reduction ranged from 30 - 100% in straw treated furrows compared to furrows without straw. Apart from the above mentioned research findings involving small quantities of mulch, more work has been done by some researchers which has proved that mulch is effective in reducing runoff and soil loss. Mannering and Meyer (1961) applied 6.25 inches of simulated rainfall at a rate of 2.5 in/hr to mulched and unmulched plots on a 5% slope. The soil loss on the unmulched plots was 12 tons/acre (30 t/ha). No runoff and soil losses were recorded from the plot that received mulch at the rate of 2 tons/ acre (5 t/ha). With one ton/acre (2.5 t/ha) of mulch the soil loss was only 0.2 ton/acre (0.5 t/ha); with 0.5 ton/acre (1.25 t/ha) of mulch the soil loss was 1 ton/acre (2.5). Swanson et al (1965) reported that mulches effectively controlled erosion on a 6% slope. Adams (1966) found that straw and gravel mulch decreased runoff and erosion. Barnett et al. (1967) reported that mulching effectively protected newly seeded 40% backslopes from erosion. In their studies, they found that the average runoff and soil loss for all mulch treatments was 17% of rainfall and 3.34 tons/acre (8.5 t/ha), respectively compared to 38% of rainfall and 20.2 tons/acre (50.5 t/ha) for the unmulched plots.

The effectiveness of mulching in reducing erosion is demonstrated further by the field experiments of Borst and Woodburn (1942a) who found that, on a silt-loam soil on a 7° slope, annual soil loss was 2.46 $kg.m^{-2}$ from uncultivated, bare land but only 0.11 $kg.m^{-2}$ on land covered with a straw mulch applied at 0.5 $kg.m^{-2}$. Similar results have been obtained in laboratory studies for the same soil, slope and mulch conditions by Lattanzi, Meyer and Baumgardner (1974). These authors quote soil loss rates under simulated rainfall of 1.87 $kg.m^{-2}.h^{-1}$ with no mulch and 0.31 $kg.m^{-2}.h^{-1}$ with mulch. Applying a mulch of lalang grass (*Imperata cylindrica*) at a rate of 0.3 $kg.m^{-2}$ to maize grown on a sandy loam soil on a 4° slope on the experimental farm of the University Pertamian Malaysia, near Serdang, Selangor, reduced the soil loss over the period from October 1978 to July 1979 to 0.05 $kg.m^{-2}$ compared with 0.75 $kg.m^{-2}$

recorded for maize grown without a mulch and 1.95 m^{-2} for bare soil (Mokhtarudin and Maene, 1979). Using pruned fronds to cover harvesting paths in an oil palm plantation in Johor, Malaysia reduced annual soil loss to 0.42 $kg.m^{2}$ from 1.49 $kg.m^{-2}$ recorded on unprotected paths (Mokhtarudin and Maene, 1979). Lal (1976) found that covering an alfisol on a 6% slope with 0.6 $kg.m^{-2}$ of straw mulch resulted in an annual soil loss of 0.02 $kg.m^{-2}$, a considerable reduction compared to 2.33 $kg.m^{2}$ recorded for bare soil. A mulch of 0.11 $kg.m^{2}$ of standing wheat stubble residue or 0.22 $kg.m^{-2}$ of flattened wheat straw will reduce annual wind erosion rates to a tolerable level of 0.02 $kg.m^{-2}$. To achieve the same effect with sorghum stubble requires a mulch of 0.67 $kg.m^{2}$ (Chepil and Woodruff, 1963). In Kenya, an experiment conducted in Kericho District by Othieno (1979) on a 10% slope to assess soil erosion on a field of young tea under different soil management practices showed that mulch was the most effective treatment for controlling soil erosion.

There is considerable experimental evidence (Wischmeier, 1973, Lal, 1977 ; Foster and Meyer, 1975; Laflen and Colvin, 1981) to show that the rate of soil loss decreases exponentially with the increase in percentage area covered by a mulch. However, Laflen et al.(1978) found that a given residue cover was less effective in reducing soil erosion on plots of 12.2% averaging slope than on plots of about 5% slope. (Laflen and Colvin ,1981) recommended that mulch should cover 70 - 75 % of the soil surface in order to adequately protect the soil. With straw an application rate of 0.5 $kg.m^2$ is sufficient to achieve this. A lesser covering does not adequately protect the soil whilst greater covering suppresses plant growth.

Mulch has a distinct advantage for soil erosion control on tropical soils. The rain drop direct impact on the soil is reduced by mulching and the runoff losses are minimized because the soil infiltrability is maintained at maximum. Runoff water from the mulched plots is generally clear with minimum sediment (Lal, 1984). Runoff water from the unmulched plots is unclear with a lot of sediment. This is what happens during high rainfall in unprotected agricultural lands, especially on sloping areas. Soil and associated plant nutrients eroded from agricultural watersheds has been recognized as a major component in the siltation and eutrophication of lakes and rivers/streams (Stein et al. 1986).

Meyer et al. (1983) pointed out that transport capacity and not soil detachment is usually the factor limiting soil loss from furrows with low slopes. Therefore, sediment yield may be slight even when interill erosion rates are high.

2.1.3 Benefits of crop residues in water conservation

Mulch application in cropped land helps in conserving moisture by reducing evaporation rate. In arid and semi-arid areas, mulching could be used in conserving water for crops. By reducing evaporation, mulches will help to conserve water in soil and, by keeping high water content near the surface for a longer time, mulches promote seed germination and seed survival (Gardner and Woolhiser, 1978). Soil moisture reserves under mulch tillage are consistently higher than that under conventional ploughing. During periods of long, dry spells there may not be a significant increase on moisture storage under mulch over conventional tillage if the overall moisture holding capacity of the soil is low (Lal, 1974).

Mulching also improves the soil moisture regime by decreasing losses caused by surface runoff. Mulch affects soil moisture storage indirectly by controlling soil erosion because since unmulched plots becomes severely eroded the loss of surface soil eventually decreases the soil water holding capacity (Lal, 1974). Some mulches increase the penetration of rain or irrigation water and reduce runoff. In some parts of South west USA, mulches are used to prevent soil surface crusting which can hinder seed germination and seedling emergence (Gardner and Woolhiser, 1978).

Moreover, mulching increases phosphate uptake by crops, partly because it contains phosphates but principally because it encourage the surface rooting of the crop, and keeps the surface soil moist for a longer time. It increases the length of time the roots can take up phosphate from the surface soil, where decomposable organic and fertilizer phosphates are concentrated (Russell, 1973).

2.1.4 Effectiveness of crop residues for water conservation

Crop residues are generally most effective for water conservation when applied on the surface. Surface residues facilitate infiltration by slowing runoff and absorbing raindrop impact that reduces soil puddling and crusting. The actual amount of water conserved by a residue mulch depends on a number of factors including type, amount and placement of the residues, precipitation and climatic characteristics, length of fallow, tillage practices and soil type (Papendick and Parr, 1978). The way the crop residues are managed during periods of high runoff and evaporation is important in determining the effectiveness of residues for soil and water conservation.

Crop residues placed on the surface increase soil water. Experiments conducted by Greb (1983) showed that increases in soil water from mulches were significant and roughly proportional to the amount of surface residues over the range of 2.2 - 6.6 t/ha. The storage efficiency of mulch decreases slightly with increase in mulch rate. Studies by Unger (1978) in Texas showed that 1 t/ha application of wheat straw increased soil water during on an 11 - month fallow by 36 mm; at a rate of 4 t/ha, each tonne increased soil water by 12 mm and at 8 t/ha, each tonne increased soil water by 10 mm.

Use of crop residues in the farm helps in saving a lot of water which would otherwise be lost. Greb (1983) found that each t/ha of crop residue saves about 9 mm of water from evaporation. Further, research work conducted by liniger (1992) in Laikipia showed that mulching reduced runoff and evaporation and as a result, the maximum storage of plant-available water was between 45 and 110% more than in areas where no mulch was used. Therefore, using crop residues in semi-arid areas would help in conserving water - which is needed most - for crop production.

2.1.5 Principles of water conservation by crop residues

The potential for significantly reducing evaporation lies in the first two stages of soil drying (see figure 1). Evaporation requires heat. Any surface condition that reduces the exchange of heat between the soil surface and atmosphere will slow the evaporation rate during either the first or second stage of drying. Surface conditions such as mulches of crop residues exert the greatest influence on the first stage (wet soil surface) of drying (Massee and Carey, 1978).

A residue mulch conserves water in three ways (Papendick and Parr, 1978). First, it tends to reflect more sunlight than most soils. Second, a mulch act as a thermal insulator and restricts the flow of heat from the atmosphere to the soil. Third, the mulch creates a dead air space above the soil surface, which reduces the transfer of vapour from the soil to the atmosphere.

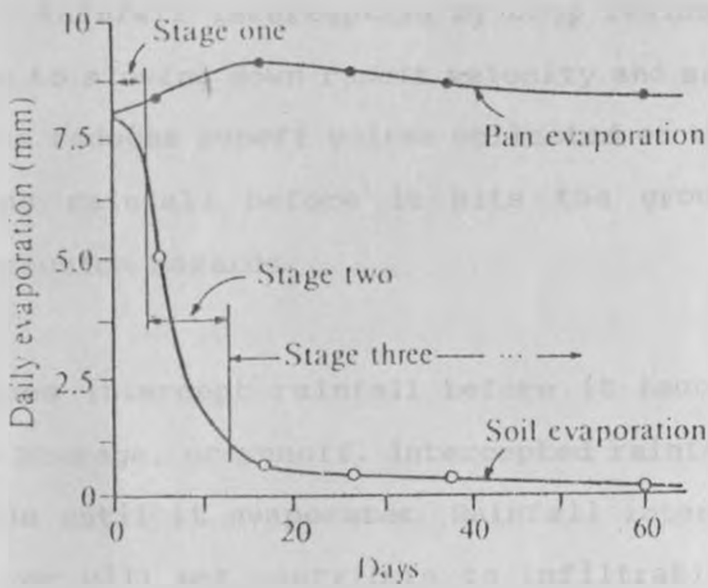


Fig 1. Different stages of soil drying as related to time and rate of soil-water evaporation (After Massee and Carey,1978).

Based on the above principles, its evident that, generally, surface residues reduce evaporation most during the rainy season when the soil surface is wet and in the first stage of drying. Slowing the evaporation rate in these conditions favours deeper soil-moisture penetration because it extends the duration of moisture movement. However, when rains cease and extended drying occurs, cumulative water loss from a residue-covered soil can exceed that from a bare soil. This is because the first stage of evaporation is slower and longer under residues, whereas the bare soil will dry at the surface and go into the second stage of drying more rapidly, thereby sharply decreasing the water loss rate and total amount (Massee and Carey, 1978).

2.1.6 Rainfall interception by crop residue

In addition to slowing down runoff velocity and sediment transport, crop residue reduces runoff volume collected on the land surface by intercepting rainfall before it hits the ground. This reduces potential erosion hazards.

Crop residues intercept rainfall before it becomes infiltration, depression storage, or runoff. Intercepted rainfall is retained by crop residue until it evaporates. Rainfall intercepted by a dense residue cover will not contribute to infiltration or runoff, and may result in a considerable effect on runoff response of a watershed (Mohamoud and Ewing, 1990). Further, some experiments they conducted in a laboratory to determine rainfall interception by corn residue - under rainfall intensities of 25.4, 63.5 and 127 mm/h for duration of 60 min applied to 54 replications - showed that corn residue intercepted an average depth of 1.55 mm for rainfall duration of 60 min, averaged over all intensities. In France, experiment done by Bussiere and Cellier (1992) showed that mulch with a leaf area index of 4.0 had a storage capacity of 2.8 mm. It is clear from the above review of work done by some researchers that large volumes of water which has a potential of causing soil erosion are intercepted. With the introduction of conservation tillage methods to control erosion (Dickey et al. 1985 and Gilley et al. 1986), rainfall interception by crop residues should no longer be ignored as its effect on the hydrologic cycle may be significant (Mohamoud and Ewing, 1990). More research should be done in future in order to come up with the actual amount of water intercepted by a given rate of crop residues used.

