EFFECT OF TILLAGE AND FARMYARD MANURE ON INFILTRATION, RUNOFF AND SOIL LOSS OF A CRUSTING SOIL

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DECLARATION

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

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Nagaya L.M. DATE

This thesis has been submitted with our approval as University supervisors.

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Thomas D.B. DATE

DEDICATION

This thesis is dedicated to my Father Badru B. Mulumba and my Mother Hasifa Mulumba whose sacrifice made it possible for me to succeed in my education.

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LIST OF ABBREVIATIONS

FAO	Food and Agricultural Organisation of the United nations
ASAL	Arid and Semi Arid Lands
cm	Centimetre
ESP	Exchangeable Sodium percentage
g	gramme
h	Hour
ha	Hectare
J	Joules
kg	Kilogramme
kpa	Kilopascal
m	Metre
r	Correlation coefficient
r^2	Coefficient of determination
a.s.l	Above sea level
ANOVA	Analysis of Variance
LSD	Least Significant Difference
P(0.05)	Probability at 95% confidence limit
pF	Negative logarithm to base 10 of the pressure in centimetre of water
me/100gm	Milli equivalent per 100 grammes of soil
pH	Negative logarithm to the base 10 of hydrogen ion concentration
CEC	Cation exchange capacity
5yr	Colour hue
3/	Colour chroma
/3	Colour Value
CT	Conventional tillage
ZT	Zero tillage
5 FYM	5 tonnes of farmyard manure per hectare
10FYM	10 tonnes of farmyard manure per hectare

ABSTRACT

The effects of tillage and farmyard manure application on infiltration, runoff and soil loss of a crusting Luvisol(FAO/UNESCO Classification, 1974) were investigated under field conditions from October 1992 to May 1993 (two cropping seasons) on micro plots of 2 m^2 at the National Dryland Farming Research Centre, Katumani, Machakos, Kenya.

Four treatments (Zero tillage, ZT; Conventional tillage, CT; 5t/ha farmyard manure, 5FYM; and lOt/ha farmyard manure, 10FYM) with three replicates were applied on the micro plots. The plots were left bare to eliminate the influence of vegetative cover on measured parameters. The measured parameters included runoff, soil loss, bulk density, soil shear strength,Soil penetration resistance and soil moisture content.

The results obtained showed some significant changes in soil micro (cloddiness) and soil aggregation with rainfall events and soil treatments. Though soil loss was highly variable even within the same treatment and for the same amount of precipitation, it was in the order of CT > ZT > 5FYM > 10FYM. Farmyard manure was found to improve soil aggregation. At the end of February, a marked decline in soil organic matter was observed, the greatest decline being under CT. There were no significant differences at (P= 0.05) between farmyard manure treatments over the experimental period. However, there were significant differences between tillage and farmyard manure treatments at P(0.05). Runoff increased with time and treatments in the order ZT>CT>5FYM>10FYM. The progressive increase in runoff and decrease in soil loss were attributed to an increase in soil compaction/ crusting due to break down in soil aggregation by raindrop impact. The high generation of high amounts of runoff decreased infiltration and profile soil moisture.

Soil shear strength and bulk density variations with the rainy season influenced soil erodibility and the moisture retention characteristics of the top soil. This study did prove the significant role of tillage and farmyard manure application in facilitating better infiltration rates, improving soil moisture, and reducing soil loss during the initial stages of the rainy season when there is no vegetative cover.

CHAPTER ONE

INTRODUCTION

1.1 General Background

About eighty five percent of Kenya's land mass is classified as arid or semi arid lands (ASAL) and 72% percent of the country receives less than 550 mm of rainfall (Braun,1982). The rainfall in these areas is erratic and undependable as regards amounts, duration of fall and onset of the rains. This was clearly demonstrated during the period of this study (1992), when the short rains extended up to March, 1993 and thereafter the long rains did not continue as expected.

In arid and semi-arid areas of Kenya, surface runoff is the single most important cause of soil erosion. It is significantly influenced by soil structure, organic matter content and both the chemical and biological nature of the soil (Kilewe and Ulsaker, 1984). These factors determine the infiltration characteristics of the soil. The higher the infiltration rate and capacity, the less the runoff losses and the higher the stored soil water.

It is common in these regions to lose 40 - 70% of the rain as surface runoff especially on sloping arable lands. During the long rains of 1993, runoff of 40 mm from a storm event of 46 mm was observed on bare plots, a loss of 87%. At the same site, Kilewe (1984) reported a 53% loss of water as runoff. The increase in runoff can be attributed to the fact that the runoff plots were bare with neither crops nor crop residues.

In addition to causing increased runoff, surface sealing, hardsetting and crusting are known to affect seedling emergence (Biamah,1991; Mullins et al,1990). The above characteristics also decrease rain infiltration and consequently result in high surface runoff rates but low soil loss. The crusts protect the underlying layers from erosion. However, once they are broken, the unstable subsoils are exposed, resulting in accelerated erosion and formation of gullies. The eroded soil and lost water carry with them nutrients which tend to be relatively more concentrated in the top soil than in the subsoil. Nutrients are also more concentrated in the soil that is eroded than in the subsoil which remains. The total result is a down ward trend in soil productivity as land gets increasingly degraded. Compaction and crusting also affect soil aeration, root penetration, nutrient availability and uptake and soil moisture conservation.

Whereas tillage research at IITA (Nigeria) indicates no till as a way to manage tropical soils, observations elsewhere show that it is mainly light shallow soils for which the foregoing tillage practice would be appropriate. This clearly shows that tillage management requirements of these soils depends on the inherent characteristics of the soil. Biamah (1991) cites clay mineralogy, workability and moisture holding capacity as some of the factors that determine the suitability of a tillage practice for arid and semi arid soils.

There is need to increase soil water storage for crop growth in ASAL. Where other factors such as soil fertility, pests and diseases are non limiting, crop productivity is directly related to soil water, a function of infiltration, runoff and precipitation.

Research at Katumani has shown that it is possible to increase sorghum yields five fold after fallow compared to a virtually failed crop after cereals (Whiteman, 1984). Such an observation is possibly due to the fact that the soil surface is covered under fallow. This results in reduced runoff hence increased infiltration of soil water. However the increase in yield can also be attributed to improvement in soil physical and chemical properties. Under fallow, very little nutrients are extracted from the soil. Better still, the grass roots and leaves that decompose add to the soil fertility. On the other hand, cereals will lead to loss of nutrients especially so during harvesting.

1.2 Significance of the Study

Low, unreliable and erratic rainfall coupled with problem soils constitute major constraints to crop and fodder production in arid and semi arid lands (ASAL) of Kenya. The very high runoff volumes and high soil losses which occur at the beginning of the season hamper agricultural production due to subsequent soil moisture deficits and decreased soil productivity respectively. In ASAL possible yields are generally so low that it is rarely worth spending large amounts of money on conservation structures. Therefore good management must work with natural processes as much as possible.

In ASAL areas of Kenya, it has been observed that approximately 70% of the most erosive storms occur during the first month of the rainy season when there is no effective crop/ground cover. In order to develop sustainable rain fed agriculture for these areas, there is need for soil management techniques that enhance rain water infiltration and water conservation especially early in the season when the soil surface is still bare.

A study of seasonal trends in aggregate stability, soil bulk density, soil moisture, penetration resistance and soil shear strength as they influence rain infiltration, runoff and soil loss would facilitate some better understanding of these dynamic soil properties and lead to the development of effective soil and water management practices for such soils.

13 Objectives and Scope of Study

Overall Objective

To study the effects of tillage and farmyard manure application on infiltration, runoff and soil loss of a crusting soil as influenced by rainfall and soil properties.

Specific objectives

1. To monitor infiltration, runoff and soil loss rates under different soil treatments.
2. To relate infiltration, runoff and soil loss rates to rainfall properties and physico-chemical properties of the soil.
3. To monitor changes in crust strength, soil bulk density and soil shear strength under different soil treatments.

Scope of Study

This study was conducted to evaluate the effects of different tillage practices and farmyard manure application rates on infiltration, runoff and soil loss of a crusting luvisol at Katumani, Machakos, Kenya.

The study looked at rainfall properties (intensity, amounts and energy) and soil properties (soil moisture, organic matter, soil shear strength, crust strength bulk density and aggregation) with a view to relating them to infiltration, runoff and soil loss.

The study was carried out in two crop growing seasons (October 1992 to July 1993).

1.4 Field Experimental Site

The site for the research study was at the National Dryland Farming Research Centre, Katumani, Machakos, Kenya. The site is located about 10 km south of Machakos Town and 80 km east of Nairobi at an elevation of 1600 metres a.s.l.

1.4.1 Climate

The site is in a semi-arid area and falls in agro-climatic zone IV. Rainfall data for 27 years, 1956-1983 (Stewart and Faught, 1984) shows that the mean annual rainfall of the study area is 701 mm. Its distribution is bimodal, occurring in two distinct rainy seasons; short and long rains periods. The short rains occur from October to December with a peak in November. However in 1992/93, the short rains occurred from October to February with a peak in January. The seasonal rainfall in the short rains period was 767mm. The long rains occur from March to May with a peak in April. During the period of study (1992/93) the long rains failed to occur. Hence there was very little rainfall over the period. Usually, the short rains are more reliable than the long rains and hence better crop yields are expected during this period. The driest month is August with a mean of 4 mm rainfall (see appendix 4).

1.4.2 Cropping systems

The farming system is characterised by crops and livestock. The Crops grown include maize, beans, pigeon peas, green grams, sorghum, millet, sweet potatoes, sunflower, cassava, forage, legumes and grasses.

1.4.3 Soils

The dominant soils in the study area are luvisols, cambisols, lithisols and vertisols (Gicheru and Ita, 1987; Kilewe, 1984, Mbuvi and Van de Weg, 1975). Apart from the Vertisols which develop deep and wide cracks upon drying and have high water storage capacity, the other soils are shallow with low organic matter content; well drained, low water infiltration, dark reddish brown, friable when wet but harden on drying (Barber and Thomas, 1979 ; Kilewe and Ulsaker, 1984). The soils also exhibit low water retention capacity and strong surface sealing and crusting properties (Biamah, 1991; Gicheru and Ita, 1987; Nadar, 1984).

Crop residues in arid areas are used to supplement pasture and little or none is returned to the soil, resulting in low nutrient and organic matter content of the arable soils consequently the fragile soil structures. Kilewe (1984) observed high erodibilities and rapid soil capping tendencies especially during the early part of the rainy season. This is possibly due to the fact that the first rains fall when the land is bare, loose and without any vegetative cover.

However, concentrated runoff which often flows along bare tracks and natural drainage ways breaks the surface, exposing the unstable subsoils. This has caused severe rill and gully erosion in areas such as the Kaibon in the Turkwell Catchment due to the dispersive property of the subsoils. Erosion is known to cause loss of soil productivity, loss of plant nutrients and water pollution. On shallow soils, erosion may cause complete denudation. Biamah (1990) was of the view that the management of such soils requires minimal exposure of the subsoil horizons.

CHAPTER TWO
REVIEW OF LITERATURE

2.1 Soil Pillage

Literally soil tillage means stirring or manipulating the soil so as to ensure proper soil tilth (Arakeri et al, 1989). Methods of land clearing and preparation are of crucial importance in preventing degradation because certain mechanical operations can damage the soil's physical properties and lead to a deterioration of the soil structure and erosion of the top soil (Arakeri et al, 1989).

Differences between the length of the growing season and the length of the rainy season have been shown to affect maize yields (Nadar, 1984). Whiteman (1984) found grain yields of cereals at Katumani to be highly correlated to the amount of residual moisture in the profile at planting time. The implication of this is that tillage after harvesting is likely to be beneficial in Katumani. End of season cultivation can kill weeds, preserve precious moisture and may save a crop when the following season's rains are marginal. At the same time, the rains find a cloddy soil surface which increases infiltration due to the increased infiltration opportunity time.

Tillage alters the pore structure not only of the top soil but also of the upper part of the subsoil in ways that have direct effect on plant growth (Arakeri and Donahue, 1989). Cultivation has been known to reduce bulk density and therefore facilitate root development. Strong positive correlations between the reduction of bulk density (increased porosity, increased root growth and yield) have been reported for many crops (Charreau and Nicou, 1971).

Soil cultivation can also play a role in improving soil fertility by incorporating organic matter, crop residues and manure. Experiments carried out in different ecological zones of West Africa have often given contradicting results particularly with regard to the effects of ploughing and mulching with zero tillage. Whereas ploughing was found to be beneficial in Senegal (Charreau and Nicou, 1971; Chorpart and Nicou, 1976), research carried out by IITA in Nigeria recommends zero tillage. This is possibly because though the soils in West Africa are fertile, they are shallow thus tillage leads to exposure of the hard rock consequently an increase in soil bulk density.

Tillage has different effects on different soils depending on their physical properties. It has been shown to improve the infiltration capacity of soil (Larson, 1962; Hoogmoed, 1981) but such improvements are often short lived as the soil settles into a dense compact medium under the influence of raindrop impact. Long term results show that after a lapse of time, the soil loses porosity and productivity (Arakeri et al, 1989). Mead and Chan, 1989 observed that sixty days after tillage and after a total of 76 mm of rainfall, the bulk density of the soils under zero tillage was still 1200 kg m ^{1} whereas that of soils under conventional tillage had risen from 1000 to 1600 kg m"\

The dynamics of tillage can be observed through the changes in soil compaction when a friable loosely tilled and highly pervious soil at the beginning of the season soon under the impact of rain drops settles into a dense less pervious medium as the season progresses.

Soils under reduced tillage were found to have lower porosity and microporosity and were less soft than those under conventional tillage (Murphy et al, 1987; Mead and Chan, 1989). At a bulk density of 1700 kg m-^{3} in loam soils, limiting resistance to root penetration may occur.

Increase of rain water infiltration and reduction of evaporation under zero tillage as compared to conventional tillage has been reported from the Guadalquivir valley in Spain (Giraldezet al, 1986).

The organic fraction of soil helps in the formation of water stable aggregates that increase the porosity and permeability of the soil. Organic matter is also known to increase the soil's ability to absorb and store water. Soils of low organic matter content are more erodible and less retentive of moisture than soils with high organic matter content. They are also less able to deliver to plants what is retained (Kilewe, 1984).

Where water stability of aggregates is low, infiltration is reduced by slaking and blocking of soil pores. 3 t/ha of maize stover applied as mulch at Katumani was found to significantly reduce runoff and soil loss leading to the conclusion that mulch application was the best soil conservation practice for this region (Kilewe, 1987).

However, crop residues have limitations due to their alternative uses such as fuel, animal feed and fencing. In Katumani, farmers value stover as stock feed far more than for soil conservation. Crop residues left on the soil surface as mulch may also not be as effective as anticipated because of destruction by termites.

Different effects of tillage on yield have been observed. Whereas maize and soya bean yields under zero tillage were greater than those under conventional tillage systems on a pacolet sandy slay loam at Piedmont, the yields were less affected by tillage on Aycock fine sandy loam at the Coastal Plains, in North Carolina (Wagger and Denton, 1989). On the contrary, Alegre et al (1991) observed reduced yields under zero tillage and minimum tillage as compared to conventional tillage (disc ploughing). High bulk densities in the surface soil and lower infiltration rates under zero tillage and minimum tillage were also observed.

From the foregoing, the choice of tillage method should depend on the soil properties, crop species and level of agricultural management.

2.1.1 Types of Tillage Practices

Conventional Tillage

This is a common practice used by many farmers in Eastern Africa. Seedbed preparation involves primary tillage operations with no secondary tillage until weed control (Beasley et al, 1984). The plain hoe (Jembe) is the most common implement for manual tillage in Eastern Africa though some times the forked hoe is also used.

Larson, 1962 observed that the loose mulch formed as a result of hoeing is not stable enough to withstand heavy storms. Furthermore the surface feeding roots of the crop may be destroyed. Hulugalle and Maurya (1991) were of the view that soil degradation associated with mechanized conventional tillage can be minimized with zero tillage. However, the success of such a move will wholly depend on the soil type and the availability of organic matter.

Appropriate measures for soil and water conservation are often site specific and vary from place to place. For Kaolinitic clay soils, Lenvian et al (1987) recommended tillage after harvest in order to minimise evaporation and maximise on the soil water intake rate. On the other hand, Harte (1984) observed an increase in bulk density due to tillage on red brown earth in New South Wales. Furthermore mechanized agricultural systems used in Southern Brazil and West Africa's semi arid areas have been observed to accelerate soil erosion, deplete plant available nutrients and reduce crop productivity (Castro, 1991; Hulugalle et al, 1991).

The break down of soil structure and the loss of fertility especially on dusty, fine sandy soils, particularly when dry; on very heavy, sticky soils are possibly the most serious consequences of conventional tillage. However, tillage can improve the structure of heavy soils (Morgan, 1986).

Conservation Tillage

Broadly, conservation tillage refers to any tillage system that reduces erosion (Donahue et al, 1983). Conservation tillage is characterised by managing residue cover which may be from a forage crop, small grain or a row crop. Conservation tillage involves the conservation of water primarily and soil. Some researchers have classified zero tillage and minimum tillage under conservation tillage (Alegre et al, 1991) hence the term may sometimes be misleading.

Poorly drained soils have been found to respond with lower yields under conservation tillage (Donahue et al, 1983; Morgan, 1986). Soil water content is almost always higher under conservation tillage (due to presence of high amounts of crop residues) than under conventional tillage. On highly compacted soils, some soil loosening may be needed. The management of the soil surface modifies surface storage capacity, infiltration and susceptibility of soil to detachment. The loosening effect of tillage creates large pores that will support rapid water infiltration and the storage of rain water(Ehlers, 1987).

However, conventional tillage may cause slaking of aggregates leading to the formation of surface seals hence reducing water infiltration on a wide range of medium textured soils. In such a case zero tillage may be preferable as the surface aggregates will be more stabilized. Mulch protects the soil and the roots of the preceding crops may create biopores that enhance rapid water infiltration (Morgan, 1986). In conventionally ploughed soils, tillage pans may impede deep rooting. Similarly conservation tillage may lead to a less porous surface resulting in increased runoff since it does not break up the soil surface (Morgan, 1986). Over time, Packer and Hamilton (1987) have found conservation tillage practices to be effective in stopping and in some cases reversing soil physical degradation. Therefore tillage systems need to be chosen putting into consideration the inherent soil properties and the climatic factors of the area under question.

Reduced/Minimum Tillage

This aims at reducing the number of tillage operations and the area affected with an aim protecting the soil surface and reducing energy costs(Morgan, 1986). It also reduces the time requirements hence facilitating the timeliness of operations. Tillage can be reduced by combining operations such as weeding and fertilizer application or mixing soluble fertilizers with water so that they can be applied simultaneously. Versions of reduced tillage include strip tillage, where narrow strips of about 20 cm are cut along the planting rows; ridge tillage; spot tillage, where only the planting holes (10X10 cm) are made using a hoe leaving the inter-row spaces undisturbed and mulch tillage.

Whereas reduced tillage systems have not been successful on easily compacted sandy soils in the semi arid regions of Latin America, zero tillage with methods utilizing crop residue mulches have been successful on some alfisols in the humid regions of Africa (Lai, 1976). While under mulch, the initial high runoff and soil loss that are characteristic of the beginning of the rainy season due to the leaving bare of friable, cultivated soils is adequately checked. The dead plant material often left on the soil surface covers the soil and absorbs the raindrop impact. Soil pulverisation which results in the break down of soil aggregates under continuous conventional tillage is checked under reduced tillage.

Tillage research in Latin America has shown that Zero-tillage and Minimum tillage practices lead to high bulk density in the surface soil, reduced macro porosity, reduced infiltration rate and reduced crop yields(Alegre, 1991).

Although Ngugi and Michieka (1989) observed that minimum tillage can be beneficial in large parts of the tropics (characterised by frequent droughts), Hoogmoed (1981) noted that conventional tillage will be instrumental in minimizing runoff and increasing soil water storage in the semi arid areas of West Africa. These areas are characterised by high rainfall intensities. This may be so in the short run but in the long run, tillage may increase soil compaction and reduce the organic matter content.

Zero Tillage

This refers to a tillage system that does not involve any disturbance to the soil between harvesting and planting. There is no breaking or opening of the soil surface thus no incorporation of organic matter (Donahue and Arakeri, 1989). Weed control is achieved by use of herbicides.

Where drainage is poor, Zero tillage may depress yields and where drainage is good, yields may increase. Morgan (1986) found zero tillage not to be always effective in the first year of its operation to the low percentage of crop residues on the surface.

A study by Jones et al (1987) revealed that zero tillage economically performed much better than conventional tillage mainly due to reduced equipment inventories and lower operating costs. Nevertheless, such an observation can only be valid under certain environmental and soil physical conditions. On an irrigated sandy loam in Nigeria, zero tillage plots with residue mulch had a higher organic carbon content, a higher soil porosity in the surface soil horizons and a 50% higher basic infiltration rate than tilled plots (Maurya, 1986).

Packer et al (1984), in New South Wales, found out that reduced tillage and zero tillage resulted in increased soil organic matter content; reduced bulk density; increased sorptivity, hydraulic conductivity and infiltration and reduced runoff and sediment loss in comparison with conventional tillage. However, observations elsewhere show that zero tillage without a cover crop or crop residue results into a lot of runoff as was observed at Katumani, Machakos during the study period.

In semi arid areas of Africa where the soils are sandy, with high bulk densities and thus low total porosities, reduced tillage or zero tillage systems that do not have the surface covered by residue tend to lose a lot of water through runoff and yet water is often the limiting factor to crop production in these areas.

Crop residues protect the soil from raindrop impact hence preventing the formation of crusts. Soils in the arid and semi arid areas are known to form crusts upon wetting and drying. Conventional tillage may be suitable in the short run since it increases macro pores, reduces bulk density and soil strength and thus ensuring that there is good root distribution even at greater soil depth but long term results show that conventional tillage may worsen the problems of structural instability and their effects on water and soil conservation and therefore on crop production (Laryea et al, 1991).

Russell(1991) in a six year study on a well drained clay loam soil in Natal, South Africa, observed least runoff and soil loss under zero tillage when all crop residues were returned as compared to conventional tillage. A similar observation was made by Daroch et al (1988) on a silty loam soil.

Several researchers have observed an increase in bulk density under zero tillage in the upper soil levels (Beisecker et al, 1991; Bruce et al, 1990) but this may not be always so. Studies by Dick et al(1991) carried out over an 18 year period revealed that on a well drained typic fraguldaf soil (Luvisol/Acrisol), crop yields were always higher under zero tillage than under conventional tillage. On poorly drained clay soil, yield trends after 18 years indicated that the negative impact of zero tillage had greatly decreased while the yield advantage associated with zero tillage on well drained soil became even more pronounced(Dick et al,1991).

Research and adoption of zero tillage or reduced tillage varies from region to region. In U.S.A, zero tillage is adopted on steep slopes and yield is not affected (Allen, 1977). However, yields are affected on poorly drained clay soils. It is possible that zero tillage and crop residues can be of benefit to poorly drained soils if their surface and subsurface drainage is improved For Buganda soils, zero tillage does not seem to work well possibly due to lack of proper soil loosening (Zake, 1991).

Zero tillage cropping systems on soils with moderate to high available nitrogen were reported to increase the water use efficiency of maize. During a hot weather and in the absence of weeds, maize yields were better under zero tillage than after ploughing (Nadarand Faught, 1983).

Crop residue under zero tillage may serve to increase the moisture content of the soil much more than under conventional tillage. Several other researchers have reported increased yields under zero tillage (Dick et al,1991; Unger and Fulton, 1990; Wagger et al, 1989; Ploey, 1988; Yoo et al, 1987; Centurion, 1985; Osuji, 1986; Gupta,1987; Giraldez et al, 1986; and Wood, 1991) yet in other circumstances yields have been depressed due to zero tillage (Heinonen,1989; Alegre et al, 1991; Hulugalle and Maurya, 1991; Maurya,1986; Hulugalle et al, 1985; Diez and Kainz, 1986; Osuji, 1986; Anonymous, 1986). These seemingly diverse observations can be attributed to differences in the soils' physical and chemical properties and the prevailing weather conditions.

Poor drainage, compaction, low soil organic matter, absence of crop residue and the prevalence of weeds could have been some of the causes for the poor performance of zero tillage (Morgan, 1986).

Zero tillage seems to be favourable on medium textured soils with high biological activity and on self structuring, cracking clay soils. Zero tillage is also recommended where the topsoil is shallow, unstable and underlain by structurally unstable sub soils (Biamah, 1991).

Problems of weeds and excessive moisture were observed under zero tillage (Ball, 1989). There is also a possibility of carrying disease and pest infestations from one season to the next (Beasley et al, 1984). Ehlers, 1989 and Lenvain observed that zero tillage seems to be disadvantageous where the soils compact under the impact of heavy machinery (sandy soils) so that either root growth is impeded mechanically or the water filled pore space is increased so that aeration limits crop growth (e g non cracking clay soils, waterlogged soils and loamy soils without biological activity.

The success of zero tillage is soil specific and dependant upon how well weeds, pests and pests can be controlled. Morgan noted zero tillage to be well suited for better drained, coarse and medium textured soil and but not on poorly drained soils or heavy soils.

2.2 Soil Compaction

Soil compaction refers to an increase in soil mass per unit volume. It is associated with a decline in soil organic matter and degradation of soil structure. Chemical analysis of soils taken at 32 locations did not indicate a limiting chemical property other than the low fertility levels found in the tropics. Thus the effects of soil compaction are physical. Bulk density measurements are used as a guide to soil compaction and porosity. Total porosity is given by:

$$P = 100(1 - Bd / Pd) \qquad [2.1]$$

where;

P = Percentage Porosity, %
Bd = Bulk density, g/crn
Pd = Particle density, g/cnv

Bulk density is not conclusive on its own especially for over compaction problems (Landon, 1984).

Compaction affects the plant root system in several ways. It increases the mechanical resistance to root penetration, decreases air filled porosity and thus reducing air supply to plant roots whilst increasing a build up of toxic products (e.g carbon dioxide and ethylene) due to poor aeration. Compaction also reduces permeability (Landon, 1984).

The effectiveness of deep tillage in overcoming compaction seems to apply only on stable top/sub soils conditions. Where the top soil is shallow and underlain by a sodic soil, deep tillage will lead to soil degradation.

The process of surface sealing is often attributed to compaction, trampling and any other physical processes. Soil compaction leads to creation of a hardpan. However this may also be due to excessive tillage. The end result is often increased bulk density. The upper layer becomes quickly saturated by water and severe runoff results with prolonged rain.

Compaction below the plough layer occurs when soil is continuously ploughed to the same depth or when soil becomes puddled when ploughed at high moisture content. Poor crop performance results due to water logging, restricted root growth and water transmission to and within the root zone. Plants are unable to make use of minerals in the deeper layers of the soil due to the restricted root growth.

Centurion and Damatte (1985) observed on a dark red Latosol under cerrado vegetation, in Brazil that all tillage methods (Conventional tillage - Ploughing, Discing and Levelling; Reduced tillage - discing and levelling and Maximum tillage -ploughing twice, discing and levelling) except Zero tillage, induced the formation of compact layers, giving rise to lower infiltration rates.

Bulk density of 1750 kg/nv for sand or 1460 - 1630 kg/nr for silt and clay cause hinderance to root penetration (de Geus, 1973). Harte(1985) reported a significant decrease in bulk density on a cultivation induced plough pan (10-20 cm) after two years of no tillage inferring an increase in total porosity and improved soil structure. These observations could have been due to the presence of crop residues often associated with zero tillage.

Field experiments on self mulching clays indicate that a rainfall intensity of 90 mm/hr caused significantly less runoff and soil loss from zero tillage with stubble as compared to conventionally tilled plots. The removal of stubble resulted in significant increases in runoff (Harte, 1985). On the contrary, Heinonen (1989) observed greater soil compaction and lower seedbed temperatures under the zero tillage systems in the Peace River Region, Canada. Other observations indicate that cultivation caused compaction in the top soil layers of a Luvisol (Mwonga and Mochoge, 1986).

Correlations have been reported between compaction and penetrometer resistance. Loosening of a compacted layer by deep tillage resulted in significantly lower penetrometer resistances, lower bulk densities and deeper rooting (0.31-0.33 m) compared with 0.24 m in the conventional tillage treatmentBarbosa et al, 1990). Intensive mechanical tillage leads to formation of plough soles. Unfortunately, deep tillage such as sub soiling does not ensure the elimination of a plough sole (Hulugalle and Maurya, 1991).

2.3 Soil Hardsetting

Hardsetting refers to the soils that set to a hard structureless mass during drying and are thereafter difficult or impossible to cultivate until the profile is rewetted. In order to establish a crop on such soils, it is necessary to first loosen it.

The most recent Australian definition of hardsetting is:

> *A compact, hard, apparently apedal condition formed on drying. The surface is not disturbed or indented by pressure of fore finger (McDonald et al, 1984).*

While problems associated with soil compaction are basically physical, the problems of hardsetting seem to be physical, chemical and biological in nature(Zake, 1991). Rainfall after sowing can cause the surface to collapse again. Unlike compaction, hardsetting involves increase in bulk density without the application of an external load. The forces causing hardsetting occur or are generated within the soil itself (Mullins et al, 1990). Even when hardsetting soils are wetted, drying may cause the surface to harden sufficiently to the extent that seedling emergence is prevented.

The process leading to soil deterioration and hardsetting can be represented as follows (Mullins etal, 1987).

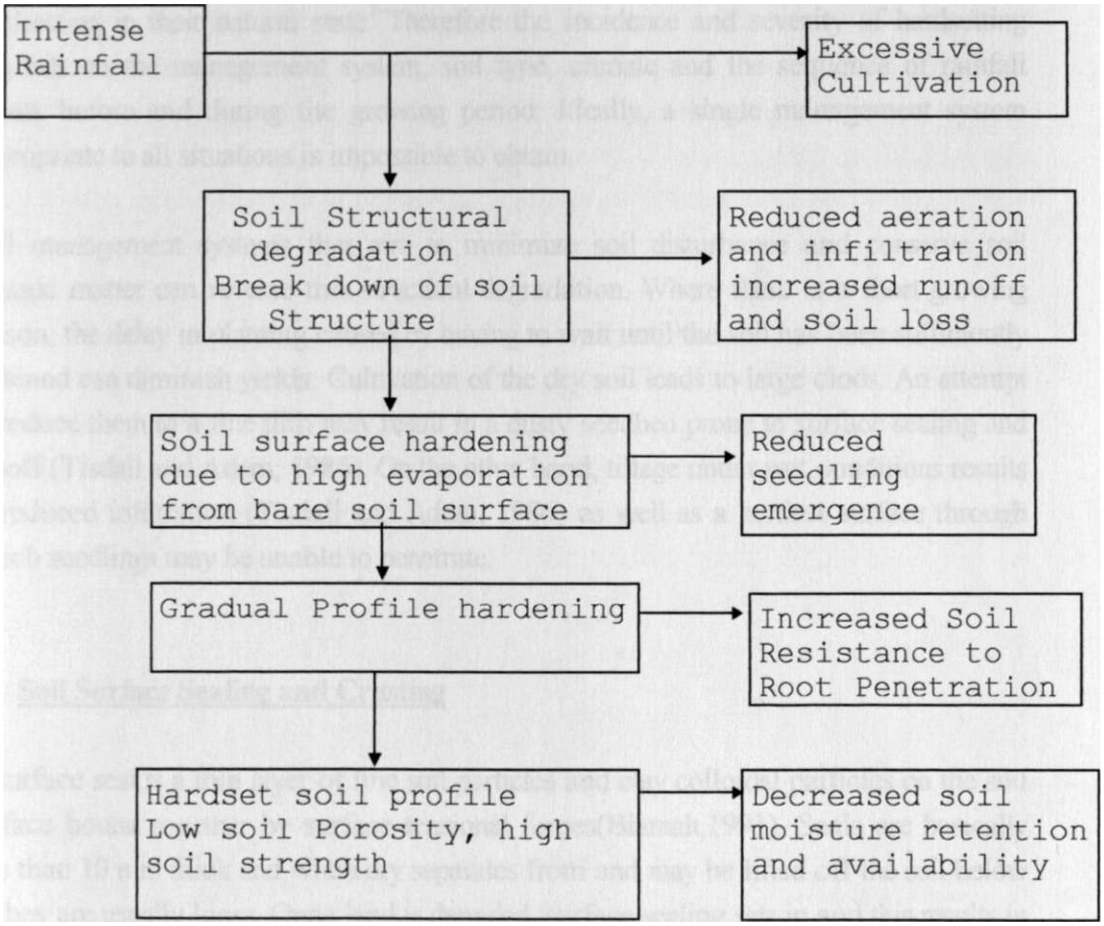

Fig 2.1 Process of Soil degradation and hardsetting (after Mullins et al, 1987)

Hardsetting is also associated with poor aeration under wet conditions, poor infiltration, increased runoff, crusting, poor or unreliable seedling emergence, high soil resistance to root growth, erosion and restrictions on the timing of cultivations. Hardsetting soils are widespread in dry regions.

Hardsetting soils are characterised by high clay content and absence of sufficient organic matter. Inorganic cementation and stabilization are also lacking (Mullins et al,1990; Mullins, 1991). They contain too little clay to shrink and crack on drying but sufficient clay and silt to bridge between sand grains. Textures of hardsetting soils range from loamy sand to sandy clay (Mullins et al, 1987).

Hardsetting can be triggered by an unsuitable system of management even on soils not hardsetting in their natural state. Therefore the incidence and severity of hardsetting depends on the management system, soil type, climate and the sequence of rainfall events before and during the growing period. Ideally, a single management system appropriate to all situations is impossible to obtain.

Soil management systems that aim to minimize soil disturbance and conserve soil organic matter can reverse this structural degradation. Where there is a short growing season, the delay in planting caused by having to wait until the soil has been sufficiently softened can diminish yields. Cultivation of the dry soil leads to large clods. An attempt to reduce them to a fine tilth may result in a dusty seedbed prone to surface sealing and runoff (TisdalI and Adem, 1986). On the other hand, tillage under wet conditions results in reduced infiltration (Tisdall and Adem, 1986) as well as a hardset surface through which seedlings may be unable to penetrate.

2.4 Soil Surface Sealing and Crusting

A surface seal is a thin layer of fine soil particles and clay colloidal particles on the soil surface bound together by surface tensional forces(Biamah,1991). Seals are basically less than 10 mm thick and when dry separates from and may be lifted off the soil below as they are usually loose. Once land is denuded, surface sealing sets in and this results in reduced infiltration (Thomas, 1991).

Where direct rain drop impact is avoided, high infiltration rates can be maintained (Morin and Yoram, 1977). Surface sealing occurs as a result of raindrop impact on inherently unstable soils and it is a prerequisite to soil crusting. Experiments carried out by Foley et al (1991) indicated that there was no surface sealing under low energy rain but under high energy rain, surface sealing reduced infiltration.

Surface sealing involves the transfer of fine soil particles between the pore spaces (washing in) resulting into a thin layer 1 - 5 mm at the surface of the soil. The layer is very dense and hard when dry, without any porosity and does not crack. Consequently infiltration of rain water into the soil is impeded and therefore runs off even on gentle slopes. It has been established that soils with 10-20% clay content are highly susceptible to sealing (Biamah, 1991).

Biamah (1991) observed that a sealed soil can take one month of continuous rainfall to soften up and he recommended such a soil to be tilled more often than a non sealing soil. On the contrary. Burch et al (1986) observed increased infiltration where the level of tillage disturbance had been reduced. Minimum disturbance produced some of the highest soil strength, aggregate stabilities and bulk densities in the top 50 cm whereas intermediate disturbance gave the lowest bulk density. This apparent contradiction can be attributed to the fact that different soil types have different physical, chemical and biological properties hence have different management requirements.

Where possible, surface sealing should be controlled or avoided by reducing the raindrop impact through use of crop residues and by means of farmyard manure to increase soil aggregation. Frequent tillage may cause soil compaction of the lower horizons and pulverisation of the soil leading to formation of more fine soil particles hence facilitating surface sealing as illustrated below.