2.1.7 Other uses of crop residues

Besides being used in soil and water conservation, crop residues have a range of other important uses too. These are mainly; animal fodder, fuel and building materials (Barnard and Kristoferson, 1985). Competition exists among the uses, and the farmers would opt to use their mulch where they are likely to benefit most.

The most popular use among the farmers is the use of crop residues as animal fodder. Many farmers would rather use their crop residues to feed animals for they are sure of high returns than use it in other ways where they are not sure of returns. It will be difficult to convince farmers to use their crop residues in soil and water conservation and abandon the other uses unless studies, to show the economic value of crop residues for soil and water conservation relative to the other uses, are carried out (Papendick and Parr, 1978).

2.1.8 Effect of crop residues on soil properties

All the evidence from literature indicates that mulching affects both the physical and chemical properties of the soil. The organic matter content, an important factor in maintaining the fertility status of tropical soils and cation exchange capacity, can be maintained at a high level by mulching. Mulching affects the soil structure and porosity both directly and indirectly. By minimizing the direct impact of raindrops, there is a minimal crusting and therefore the initial pore space is maintained. Indirectly, mulching influences the activity of microflora and fauna and hence soil structure.

2.1.9 Demerits of using crop residues as mulch

"Controlling erosion with a mulch poses special problems for arable farmers because tillage tools become clogged with the residue, weed control and pest control are more difficult, planting under the residue is not always successful and crop yields especially in humid and semi-humid areas, are sometimes lower" (Morgan, 1986). In semi-humid tropical areas, the side effects of a mulch in the form of lower temperatures and increased soil moisture are beneficial and may increase the yield of coffee, banana and cocoa. Elsewhere, the effects of mulching can be detrimental. In cool climates, the reduction in soil temperature shortens the growing season whilst in wet areas, higher soil moisture may induce gleying and anaerobic conditions. Other problems with mulching are that the mulch competes with the main crop for nitrogen as it decomposes, special equipment is required to plant crops beneath a mulch and with normal usage, weed growth is encouraged. Mulching on its own is not always an appropriate technique but where its combined with conservation tillage, many of these problems can be overcome and it has tremendous potential as a method of erosion control.

After conducting a research in Laikipia District, Gicheru (1990) recommended residue mulching as a soil management despite the problems which can be associated with its availability. The farmers can overcome the availability problem by planting fodder crops which would reduce competition of available crop residues between animals and soil and water conservation practices.

2.2 Rate of application

Several benefits have been attributed to the practice of adding mulch. For example, Lal (1973,1975) has shown experimentally maize yield increases of 46, 55 and 22 per cent as a result of mulch at IITA, Nigeria over the period 1970 to 1972. Such yield increases represent the net effect of a number of favourable effects ranging from seedling emergence and growth aspects to nutrient relations. Moreover, the presence of organic cover on the soil not only reduces raindrop impact on the soil, but also improves both the physical conditions (Lal, 1979) and fertility status of the soil (Abu-Zeid, 1973).

Despite the many benefits to be expected as a result of using crop residue, the problem of obtaining it in adequate quantities discourages farmers from using it. Most experiments indicate that some 5 to 10 tonnes per hectare of air-dried mulch are needed annually in order to realize the beneficial effect to any discernible extent (Nair, 1984); getting that much quantity of material could be a problem, especially in semi-arid climates. In addition to the availability problem, other disadvantages of inefficient mulching, such as termite problems, mechanical damage to emerging crop seedlings, the possibility of weeds thriving in gaps left by woody mulch and creation of anaerobic conditions during rainy periods, have to be taken into account when deciding the amount of mulch to use on the farm, as Huxley (1982) pointed out.

The generally recommended straw-mulch rates of around 5 tonnes per hectare are frequently difficult to obtain and may adversely affect crop growth (Anderson and Russel, 1964 ; Larson, et al. 1960). Too much organic mulch can cause excessive water loss by intercepting rain and holding it until it evaporates. In this case, the mulch is so thick that precipitation never penetrates to the soil (Gardner and Woolhiser, 1978). Further, very thick mulches can also slow early-season plant growth by slowing the rate at which the ground warms, especially during the spring (Packer and Aldon, 1978). Kay (1978) stated that on properly mulched dry sites seeds may germinate with the first rainfall and soon die from lack of sufficient moisture for continued growth.

Research in Indiana showed that mulch rates of 0.56 and 1.12 t/ha greatly reduced erosion from intense simulated storms on tilled, permeable soils of 3 and 5 percent slopes and 2.24 t/ha cut soil losses to very low levels (Meyer et al. 1970). Studies conducted in laboratory with simulated soils in an adjustable soil bed confirmed the effectiveness of small mulch rates on short, gentle slopes but indicated that heavier rates would be required to control erosion on steeper slopes (Kramer and Meyer, 1969).

Studies done by Meyer et al.(1970) using various mulch rates showed that 0.56 t/ha mulch rate reduced erosion rate to about one-half or less of that from the unmulched treatment, and 1.12 t/ha reduced it to one-third or less. A quantity of 4.48 t/ha was necessary on steep, untilled Fox loam of low permeability ; 2.24 t/ha was sufficient on the loosely and thus permeable Xenia silt loam of 3 percent slope and only 1.12 t/ha was needed on the very permeable loosely tilled Wea silt loam of 5 percent slope. Further, research by Meyer et al. (1970) showed that rates of only about 1 t/ha can greatly reduce soil erosion on slopes where serious hazard exists and Moges (1989) found that small amounts of crop residue retained on the land also reduce soil loss.

Thus, in situations where heavy mulches cause adverse soil-temperature effects on crop growth or where only limited amounts of mulch material are available, even a small rate of mulch can be a valuable aid in soil conservation.

2.3 Method of application

Mulch may be applied on the surface as a soil cover, or may be partially mixed with the ground. As a cover, it is more effective in protecting the soil from direct impact of the raindrops. However, if its partially mixed with the soil surface, it decomposes sooner and helps make the soil more detachment resistant. Incorporation of crop residues increases the organic matter content and improves the soil structure over time and, as a result reduces soil erosion (McGregor et al. 1990). A lot of research work has been done using crop residues. Amado et al. (1989) found that surface - applied mulch was relatively more effective than mulch partially incorporated into the soil, even though both methods of residue management were very effective in controlling soil losses when compared to the bare soil even under low residue rates and/or percentages of soil cover by mulch. Further, an experiment done by Cogo et al.(1984) on 4.5% and 6.5% slopes using anchored and unanchored corn and soybean residues showed that erosion was reduced by residue cover that protected the soil surface from direct impact of raindrops, slowed runoff, decreased capacity of runoff to detach and transport soil particles, and increased deposition of sediment in small ponded areas created by pieces of crop residues.

Adams (1966), Othieno (1979) and Mannering and Meyer (1963) emphasized that surface mulches reduce erosion by dissipating part of the energy of rainfall and runoff. However, other studies have shown that surface mulches often adversely affect crop growth by modifying the plant micro-environment. Surface mulches of one ton per acre or more delayed seed germination and early crop growth because the soil warmed more slowly under the mulch (Kramer and Meyer, 1969). It would be desirable, therefore, for the mulch to decompose quickly after the crop cover develops and start protecting the soil. Hence, knowledge of how surface crop residues decompose will be useful in assessing the effects of residues on erodibility and soil structure and designing management practices to optimize the beneficial effects of crop residue on soils.

It is unlikely that the surface-managed crop residues will decompose as rapidly as incorporated residues because surface residues are subject to greater extremes in temperature and moisture than residues incorporated into soil (Papendick and Parr, 1978). This relatively rapid drying and heating poses a difficult environment for the micro-organisms to multiply. Also, nutrient availability from the soil is more limited to surface residues because soil contact and moisture are decreased relative to buried residues.

In humid areas, burying residues in the soil hinder penetration of water into the profile. This may lead to waterlogging problems which might affect both farm operations and crop production (Biamah, personal communication). Further, incorporation of residues can easily lead to the depletion of available nitrogen for crop growth as the microorganisms use all available nitrogen while growing and multiplying as a result of the increased organic material. This can lead to a yellowing of the crop and low yields in the absence of nitrogenous fertilisers. Therefore, it is important that we try and manage our crop residues in a way which will maximize the benefits and minimize the problems.

3. MATERIALS AND METHODS

3.1 The Site

The site was located at the Kabete campus farm at the University of Nairobi. It was on a 16% slope. The soil was classified as a humic nitisol (Sombroek et al. 1980). The climate of Kabete is semi-humid (Sombroek et al. 1980) with a mean temperature of 19.4°C and mean annual rainfall of 925 mm. The rain occur in a bimodal pattern. The two seasons are referred to as the "long rains" (LR) and "short rains" (SR) which respectively peak in April and November.

3.2 Plots

After several decades of specialized research on soil erosion and conservation problems, it has been found that there is no satisfactory substitute for runoff plots, as they supply basic data which may be secured only by actual measurement of the quantities of soil and water loss by erosion and runoff (Kirkby and Morgan, 1980). Therefore, runoff plots were used in this study.

Fifteen Djorovic (1977) type simple runoff plots installed on a natural 16% slope were used. Each plot was two metres wide and ten metres long. Each plot was bounded by galvanized sheet metal, 20 cm width, with 10 cm driven into the ground. A 50 cm and a 3.0 m wide space were left between plots and blocks respectively. Main components of each runoff plot were; a boundary to prevent water and soil from entering or leaving the plot, an end plate which serves as a weir at the lower end of the plot, a collecting trough, a conveyance pipe to carry the flow of soil and water, and a storage tank to contain the sediment and runoff.

3.2.1 Collecting trough and end plate

Runoff from a plot was collected in the trough and channelled to the collecting tank. The end plate provided a firm seal and smooth contact between collecting trough and ground surface.

3.2.2 Conveyance

Two and half inches diameter (6.4 cm) PVC pipes at an average slope of 17% were used for conveying runoff to the collecting tanks. These were far higher than the calculated minimum values (6.2 cm in diameter and 4.55% slope) based on Mutchler's (1963) recommendations. These higher values of slope and pipe size have assured a very safe conveyance without any sign of siltation in the conduit although deposition occurred in the collecting trough.

3.2.3 Storage tank

A storage tank of 1,325 Litre capacity was used. Size and capacity of the storage tank was determined by using design considerations of a one hour 20 years return period storm of 60 mm/hr intensity with a runoff coefficient of 50% (Barber et al. 1979). The tanks were buried half way into the ground to secure safety from theft.

A 90 litre small tank/drum was placed in the storage tank directly below the in-flow splout of the conveyance pipe so as to collect most sludge and reduce the time and labour required to sample and clean up after small storms. The small tank/drum collected small volumes of runoff and soil loss from the plot and held it for measurement and analysis.(See plate 1).

Plate 1. Storage tank with container for small storm.

3.2.4 Rain gauges

Manual rain gauge was used to record rainfall on site. However, figures obtained were counter-checked with that obtained from the S.A.R.E.C. site weather station to make sure that the figures do not vary much.

3.3 Treatments

3.3.1 Experimental design

The experimental design used was a completely randomized block design.

There were five treatments, namely:

(a) distributed mulch at rate of 3.0 t/ha.