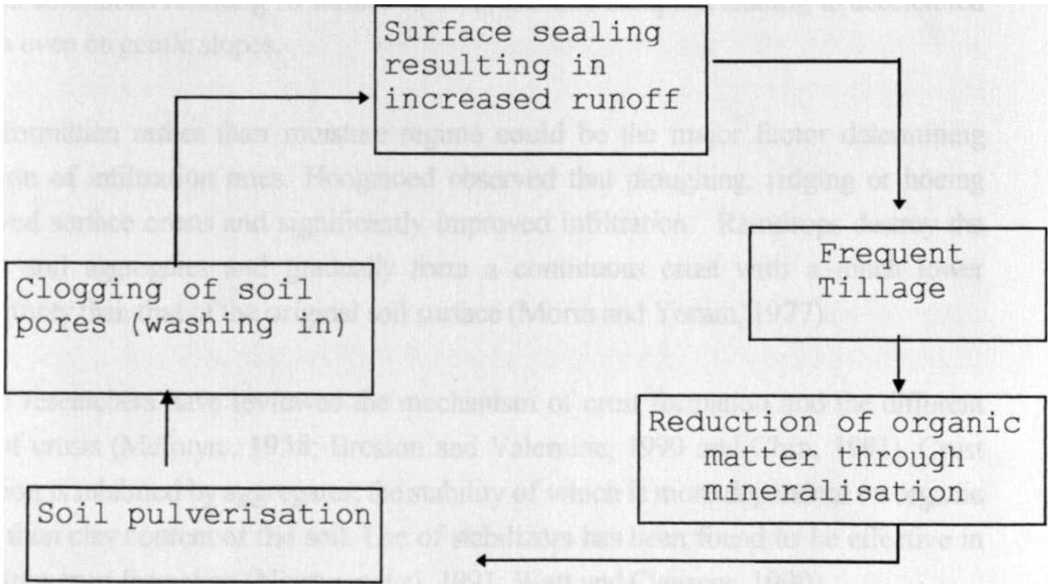

Fig 2.2 Relationship between surface sealing and soil tillage

A soil crust is a thin brittle layer of hard soil formed on the surface of soil when dry. Rain drop impact and dispersed soil particles seal the soil and form a crust comprising of two parts, a very thin (0.1 mm) non porous layer and a zone of up to 5mm thick of unwashed fine particles which is more dense than the soil below (Kirkby and Morgan, 1980).

Soil crusting may also occur after a sealed soil is exposed to high temperatures. Soil layers tend to peal off. Soil crusts are of two types namely: depositional crusts (due to deposition of silt laden sediment) and structural crusts (due to physical forces and inherent soil properties).

Crusting and sealing are basically different from hardsetting. A hardsetting soil is distinguished from a crusting one by the fact that hardsetting affects the whole of the A] horizon. The horizon is so unstable to the extent that without the aid of the factors that facilitate crusting (raindrop impact and low electrolyte concentration of soil solution due to leaching by rainwater), wetting causes the break down of aggregates and mobilization of fine materials (Mullins et al, 1987).

Reduction of soil organic matter under continuous tillage leads to deterioration of soil physical conditions resulting in surface seals, crusts and hardpans leading to accelerated erosion even on gentle slopes.

Crust formation rather than moisture regime could be the major factor determining reduction of infiltration rates. Hoogmoed observed that ploughing, ridging or hoeing destroyed surface crusts and significantly improved infiltration. Raindrops destroy the surface soil aggregates and gradually form a continuous crust with a much lower conductivity than that of the original soil surface (Morin and Yoram, 1977).

Several researchers have reviewed the mechanism of crust formation and the different types of crusts (Mclntyre, 1958; Bresson and Valentine, 1990 and Chiti, 1991). Crust formation is inhibited by aggregates, the stability of which is more dependent on organic matter than clay content of the soil. Use of stabilizers has been found to be effective in preventing crust formation (Neururer et al, 1991; Watt and Claasens, 1990).

Soil crusting is often obscured by the more conspicuous forms of degradation. However in marginal rainfall areas (e.g the semi arid tropics), soil crusting is a common phenomenon. Crust formation is known to affect seedling emergence, root penetration, rainwater infiltration and soil aeration. Crusted soils require some excessive force in tillage operations in order to break the crusts and enhance infiltration of rainwater (Biamah, 1991).

Surface crust can trigger erosion even on gently sloping land. The increased runoff can erode the surface soil then the subsoil and then start forming gullies. The strength of crusts depends on the amount of insolation. The higher the rate of moisture loss to the atmosphere, the stronger the crusts become. Susceptibility to crusting is increased by: mechanical impact of the rain drops; low electrolyte concentration of the soil solution due to leaching by rain water and low aggregate stability leading to clay dispersion and mobilisation of fine materials (Murphy et al, 1987).

2.5 Soil Amendments

These are organic or inorganic substances added to the soil in order to improve its physical or chemical characteristics. The primary objective of their use is to increase food and fibre production.

Inorganic amendments are manufactured and transported before placement. They include polythene, gravel, gypsum, pressmud, sulphur and stabilizers (Hussain et al, 1988) and they are basically used to provide a soil cover so as to reduce evaporation from the soil surface and prevent rain drop impact on the soil. They also provide a rough soil surface which enhances infiltration by increasing the infiltration opportunity time.

In this study, emphasis was put on the organic amendments because they are more practical in this part of the world. Organic amendments differ from the inorganic amendments in that they may improve the chemical properties of the soil as well as its physical properties. Organic amendments are derived from crop residues and animal droppings (dung). They include compost, manure and organic mulches. Mathan et al (1986) found that liming at 4 t/ha and farmyard manure at 20 t /ha, in Tamil Nadu, was effective in ammeriolating soil crusting and improving soil physical properties and crop yield.

2.5.1 Crop Residue Mulch

Many definitions of mulch have been given (Jacks et al, 1955; Moody et al, 1969; linger, 1975; Stigter,1987;and Othieno and Ahn, 1980) but they all point to the fact that mulch makes an ideal cover to protect the soil against erosive raindrops, modify soil temperature, reduce loss of water by surface evaporation, reduce weed emergence, add nutrients for growing plants and encourage earth worms and other desirable soil fauna. Mulch also increases organic matter in the soil and reduces runoff velocity.

Materials used for mulching include crop leaves and stalks, coffee husks, sawdust, napier grass and banana trash. Soil and water conservation are the most important reasons advanced for mulching (Pereira and Jones, 1954).

Mulching affects crop growth indirectly through reducing evaporation, improving soil physical properties and hence improving infiltration. Provision of a rough surface also increases the infiltration opportunity time. In this way, runoff is reduced by mulching. Mulch is known to increase the water holding capacity of the soil (linger, 1975).

On degraded and marginal soils which are often infertile, low in organic matter, often acidic and subject to severe runoff and erosion, liming and proper use of organic amendments can restore high levels of productivity in as little as three years (Homick and Parr, 1987).

It has been shown that during a prolonged drought, mulching helped to conserve soil moisture up to 90 cm depth in tea plots (Othieno, 1980). Several other researchers have reported increase in soil moisture as a result of mulching (Black, 1973; linger, 1978; Pereira and Jones, 1954). It is important to note that the low temperatures under surface residues may do more damage to the crop than water conservation benefits (Ulsaker and Kilewe, 1984).

Work on a chromic luvisol at Katumani (Gicheru et al, 1987) revealed that bare soil had strong sealing properties whereas soils covered by grass pastures were not affected by sealing. At the same site, Njihia (1979) found that maize stover mulch was effective in dissipating the kinetic energy of raindrops and thus reducing its erosive power. Mannering and Meyer (1963) showed that the application of wheat straw at a rate of 1, 2 and 4 t/ha maintained very high infiltration rates resulting in no erosion whereas absence of mulch at the same site resulted in the loss of 12 t/acre of soil.

The transport capacity of flowing water is roughly proportional to V^ where V is the flow velocity (Laursen, 1958) hence by reducing V, mulch significantly reduces the transport capacity of flow thus reducing soil erosion.

Observations by Kilewe and Mbuvi (1988) showed that application of 3 tonnes/ha of maize residues on an oxic paleustalf (chromic luvisol) of Kenya reduced runoff by 59% and 79% and soil loss by 94% and 64% in the long and short rain seasons respectively. The greatest runoff and erosion were on the bare fallow soil.

In Uganda, the author has observed that use of banana leaves, fibres and pseudo stem after harvesting, as a mulch, has proved to be very effective in controlling runoff, soil erosion and weeds. Crop performance appears to be better where mulching is done and often there is very little tillage required. A similar observation was made by Bruce et al (1990) who found that maintaining crop residues on the soil surface was more effective than a disc-harrow prepared seedbed in creating soil surface characteristics that sustain infiltration and reduce erodibility.

Continuous cropping systems have resulted in a decline in the fertility of soils. In order to retard the decline in soil nutrient status, there is need to recycle nutrients within the farming system. In this way, the systems will be less demanding on the input of nutrients from other sources.

Increased infiltrability by residue mulch through prevention of surface sealing has been reported (Lai, 1976; Borst and Woodburn, 1942). The major water conserving feature of residue mulch seems to be evaporation reduction (Van Wijik et al, 1959; FAO, 1965; Papendeck et al, 1973; Unger and Parker, 1975 and Van Doren et al, 1979). Mulch intercepts the solar energy that reaches the soil surface. The placement of the mulch is of crucial importance. Experiments by Mcgregor et al (1990) indicate that soil erosion benefits credited to incorporation of crop residues are not merited for recently incorporated residues and therefore the main benefit from residues is when they are left on the surface.

Though mulching is beneficial in most of the and and semi arid areas, it is not practical to recommend it to farmers because it has alternative uses such as fodder for animals, fuel and fencing which often take first priority in comparison to mulching. It is these factors that led Kilewe (1987) to conclude that mulching is not a feasible recommendation in the semi arid areas of Eastern Kenya. Therefore there is need to explore other alternative methods of conserving soil and water in these areas.

2.5.2 Farmyard Manure

The excreta of farm animals is rich in plant nutrients. When farmers feed their animals on crop residues, what remains is trampled upon, mixed with urine and dung and left to decompose. The final product is known as farmyard manure. It may contain about 1% of Nitrogen, 0.5% Phosphorous and 1% Potassium depending on the type and age of animals, the way they are fed, the quantity and quality of plant materials used and the care taken in preserving and handling of materials (Arakeri and Donahue, 1989). Availability of farmyard manure poses little problems in Machakos as livestock is still kept (Ikombo, 1984).

For resource poor subsistence farmers in semi arid areas such as Katumani, Machakos, the principal source of nutrients available for their crops is farmyard manure. This provides a means of recycling nutrients. Where animals have access to forages outside the cropland, it provides a means of collecting nutrients from the surrounding areas (Probert etal, 1990).

Application of manure can have beneficial effects on both the physical properties (e g structure, infiltration rates) and chemical fertility of soils. At Katumani, increased yields were observed where farmyard manure was applied. Maize crops on plots with farmyard manure were found to be more resistant to drought than those on plots where fertilizers had been applied (Ikombo, 1984). Residual effects of farmyard manure were still apparent in the third season after application.

In very dry seasons, application of fertilizers was found to depress grain yield (Ikombo, 1984). However the beneficial effects of farmyard manure depend on the source of manure. Kilewe (1987) showed that 40 tonnes/ha of air dry manure yielded a crop as good as that obtained from the highest input of fertilizers which supplied 120 kg N and 40 kg P per hectare. Ikombo (1984) at Katumani observed a good residue effect on subsequent seasons when manure was applied. He concluded that application of farmyard manure at the rate of 8 tonnes/ha gave high and consistent yields close to those obtained by applying the standard rate of mineral fertilizers (40 kg/ha N and 17 kg/ha P).

The discrepancy in the applications rates can be attribute to the manure having come from different sources. Manure provides both N and P (and other nutrients) but the quantities supplied depend on the source of manure. The response obtained depends upon the deficiencies that occur in the soil and the rate at which the nutrients in the manure are made available.

Manure system studies in USA showed that conservation tillage and manure management are compatible and that losses of manurial nutrients by runoff are greatly reduced by incorporation (Walter et al, 1987). The studies also revealed that manurial residue can reduce runoff from crop land where residue has been removed.

Increases in organic carbon, available nitrogen and available phosphorous have been reported under farmyard manure (Badanaur et al, 1990). However it is important to note that the management costs of utilising manurial nutrients are high and manure may present a potential ground water problem with very high rates as under some intensive farming systems in temperate countries.

There is also a possibility of manure creating weed problems. Nevertheless, farmyard manure has been found to improve bulk density, resistance to penetration, infiltration rate, pH, organic carbon content, CEC and available N, P and K (Ganal and Singh, 1988).

In a rainfall simulation study on the effects of farmyard manure application rates on soil surface sealing and crusting of Luvisols from Kaibon, West Pokot, Chiti (1992) observed an improvement in soil aggregation, decrease in bulk density and a decrease in crust strength with farmyard manure application. Bulk density and resistance to penetration showed lower levels when farmyard manure was applied.

2.6 Aggregate Stability

An aggregate is a group of primary particles that cohere to each other more strongly than the other surrounding soil particles. Aggregate stability is a measure of the soil's vulnerability to externally imposed destructive forces. The stability of aggregates is determined by the ability of the cohesive forces between the particles to withstand the applied force.

The disintegration of the soil mass requires imposition of a disrupting force. Erodibility increases as aggregate stability decreases. Certain factors destroy structure while others regenerate it. Aggregate size distribution is affected strongly by the tillage treatments to which the soil has been subjected. It is also affected by the procedure used in sampling and sieving.

Excessive tillage reduces the stability of the aggregates as does very sudden hydration followed by rapid drying (Kemper and Resenau, 1986). The determination of aggregate stability involves subjecting known amounts of same size fraction to a disintegrating force designed to simulate some important field phenomenon. The amount of disintegration is measured by determining the portion that is broken down into aggregates and primary particles smaller than some selected size.

Broadly, two methods of sieving are employed in determining aggregate stability depending on the purpose of the study. Where stability of aggregates is being determined relative to wind erosion, dry sieving is used while wet sieving is used to test the soils' resistance to the erosive forces of water.

Wet Sieving

The wetting process can be highly disruptive. Wetting of aggregates may cause their collapse as the bonding substances collapse or weaken. Quick wetting can cause swelling. Quick wetting of dry aggregates is also known to cause disintegration and slaking (Panabokke and Quirk, 1957). Lyles et al (1974) found that more than twice as much soil was detached from large dry aggregates as from aggregates which had been moistened prior to the rainfall event.

The reaction of a soil to forces acting on it depends not only on the soil itself but also to a large degree upon the nature of the forces and the manner they are applied. Non uniform wetting may cause one part of the aggregate to swell more than the other. The resulting stress compounded during subsequent shrinkage may fracture the aggregate.

Some of the bonding materials are soluble and dissolve as water enters the soil. Others are hydratable and become weaker. Reproductivity of the measurements varies with the texture of the soil. High variations have been observed at the same site on successive days (Kemper and Koch, 1966). Therefore aggregate stability is more of a relative concept. Most often, the concept of aggregate stability is applied in relation to the destructive action of water.

2.7 Rainwater Infiltration

Infiltration refers to the vertical intake of water into a soil usually at the soil surface. Infiltration should not be confused with hydraulic conductivity or permeability which is a measure of the ability of the soil to transmit water in all directions, horizontally and vertically (Landon, 1984).

Infiltration occurs across the soil surface while permeability takes place within the soil. The different methods of measuring infiltration, their advantages and shortcomings have been documented by Landon (1984).

Infiltration has a high degree of variability even within a small area. This variability has been attributed to the nature of the water flow in the soil and its initial water content (Turner and Sumner, 1978). Poiseuilie's law of flow relates the rate of flow to the fourth power of capillary radius, hence a small difference in radius can account for correspondingly much larger differences in flow rate. This can help explain the high variation in infiltration rates which occur over short distances within apparently uniform soils.

Since it might be difficult to standardize conditions under which infiltration measurements are taken, it is imperative that the soil water content for all infiltration tests is taken before the exercise is began.

Rainwater infiltration depends on the rate at which water is transmitted through the soil and the duration. Sealing from raindrop impact significantly reduces rain water infiltration. Poor soil porosity, low permeability, low organic matter content and compaction are also known to affect infiltration adversely. Increasing tillage depth of two Bangladesh soils was found to be effective in destroying plough pans and it resulted in increased cumulative infiltration rates (Rahman and Islam, 1989).

Mulching has been reported to increase infiltration rates while continuous tillage and animal trampling causes compaction (Golabi et al, 1988; Roth et al, 1988; Hulugalle, 1985; Okwach et al, 1990; Mannerings and Mayer, 1963; Lai et al, 1990; Lai, 1975).

Reducing the level of tillage disturbance enhanced field infiltration of simulated rain while grazing the site with sheep generally reduced infiltration (Burch et al, 1986). Mulching can maintain high infiltration rates by increasing the opportunity time for infiltration, absorption of raindrop energy and reduction of aggregate break down and surface crusting.

It is generally accepted that lower bulk densities favour high infiltration. Plant roots improve soil physical properties and aggregation and thus infiltration. High infiltration rates are possible by maintaining the soil surface in a porous condition and promoting runoff detention and maximum ground cover through good conservation farming techniques.

As infiltration rate increases compared to rate of precipitation, less water flows on the soil surface as runoff and less entrainment takes place (Okwach et al, 1990). Soil water uptake rate is often influenced by the proportion of coarser pores in the surface of the soil (Russell, 1961).

During an infiltration process, infiltration rate decreased with time (Baver, 1972) possibly due to presence of crusts or decrease in matric potential gradient. A constant rate of infiltration is reached and this is close to the hydraulic conductivity.

The hydraulic conductivity or permeability of a soil defines the volume of water which will pass through unit cross sectional area of a soil in a unit time given a unit difference in water potential (Landon, 1984). Coote et al (1989) reports that in experiments carried out in Eastern Ontario, Canada, saturated hydraulic conductivity was greater under zero tillage as compared to conventional tillage.

Cone penetrometer resistance was found to be greater in the upper 0.2 m of the zero tillage plots but at lower depths, greater penetration resistances were observed under conventional tillage than in the zero tillage sites below 0.25 m depth. On the other hand, Roth et al (1988) observed that hydraulic conductivity did not differ significantly between zero tillage, minimum tillage and conventional tillage. This was attributed to lack of proper soil loosening under zero tillage and formation of plough pans under conventional tillage and minimum tillage. A similar observation was made by Obi and Nnabude (1988) and Burch et al (1986). It was suggested that crusts or seals formed on cultivated soils were responsible for the differences observed in field infiltration (Burch etal, 1986).

While incorporation of straw and farmyard manure on a river deposit with maize as a test crop resulted in gains in soil water retention, there were reductions in hydraulic conductivity and infiltration rate (Bhagat and Acharya, 1989). The addition of organic matter and crop residues can therefore improve the soils' physical properties and hence infiltration.

2.8 Soil Shear Strength

The shear strength of the soil is a measure of its cohesiveness and resistance to shearing forces exerted by gravity, moving fluids and mechanical loads (Morgan, 1986). The strength is derived from the frictional resistance met by the soil's constituent particles when they are forced to slide over one another or interlocking positions. Cohesive forces related to chemical bonding of the clay minerals and surface tension forces within the moisture films in unsaturated soils also contribute to shear strength (Morgan, 1986).

Increases in the moisture content of a soil decreases its shear strength and brings about changes in its behaviour. At low moisture contents, the soil behaves as a solid and fractures under stress but with increasing moisture content, it becomes plastic and yields by flow without fracture (McKyes, 1989).

The behaviour of a compressible soil when saturated depends upon whether the water can drain (Morgan, 1986). If drainage can occur, more of the load will be supported and the soil is more likely to remain below the plastic limit and retain a higher shear strength.

It is worth noting that the mode of failure is usually static, being the result of overcoming the frictional resistance required to initiate motion rather than the dynamic force to maintain one particle sliding over another. It has been shown that the detachability of a soil by raindrop impact depends upon its shear strength (Cruse and Larson, 1977).

2.9 Rainfall Properties

Rainfall refers to precipitation in the form of falling water droplets. The damage caused by raindrops hitting the soil at high velocity is the first step in the erosion process (Schwab et al, 1981). Falling raindrops breakdown soil aggregates, detach and transport soil particles; keep the runoff water loaded with finer particles causing sealing and compaction of the soil surface (Beasley et al, 1984). This reduces the ability of the soil to absorb water and increases surface runoff.

The principal characteristics of rain that affect runoff and erosion are intensity and duration; distribution of rainfall intensity and storm frequency (Beasley et al, 1984). As soon as rainfall is high enough to support semi arid vegetation, the increasing vegetation cover does more to limit water erosion than the greater runoff does to increase it so that net erosion decreases as rainfall increases (Kirkby and Morgan, 1980).

Storms of high intensities generally last for fairly short periods and cover relatively small areas while low intensity storms are usually of long duration and cover large areas (Schwab et al, 1981; Beasley et al, 1984). Most erosion is caused by high intensity storms. However, low intensity storms that continue after the soil has become saturated also cause runoff(Schwab et al, 1981).

Frequency of occurrence and seasonal distribution of intense rains are extremely important factors affecting runoff and erosion. Intense rains occurring early in the season usually cause considerable runoff and erosion (Morgan, 1986). Very intense storms are not necessarily more frequent in areas having a high total annual rainfall.

Rainfall seldom occurs at uniform rate throughout the duration of the storm. If the intensity is greatest at the beginning of a storm, it is classed as advanced storm. If the intensity is greatest near the middle, the storm is classed as intermediate storm while if it is greatest at the end, it is classed as a delayed storm (Schwab et al, 1981; Beasley, et al, 1984). Advanced storms cause some reduction in runoff peaks unlike the delayed storms that cause high runoff peaks because of their occurrence when the infiltration rate is at a minimum and depressional storage has been largely satisfied. Schwab et al, 1981 have classified storms of five minutes or longer and exceed (5+0.25t), where t is the duration in minutes, as excessive storms.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Characterization of Soil at Site

Augerings were made randomly at the site and composite samples taken to a maximum depth of 150 cm. The following properties were examined from the soil samples taken: colour, structure, pH, consistency, depth and texture. The soil type used in this field study was then classified as a sandy clay loam and an *orthic Luvisol* (Unesco classification after Gicheru). A profile pit was dug at the site and soil samples were taken for laboratory analysis. Infiltration and hydraulic conductivity tests at the site were conducted using a disc permeameter.

3.2 Experimental Design

The experiment was based on a completely randomized block design. Each block consisted of four runoff plots made up of four treatments. Each treatment was replicated three times and a total of 12 runoff plots was used for the experiment. The size of each runoff plot was 2 m^2

3.3 Treatments

The four treatments applied were as follows:

a) Conventional tillage (using a forked hoe) with no manure.
b) Conventional tillage with 5 tonnes/ha of farmyard manure.
c) Conventional tillage with 10 tonnes/ha of farmyard manure.
d) Zero tillage with no manure.

3.3.1 Farmyard manure

The farmyard manure used in the study was obtained from the dairy farm at the Research Centre. Respective quantities of 5 and 10 tonnes per hectare of air dry manure were weighed, spread evenly and then incorporated into the soil in the appropriate plots at the beginning of each season.

The farmyard manure was incorporated during cultivation. laboratory analysis of the farmyard manure revealed that it had 1.62% nitrogen, 1.62% potash, 0.36 % calcium, 1.49 % magnesium oxide, 500 ppm manganese, 200 ppm zinc, 30 ppm cu and 1500 ppm iron, on a dry matter basis. The farmyard manure used was a mixture of cowdung and grass straw.

3.3.2 Tillage

Conventional tillage was achieved using a forked hoe. One digging operation was carried out at the beginning of each season before the onset of the rains. Thereafter no more tillage was done. Weed control was done manually by uprooting the weeds.
Zero tillage was achieved by leaving the soil weed free and undisturbed. This treatment served as a control representing extremes in runoff and soil loss.

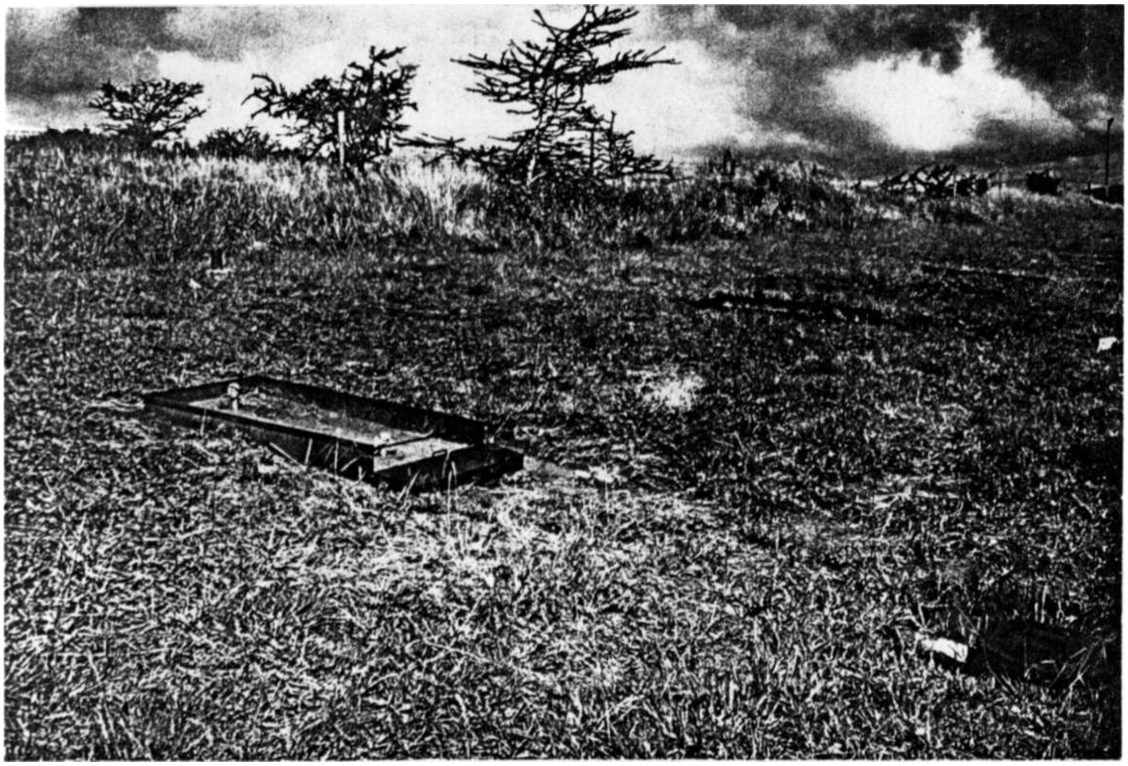

Plate 1 layout of Plots at Katumani Experimental Site

In all tillage treatments, the soil was left bare to eliminate the effect of crop cover on soil loss and runoff The plant roots would also have had a binding effect on the soil hence affecting its behaviour.

3.4 Experimental Equipment

3.4.1 Runoff and Sediment Collection Equipment

The runoff collection equipment used in this experiment consisted of sheet metal borders around the 2 m^2 plot size, a collection trough, a PVC pipe to convey the runoff and suspended sediment into the collector. The collector used in each experiment plot comprised of a 200 litre metallic drum and a 20 litre plastic container.

Inside the drum, the 20 litre capacity bucket was placed directly below the inflow spout to the drum so as to reduce the time and labour requirements to sample and clean up the drum after light rainstorms and to improve on the accuracy of volume measurements. The drum had a tight fitting cover to reduce evaporation of water collected in the drum after a rainfall event.

3.4.2 Neutron Access Tubes

In each plot, two access tubes (positioned at 30 cm from each plot end) were installed to a maximum depth of 120 cm or lower depending on where the stone line was located. The stone line was so variable that it was impossible to reach a depth of 120 cm in some of the plots. The inner and outer diameters of the tube were 48 mm and 50 mm respectively.

3.4.3 Disc Permeameter

Installation Procedure

The disc permeameter is a three dimensional flow equipment used for in situ measurement of infiltration and hydraulic conductivity. This equipment involves minimum soil disturbance during flow, is relatively rapid, robust, easy to use and is relatively cheap. The disc geometry minimizes the effect of capillarity and hence is biased towards flow in the vertical direction as is the case with infiltration and hydraulic conductivity.

The penneameter is designed for accurate control of pressure at the supply surface. This permits macropores of various sizes to be included in or excluded from the flow process. The disc is often placed against the soil surface (with suitable contact material where necessary) and three dimensional flow commences. Sorptivity is determined from the early stages of flow

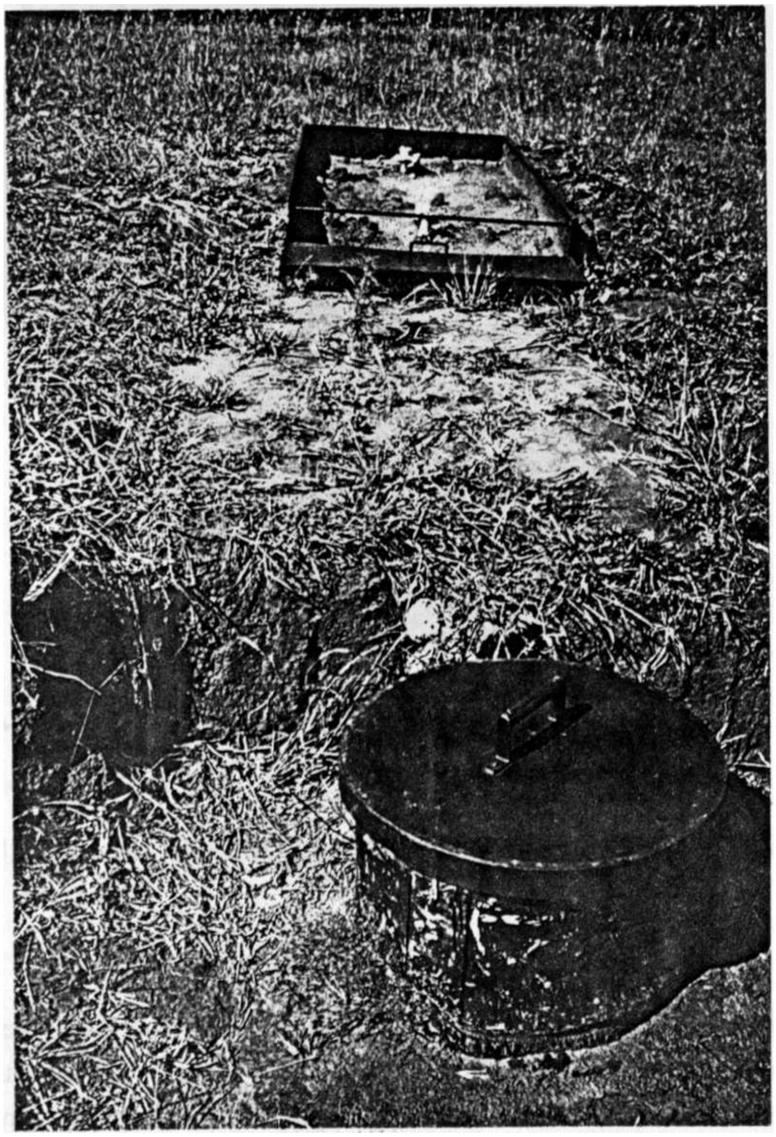

Plate 2 Runoff and Sediment Collection Assembly at Experimental site.

Plate 3. Sediment Collection Unit Comprising of a metallic drum, Plastic bucket and pvc pipe

For steady state flow (final infiltration rate), at least ten measurements should be taken to ensure that an accurate value is obtained. To calculate the hydraulic conductivity, the sorptivity, steady state flow rate, the initial volumetric moisture content and volumetric moisture content at the supply potential are required.

During hydraulic conductivity measurements, the disc permeameter was placed on the soil surface with the edge of the steel ring coming into contact with the soil. Any large stones that would interfere with the disc were removed. The ring was inserted about 10 mm into the soil surface making sure that the depth of insertion was constant as this affects the supply potential.

In order to ensure that the permeameter was as level as possible on the ring, a spirit level was used. The permeameter was then placed into a bucket of clean water after which the side tube was filled with water to the desired volume. The reservoir tube was also filled with water ensuring that the one way valve had been wetted to an air tight seal.
The permeameter was then carefully placed in the ring. To begin infiltration measurements, the stop cock on the side tube was opened. The stop watch was used to monitor the time taken to empty the water reservoir after all the water in the side tube is drained into the ponded surface. On a single day, one plot was monitored. This was done twice, both during the long rains and during the short rains.

3.4.4 Neutron Moisture Probe

Profile soil moisture was determined on a weekly basis using a neutron probe. This was done at specific depths through access tubes installed in the runoff plots.

The neutron moisture probe consists of a shield, a detector tube, a pre-amplification circuit to send a signal from the detector and a counting device. The neutron source is often a Radium/Americum-Beryllium mixture. The count ratio is used to obtain the water content on a volume basis through the use of a calibration curve provided by the manufacturer or plotted from wet and dry calibration measurements taken in the field.

The Americum Beryllium mixture (radioactive source) emits fast moving neutrons which are slowed down by water in the immediate surrounding (often about 10-15 cm from the probe). The neutron moisture probe can be used for frequent moisture determinations in the field without disturbing the soil as in gravimetric sampling. The neutron scatter method of measuring soil water content gives the amount of water on a volume basis.

Calibration of Neutron Probe

This was done for both wet and dry runs. The access tubes used for the calibration were installed outside the experimental plots. The tubes were left in the ground for three weeks to ensure that the soil around the access tube settled. For either of the two calibrations, three access tubes were used.

For the wet calibration, a drum was opened on both sides and then cut into two equal parts transversely. One half of the drum was put around the access tube and driven into the soil to a depth of about 20 cm. The diameter of the drum was 1 m. Water was then poured in the installed drum and allowed to pond around the access tube for three consecutive days after which ponding was stopped and soil moisture allowed to redistribute within the profile. An area equal to the cross sectional area of the drum was covered by polythene to avoid evaporation.

Probe readings were then taken at various depths after which core samples were taken at the same depth for gravimetric moisture determination. At each depth, three samples were taken. The gravimetric soil moisture of the three samples was averaged and the mean was taken to correspond to the mean probe reading at that depth.

The percentage soil moisture on weight basis was converted to percentage soil moisture on volume basis by multiplying it with the soil bulk density at the given depth. Calibration was done at the 20-60 cm and 80-120 cm because the average depth of the stone line was 60 cm and from 60 cm onwards the profile had concretions of iron.

The iron concretions are known to affect the count readings (Lai, 1975). For precise measurements, the neutron probe should be calibrated separately where there is exceptionally high clay content, high organic matter or any material containing high concentrations of hydrogen or other light weight elements.

Some of the access tubes went deeper than 70 cm while others went only up to 70 cm. The dry calibration was done at the peak of the dry season using the same procedure as above.

3.4.5 Cone Penetrometer

A hand held cone penetrometer for top soil layers (type 1B, Eijkelkamp Equipment) was used in this study. This instrument measures the penetration resistance by means of a compression spring

There are two cone types (0.25 cm' and 0.5 cm") and three kinds of compression springs (50 N, 100 N and 150 N). A particular combination of a cone and a compression spring can be selected depending on the penetration resistance to be expected.

The spring within the penetrometer is compressed when the cone encounters a resistance as it is driven into the soil. A slip ring on a graduated scale is taken along as the spring is compressed and so it indicates the maximum compression measured. Using spring constants and cone areas, the compression can be translated into penetration resistance. Shown below is a cone penetrometer.