(b) distributed mulch at rate of 1.5 t/ha.

(c) trashlined (lined) mulch at rate of 3.0 t/ha.

(d) trashlined (lined) mulch at rate of 1.5 t/ha.

(e) control.

(see plates 2, 3 and 4).

Each treatment was replicated three times. In total,there were fifteen plots. The treatments were applied at random in the plots.

Plate 2. Control treatment plot before bean crop was planted.

Plate 3. Trashlined mulch at 3 t/ha treatment plot.

Plate 4. Distributed mulch at 3 t/ha treatment plot.

3.3.2 Crop residue mulch

Maize stover was used as a mulch at a rate of 1.5 t/ha and 3.0 t/ha. To get the amount equivalent to 1.5 t/ha and 3.0 t/ha, a sack of known weight and a spring balance were used. The mulch was placed on the sack and weighed until three and six kilograms per 20

m^2 weight was attained respectively. This amount of mulch was equivalent to 1.5 t/ha and 3.0 t/ha on a 2 m by 10 m plot. The runoff plots were prepared according to the conventional tillage practice in the area (hand digging with a jembe). Then, the mulch treatments were assigned in all the plots randomly. The rates selected (1.5 t/ha and 3.0 t/ha) were based on an estimate of Barnard and Kristoferson (1985) for the average residue production of approximately 1.0 t/ha for small holder maize under tropical conditions.

3.3.3 Test crops

Beans and maize were used as test crops in the short and long rains respectively. Rosecoco type of beans was planted in a spacing of 50 by 15 cm. Maize of hybrid 614 was planted in a spacing of 75 by 25 cm. Diamonium phosphate fertilizer was used during planting time in both seasons.

3.3.4 A brief visit to selected farms in Makuyu division, Murang'a district

A brief visit to selected farms in Makuyu division, Murang'a district took place. This was to help in knowing how farmers use their crop residues in the field.

3.4 Data collection

3.4.1 Sampling of runoff and suspended sediment

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

(i) When there was a small storm, the runoff was stirred well and poured into a measuring bucket. After measuring the volume, it was stirred vigorously and a sample taken in a 0.5 litre screw topped plastic bottle which had been previously numbered with a serial number.

(ii) when there was a large volume of runoff which nearly filled the drum, it was found that the heavy particles and aggregates fell to the bottom and it was not possible to stir the whole into a uniform mixture. In this situation, the runoff was withdrawn bucket by bucket, the volume of each bucket measured and a sample taken until the sludge at the bottom of the drum was reached. From each bucket, a sample of 0.5 litres was taken. These samples were then poured into a bucket, stirred thoroughly and a sample of 0.5 litres taken.

All the samples were then taken to the laboratory for analysis of total soil in the runoff.

Throughout the experimental period, the rainfall was very little. The volume of the runoff collected was very small and it overflowed the small drum only once, when there was a big storm.

3.4.2 Sampling of sludge

Sampling of sludge was carried out for every plot as follows:

(i) The suspended sediment overlying the sludge was decanted. After decanting it, the sludge was then scooped out of the small drum, placed in a bucket of known weight and then weighed using a spring balance. The weight of the sludge was recorded and the sludge thoroughly mixed till it formed a uniform consistency. The samples were then taken in 0.5 litre plastic bottles to the laboratory for analysis of total soil and water in the sludge.

Finally, the storage tanks were drained and cleaned, ready for the next storm.

3.4.3 Infiltration

This was determined by getting the difference between the amount of rainfall and runoff, that is:

Infiltration depth(mm) = Amount of rainfall(mm) - Runoff(mm)

3.4.4 Crop residue cover measurement

A string and bead method was used. A string with beads at regular intervals was stretched diagonally across each plot.The beads that touched crop residue were counted and recorded. Then, to get the percentage residue cover, the following formula was used:

$$\%cover=\frac{positive\ counts}{total\ no.\ of\ beads}*100 \qquad (1.1)$$

The string and bead method was also used by Sloneker and Moldenhauer in (1977) to assess residue cover.

The main disadvantage of this method is that it tends to overlook the underlying layers of vegetation with the consequence of underestimating the quality of the cover. Further, operator bias can lead to substantial over-estimation of residue cover, as there is tendency to adjust the line of sight if there is residue in sight nearby (Laflen et al. 1981). Only careful use and regular self-calibration overcomes this bias. Precision can be increased by minimizing the gap between beads and by increasing replicates. Crop residue cover was measured several times just after placing on the land and then the average cover was taken.

3.4.5 Crop cover

Crop cover was taken once per week. The crop cover measurement started one week after planting. This was important because the crop cover has an effect on soil loss and runoff.

A sighting frame was used for the crop cover measurement. The sighting frame was placed three times in the plot (centre and both sides of the plot). Each time the full hole of the sighting frame was covered by a crop, it was recorded as full. For half full hole, it was recorded as half. The sighting had ten holes and each full hole represented ten percent. For the three measurements, the average was taken and assumed to be the percentage crop cover in that plot at that particular time.

3.4.6 Crop yield

Beans and maize were planted during the short and long rainy seasons respectively. After maturity, the bean crop was harvested and its yield recorded. The maize crop however, wilted due to lack of rainfall during the second season and therefore no yield data was obtained (see plate 5).

Plate 5. Maize crop that failed because of drought.

3.5 Laboratory analysis procedures

3.5.1 Soil loss

Total soil loss = soil in sludge plus soil in suspended sediment.

(a) Total soil in sludge

The sludge sample was emptied onto a metal bowl (already numbered and weighed empty). The weight of the bowl plus sludge was determined. Then, the bowl was placed in the oven for drying at 105°C until it reaches a constant weight. The dry sample was weighed. The weight of the bowl was then subtracted to get the actual weight of the dry soil. Since this amount of soil was obtained from a known weight of sludge, the amount of soil in the original sludge could be calculated.

(b) Total soil in suspended sediment

The sample bottle was shaken and the sample poured into a 1,000 cc measuring cylinder. The volume was determined and it was poured into a metal bowl (already numbered and weighed empty). A little clean water was used to rinse out any sediment left in the measuring cylinder which was then added into the bowl. A small quantity, 0.6 cc, of alum (potassium aluminium sulphate) was added to settle the suspended sediment. After 12 hours, precipitation was complete and most of the clean water was poured off. The bowl was then put in the oven for drying at 105 degrees celsius until it reached a constant weight. The weight of the sediment was then determined. Since this amount of sediment was obtained from a known volume of runoff, the amount of soil in the volume of original runoff could be calculated.

3.5.2 Runoff

This was obtained by the formula:

Total runoff volume = Volume of runoff overlying the sludge plus volume of runoff in sludge.

The amount of runoff overlying the sludge was obtained by decanting it, and measuring its volume with a calibrated bucket. This runoff amount was measured and recorded in the field.

For the runoff volume in the sludge, a sludge sample of known weight was taken to the laboratory. The sample was put in a bowl of known weight and oven dried at 105°C for 24 hours. The amount of runoff in the sludge sample was obtained by getting the difference between the sludge sample weight and oven dried sample weight. The total amount of runoff in the sludge was then extrapolated using the weight of the total amount of sludge obtained in the field.

4. RESULTS AND DISCUSSION

4.1 Rainfall pattern during the experimental period

During the period this experiment was conducted, the rainfall pattern was characterised by rainfall unreliability, intermittent drought, low rainfall during the 1992 short rain season and 1993 long rain, and unexpected high rains in January 1993. The unexpected low rainfall affected the second season data collection.

During the short rainy season, very little rain fell in October, November and December 1992 (appendix 1.). Only three storms which resulted in runoff were received in the short rains. Unexpectedly, most of the rain fell in the month of January 1993 (228 mm). This was a time when the ground was well covered by beans. In the long rains season, rainfall was very little and this caused the crop to wilt. Only one big storm fell in the month of May 1993 but no runoff was obtained as all the water infiltrated into the soil. In all the other days of the long rains, only drizzles occurred. Therefore, no soil loss and runoff data was collected during the long rains season. Thus, rainfall distribution during the experimental period was poor and it was not possible to collect as much runoff and soil loss data as expected (see figure 2).

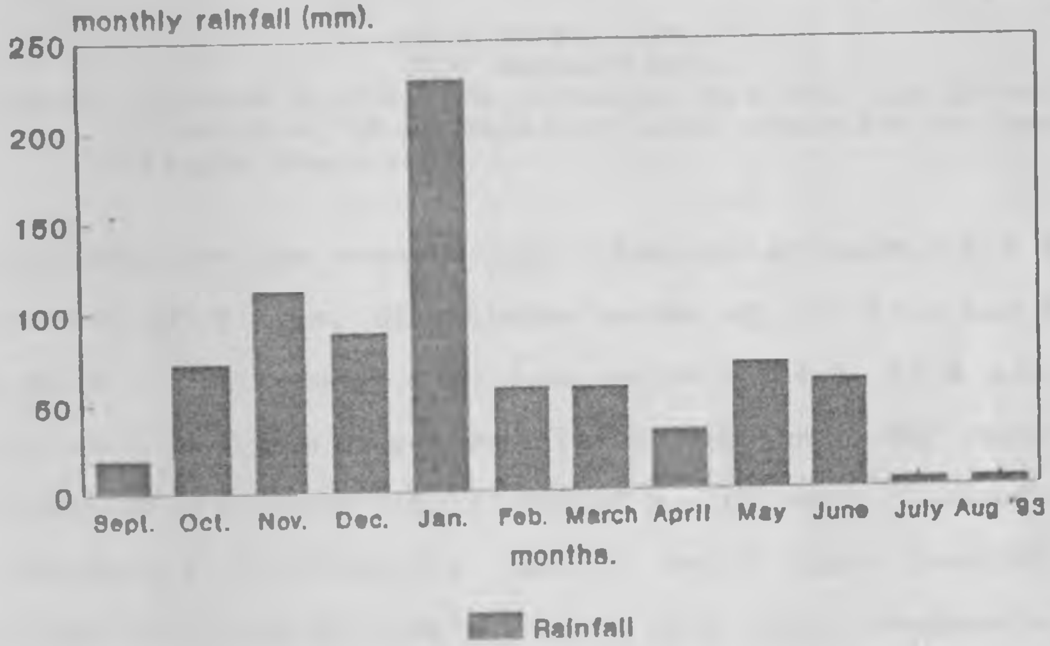


Fig 2. Rainfall distribution during the period of the experiment.

4.2 Soil loss

4.2.1 Comparison of mulched treatments and control

Total soil loss (t/ha) for the control and different maize residue treatments during the 1992 short rains season and January rain are given in table 1.

Table 1. Mean soil loss (t/ha) for the five mulch treatments during the 1992 short rain season and 1993 January rain.