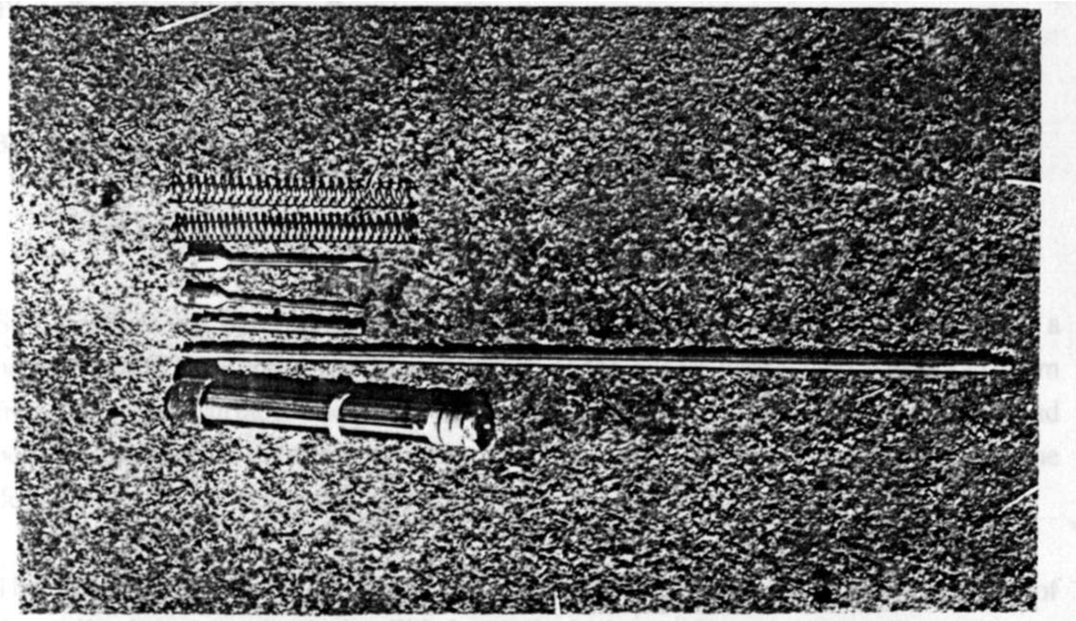

Plate 4:. Components of a Cone Penetrometer

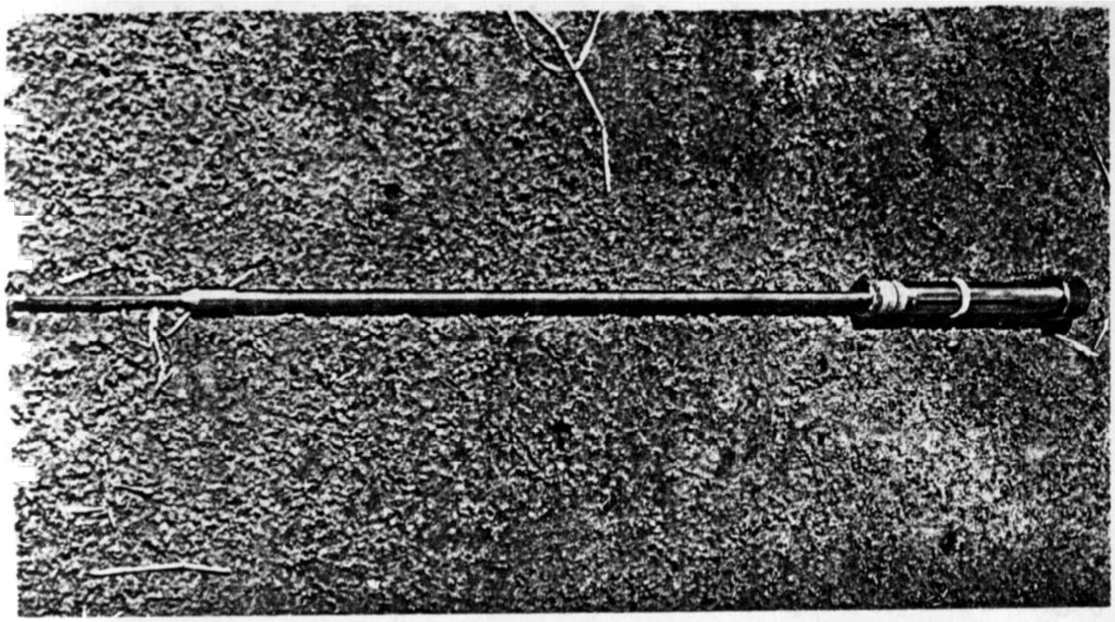

Plate 5.: Assembled Cone Penetrometer

3.5 Collection of Data

3.5.1 Soil Moisture

Soil moisture was determined down the profile on a weekly basis in every plot using a neutron probe. The probe was placed on top of the access tube which was about 5 cm from the ground surface. The probe was then switched on and the shield count was read before lowering the detector into the tube. The probe was then switched off, and the detector lowered to the desired depth and the probe switched on again.

The soil count readings appearing on the screen were equivalent to the number of thermalized neutrons that had collided with the hydrogen atoms in water The soil count readings were taken at 30 second intervals. The count ratio was given as the ratio of the soil count to that of the shield count

3.5.2 Rainfall, Runoff and Soil loss

Rainfall was recorded on a storm basis using two manual rain gauges installed at the site. Runoff after every downpour was collected and the volume measured using a calibrated bucket and a measuring cylinder of capacity 2000 ml. For small rainfall events, the bucket was sufficient for all the runoff. In such a case, water with suspended sediment was decanted from the bucket, its volume determined, agitated and a sample was taken using sampling bottles of 500 ml capacity.

The sludge was weighed, thoroughly mixed and a sample was taken for laboratory analysis. Weighing was achieved using a spring balance. When the sludge was little, it was all taken for laboratory analysis. In each storm, three samples per plot were collected for analysis.

For big runoff events where there was overflow into the drum, the calibrated bucket was used to get out the water. The little water that remained was removed using a rimless plastic bottle.

In each bucket of 20 litres, three samples were taken. The samples were then thoroughly agitated and one composite sample taken for laboratory analysis. Where the water in the bucket was less than 20 litres, it was thoroughly mixed and one sample was taken for laboratory analysis.

In the laboratory, the samples were dried at 105°C for 24 hours until there was no more water. The sediment left in the drying dish was then weighed. Suspended sediment was calculated as follows:

$$Wt,$$

$$SS = (- \wedge -)\ v_{r} \qquad [3.1]$$

$$sb$$

Where;

SS = Suspended sediment (g)

$V_{S}b$ = Volume of sample taken in the bottle (litres).

V_r = Total volume of runoff from which the ample was obtained (litres).

Wt* = Weight of dry sample (g)

The weight of soil in the sludge was calculated as shown below;

Where;

W_s = Weight of soil in the sludge
Wtd_S = Weight of oven dried sediment
Wtw_S = Weight of sample of sludge before oven drying
Wtsc = Total weight of sludge collected in the bucket or drum

The volume of water in the sludge, V_s, was calculated as shown below;

$$y = \frac{(Wt_{m_k} - Wt_{m}}{wn}$$

Where;

V_s = Volume of water in the sludge (litre).
Wtb= Weight of wet sludge
Wt_a = Weight of oven dried sludge

Runoff was expressed in mm while soil loss was in g/m^2

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

$$KE = 29.8 - \frac{127\ 5}{j} \qquad [3.4]$$

Where KE is the kinetic in J M^{-2} mm^{-1} and I is the rainfall intensity in mm/hr.

3.5J Soil Bulk Density

This was determined using undisturbed soil cores of volume 100 cm^3 from the top soil depth. It was determined on a weekly basis.

3.5.4 Penetration Resistance

It was not possible to take cone penetrometer readings at the beginning of the season due to lack of equipment. However, later in the season, penetrometer readings were taken. The maximum compression of the spring was in mm from the scale of the penetrometer. Using the spring constant and cone area the compression was translated into cone resistance using the equation:

$$= \text{compression of spring (cm)} \times \frac{\text{springconstant N / cm}}{\text{conearea}} \qquad [3.6]$$

$$\text{Cone resistance } (\text{N / cm}) = \frac{\text{total force (N)}}{\text{cone area (cm)}} \qquad [3.5]$$

The cone area was 0.25 cm^2 while the spring constant was 20 N/cm.

3.5.5 Soil Shear Strength

Soil shear strength was measured on a weekly basis using a shear vane and it was expressed in kPa.

3.5.6 Soil Aggregate Stability

Aggregate stability was determined using wet sieving to determine the water stability of the aggregates. A representative sample of air dry aggregates were passed through a 2 mm sieve which was placed on the uppermost level of a set of graduated sieves (1.00 mm, 0.5 mm, 0.212 mm and 0.063 mm).

A spray of water was applied and the sieves were shaken for ten minutes after which they were oven dried. The oven dry weight of the soil left on each sieve was determined. The results obtained were correlated with the coarse primary particles retained on each sieve to avoid designating them falsely as aggregates. This was done by dispersing the material collected from each sieve using a mechanical stirrer and a dispersing agent (Calgon).

The soil sample and the dispersing agent were stirred for 10 minutes. The material was passed through the same sieve and washed until only sand was retained or clear water was coming out of the sieve. The sample was then dried and weighed.

The weight of sand retained after the second sieving was subtracted from the total weight of the undispersed material retained after the first sieving. The percentage of water stable aggregates, %SA was calculated as follows:

$$\%SA = 100 \times \frac{(\text{wt-retained})-(\text{wt. sand})}{(\text{total sample wt.}) - (\text{wt. sand})} \qquad \text{p ?]}$$

3.5.7 Infiltration

The amount of rainwater that had infiltrated into the soil after each rainstorm was taken as the difference between rainfall and runoff. During each rainstorm, there was minimal evaporation since the relative humidity was high. Surface storage on the plots was negligible because the soil surface was almost smooth.

Using a disc permeameter, the infiltration rate at predetermined scale increments on the reservoir tube were recorded. Recording continued until flow became steady (i.e. the time when scale increments did not change). At least ten measurements were taken to ensure that an accurate value for steady state flow rate was obtained. Several reservoir volumes were required before steady state flow was reached.

At the end of the infiltration measurements, the stop cock was closed and the permeameter removed. The water level in the ring was observed and a soil sample taken off the surface with a spatula. The samples were then placed in an air tight container for the determination of saturated hydraulic conductivity.

Cumulative infiltration at any time, t, is the total amount of water, Q, that has gone into the soil at time, t, divided by the cross sectional area, pr^2 (area of the ring). Cumulative infiltration was calculated by:

$$\begin{array}{ll} S_t = (SR- & \\ JW & 7W \end{array} \qquad [3.8]$$

Where SR is scale reading at the time of measurement; SR, is the initial scale reading and RC is the reservoir calibration.

Sorptivity, S,, was calculated from the initial time data. Q/pr^2 on the Y axis was plotted against the square root of time $t^{0\ 5}$ on the X axis. The slope of the straight line was the sorptivity and had the units of length/time.

The steady state flow rate, Q/pr^2, was found by plotting the cumulative infiltration during the last part of the experiment as a function of time.

3.5.8 Soil Hydraulic Conductivity

The saturated hydraulic conductivity at the site was determined in situ using a CSIRO disc permcameter which had been calibrated to give the volume of water per scale reading. The initial soil water content and bulk density were needed to calculate the hydraulic conductivity and were obtained from soil samples taken prior to the beginning of the experiment. Three samples were taken for each infiltration measurement.
The hydraulic conductivity was given by:

$$K_{\circ} = \frac{Q \qquad {}^4bS_{,,}^{2}}{7i\ {ro}^{2} \qquad nr_0(Qo \quad - \quad 0.)} \qquad [3.9]$$

Where $r_{t)}$ is the radius of the ring, q_n is the volumetric moisture content at the measurement potential, r_G is the volumetric moisture content at the initial potential and b is approximately 0.55.

3.5.9 Soil Organic Matter

Organic carbon was determined using the Walkley and Black method. The Percentage of organic carbon was multiplied by 1.72 to get the percent organic matter content in the soil.

3.5.10 Soil Texture

This was determined using the hydrometer method to determine the proportion of the different sized particles in the soil and hence its textural class.

3.6 Analysis of Data

Three methods of data analysis used in this study included analysis of variance (ANOVA), regression and correlation analyses. All these analyses were based on a 5% level of significance. The variables analyzed included; treatment, runoff, soil loss, infiltration and rainfall properties (amount, duration, intensity and energy). Soil properties such as bulk density, soil moisture and soil shear strength were also monitored.

The least significant difference (LSD) at 5% level of significance was used to determine the differences between the treatments as discussed in chapter four.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Characterization of Soil at Site

4.1.1 Selected Physical and Chemical Properties

Soil physical and chemical properties at the experimental site are given Table 4.1. The soil properties considered include soil bulk density, percentage size fraction and organic matter at various depths.

An increase in clay down the profile was observed leading to textural changes from sandy clay loam to clay (Table 4.1). The soil had a low organic matter content, decreasing with depth (Table 4.1). The percentage of stable aggregates also decreased with depth possibly as a result of the decrease in soil organic matter.

Soil bulk density decreased with depth implying that there was an increase in soil porosity down the profile. Bulk density of the soil ranged from 1.42 g cm" in the top 15 cm to 1.34 g cnr in the 60-100 cm horizon. The high bulk density in the top horizons was attributed to physical degradation due raindrop impact.

Changes in percent organic matter, bulk density and texture with depth were consistent with the changes in moisture characteristics for the different depths.

Table 4.1 Selected Physical and Chemical Properties at Experimental Site.

Soil Profile Depth (cm)	Bulk Density g cm$^{'3}$	Percentage Size Fraction			Organic Matter Content	Textural Class
		Sand 2-0.05mm	Silt 0.05-0.002mm	Clay <0.002mm		
0-15	1.42	67.2	4.9	27.9	1.55	SCL
15-35	1.40	64.3	6.8	28.9	1.41	SCL
35-60	1.37	57.4	7.9	34.7	0.74	SCL
60-100	1.34	51.4	7.9	40.6	0.56	SC

4.1.2 Soil Moisture Release Characteristics

Table 4.2 Soil moisture status in the profile

Depth (cm)	Field Capacity %	Wilting Point %	Available Water %
0-10	26.3	9.3	17.0
10-30	27.4	13.3	14.1
30-60	21.7	10.7	11.1
60-100	24.0	15.2	8.8

Table 4.2 is a summary of the soil moisture status in the profile determined from the moisture characteristic curves. Suction at field capacity was 0.33 bars.

Field capacity water content is the maximum water content that a soil will hold following free drainage. Usually, soil is at field capacity one to two days after saturation. On the other hand, wilting point is defined as the soil moisture content at which plants wilt permanently. The difference between the moisture content at field capacity and wilting point constitute the available water capacity.

Field capacity moisture was 26.3% at (0-10 cm depth) but came to a minimum of 21.7% at the 30-60 cm depth. Maximum field capacity moisture was observed at the 10-30 cm depth (27.4%) The high field capacity moisture at the 0-30 cm depth was attributed to the high organic matter content relative to the other horizons (see table 4.1)

Available soil moisture decreased with depth as a result of increase of clay content down the profile. Thus the highest available water was in the 0-10 cm depth while the lowest was in the 60-100 cm depth.

4.2 Calibration of the Neutron Probe

Figures (4.1a and b) show the calibration curves of the neutron probe for soil at the Experimental Site. The curves were obtained by plotting % volumetric moisture content against the count ratio (soil count/shield count). The samples for calibration were taken under wet and dry soil conditions so as to have curves that represent extremes in soil moisture content.

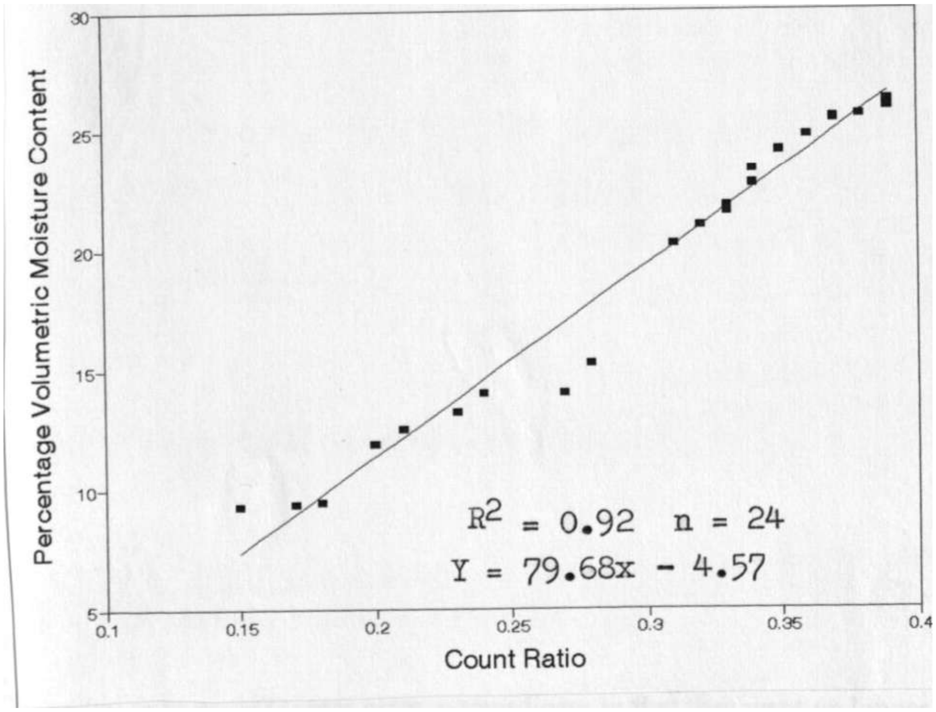

Fig 4.1 a Neutron Probe calibration curve (20-60 cm)

Regression lines were plotted and it was found that the relationship between the volumetric moisture content and the count ratio was linear and fairly good as indicated by the regression coefficients of 0.92 and 0.98 for the 0-60 cm and 80-120cm depth respectively, (see appendix 2).

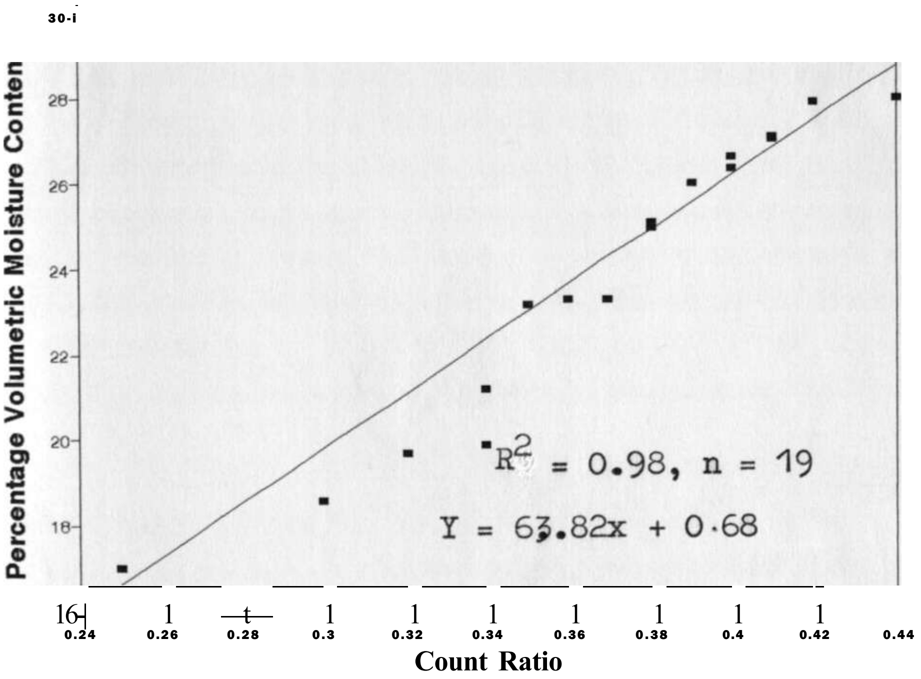

Fig 4.1 b Neutron Probe calibration Curve (80 - 120 cm)

4.3 Seasonal Variability in Rainfall

4.3.1 Rainfall Amount and Duration

The short rains of 1992 were quite extraordinary in that they went on longer than usual. The peak of the rainy season was experienced in January 1993 (35%) though long term data indicate that peak rainfall is often expected in the month of November.

By December 1992 the time when the short rains are expected to stop, only 52% of the total rainfall had been received (October-February).

Recorded rainfall varied between 0.5 mm and 70 mm with a mean of 12 mm and standard deviation of 17 mm. On a monthly basis, the highest amount of rainfall was received in January (269 mm), five times as much as the long term mean of 50 mm for that month (see appendix 4). This marked the peak of the short rains.

The maximum storm duration was 10 hours and 48 minutes with a rainfall amount of 24 mm while the minimum storm duration was 6 minutes and a rainfall amount of 1 mm. The mean storm duration was 2 hours and 30 minutes throughout the study duration.

From October to December, a total rainfall amount of 404 mm of rainfall was received and this was much higher than the seasonal average of 286 mm (27 years record). The total rainfall received in the short rains period of October 1992 -February 1993 was 767mm compared to the mean of 379 mm (27 years record). In the study period, the short rains peaked in January 1993 and not in November as expected. The month of April, which is often the peak of the long rains received only 38 mm of rainfall, far below the monthly average of 144 mm (27 years record). The comparison of the mean (27 years record) and seasonal monthly rainfall distribution for 1992/93 are shown in Figure 4.2.

During the short rains period, the rainstorms were well distributed. It was raining continuously for several days after an interval of two to seven days during the first 35 days as shown in Appendix 4. and in Table 4.3.

However, towards the end of the crop growing season (February), the rains that fell were not utilized by the crop which had dried and was being harvested. Nevertheless, the farmers reported having had the highest maize/bean yields in a period of about ten years.

When the fields were prepared anew in February/March for the long rains season, the rainfall received was not adequate and hence all the crops in the field wilted and dried up. The rains virtually stopped by May. Throughout the months of June, July and August, no rainfall was recorded.

The long rains were a complete failure. A storm of 46 mm received on 13/3/93 completely destroyed the clods of a recently tilled soil as shown in plate 4. This was the first rainstorm during the long rains and it contributed 60% of the erosive rainfall for that season. This rainfall event was the only excessive storm during the entire duration of study.

There was a positive correlation (0.71) between rainfall amount and storm duration. A coefficient of determination of i*=0.5 was obtained implying that storm duration accounted for 50 % of the variation in rainfall amounts.

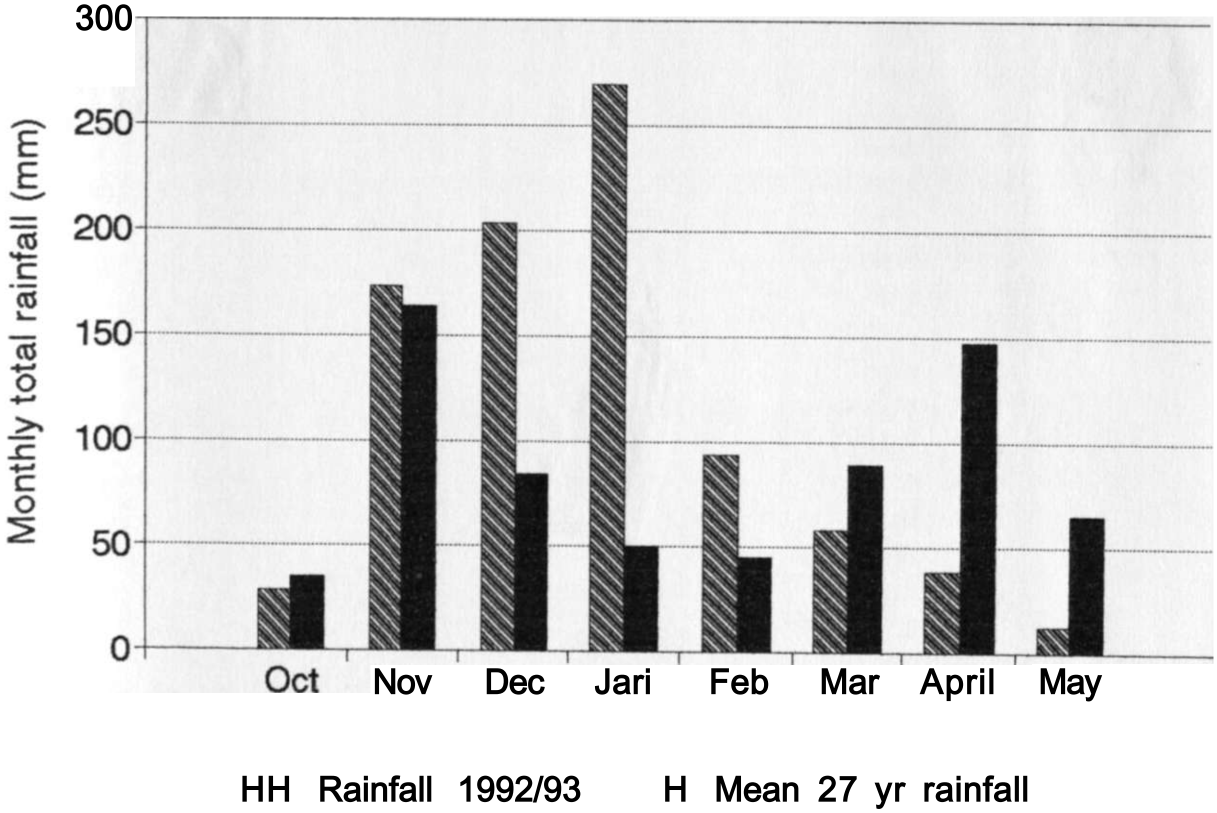

Fig 4.2 Comparison of Short term (1992/93) with long term (27 years record) rainfall distribution

From 15/3/93 to 31/3/93 (18 days), only 11.6 mm of rainfall were received, giving crops a poor start.

Table 43 Rainfall Occurrence 1992/93

Date	Days of consecutive rainfall	Rainfall (mm)
28/10- 1/11	4	9.85
3/11 - 6/11	4	37.60
11/11 - 15/11	5	41.30
17/11	1	0.75
23/11 - 25/11	3	9.75
28/11- 1/12	4	83.65
7/12	1	3.50
9/12	1	6.50
11/12-12/12	2	74.65
14/12	1	7.20
17/12-19/12	3	80.60
28/12- 2/01	6	37.55
6/01 -10/02	5	48.50
13/1 -21/01	9	143.45
23/1	1	10.40
26/1 -1/02	7	77.85
8/2 -12/2	5	84.20
14/2 - 15/2	2	7.10
13/3	1	45.75
15/3	1	2.30
19/3	1	2.00
23/3 -24/3	2	7.30
1/4	1	12.30
16/4 - 17/4	2	22.00
19/4	1	3.80
6/5	1	8.75
12/5	1	3.90

From March to May, only 103 mm of rainfall were recorded as compared with a mean of 297 mm (27 years record). Rainfall kept on reducing progressively from January to May. In May, 13 mm were received whereas the mean monthly value is 65 mm.

Plate 6 Runoff Plots after a 46 mm storm on 13/4/93

4.3.2 Rainfall Events Frequency Distribution

The highest number of rainfall events in any one month was recorded in January (23 events) while the least was recorded in May (2 events)(see appendix 4). For the other months, the number of rainfall events were as follows: October (3), November (17), December (23), February (8), March (5), April (4) and May (2).

From October 1992 to March 1993, there were 69 rainy days over a 151 day period while from October to May there were 75 rainy days over a 200 day period. The period of March to May had only 11 rainy days stretched over a 61 day period

During the first 40 days of a crop growing season when the plant is devoted to producing leaves, most crops are sensitive to soil moisture deficits. In this long rains period, a total rainfall amount of 95 mm had been received. Except for an initial storm of 46 mm, the rest of the rainfall was low and thinly distributed. Hence the maize crop planted in the adjacent area experienced a very serious soil moisture shortage, and hence dried up eventually. Consequently no maize/bean crop was realized in the area during the long rains period.

Total rainfall in the short rains season of as little as 155 mm(1981) and as much as 925 mm (1961) has been recorded. On the other hand, total rainfall in the long rains season of as little as 133 mm (1973) and as much as 660 mm(1979) has been observed (Stewart and Faught, 1984). See appendix 4 for the monthly rainfall means and 27 year recorded extremes.

4.3.3 Storm Intensity, Energy and Erosivity

Erosivity refers to the power to erode. It is dependent on storm energy which is a function of rainfall intensity and duration. The product EI_{30} (Wischmeier's erosivity index) and storm kinetic energy are often used indices of storm erosivity (Morgan, 1986). Where E is the total storm energy and I_{30} is the maximum 30 minute intensity.

I_{30} varied from 46 mm to 0.5 mm with a mean of 8 mm/hr while storm Kinetic energy varied from zero to 1360 J/m^2.
Correlation analysis produced coefficients of 0.76 between I_{30} and rainfall and 0.40 between I_{30} and storm duration. This means that rainfall amount had more influence on I_{30} than storm duration. On the other hand the correlation coefficient obtained between KE and rainfall amounts was 0.94. Correlation coefficients between KE and runoff (0.92) and KE and soil loss (0.89) were also high (see appendix 6).

High correlation coefficients of 0.71 and 0.80 were obtained between I_{30} and runoff and I_{30} and soil loss respectively. These coefficients increased to 0.79 and 0.84 respectively when I_{30} was multiplied by total storm energy E. The implication of this is that EI_{30} is a better index of erosivity than either E or I_{30} when used alone.

Coefficients of determination were higher between I_{30} and soil loss than between I_{30} and runoff. The coefficients of determination (R^2) between I_{30} and runoff for the various treatments were 0.55 (CT), 0.48 (10 FYM), 0.49 (5 FYM) and 0.57 (ZT). For and soil loss r^2 values were 0.72 (CT), 0.66 (10 FYM), 0.65 (5 FYM) and 0.64 (ZT) while for EI30 and soil loss, they were 0.86 (CT), 0.67 (10 FYM), 0.68 (5 FYM) and 0.71 (ZT). (For details, see appendix 6).

4.4 Runoff and Infiltration

4.4.1 Rainfall and Runoff Response

There was a strong positive correlation between rainfall and runoff ($r = 0.94$) implying that rainfall amounts strongly influenced runoff. The amount of runoff is influenced by rainfall intensity, rainfall amounts and the soil infiltration rate. Infiltration is dependent on the soil surface conditions and the physical characteristics of the soil. It is also dependent on antecedent soil moisture conditions.

The best predictors of runoff were rainfall amounts and total storm kinetic energy with regression coefficients ranging between 0.94 and 0.84 for the four treatments. From initially dry soil conditions, rainfall amounts less than 6 mm never caused runoff (see appendix 5). However this was not the case according to observations made. There was a storm of less than 5 mm that caused runoff just as there were storms of more than 5 mm that never caused runoff indicating the significance of antecedent moisture content, soil surface conditions and rainfall characteristics.

The influence of rainfall amount on runoff was greatest under CT ($r^2 = 0.93$) followed by ZT (0.92), 10FYM and 5FYM (0.89). The influence of kinetic energy on runoff was also highest under CT (0.90) and least under 10FYM (0.84) as shown in appendix 6.

Storm kinetic energy explained more of the variations in runoff as compared to I_{30} possibly because the latter looks at the entire storm hence covering short duration storms of high intensities and long duration storms of low intensities.

The correlation coefficient (r) between storm duration and runoff was 0.54 meaning an increase in storm duration of one unit led to an increase in runoff of 0.54 units. Therefore storm duration postively influenced runoff.

I30 coefficients of determination (r^2) with runoff were 0.72(ZT), 0.66(CT), 0.59(5FYM) and 0.57(1 OFYM) (see appendix 9). Therefore rainfall amount influenced runoff more than I30- This was attributed to the many rainfall events of low intensity, high amounts and long duration that caused runoff Many rainfall events occurred intermittently over several hours. During prolonged storms, rainfall intensity might be low but because of the duration, saturation results leading to runoff In such a case rainfall amount would be a better estimator of runoff as compared to rainfall intensity. I_{30} would therefore be good for intense rainfall events of short duration and high amounts.

There were no significant differences in runoff between Conventional tillage and zero tillage. However the two treatments had in much higher runoff when compared to the farmyard manure treatments. For small storms, the differences in runoff between the four treatments were less marked. There were significant differences for large storms.

The occurrence of runoff was influenced by the interval between storms. The shorter the interval, the more the runoff. When there had been a large storm the previous day (above 37 mm), even a small storm of 3.5 mm caused runoff whereas when there had been dry spell of two days, rainfall of 13 mm (14/1/93) never caused runoff.

There was a noticeable trend between runoff and rainfall. When rainfall amounts were high, the amount of runoff and soil loss was also high while low runoff' and low soil loss were observed under small storms. When Kilewe and Ulsaker (1984) related total kinetic energy to rainfall amounts for the storms in Katumani, the resulting relation had a an R^2 of 0.97 indicating that nearly all variations in total energy can be accounted for by rainfall amount. For this reason, rainfall amount and total storm kinetic energy when used as erosive factors produced similar results (Ulsaker and Kilewe, 1984).

Total runoff expressed as a percentage of erosive rainfall during the duration of the study was 47 (ZT), 38 (CT), 29 (5FYM) and 27 (1 OFYM) (see Table 4.4).

Table 4.4 Runoff Expressed as a percentage of erosive rainfall.

		Treatment (% Runoff)			
Date	Rainfall mm	CT	10FYM	5FYM	ZT
12/11	16.00	33.38	3.50	5.81	45.63
15/11	16.60	35.18	10.72	15.42	45.30
28-1/12	83.65	63.84	37.06	9.95	75.03
9/12	6.50	13.69	6.15	7.69	14.92
11/12	67.25	70.01	61.49	63.84	75.18
12/12	7.40	16.62	12.97	13.78	20.27
17-18/12	75.35	63.57	46.94	49.38	66.54
19/12	5.25	57.90	46.10	46.67	63.62
31/12	16.90	25.15	15.27	17.57	31.07
7/1	23.50	2.64	1.53	1.74	3.02
10/1	11.25	36.53	12.71	14.84	64.53
14/1	6.80	18.39	14.05	14.76	32.32
16/1	36.95	48.58	31.80	35.24	56.48
17/1	3.45	17.97	10.43	11.88	20.58
18/1	10.50	16.29	11.43	11.24	26.10
20/1	38.10	60.34	53.23	54.70	66.80
28/1	9.50	40.53	24.32	25.68	48.84
30/1	52.25	65.03	55.94	62.99	72.94
8-9/2	50.20	27.91	19.22	20.54	32.25
11/2	30.10	47.11	39.27	38.17	52.43
13/3	45.75	68.2	48.70	55.85	87.32
1/4	12.30	25.69	23.74	22.93	41.30
17/4	19.50	30.67	28.41	27.69	34.26
	Mean %	38.49	26.74	28.63	46.81
Total	Runoff (mm)	326.42	237.91	254.92	378.94

4.4.2 Seasonal Runoff and Infiltration

Though the first storm was received on 28/10/1992 it was not until 12/11/1992 that runoff was observed. Throughout the season, 75 rainfall events of various magnitudes were received but only twenty five caused runoff. The first nine storms never caused any runoff or soil loss and they totalled up to 70 mm. This can be attributed to the fact that they were small in magnitude, spread over long time durations and occurred at the time when the soil was dry following the dry season.

The initial results did not reflect significant treatment differences between 5 tonnes FYM/ha and 10 tonnes FYM/ha though there tended to be less runoff under the latter treatment. This is clearly shown in Figures 4.3 to 4.4.