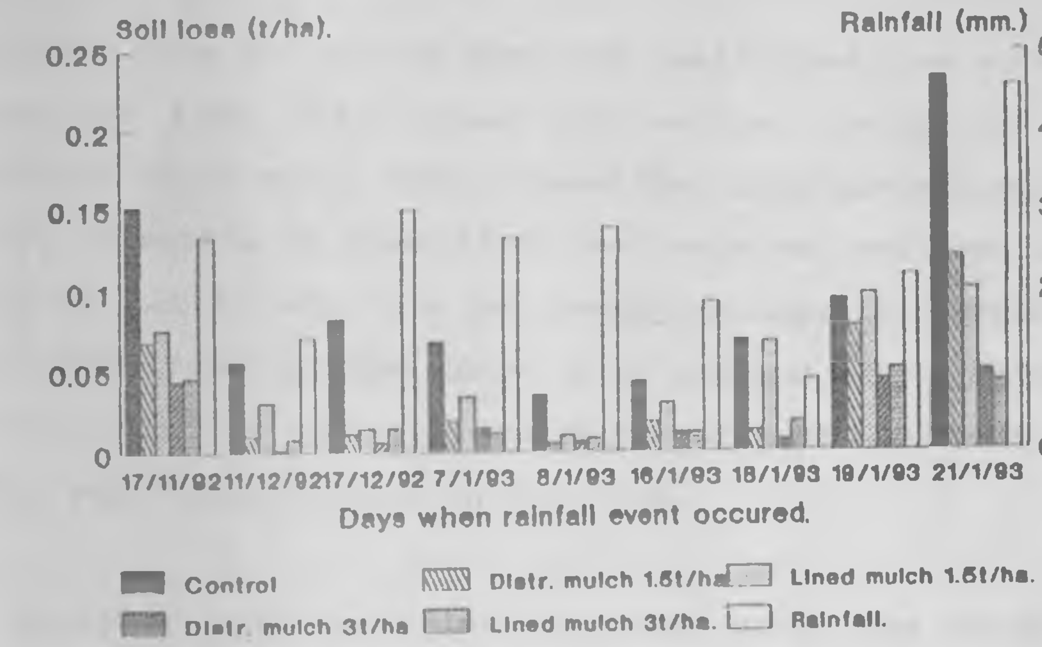
		Treatment			
Season.	Control	Lined mulch 1.5 t/ha	Distributed mulch 1.5 t/ha	Lined mulch 3 t/ha	Distributed mulch 3 t/ha
1992 SR	0.0967a	0.0411b	0.0308b	0.0237b	0.0177b
1993 JR	0.0908c	0.0511d	0.0428d	0.0246d	0.0227d
Total	0.1875	0.0922	0.0736	0.0483	0.0404

Key:
SR - Short rain.
JR - January rain.

Means followed by the same letter(s) are not significantly different at 5% probability level according to Duncan's multiple range test.

It is clear from the results that distributed mulch at 3 t/ha, lined mulch at 3 t/ha, distributed mulch at 1.5 t/ha and lined mulch at 1.5 t/ha reduced soil loss by 78 %, 74 %, 60 % and 50 % respectively. Analysis of variance (ANOVA) (appendix 2b) shows that the treatment effect was significant at p = 1% level. Comparison of the treatments by Duncan's method shows that control was significantly different from the other four mulch treatments.

Figure 3 shows the effect of different mulch treatments on soil loss during the 1992 short rains season and January 1993 rains.



Soil loss is the mean of 3 replicates.

Figure 3. Effect of different mulch treatments on soil loss during the 1992 short rain season and January 1993 rains.

From figure 3, it is clear that soil loss in the control was higher than in the other mulch treatments. This is because there was no mulch cover on the control plots. From 11/12/92, the soil loss in both control and mulch treatments was lower probably because the beans crop provided cover on the soil. On 21/1/93, the soil loss was relatively higher probably because of the high rain (45.5 mm) which fell on that day and weeding that was done on 18/1/93. The weeding made the soil loosely attached to the land surface and hence easily carried in the runoff.

It is clear from the results that even small quantities of mulch reduced soil loss. This agrees with earlier findings by some researchers. Meyer et al. (1970) showed that large amounts of cover are very effective in controlling soil erosion, but even small amounts of stubble materials can greatly decrease it. Moges and Thomas (1989) found residue cover to be exponentially related to runoff and soil loss, and concluded that even small amounts of crop residues are worth retaining in the field.

Mulch provides cover which intercept and absorb the energy of raindrops before they reach the soil surface. When there is a lot of cover on the surface, the soil is well protected. When there is no cover, the soil is exposed to direct rainfall which causes high amount of soil loss. Lack of cover was therefore the reason for the high soil loss in the control relative to the mulch treatments. There are four possible ways in which mulch could reduce soil loss. These are:

(i) absorbing flow shear forces that would otherwise be expended on the soil.

(ii) reducing effective slope steepness by causing runoff to meander as it flows down the slope.

(iii) increasing the hydraulic roughness of the flow surface.

(iv) Preventing soil and water from passing down the plots resulting in ponds.

It is likely that all the four processes were contributing to the effectiveness of mulch during the experiment but the ponding effect appeared to be greater with trashlined mulch.

4.2.2 Comparison of lined versus distributed mulch treatments

Total soil loss (t/ha) for lined and distributed mulch treatments during the 1992 short rains season and 1993 January rains was as shown in table 1. The order of soil loss, from lowest to the highest, was; distributed mulch at 3 t/ha - 0.0404 t/ha, lined mulch at 3 t/ha - 0.0483 t/ha, distributed mulch at 1.5 t/ha - 0.0736 t/ha and lined mulch at 1.5 t/ha - 0.0922 t/ha. From the results, distributed mulch at 3 t/ha treatment reduced soil loss most, and lined mulch at 1.5 t/ha treatment reduced soil loss least. However, both analysis of variance and comparison of the treatments using Duncan's method showed that the mulch treatments were not significantly different at 5% probability level. This is because the random error was too great. The variations between the blocks was enormous (appendix 2) probably due to the previous treatments. These random variations obscure treatment differences.

Distributed mulch treatments provided a higher percentage cover relative to lined mulch treatments (table 2). The cover protects the soil from raindrop impact and reduces runoff velocity (Hudson, 1971). Mulch provide a cover which protects the soil from being eroded by rainsplash or runoff when crop cover is not fully developed. Fisher (1977) and Moore (1978) showed that it is at the beginning of the rains, before a protective crop cover has been established, that the most erosive rains are likely to occur.

Table 2. Average percentage of crop residue cover (mulch) for three replications as measured by string/bead method.

Treatment.	Average % cover
Distributed mulch 3.0 t/ha.	47.1a
Distributed mulch 1.5 t/ha.	22.3b
Lined mulch 3.0 t/ha.	15.0bc
Lined mulch 1.5 t/ha.	11.2c
Control	0d

Mean values followed by the same letter(s) are not significantly different at 5% probability level according to Duncan's multiple range test.

The relatively high percent cover provided by distributed mulch at 3 t/ha treatment was probably the reason why the soil loss was low relative to the other three mulch treatments. The soil loss in lined mulch at 3 t/ha treatment was almost equal to that from distributed mulch at 3 t/ha treatment. Lined mulch reduced soil loss because it held soil and water causing ponding. This stopped detached soil particles from being transported away. Lined mulch at a rate of 3 t/ha provided a bigger pond and more soil was trapped hence the lower soil loss. This was in agreement with the field observations made by Brenneman and Laflen (1982) where they found that cornstalk residues act as small dams, creating ponds behind them. This ponding allows deposition of sediment, often within a few feet of where it was eroded (see plate 6).

When the mulch rate was low, such as in case of lined mulch at 1.5 t/ha, the dam / pond height was small and therefore during high rainfall events, water overflowed the dam / ponds and more soil was lost. Thus, as mulch rate becomes lower, lined crop residue becomes less effective in controlling erosion. Not only do small ponds trap less sediment, but they become filled more quickly, resulting in more sediment being carried down the slope. This explains why the soil loss was high in lined mulch at 1.5 t/ha treatment.

Plate 6. Trapped soil deposited in the lined mulch at 3 t/ha.

4.2.3 Comparison between mulch cover and soil loss

The mulch mean percent cover before the onset of short rains season as shown in table 2 was; distributed mulch at 3 t/ha - 47.1%, distributed mulch at 1.5 t/ha - 22.3%, lined mulch at 3 t/ha - 15%, lined mulch at 1.5 t/ha - 11.2% and control - 0%. On the other hand, the total soil loss was; distributed mulch at 3 t/ha - 0.0404 t/ha, distributed mulch at 1.5 t/ha - 0.0736 t/ha, lined mulch at 3 t/ha- 0.0483 t/ha, lined mulch at 1.5 t/ha - 0.0922 t/ha and control - 0.1875 t/ha (see table 1.). From figure 3, the soil loss was highest in the control treatment which had 0% mulch cover followed by lined mulch 1.5 t/ha, distributed mulch 1.5 t/ha, lined mulch 3 t/ha and distributed mulch 3 t/ha which had 47.1% mulch cover. Thus, the amount of mulch cover and method of its placement on the surface greatly influence amount of soil loss.

4.2.4 Soil erodibility

Erodibility is the resistance of the soil to both detachment and transport (Morgan, 1986). Various workers have attempted to calculate the erodibility factor 'K' of universal soil loss equation (U.S.L.E). This however assumes that the U.S.L.E. can be applied to small plots for short term soil losses, and that the values selected for other erosion factors used in the U.S.L.E. are valid.Despite these limitations, the 'K' factors do allow a direct comparison with results obtained by other workers.The soil loss can be represented:

A = R.K.L.S.C.P, where;

A = soil loss per unit area.

R = rainfall erosivity factor.

K = soil erodibility factor.

LS = slope length (L) and slope steepness (S) factors.

$$LS = \frac{\sqrt{L}}{22}(0.065+0.045S+0.0065S^2) \qquad (2.1)$$

(Morgan,1986)

C = crop factor.

P = soil conservation factor.

(Wischmeier and Smith, 1978).

For the control treatment, the K factor has been calculated basing the figures in metric units (appendix 3.). The rainfall factor (R) has also been calculated (see appendix 3). LS was taken to be 0.352 (16% slope, 10 m length), C is 0.9 (old arable field) and P is 0.8 (neither terraces, contour ploughing nor downward ploughing). The calculated K value, using soil loss data from the control plot which had no cover, was 0.002 for both 1992 short rains and 1993 January rains (appendix 3). The value was very small probably because the rainfall was very little during the experimental period. Further, the experiment was conducted for a very short time.

The K-value was less than those given by Barber et al.(1979), Gachene (1982) and Tefera (1983). Barber et al.(1979) reported maximum K value of 0.15 for wet run from 1.5 m plots of newly ploughed field with high percent of clay (79.2%). Gachene (1982) working on disturbed samples under simulated rainfall got K values of 0.077 for tray dry, 0.05 for field wet and 0.076 for nomograph of Wischmeier and Smith. His soils had 64% clay. Tefera (1983) working under natural and simulated rainfall reported a maximum value of 0.40 for Kabete soil. Use of nomograph for soil erodibility values gives values of 0.06 for Kabete nitisol (Barber et al. 1979).

Kabete soil has high clay content, which has approximately 64% clay (Gachene, 1982), but has very good physical characteristics because the particles are aggregated as a result of iron and aluminium (Thomas, personal communication). The soil is aggregated into predominantly fine sand and medium silt particles (Ahn, 1977). The high clay content leads to good aggregate stability reducing the susceptibility of the soil to erosion, and this could be one of the reasons for differences in K values. Secondly, Barber et al.(1979) and Gachene (1982) used small plots and simulated rainfall. Further, U.S.L.E. is not recommended for prediction of specific soil loss events, rather for long term average soil losses (Wischmeier and Smith, 1978). The other reason for differences in K values is that the experiment was conducted for a very short time. It will be important to monitor both soil loss and erosivity for more years to come so as to arrive at a reliable figure

4.3 Runoff

4.3.1 Comparison between mulch treatments and control

Total runoff (mm) for the five mulch treatments during the 1992 short rains and 1993 January rains is given in table 3. It is clear from table 3 that the order of runoff volume from lowest to the highest was; lined mulch at 3 t/ha - 3.61 mm, distributed mulch at 3 t/ha - 3.77 mm, distributed mulch 1.5 t/ha - 5.37 mm, lined mulch at 1.5 t/ha - 6.54 mm and control - 11.74 mm.

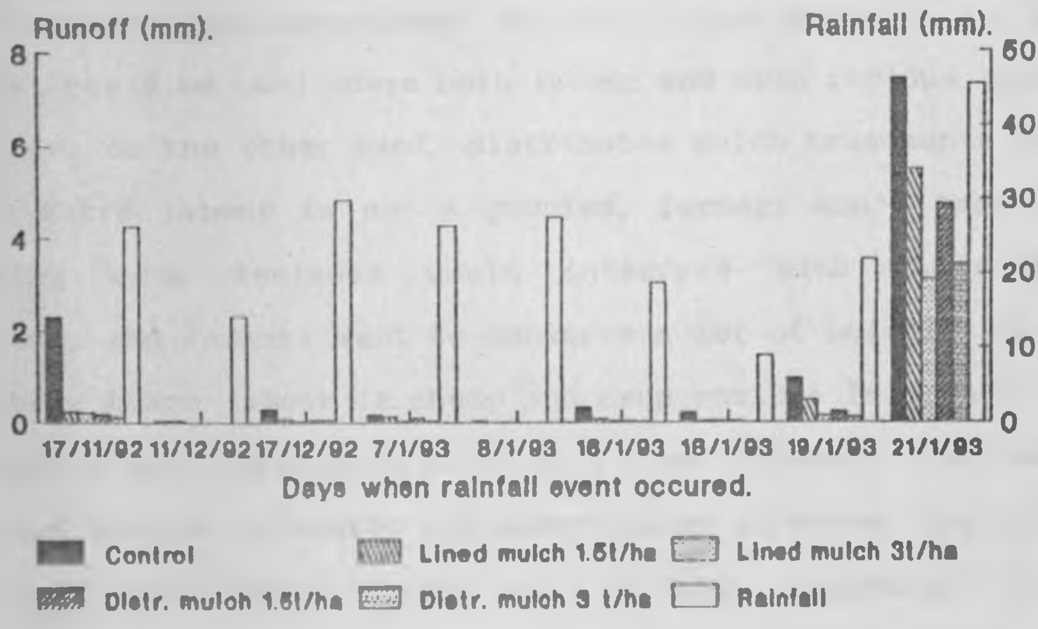
Table 3. Mean runoff (mm) for the five mulch treatments during the 1992 short rains season and January 1993 rains.

		Treatment			
Season.	control.	Lined mulch 1.5 t/ha	Distributed mulch 1.5 t/ha	Distributed mulch 3 t/ha	Lined mulch 3 t/ha
1992 SR	2.64a	0.36b	0.27b	0.20b	0.26b
1993 JR	9.10c	6.18d	5.10d	3.57d	3.35d
Total	11.74	6.54	5.37	3.77	3.61

Means followed by the same letter(s) are not significantly different at 5% probability level according to Duncan's multiple range test.

From the results, lined mulch at 1.5 t/ha treatment reduced total runoff volume by 44%, distributed mulch at 1.5 t/ha by 54%, distributed mulch at 3 t/ha by 67% and lined mulch at 3 t/ha by 69% compared to the control. Analysis of variance showed that there was statistical evidence to prove that the treatments were significantly different at p = 1% (appendix 4b). However, comparison of the treatment means using Duncan's method showed the control treatment was significantly different from the other four mulch treatments at P = 0.05.

Figure 4 shows the effect of different mulch treatments on runoff. On 17/11/92, the runoff volume in the control treatment was more than in the other four treatments because there was no cover. In the other four treatments, there was runoff volume reduction because of the cover provided by mulch at the initial stages when the crop cover had not developed (appendix 5 a.). From 11/12/92 to 19/1/93, the runoff volume was very little because of both the crop residue cover and the developed bean crop cover which blocked and slowed runoff movement leading to greater infiltration and a lower volume.



Mean runoff vol (mm) for 3 replicates.
rain season, 1992.

Fig 4. Effect of different mulch treatments on runoff during the 1992 short rain season and January 1993 rains.

Mean comparison of the treatment means using Duncan's method (table 3) showed that lined mulch at 1.5 t/ha treatment, distributed mulch at 1.5 t/ha, distributed mulch at 3 t/ha and lined mulch at 3 t/ha treatments are not significantly different at P=0.01. Depending on the availability of mulch, the farmer can use any of the mulch treatments to control runoff. Thus in areas where mulch or crop residue is scarce, the farmer could use small amounts of crop residues to reduce runoff. In areas where labour is scarce and expensive to hire, lined mulch treatment could be used, as distributed mulch interfere with cultivation and weeding. Lined mulch at 3 t/ha treatment could be used where labour is scarce, crop residue is plenty and where farmers feel that scattering would obstruct their farm operations. Further, lined mulch at 1.5 t/ha treatment could be used where both labour and crop residue (mulch) are scarce. On the other hand, distributed mulch treatments could be used where labour is not a problem, farmers don't feel that scattering crop residues would interfere with their farm operations, and farmers want to conserve a lot of moisture in the soil. Where human labour is cheap and crop residue is plenty, the farmer could use distributed mulch at 3 t/ha treatment. Similarly, where crop residue is scarce and human labour is cheap, the farmer could use distributed mulch at 1.5 t/ha treatment. Thus, availability of labour, cost of labour, availability of crop residues and mode of field operations used by the farmers in a locality could be the guiding factors that could be used when deciding which method to use.

4.3.2 Comparison between lined and distributed mulch treatments

Total runoff (mm) for the lined and distributed mulch treatments was as shown in table 3. From the table, it is clear that the order of effectiveness (from most to least) in reducing runoff volume by the mulch treatments was; lined mulch at 3 t/ha, distributed mulch at 3 t/ha, distributed mulch at 1.5 t/ha and lined mulch at 1.5 t/ha respectively. Therefore, lined mulch at 3 t/ha treatment was the most effective in reducing runoff volume. However, comparison of the treatments by Duncan's method showed that the mulch treatments were not significantly different at P = 0.05 level.

During the January 1993 rains, lined mulch at 1.5 t/ha had the highest runoff volume followed by distributed mulch at 1.5 t/ha, distributed mulch at 3 t/ha and lined mulch at 3 t/ha treatments respectively. However, the total runoff volume (table 3) showed that distributed and lined mulch at 3 t/ha treatments had similar effectiveness in reducing runoff. Thus, the performance of the residue treatments in reducing runoff volume varied with rainfall season and amount. During the 1992 short rains, distributed mulch at 3 t/ha was the most effective in reducing runoff volume. Lined mulch at 3 t/ha treatment was the most effective in reducing runoff during January 1993 rains because it formed ponds/dams which prevented runoff from flowing down the plots. The water stopped and infiltrated into the soil. In distributed mulch plots, runoff often followed very tortuous paths thus decreasing the effective slope steepness and the average runoff velocity. This, together with the variability in the distribution and orientation of the mulching materials (maize stover) increased infiltration of runoff into the soil, thus decreasing the collected runoff volume. In distributed mulch at 1.5 t/ha treatment, more runoff volume was obtained than in distributed mulch at 3 t/ha treatment because at low mulch rate, the paths the runoff followed before reaching the collector were very few and therefore runoff did not take a long time in the plot. Therefore, only little runoff infiltrated into the soil leading to the relatively higher runoff volumes. However, lined mulch at 3 t/ha treatment reduced runoff more than lined mulch at 1.5 t/ha treatment because the former had twice as much crop residues than the latter. A higher level of crop residues resulted in bigger ponds/dams relative to the lower amounts. Bigger dams/ponds held more water which eventually infiltrated into the soil thus decreasing the runoff volume. Small ponds held only small volumes of water and therefore a small volume of water infiltrated. The rest passed and was collected as runoff.

4.3.3 Relation between mulch cover and runoff

Percentage mulch cover was given in table 2. From table 3, it was clear that mulch treatments reduced runoff volume relative to the control. The high percent mulch cover, the small the runoff volume. However, the effectiveness of mulch in controlling runoff depended mainly on the amount and placement of cover on the soil surface. Thus, in table 3 lined mulch at 3 t/ha treatment reduced runoff volume most followed by distributed mulch at 3 t/ha treatment which had the highest percentage mulch cover.

In figure 4, runoff volume from the control treatment was highest relative to that from mulch treatments. This is because there was no mulch cover in the control treatment. The decrease in runoff volume between 11/12/92 to 18/1/93 was probably due to development of the crop (beans) which provided cover. The high runoff volume on 21/1/93 was probably due to the high rainfall amount (45.5 mm.) which fell on that day.

4.4 Infiltration

Table 4 shows the mean infiltration depth of water in the soil for the five treatments during the 1992 short rains and January 1993 rains. From the table, it is clear that during the 1992 short rains, the infiltration depth of water was highest in distributed mulch at 3 t/ha treatment followed by lined mulch at 3 t/ha, distributed mulch at 1.5 t/ha, lined mulch at 1.5 t/ha and control treatment respectively.

Figure 4 shows the effect of different mulch treatments on infiltration depth during the 1992 short rain and January 1993 rains. Infiltration depth was high in distributed mulch at 3 t/ha treatment because distributed mulch slowed runoff as a result of variability in distribution and orientation of the mulch.

Table 4. Mean infiltration depth (mm) in the five mulch treatments during the 1992 short rain season and January 1993 rain.

Season	Mean rainfall (mm)	Contr.	Treatment Distr. mulch 1.5 t/ha	Lined mulch 1.5 t/ha	Distr. mulch 3 t/ha	Lined mulch 3 t/ha
1992 SR	23.6	21.0a	23.4b	23.3b	23.4b	23.4b
1993 JR	24.9	15.8c	19.8d	18.7d	21.3d	21.5d
Total	48.5	36.8	43.2	42.0	44.7	44.9

NB. Mean rainfall = mean of the rain that produced runoff during a particular season.

Mean values followed by the same letter(s) are not significantly different at 5% probability level according to Duncan's multiple range test.

Further, distributed mulch absorbed raindrop impact thus reducing soil puddling and crusting hence facilitating infiltration (Lal, 1974). High concentration of mulching materials on the plots increased infiltration of water relative to sparsely distributed mulch and hence the reason why distributed mulch at 1.5 t/ha treatment had lower infiltration depth than distributed mulch at 3 t/ha treatment.

During the 1993 January rains, the infiltration depth was highest in lined mulch at 3 t/ha treatment followed by distributed mulch at 3 t/ha, distributed mulch at 1.5 t/ha, lined mulch at 1.5 t/ha and control treatment respectively. During the January rains, most of the rain that fell resulted in more runoff relative to 1992 short rains. During the occasions when the runoff amount was high, the lined mulch prevented runoff water from passing down the plot,thus creating some ponds. These ponds allowed more water to infiltrate. Lined mulch at 3 t/ha treatment resulted in bigger ponds thus allowing more water to infiltrate than on the distributed mulch treatments. Lined mulch at 1.5 t/ha resulted in small ponds which allowed only a smaller amount of water to infiltrate. This resulted in lower infiltration depth in lined mulch at 1.5 t/ha treatment than in distributed mulch at 1.5 t/ha treatment which slowed runoff due to variability in distribution and orientation of mulching materials. Control treatment had the smallest infiltration depth. This is because there was no mulch cover.

Analysis of variance (ANOVA) showed that there was no significant difference at P = 0.01 level in infiltration depth among the treatments (appendix 6). This is probably because of the fact that the soil had a high infiltration rate and the bean crop provided cover in all the treatments which made water infiltrate almost uniform in all the plots. According to experiment done by Barber, et. al.(1979), Kabete soil has an infiltration rate of 32 - 100 mm/hr.