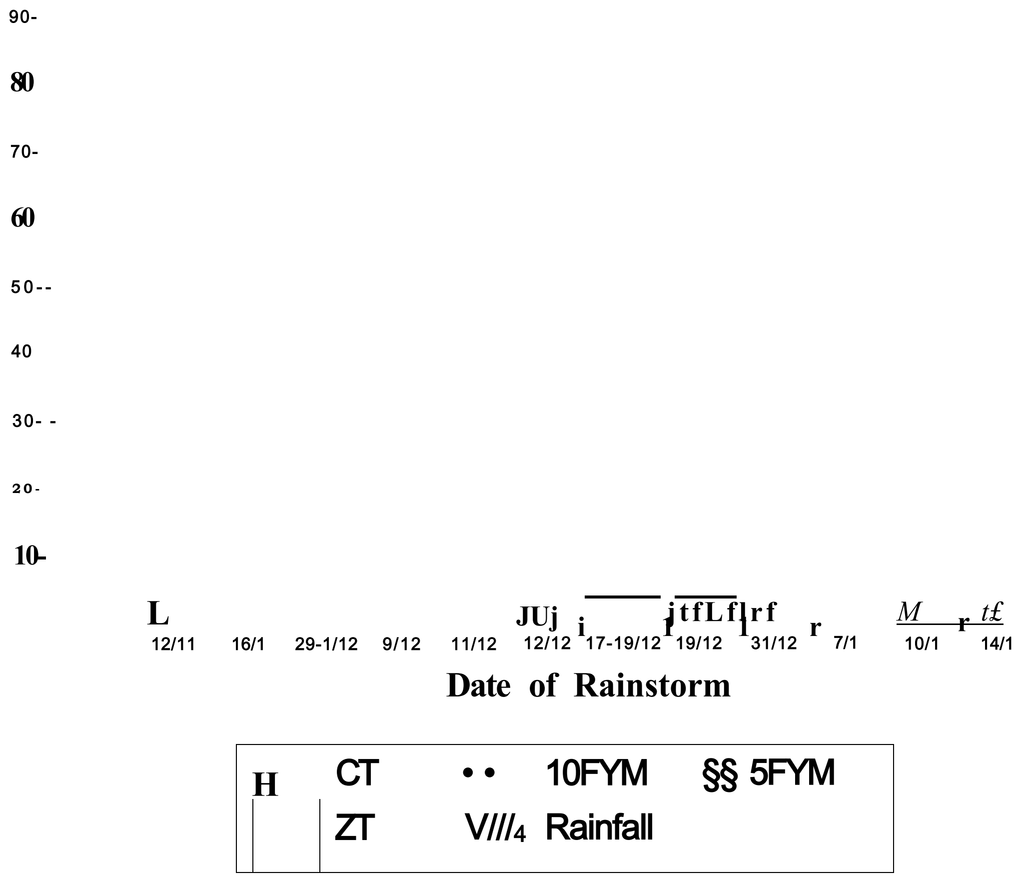

Fig 43 Treatment Differences in Seasonal Runoff

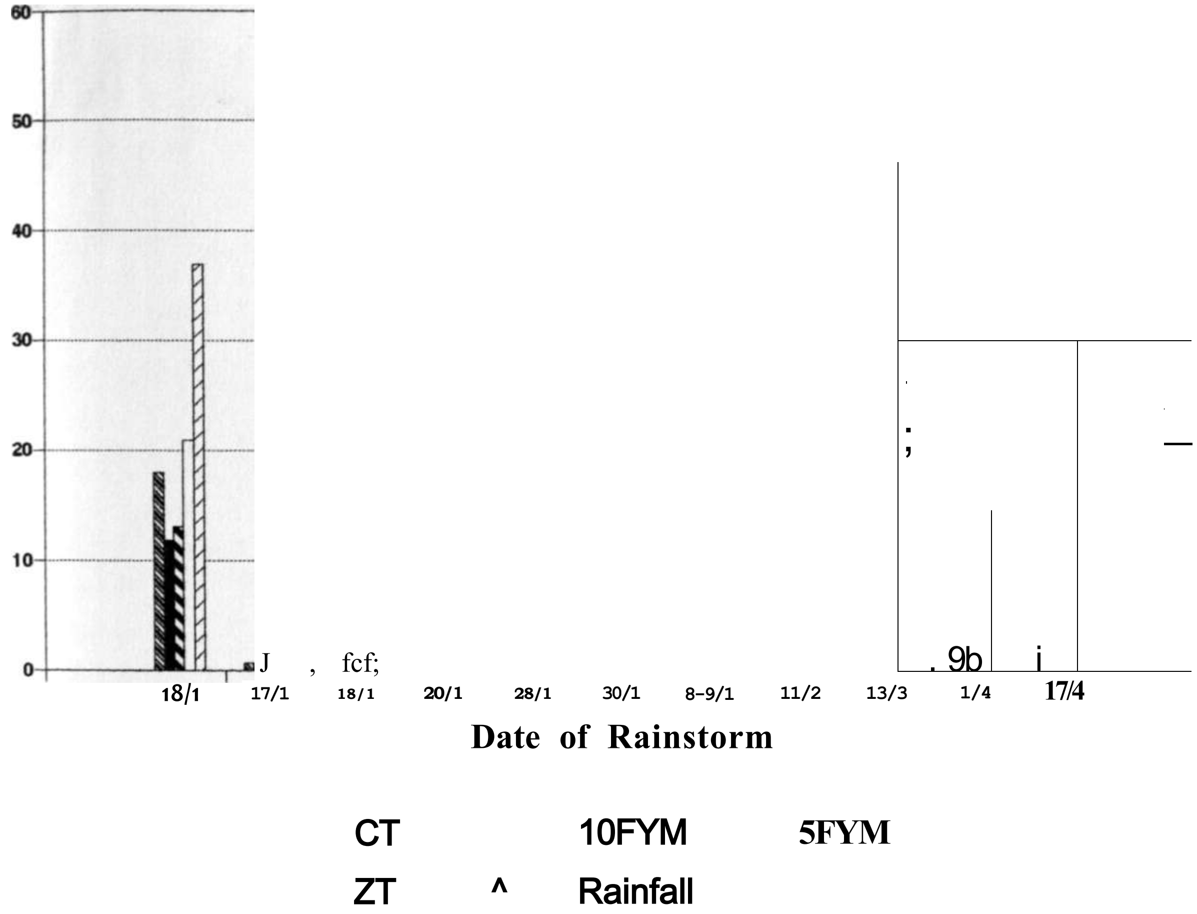

Fig 4.4 Treatment Differences in Seasonal Runoff

Table 4.5 The effect of ZT, CT, 5FYM and 10FYM on runoff at Katumani during 1992/93.

	Rainfall (mm)	(Runoff mm)			
Year and Season		ZT	CT	5FYM	10FYM
1992 Short rains	767	327(a)	286(a)	221(b)	207(b)
1993 Long rains	108	52(a)	40(b)	34(c)	31(c)
Total	875	379(a)	326(b)	255(c)	238(c)

Values along with the same letter in parenthesis were not significantly different at 5% level.

Looking at the seasonal trend in rainstorms, it was observed that the more close the storms were, the more the runoff. Antecedent soil moisture therefore influenced infiltration.

4.5 Seasonal Variability in Soil Conditions and Soil loss

4.5.1 Soil Infiltration and Moisture Retention Characteristics

All the rainfall from the first eight storms infiltrated into the soil since there was no runoff. Under all treatments, infiltration was observed to decrease with time. The highest infiltration amount was observed under 10 FYM followed by 5 FYM, CT and ZT. This is the reverse of the pattern observed with runoff. The soil at the study area had a moderate basic infiltration rate. The high volumes of surface runoff are therefore a result of surface sealing and crusting. The soils have a low aggregate stability which makes them prone to surface sealing and consequently crusting.

It took only 310 seconds for the scale reading of the disc permeameter to fall from 99 cm to 0.5 cm under 10 FYM. For the other treatments the time taken, in seconds, for a similar fall in scale reading was 490 (5 FYM), 740 (CT) and 810 (ZT). No significant differences in infiltration between ZT and CT were observed.

Hydraulic conductivity varied from moderate to moderately rapid according to Landon's (1984) classification (see Table 4.6). Therefore if the surface soil characteristics can be improved so as to eliminate surface sealing and crusting, runoff can be markedly reduced. This can result in increased soil moisture for crop growth.

Improvement of surface soil characteristics can be done by increasing the soil organic matter. This can be achieved using farmyard manure and crop residues when available. Some tillage is also necessary for soil loosening since the highest bulk densities were observed under zero tillage. However tillage should not be excessively done as it is bound to lead to increased soil loss as was the case under CT. The soils at the study site were observed to form large clods which were easily broken by increased tillage and raindrop impact.

By reducing runoff volume, soil loss will also be significantly reduced as a result of the decrease in transport capacity of the runoff. The highest hydraulic conductivity values were observed under 10 FYM (70 mm/hr) while the least hydraulic conductivity was under ZT (57 mm/hr) 5 FYM and CT had hydraulic conductivities of 66 mm/hr and 58 mm/hr respectively.

The main factor affecting soil infiltrability seems to be surface sealing and crusting. Roth et al (1988) observed that irrespective of tillage treatment, a 100% cover led to the complete infiltration of 60 mm of rainfall whereas only 20% of the applied rainfall infiltrated when the soil was bare and the surface completely sealed. Therefore it appears that cover is the most important determinant of infiltration and the effect of different tillage methods or manure application seems to be insignificant when compared with the effect of crop and residue cover. Nevertheless, tillage methods and manure application can be very instrumental in establishing early cover through increased soil water storage capacity and reduced runoff therefore increased infiltration.

Table 4.6 Hydraulic conductivity and volumetric water content at saturation for the different treatments.

Treatment	Hydraulic conductivity (mm/hr)	Volumetric water content at saturation (%)	Remarks
CT	58	44	Moderate
ZT	57	41	Moderate
10 FYM	70	47	Moderately rapid
5 FYM	66	47	Moderately rapid

(Source: Landon, 1984)

ZT had a the least hydraulic conductivity followed by CT and more water was retained at saturation under CT (44%) than under ZT (41%). 5FYM and 10FYM retained 47% soil moisture at saturation.

Soil Moisture Release Characteristic Data.

Soil moisture held in the profile increased with depth at all suctions as shown in Table 4.7. This was consistent with the soil texture and bulk density changes with depth. Clay content was highest at lower horizons while sand content was highest in the top 0-15 cm. Clay has a high water holding capacity. This can therefore explain the high water content held at lower horizons (40.6% clay and 51.4% sand) as compared to the 0-10 cm depth (27.9% clay and 67.2% sand).

With increasing depth there is a higher water content on a volume basis at 0.1 bar and at 15 bar but there is less available water (17% - 9%) possibly due to increased clay content. This implies that deep rooted plants that are unable to extract water from the top soil may not perform satisfactorily. Therefore it is advisable to plant crops that are able to extract soil moisture from a wide horizon range including the top horizon where the highest quantity of available water was recorded.

Table 4.7 Profile Soil Moisture Release Characteristics of a Luvisol.

Depth	**% Volumetric Moisture Content**						
	Suction (bars)						
	0	**0.10**	**0.50**	**1**	**5**	**10**	**15**
10	**40.2**	**32.5**	**26.3**	**15.4**	**11.9**	**10.9**	**9.3**
30	**43.3**	**28.9**	**21.7**	**16.3**	**12.7**	**11.9**	**10.7**
60	**44.8**	**34.3**	**27.4**	**17.2**	**15.2**	**14.4**	**13.3**
100	**46.6**	**38.1**	**24.0**	**19.6**	**16.1**	**15.7**	**15.2**

At low suctions (0.0-10 bars), there was more water held in the treatments where farmyard manure had been applied compared to any other treatments. The high water content dramatically decreased as suction increased implying that it can be easily extracted by plants (see Table 4.8). At suction 15, the treatment differences in soil moisture became less marked. It can therefore be concluded that the effect of farmyard manure on soil moisture release characteristics became diminished at very high suction pressures.

Table 4.8 Treatment Soil Moisture Release Characteristics

Treatment	% Volumetric Moisture Content						
	Suction in Bars						
	0.00	0.10	0.50	1	5	10	15
10FYM	45.47	34.87	22.37	21.97	19.25	17 84	13.34
5FYM	43.93	34.01	20.53	19.80	18.31	16.70	13.96
CT	41.23	31.91	20.08	19.52	16.96	15.15	14.50
ZT	40.71	31.03	17.82	17.19	15.52	14.74	14.00

4.5.2 Seasonal and Storm Soil loss

The highest amount of soil loss was observed under conventional tillage followed by zero tillage, 5 FYM and 10 FYM (see Figure 4.5 to 4.6 and Table 4.9). The amount of soil loss during the study period was 18.6, 14, 12.4 and 11.5 kg/m^2 under conventional tillage, zero tillage, 5 FYM and 10 FYM respectively. More soil was lost during the short rains as compared to the long rains as a result of the many rainfall events during the short rains period.

The initial storms never caused runoff and soil loss. This was attributed to the low initial soil moisture conditions and high infiltrability of the soil. Light rainfall facilitated erosion by loosening the soil surface such that Loose material was then easily removed by the next runoff event.

On a storm basis the lowest and highest amounts of soil loss were experienced on 9/12/93 (6.5 mm) and 13/3/93 (46 mm) respectively. The soil loss on 13/3/93 was as follows: 2.70 kg/m^2 (CT), 2.17 kg/m^2 (ZT), 1.46 kg/m^2 (10 FYM) and 1.52 kg/m^2 (5 FYM). The duration of the storm was one hour and the total kinetic energy was 1235.85

J/m . The high amount of soil loss was attributed to the fact that the land had i_ tilled and the storm was very erosive (56540 Jm"^{2} mm hr"^{1}.

There was good correlation between soil loss and storm kinetic energy (r implying that kinetic energy strongly influence soil loss. Soil loss was also influen.. Runoff(rH).74) and rainfall amount (1^=0.71).
High antecedent moisture increased the likely hood of surface runoff and thus so:

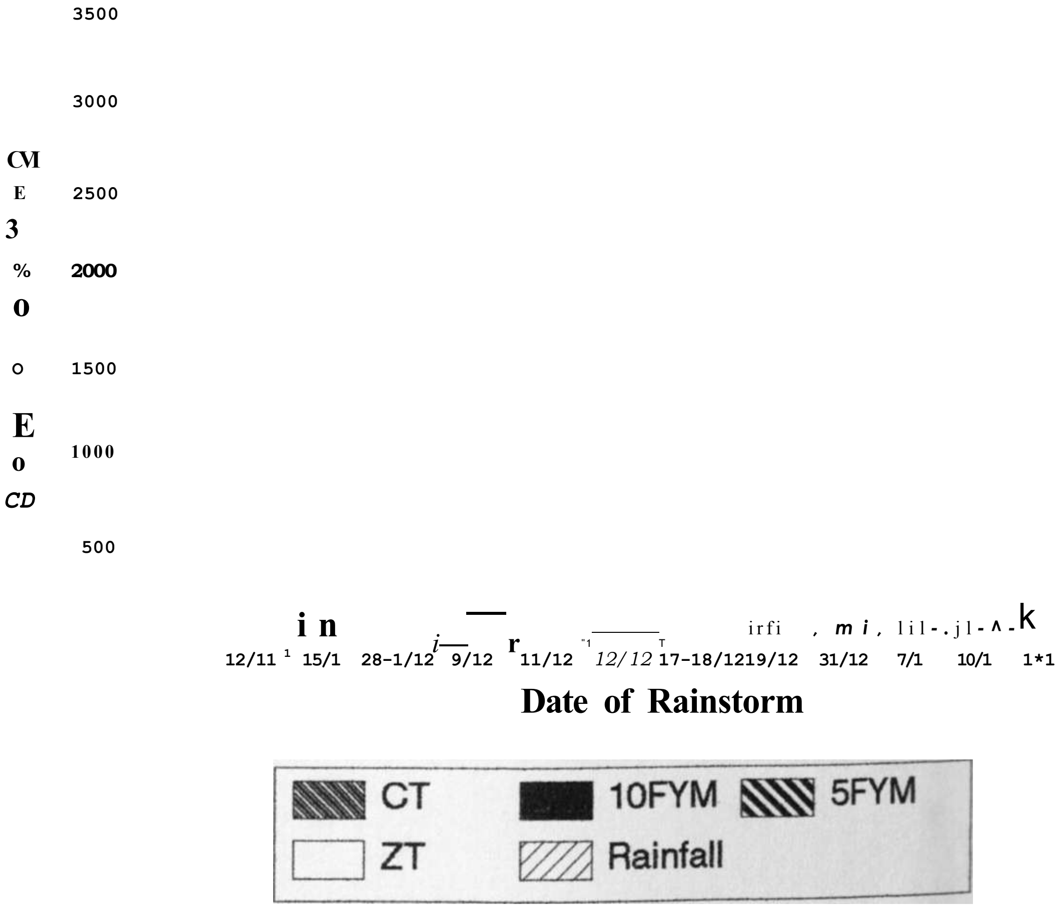

Fig 4.5 Treatment differences in storm soil loss over the experimental period, 1992/93.

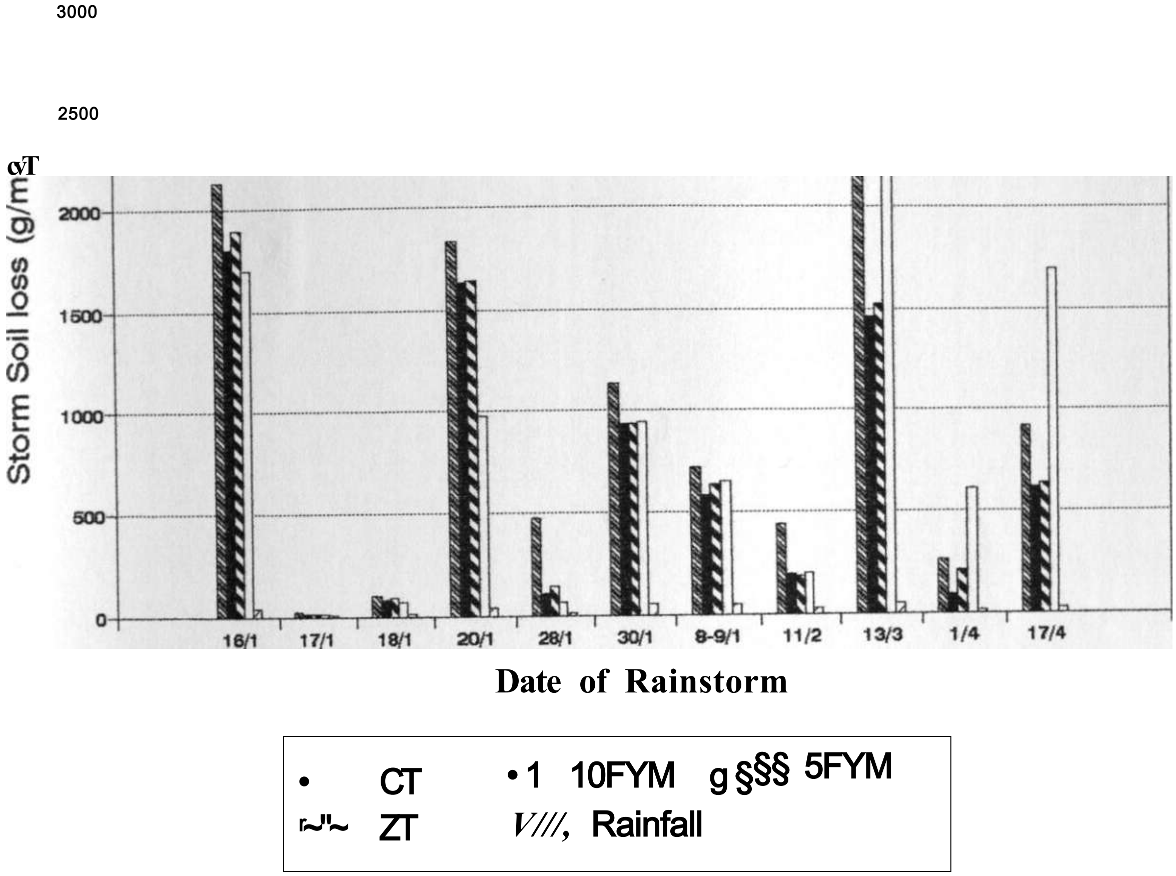

Fig 4.6 Treatment differences in storm soil loss over the experimental period, 1992/93.

Table 4.9 Effects of ZT, CT, 5FYM and 10FYM on soil loss at Katumani, 1992/93.