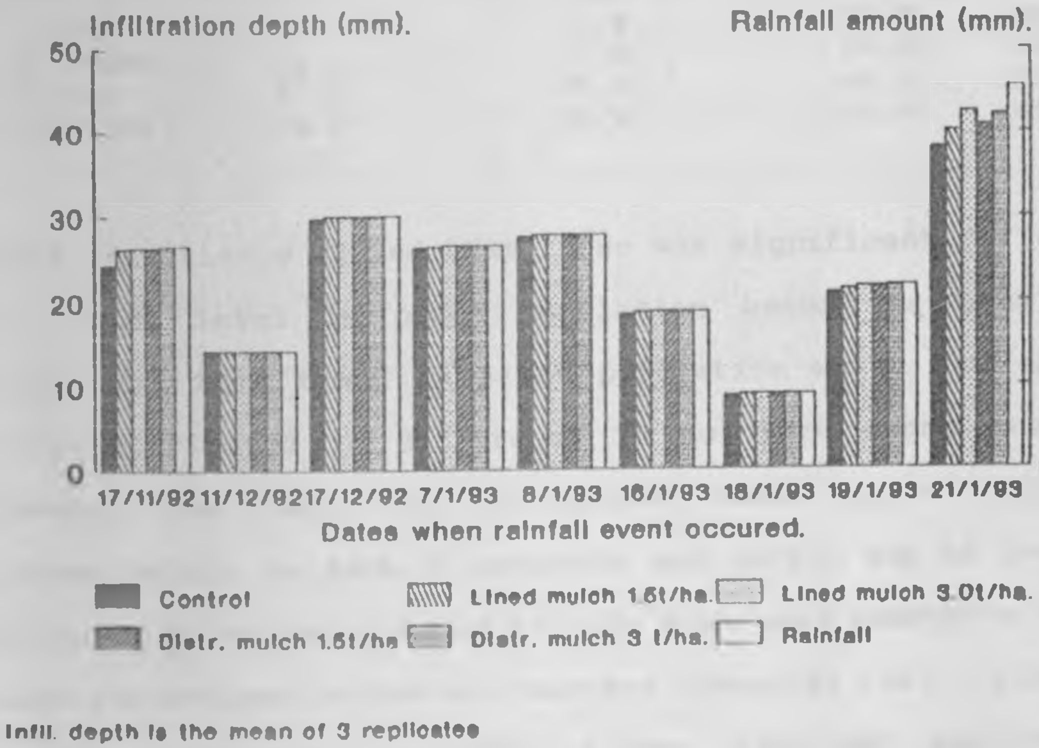


Fig 5. Effect of different mulch treatments on infiltration depth.

4.5 Crop performance

Crop performance was monitored after germination in each of the treated plots. Two weeks after planting, the average population of plants in each of the treatments were counted and expressed as a percentage expected population, that is;

$$\% \ population = \frac{No\ of\ germinated\ plants}{Total\ no.\ of\ expected\ plants} \times 100 \quad \ldots\ldots\ldots\ldots\ 2.2$$

The plant population at emergence was as shown in table 5.

Table 5. Percent of bean seed planted which germinate (% emergence) during 1992 short rains and January 1993 rains.

	Block			
Treatment	1	2	3	Average
Control	30.1	34.3	34.9	33.1
Distr.3t/ha	41.2	40.8	38.9	40.3
Distr.1.5t/ha	51.3	67.6	50.6	41.8
Lined 3t/ha	39.2	48.3	48.1	56.5
Lined 1.5t/ha	51.1	30.4	43.9	45.2

Analysis of variance showed that there was significant difference at P = 0.01 level in plant population among the treatments (appendix 8). This trend in plant population which had emerged could be attributed to difference in moisture among the five treatments. The delay in distributed mulch plots could be attributed mainly to lack of moisture and partly due to low soil temperature. Mulching is known to slow down seed emergence due to coldness and wetness in the soil surface (Donahue, 1983). Kilewe et al. (1983) reported that the slower rate of ground-cover development in the mulched as compared with unmulched maize may be partially due to the former's greater frequency of below-optimum soil temperatures. The emergence of seedlings could also be delayed due to inhibition by surface residue cover. Wilson (1981) in his studies on the effect of mulch on maize emergence found that the seedlings could require some force to penetrate through the mulch and this phenomenon delayed seedling emergence. Distributed mulch at 3 t/ha treatment had a lower emergence percentage than distributed mulch at 1.5 t/ha treatment because in the former treatment, a lot of force was needed for seedlings to penetrate than the latter where the density of crop residue was lower. In lined mulch treatments, the percentage emergence was higher. This is because there was no inhibition, temperature of the soil was probably high and water required for germination was provided by the ponds. In the control treatment, the beans emergence percentage was very small. This was perhaps because of lack of enough moisture required for seed germination and damage by pests. Table 6 shows the average yield of beans during the 1992 short rains and January 1993 rains. The table show that lined mulch at 3 t/ha treatment had the highest average yield followed by distributed mulch at 3 t/ha and distributed mulch at 1.5t/ha, lined mulch at 1.5 t/ha and control treatments respectively.

Table 6. Grain yield (Kg) of beans during the 1992 short rains season and January 1993 rain.

		Block		
Treatment	1	2	3	mean
Distr. mulch 3 t/ha	3.0	3.0	3.0	3.0b
Distr. mulch 1.5 t/ha	3.0	3.0	3.0	3.0b
Lined mulch 3 t/ha	2.0	3.5	3.0	2.8b
Lined mulch 1.5 t/ha	2.0	2.5	3.0	2.5b
Control	1.5	2.0	1.8	1.8a

Mean values followed by the same letter(s) are not significantly different at P = 5% level according to Duncan's multiple range test.

Analysis of variance showed that there was significant difference in yield among the treatments at P=5% (appendix 7). Duncan's test showed that control treatment's yield was different from that obtained in the other treatments at P = 5% level. The most likely explanation is that mulching increased availability of water which resulted in higher yield. Lined mulch at 3 t/ha trapped water forming ponds. It is assumed that these provided more water to the crops than the other four treatments which provided less water resulting in lower yield. Distributed at 3 t/ha and at 1.5 t/ha slowed down runoff which infiltrated thus increasing water availability to the crops. This resulted in the relatively high yield. Lined mulch at 1.5 t/ha trapped less water resulting in small ponds. This provided less water to the crops resulting in the lower yield. The control treatment had the least yield probably because availability of moisture was limited and some of the soil rich in nutrients had been carried away through erosion by water. Chaudhary and Khera (1989) and Unger (1978) showed that residue mulch could aid crop growth and cause increase in yield due to increased water availability.

The mean heights of beans (for the five treatments) during the 1992 short rains and 1993 January rains are shown both in appendix 10 and figure 6. The order of crop height in the treated plots, from the tallest to the shortest, was; distributed mulch at 3 t/ha > lined mulch at 3 t/ha > distributed mulch at 1.5 t/ha > lined mulch at 1.5 t/ha > control. This was perhaps because mulch at 3 t/ha treatments increased water availability which resulted in fast crop growth. Distributed mulch at 1.5 t/ha and lined mulch at 1.5 t/ha treatments increased water availability but less than the mulch at 3 t/ha treatments and therefore gave lower crop heights. In the control treatment, the crop height was shortest perhaps because less water was available for the beans' fast growth. Plant height could be used as a measure of vegetative growth which sometimes reflects the amount of moisture available to the crop (Murray - Harrison and Lal, 1977).

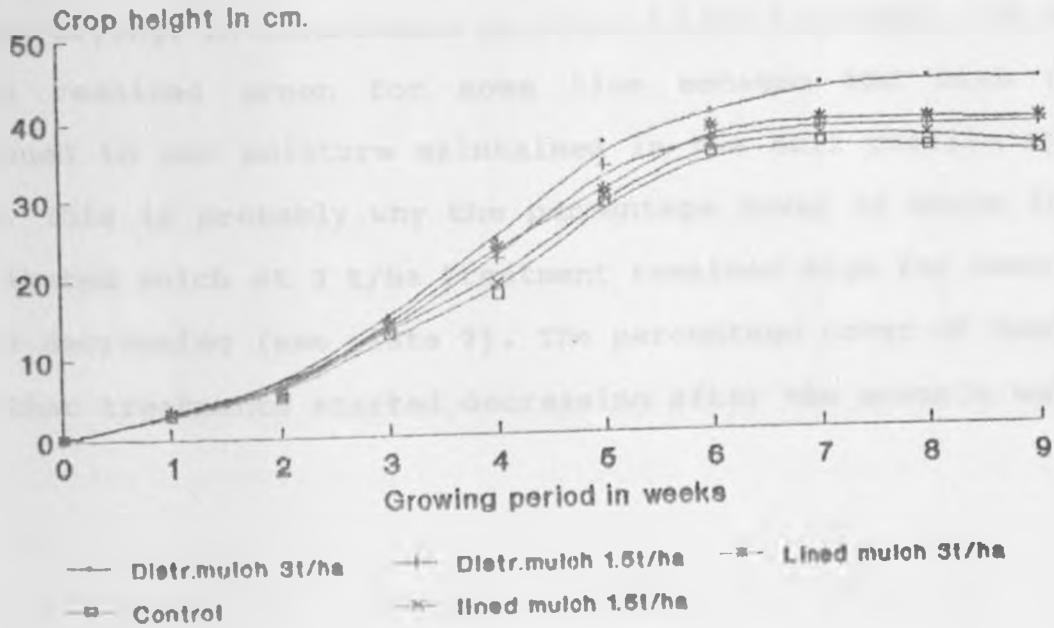


Fig. 6. The change of mean height of beans during the 1992 short rains and January 1993 rains.

In general, the beans height started increasing rapidly two weeks after germination (see fig.6). After the eighth week, the beans height became almost the same for all treatments. This was probably due to phenological maturity of the beans crop.

Figure 7 shows changes in mean percentage cover of beans during 1992 short rains and January 1993 rains.

It is clear from figure 7 that in all the treatments, the cover increased with the growing period up to about seventh week after which cover started decreasing (appendix 9). This was because the beans reached physiological maturity after which the bean leaves started drying. In distributed mulch at 3 t/ha treatment, the beans leaves remained green for some time because the bean plant continued to use moisture maintained in the soil profile by the mulch. This is probably why the percentage cover of beans in the distributed mulch at 3 t/ha treatment remained high for some time before decreasing (see plate 7). The percentage cover of beans in the other treatments started decreasing after the seventh week.

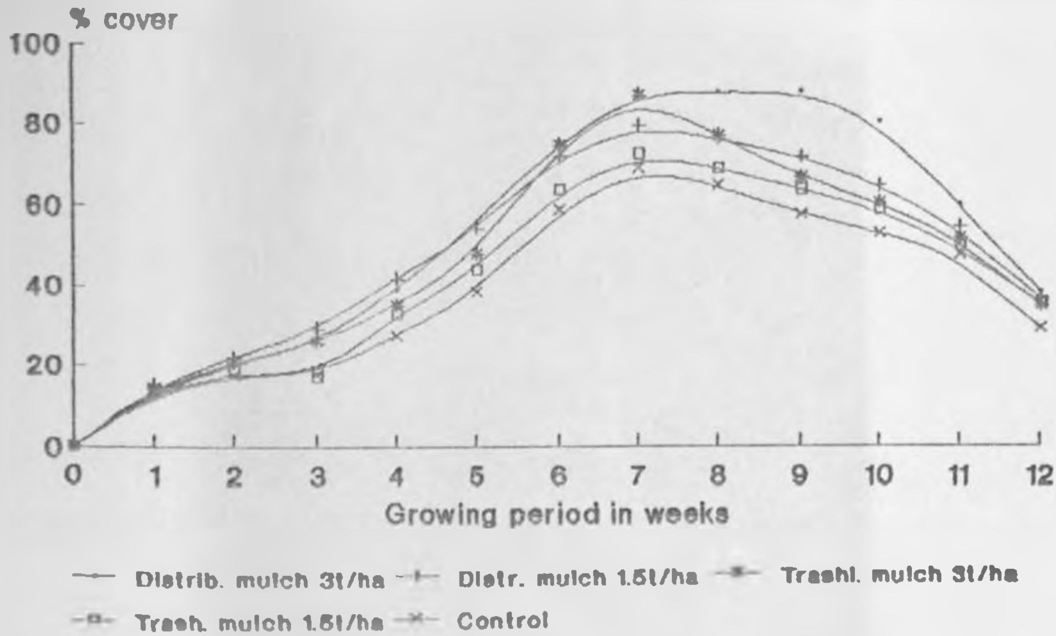


Fig. 7. Change in the mean % cover of beans during 1992 short rain season and January 1993 rains.

From the results, it could be argued that the amount of cover was dependent on the availability of moisture to the crops. Thus, the treatments which conserved more moisture in the soil had a higher percentage cover. The order of percentage cover, from the highest to the lowest was; distributed mulch at 3 t/ha > lined mulch at 3 t/ha > distributed mulch at 1.5 t/ha > lined mulch at 1.5 t/ha > control. In the control treatment, less moisture was conserved and probably, this caused the wilting and death of some plants. This could have led to the low percentage cover during the crop growing period.

Plate 7. Beans growing in a distributed mulch 3 t/ha treatment plot.

4.6 A FIELD VISIT IN MAKUYU DIVISION, MURANG'A DISTRICT

After performing field experiments, it was necessary to find out how the farmers really use their crop residues in the field. This was done by making a brief visit to nine farms in Makuyu division and asking farmers how they use the crop residues they get from their farms. During the visit, it was found that:

(i) The farmers are aware of the role of the crop residues (mulch) in soil and water conservation. Most farmers use the crop residues to conserve water during the dry seasons, and to reduce the velocity of runoff and reduce soil loss during rainfall seasons. Some farmers spread a thick layer of crop residues on areas where potatoes are planted. This helps to conserve water if rains are delayed and protect the potatoes from the scorching sun.This method of spreading crop residues on areas planted with potatoes seemed to be a popular practice with farmers in the area. Some farmers also spread some of their crop residues in the coffee farms. They do this in order to conserve water and improve the soil fertility when the crop residues rot.

(ii) The farmers mainly used lined mulch in their farms. Lined mulch was noticeable in some steep areas. The farmers argued that lined mulch does not affect crop emergence and work is relatively easier especially when ploughing and weeding compared to when crop residue is scattered. Another reason why farmers put lines was that it reduced labour of carrying mulch to the cattle shed. When the crop residue is too much to carry off, labour is scarce and time is short, the farmers might be forced to leave the crop residue scattered on the farm. One farmer said that residue left scattered on the surface rots down and fallowing with residue for one season improved soil fertility and crop yields in the next season. The farmers place mulch lines on different locations from the previous season's. This enable crops to derive maximum benefit from last season's rotten crop residues.

(iii) Farmers use part of their crop residue as animal feed. However, the number of the animals are rather few and therefore there is a surplus at certain times. Hence more is left in the field as trashlines than would be left in say, the more humid areas where there would be more livestock and less crop residue.

(iv) Most of the farmers do not sell their crop residue. Only very few isolated cases of farmers selling their crop residues were heard of. These were mainly the newly settled and economically handicapped farmers who sold it in order to buy fertilizer for use in their farms. These farmers had no animals in their farms and therefore no manure. These farmers without stock sell some part of their crop residues sometimes at a throw a way prices in order, for example, to buy fertilizer.

(v) The farmers do not experience firewood problems. The farmers use tree branches from trees planted on their farms. They pollard the trees from time to time when they need firewood. No farmer was found to use crop residue as a firewood substitute. Moreover, the majority of farmers do not burn their crop residue in the field. Only one farm had burnt crop residue.

(vi) The farmers grow a number of crops.These are mainly; pigeon peas, maize, beans, bananas, sweet potatoes, cassava, french beans, orange, pawpaw and coffee.The farmers use crop residue to conserve water which is used by crops during dry season.

In conclusion, it is very clear from this brief field visit that the farmers are aware of the value of crop residues for livestock feed and for mulch. They sometimes leave them in the field because of the labour of carrying them off. In areas such as Makuyu, crop residues can play a very important role in minimising runoff and erosion and reducing loss of moisture by evaporation.

5. CONCLUSIONS AND RESEARCH NEEDS

A farmer would do well to use all of the "good quality" (i.e, weed and disease free) maize stover that is obtainable. Where enough is not available, the farmer should use the small amount he is able to get, as it has been shown that even small quantities of mulch are effective. If no maize stover is available, the farmer should consider using other comparable type of materials for mulching.

Where labour is scarce, and farmers insist that distributing mulch affect their farming operations, the farmers should be advised to use lined mulch to prevent soil erosion. On the other hand, where farmers don't have any resistance to distributing mulch in their farms, they should be encouraged to use distributed mulch as this would enhance infiltration and reduce runoff and soil erosion.

In cases where crop residue is scarce, the farmers should be advised to use the little quantities of mulch available. This is because, as stated earlier, it has been shown by several researchers that even very low mulch rates are effective in reducing soil loss. However, the farmer should also consider using other types of crop residues such as millet and gin trash mulches. These has shown to be very effective in controlling soil and water losses (Bilbro and Fryrear, 1991). In order to eradicate the possibility of high soil loss during high rainfall events, crop residues should be used together with other soil and water conservation techniques. This would reduce soil and water losses, nd finally increase crop production.

s we advocate the use of crop residues in soil and water onservation, it is imperative that we conduct more research in future in order to give extension agents more research findings so as to be able to convince farmers to use it. The research areas, among others, should aim to:

(1) Study the use of mulch on steeper slopes to determine whether mulch is equally effective on steep slopes as on lower slopes.

(2) Determine how the value of crop residues for soil and water conservation compare economically with other uses where residues are removed from land.

(3) Determine how residue management (residue placement, timing and tillage practice) can be optimized to achieve maximum efficiency of residue for soil and water conservation.

(4) Determine the effectiveness of residues during periods when the amount and intensity of rainfall is high.

(5) Determine the rate and duration of mulch decomposition or consumption by termites.

(6) Determine the practices of using mulch in other areas of the country.

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APPENDICES

Appendix 1. Rainfall data in mm for the experimental period (September - December 1992 and January - August 1993)

(a). 1992

DATE	Sept.	October	November	December
			Months	
1	-	-	5.7	7.4
2	-	-	1.8	1.3
3	-	1.4	1.8	-
4	-	2.3	28.8	-
5	0.5	7.3	8.2	-
6	-	-	7.1	-
7	-	-	6.0	1.5
8	-	-	-	7.7
9	-	-	0.4	3.9
10	-	-	2.8	4.4
11	1.4	-	-	16.1
12	13.4	-	1.0	1.4
13	-	6.5	2.5	0.5
14	-	-	0.5	4.1
15	-	-	5.1	-
16	-	0.6	-	-
17	-	-	28.5	30.0
18	-	9.2	-	2.6
19	-	8.1	-	0.7
20	-	-	-	-
21	-	-	-	-
22	-	-	-	-
23	-	-	-	-
24	-	-	0.3	0.4
25	-	-	4.1	-
26	-	-	-	-
27	-	-	-	-
28	1.5	22.0	1.3	-
29	-	8.0	-	-
30	-	6.5	6.5	2.8
31		-		4.3
TOTAL	18.6	71.9	112.4	89.1

(b). 1993

DATE	January	February	March	April	May	June	July	August
			Months					
1	8.4	2.9	-	1.7	22.1	-	-	-
2	14.0	0.5	-	1.7	8.5	-	-	-
3	0.5	-	-	-	-	-	-	-
4	-	-	-	-	0.7	-	-	-
5	-	-	-	-	0.6	33.6	-	-
6	4.0	-	-	-	-	0.9	-	-
7	26.5	1.3	-	5.7	4.4	-	-	1.8
8	27.7	-	-	-	0.7	-	-	-
9	-	15.9	14.4	-	19.3	0.9	-	-
10	1.7	0.3	-	-	-	7.9	-	-
11	-	19.0	-	-	-	11.4	-	-
12	6.8	4.1	-	3.4	-	1.8	-	-
13	2.0	-	26.6	-	0.8	1.0	-	-
14	7.6	-	-	2.2	-	-	1.0	2.9
15	0.6	-	-	2.4	4.8	0.6	-	-
16	18.7	-	-	4.1	1.8	-	-	-
17	-	-	-	6.6	0.2	-	-	-
18	9.0	-	-	1.3	-	-	-	-
19	21.9	-	-	2.1	3.4	-	-	-
20	4.7	-	-	-	-	-	-	-
21	45.5	-	-	-	-	-	2.6	-
22	4.2	-	-	-	0.5	-	0.4	-
23	-	-	1.7	-	-	-	-	-
24	-	-	0.4	0.6	2.3	-	-	-
25	-	13.5	-	0.9	-	-	-	-
26	10.6	-	-	-	-	-	-	-
27	6.3	-	-	-	-	-	-	-
28	-	-	0.6	-	-	-	-	-
29	1.0		-	-	-	0.7	-	-
30	5.5		-	-	-	-	-	-
31	0.8		14.4		-		-	-
Total	228	57.5	57.7	32.7	70.1	60.4	4.0	4.7

Appendix 2.
(a). Mean soil loss (kg/ha) for the five mulch treatments during the 1992 short rain and January 1993 rains.

Treatment	Blocks 1	2	3	mean
Control.	167.95	105.76	56.32	110.01
Distributed mulch 1.5 t/ha	52.49	43.13	17.99	37.87
Distributed mulch 3.0 t/ha	29.76	31.88	14.57	25.40
Lined mulch 1.5 t/ha	53.37	66.26	30.20	49.94
Lined mulch 3.0 t/ha	55.11	21.19	3.87	26.72

$\Sigma Y = 749.85$

(b). Analysis of variance (ANOVA).

Source	df	ss	ms	Fcal.	Ftab.(1%).
Block	2	5657.00	2828.5		
Treatment	4	14685.42	3671.36	8.78**	7.01
Error	8	3343.00	417.88		
Total	14	23784.50	1698.89		

Conclusion: There's statistical evidence that a significant difference exists between the treatment means.

(c). Soil loss data.

Soil loss (kg/ha)

Plots

Date:	1	2	3	4	5	6	7	8
17.11.92	73.95	243.10	38.75	80.45	85.00	141.45	45.55	121.75
11.12.92	2.00	75.74	47.50	19.60	16.55	90.20	0.72	43.17
17.12.92	16.20	63.56	15.15	12.60	45.70	51.0	1.85	16.55
7.1.93	37.20	118.80	89.0	54.0	31.50	37.40	0.0	16.80
8.1.93	2.0	84.70	13.25	3.0	1.40	2.41	0.0	3.85
16.1.93	3.26	98.15	36.15	39.0	37.62	123.40	33.0	33.20
18.1.93	0.0	264.76	73.75	12.90	54.16	44.44	1.28	30.89
19.1.93	30.50	253.0	71.30	95.10	132.90	227.5	77.50	184.8
21.1.93	102.0	309.7	95.51	155.72	91.15	234.08	127.0	145.3

Data continued.

Plots

Date:	9	10	11	12	13	14	15
17.11.92	75.8	48.35	14.05	71.50	6.5	51.0	71.65
11.12.92	9.4	0.71	1.88	2.10	0.0	4.72	2.86
17.12.92	18.6	0.60	1.35	5.80	0.0	5.50	14.15
7.1.93	29.2	23.60	8.80	49.40	1.54	29.38	0.0
8.1.93	2.55	6.40	2.90	4.65	0.0	0.0	1.24
16.1.93	17.83	0.84	0.88	210.34	0.0	0.20	22.59
18.1.93	14.83	1.22	0.16	2.73	0.81	0.16	1.30
19.1.93	124.50	21.90	40.80	7.20	1.46	13.09	36.40
21.1.93	95.50	87.10	60.35	153.16	11.74	57.90	121.58

Appendix 3.

Calculating K value:

$$K=\frac{A}{R.L.S.C.P} \quad (3.1)$$

where:

A is soil loss per unit area.
R is rainfall erosivity factor.
L is slope length factor.
S is slope steep factor.
C is crop factor.
P is soil conservation factor.

R is calculated as follow:

$$R=\sum \frac{EI_{30}}{100} \quad (3.2)$$

(Wischmeier and Smith, 1978).

where:

E is energy (J $m^{-2}.mm^{-1}$).
I_{30} is the maximum rainfall intensity for 30 minutes duration.

Energy per mm of rain in each interval was calculated from rainfall charts. By substituting the intensity of each increment (incremental amount divided by the time intervals times 60) in the equation below, we get the energy per mm of rain in the increment. The incremental energy amounts were then calculated by multiplying the energy per mm by the corresponding rainfall amount at that intensity. The energy (E) was the sum of all incremental energies. These are summarized below:

$$KE = 11.86 + 8.73 \log_{10} I.$$

Date	E	I_{30}
SR		
17/11/92	444.2	18
11/12/92	552.9	10
17/12/92	264.2	12
JR		
7/1/93	362.5	13
8/1/93	426.8	10
16/1/93	301.4	15
18/1/93	214.5	17
19/1/93	389.4	12
21/1/93	1108.8	60

For short rains

Total EI_{30} =(444.2 * 18) + (552.9 * 10) + (264.2 * 12) = 16695

$$R=\frac{EI_{30}}{100} \qquad \text{.......3.3}$$

$$R=\frac{16695}{100} \qquad \text{.......3.4}$$

R = 166.95

Taking A = 0.0967 t/ha, LS = 0.35, C = 0.90, P= 0.80, R = 166.95 and substituting in equation 3.1, we get;

$$K=\frac{0.0967}{166.95\times0.35\times0.90\times0.80} \qquad \text{.......3.5}$$

K = 0.002

For January rain

$$R=\sum\frac{EI_{30}}{100} \qquad \text{.......3.2}$$

$$R=\frac{88349}{100} \qquad \text{.......3.6}$$

R = 883.49, A = 0.0908 t/ha and Substituting in equation 3.1, we get K = 0.002.

Appendix 4

(a). Mean runoff (l) for the five mulch treatments during the 1992 short rain season and January 1993 rains.

Treatment	Block 1	2	3	mean
Control	30.67	20.28	16.64	22.53
Distributed mulch 3.0 t/ha	10.86	6.58	7.80	8.41
Distributed mulch 1.5 t/ha	16.30	9.81	9.72	11.94
Lined mulch 3.0 t/ha.	8.38	8.03	3.70	6.7
Lined mulch 1.5 t/ha	18.13	16.00	9.66	14.60

(b). Analysis of variance (ANOVA)

Source	df	SS	MS	Fcal.	Ftab(1%)
Total	14	661.75	47.27		
Treatment	4	465.12	116.28	16.19**	7.01
Block	2	139.22	69.61		
Error	8	57.41	7.18		

Conclusion: Treatments are significantly different at P=0.01.

(d). Runoff data.

Runoff (l)

Date:	Plots: 1	2	3	4	5	6	7	8	9
17.11.92	4.00	24.0	7.0	6.0	5.0	15.0	3.0	6.0	3.0
11.12.92	.56	2.5	2.0	0.45	0.4	0.08	0.02	0.04	0.02
17.12.92	3.00	8.5	1.0	2.0	1.4	4.0	0.5	1.50	1.0
7.1.93.	2.00	7.0	7.0	2.0	1.0	2.0	0.0	0.65	2.0
8.1.93	0.26	0.27	2.0	0.33	0.1	0.25	0.0	0.15	0.12
16.1.93	0.49	16.26	3.01	1.20	2.0	2.11	0.74	1.53	1.02
18.1.93	0.0	9.39	1.01	1.05	1.5	2.07	0.46	1.79	1.66
19.1.93	2.17	37.02	12.36	6.19	5.4	9.42	3.25	8.42	6.34
21.1.93	85.30	171.10	127.80	127.45	58.5	147.55	51.30	123.90	73.10

Runoff data continued.

Date:	Plots 10	11	12	13	14	15
17.11.92	6.0	1.0	7.0	1.50	2.50	2.0
11.12.92	0.03	0.02	0.05	0.0	0.01	0.05
17.12.92	1.40	0.20	3.0	0.0	1.0	2.0
7.1.93	1.0	1.0	2.0	0.24	2.0	0.0
8.1.93	0.10	0.18	0.27	0.0	0.0	0.28
16.1.93	0.48	0.22	0.99	0.0	0.23	0.31
18.1.93	0.54	0.29	0.85	0.18	0.18	0.38
19.1.93	3.20	1.0	0.32	0.71	1.0	7.33
21.1.93	59.50	66.30	121.85	30.70	80.55	74.55

Appendix 5.

(a). Mulch (crop residue) % cover as measured by string/bead method before the onset of short rain season.

Treatment	Block 1	Block 2	Block 3
Control	0.0	0.0	0.0
Distributed mulch 1.5 t/ha.	25.9	15.3	24.9
Distributed mulch 3.0 t/ha.	40.5	50.7	50.3
Lined mulch 1.5 t/ha.	12.4	10.6	10.5
Lined mulch 3.0 t/ha.	10.6	20.5	14.0

(b). Analysis of variance (ANOVA)

Source	df	SS	MS	Fcal	Ftab.(1%).
Total	14	3818.05			
Block	2	13.992	6.996		
Treatment	4	3631.9	907.98	42.19**	7.01
Error	8	172.16	21.52		

Conclusion: There is high significant difference between the mulch cover.

Appendix 6.

(a). Infiltration depth (mm) in the five mulch treatments during the 1992 short rain and January 1993 rain.

Treatment	Block 1	Block 2	Block 3
Control	22.934	23.453	23.632
Distr.3t/ha	29.923	24.134	24.077
Distr.1.5t/ha	23.652	23.976	23.930
Lined 3t/ha	24.048	24.065	24.282
Lined 1.5t/ha	23.560	23.667	23.984

(b). Analysis of variance (ANOVA).

Source	df	SS	MS	Fcal.	Ftab.(%).
Total	14	36.46			
Block	2	2.76	1.38		
Trt	4	13.44	3.36	1.32 ns	7.01
Error	8	20.26	2.53		

Conclusion: There is no statistical evidence to show that there was significant difference between the treatments at P=0.01.

(d). Infiltration depth data.

Infiltration depth (mm)

Date:	Plots: 1	2	3	4	5	6	7	8
17.11.92	26.40	25.40	26.25	26.30	26.35	25.85	26.45	26.30
11.12.92	14.27	14.16	14.20	14.28	14.28	14.29	14.27	14.29
17.12.92	29.85	29.58	29.95	29.90	29.93	29.80	29.98	29.93
7.1.93	26.40	26.15	26.15	26.40	26.45	26.40	26.50	26.47
8.1.93	27.69	27.69	27.60	27.68	27.70	27.69	27.70	27.69
16.1.93	18.68	17.89	18.55	18.64	18.60	18.59	18.66	18.62
18.1.93	9.0	8.53	8.95	8.95	8.92	8.89	8.98	8.91
19.1.93	21.79	20.05	21.28	21.59	21.63	21.43	21.74	21.48
21.1.93	41.24	36.95	39.11	39.13	42.58	38.12	42.94	39.31

Infiltration depth data continued.

Date:	Plots: 9	10	11	12	13	14	15
17.11.92	26.45	26.30	26.55	26.25	26.53	26.48	26.50
11.12.92	14.29	14.29	14.29	14.29	14.30	14.29	14.29
17.12.92	29.95	29.93	29.99	29.85	30.00	29.95	29.90
7.1.93	26.40	26.45	26.45	26.40	26.49	26.40	26.50
8.1.93	27.69	27.69	27.69	27.69	27.70	27.70	27.69
16.1.93	18.65	18.68	18.69	18.65	18.70	18.69	18.68
18.1.93	8.92	8.97	8.98	8.96	8.99	8.99	8.98
19.1.93	21.58	21.74	21.85	21.38	21.38	21.34	21.53
21.1.93	41.85	42.53	42.19	39.21	43.97	41.47	41.77

Appendix 7.

Analysis of variance (ANOVA)

Source	df	SS	MS	Fcal.	Ftab.(1%)	(Ftab 5%)
Total	14	5.024	0.3589			
Block	2	0.772	0.386			
Trt	4	3.231	0.8078	6.326	7.01 ns	3.84
Error	8	1.021	0.1277			

Conclusion: There's a significant difference in yield within the treatments at 5% level.

Appendix 8.

Analysis of variance (ANOVA).

Source	df	SS	MS	Fcal.	Ftab(1%)
Total	14	1355.96			
Block	2	7.296			
Trt	4	879.32	219.83	3.747 ns	2.81
Error	8	469.344	58.668		

Conclusion: There is statistical evidence to show that there was significant difference in % emergence of beans among treatments at P=0.1.

Appendix 9.
Mean % cover of beans during short rains- 1992.

	Treatments				
Time (wks)	Dist. mulch 3t/ha	Dist. mulch 1.5t/ha	Trash. mulch 3t/ha	Trash.mulch 1.5t/ha	Control
0	0	0	0	0	0
1	14.0	15.2	14.5	13.6	13.3
2	20.0	22.0	20.9	18.8	17.6
3	26.1	29.4	26.1	17.2	17.8
4	39.0	42.0	35.0	33.0	27.7
5	56.0	54.3	48.0	44.0	38.5
6	75.4	72.1	74.8	63.8	59.0
7	88.0	79.7	87.3	72.5	69.0
8	88.0	76.4	77.3	69.2	65.0
9	88.3	72.0	66.8	64.0	58.0
10	80.9	65.0	60.7	59.0	53.4
11	60.3	54.8	52.3	50.0	48.1
12	38.9	37.1	35.3	36.1	29.6

Key:

a) week 0 corresponds to 28/10/92
   week 1 corresponds to 9/11/92
   week 2 corresponds to 16/11/92
   .
   .
   week 12 corresponds to 25/1/93

(b) Trash.- trashlined mulch
    Dist.- distributed mulch

Appendix 10.

Mean height (cm.) of beans during short rains in 1992 at Kabete.

	Treatment				
Time (wks)	Distr. mulch 3t/ha	Distr. mulch 1.5t/ha	Trash.mulch 3t/ha	Trash.mulch 1.5t/ha	Control
0	0	0	0	0	0
1	2.8	3.0	3.2	3.1	2.9
2	6.2	6.4	5.3	5.0	4.9
3	15.0	13.3	14.1	13.8	12.7
4	24.4	22.0	23.5	19.0	17.5
5	36.5	33.6	30.4	29.7	28.8
6	40.1	36.8	38.3	36.1	35.0
7	43.4	38.2	39.0	37.0	36.0
8	43.9	38.1	38.8	36.9	34.5
9	43.0	35.6	37.5	35.3	33.9