	(Soil loss g/m^2)			
Year and Season	**ZT**	**CT**	**5FYM**	**10FYM**
1992 Short rains	9518	14770	10038	9346
1993 Long rains	4478	3874	2373	2162
Total	13996	18644	12411	11508

Table 4.10 Storm Rainfall and Treatment Soil loss at Katumani, 1992/93

Date	Rainfall mm	CT	10FYM (Soil loss gm/m2)	5FYM	ZT
12/11	16.00	106.33	1.83	4.06	79.86
15/11	16.60	251.64	21.62	25.01	177.52
28-1/12	83.65	3335.79	1368.44	1448.31	1731.96
9/12	6.50	4.50	0.45	0.94	2.10
11/12	67.25	1980.12	1469.32	1502.57	1512.41
12/12	7.40	17.13	5.32	5.49	4.24
17-18/12	75.35	1514.25	814.58	1152.14	910.00
19/12	5.25	149.63	49.42	58.68	78.59
31/12	16.90	106.12	85.81	89.63	103.48
7/1	23.50	119.96	9.78	17.50	112.37
10/1	11.25	81.01	10.40	19.48	13.57
14/1	16.80	257.02	160.27	192.50	196.81
16/1	36.95	2130.78	1802.12	1898.04	1695.68
17/1	3.45	19.87	12.23	12.77	12.85
18/1	10.50	101.37	83.76	84.57	65.55
20/1	38.10	1834 .73	1635.22	1636.67	70.27
28/1	9.50	475.56	108.25	136.62	62.18
30/1	52.25	1127.97	931.73	932.12	940.42
8-9/2	50.20	720.25	583.32	633.92	651.24
11/2	30.10	436.64	191.95	187.12	196.56
13/3	45.75	2697.07	1460.23	1521.30	2174.61
1/4	12.30	261.76	86.68	213.09	610.59
17/4	19.50	914.84	615.07	638.51	1693.26
Total Soil loss	g/m2	18644.34	11507.80	124111.04	13996.12

For small storms, the differences in soil loss were small and most often not significant. On the whole, the amount of soil loss was high irrespective of treatments. This became more marked under heavy rainstorms (see Table 4.10).

As the season progressed soil loss under zero tillage became markedly reduced to the extent that it was at times less than that lost under 10 FYM or 5 FYM while soil loss under conventional tillage remained consistently greater than that under ZT, 10 FYM and 5 FYM throughout the season. However, after 11/2/93, soil loss under ZT increased markedly in comparison to 5 FYM and 10 FYM because the land had just been tilled leading to increased macroporosity, increased surface storage and therefore reduced runoff.

Variations in soil erosion can be attributed to compaction of the soil surface and surface sealing and crusting (due to intense rainstorms). Although tillage can facilitate the break down of soil crusts, soil mixture and inversion could have disturbed the top soil in the conventionally tilled treatment and hence led to the high soil loss.

4.5.3 Seasonal Variation in Soil moisture

The trend of soil moisture in the top soil depth (0-10 cm) 10 cm was more or less similar under all treatments (see Figure 4.7), though the seasonal soil moisture kept on fluctuating as a result of wetting (rainfall) and drying during the dry spells. Variation of soil moisture with time was more pronounced in the 0-10 cm range as compared to the 0-100 cm range. The highest soil moisture content was observed under 10 FYM followed by 5 FYM, CT and ZT.

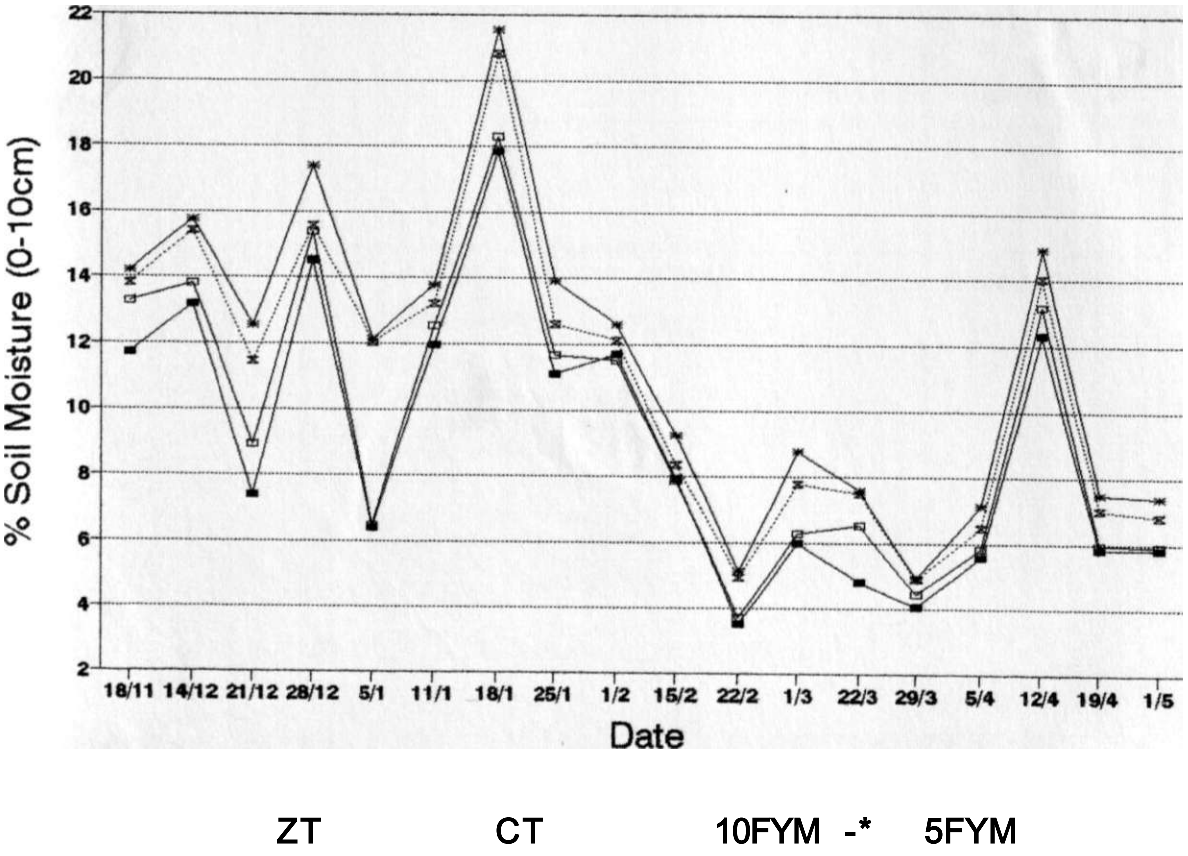

Fig 4.7 Seasonal Variation in Soil Moisture (0-10 cm), 1992/93

Down the profile (0 - 100cm) maximum soil moisture was observed under 10FYM, followed by 5FYM and CT. Soil moisture was always least under ZT except at the beginning of the study period when ZT had more moisture than CT. As the short rains season progressed, the differences in soil moisture between CT, ZT and 5FYM became less marked as shown in Figure 4.8

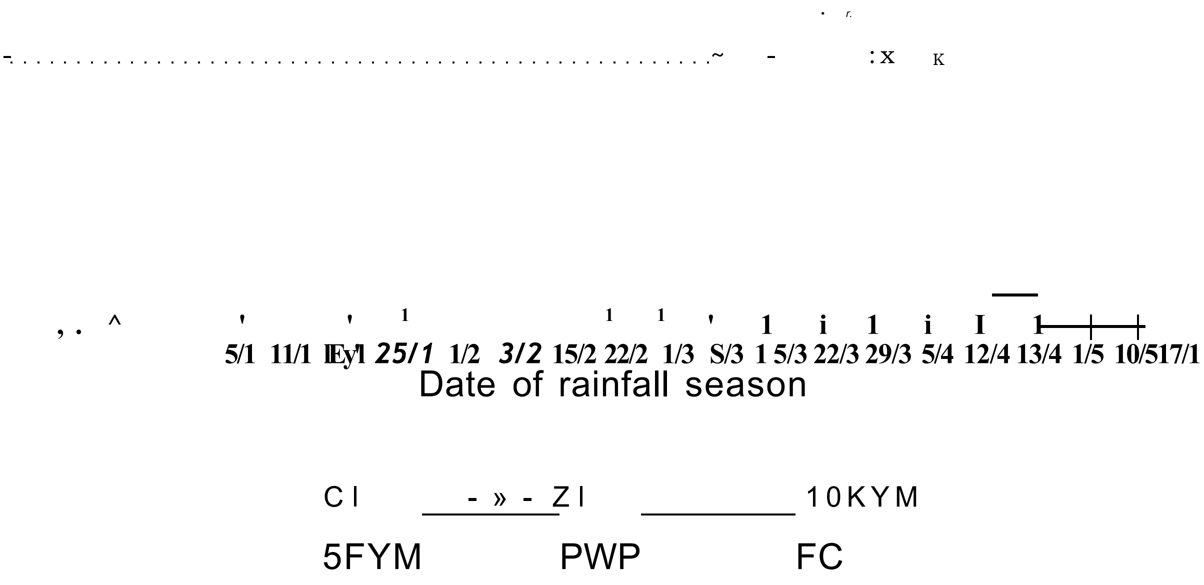

Fig 4.8 Treatment Effects on Profile Soil Moisture (0-100 cm)

It was also noticed that on 1/2/93, 15/2/93 and 29/3/93, the differences in soil moisture were not statistically significant for the four treatments. This could be attributed to the fact that it had rained a day earlier for the first two cases while on 29/3/93, there had been a prolonged dry spell of five days which had affected all treatments leading to the low soil moisture content in the top 10 cm of the soil.

The soil moisture down the profile (0-100cm) was lowest at the onset of the rains. This was attributed to the just ended dry season (April to October). Under all treatments, profile soil moisture increased with time and peaked in mid January, coinciding with the period of maximum rainfall.

At all depths, profile soil moisture was highest under 10FYM, followed by 5FYM. Profile moisture under CT and ZT never differed much. Field capacity moisture conditions (248 mm in the first metre depth) were never reached even in January when 270 mm were received. In practice the 270 mm of rainfall received could have brought the soil conditions upto field capacity but it did not. This was attributed to the high runoff generated from the bare runoff plots. Evaporation from the surface could also have contributed to the soil moisture deficit.

The profile soil moisture was above the permanent wilting point for the larger part of the study period as shown in Figure 4.8. Despite the low profile soil moisture within the study period, crop performance in the area was very good and farmers had a bumper maize crop.

The observations in profile soil moisture were consistent with the observed trends in treatment runoff.

The high soil moisture content under 10 FYM and 5 FYM can be attributed to the addition of farm yard manure. Farm yard manure improved soil aggregation and hence increased the water retention capacity of the soil.

4.5.4 Seasonal Variation in Soil Bulk Density.

During the study period, the highest bulk densities were observed under ZT followed by CT, 5 FYM and 10 FYM (see Figure 4.9). This is similar to the trend that was observed for treatment runoff. High bulk density is known to impede root growth leading to poor water and nutrient extraction from deep soil horizons. It also leads to inadequate aeration and subsequently to poor crop performance.

The relatively low bulk density under 5 FYM and 10 FYM can be attributed to the incorporation of farmyard manure into the soil. On the other hand, the high bulk density observed under ZT can be attributed to soil compaction as a result of rain drop impact. The differences in bulk density observed between 5 FYM and 10 FYM were not statistically significant as was the case with runoff and soil loss under the same treatments.

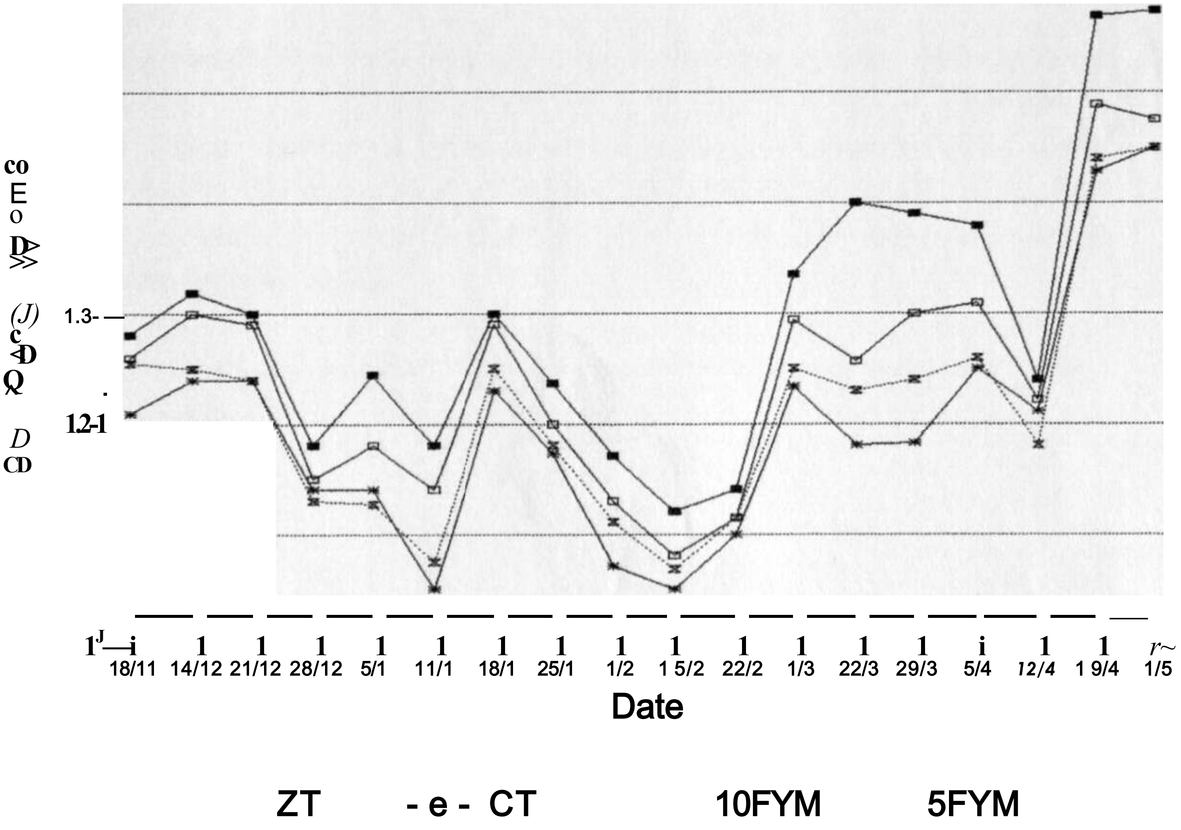

Fig 4.9 Seasonal Variation in Bulk Density, 1992/93.

Just like soil moisture, the soil bulk density tended to increase under low moisture content (end of season) and to decrease under high soil moisture (after a rainstorm). After 12/4/93, a steady increase in soil bulk density was observed under all treatments, the highest increase being under zero tillage (ZT). The differences among 5 FYM, 10 FYM and CT were not significant by May 1993.

For all treatments, the least bulk density was observed on 15/2/93 after 91 mm rainfall had been in a period of eight days with a dry spell of only one day. The highest bulk densities were observed at the end of the study period. During the long rains period, the soil moisture was fairly low because the rainfall was sparsely distributed and of low amounts.

4.5.5 Seasonal Variation in Soil Shear Strength

Soil shear strength is an important feature of soils in relation to their response to tillage and their resistance to fracture, compression, smearing, moulding and compaction. Soils with high shear strength are more resistant to root penetration than soils of low shear strength. The variability of soil strength over short distances can be very high particularly because the values are highly dependant on soil water content and physical disturbance (Landon, 1984).

The highest values for soil shear strength were recorded at the beginning of the season (see Figure 4.10).

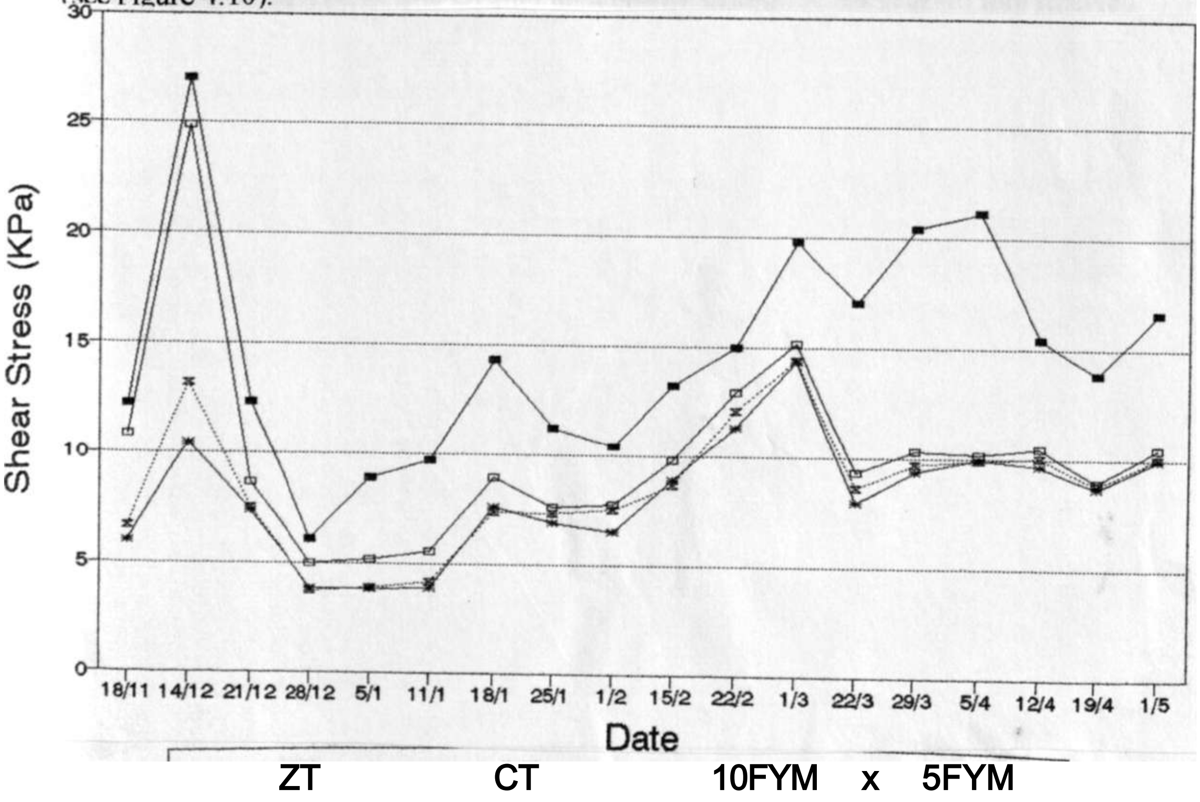

Fig 4.10 Treatment Variation in Soil Shear Strength, 1992/93

Initially the soil shear strength between ZT and CT; and 10 FYM and 5 FYM were not significantly different. However as the season progressed, soil shear strength under ZT remained relatively higher than under the other three treatments (CT, 5 FYM and 10 FYM) while the differences between the latter treatments became less marked. Over the period, shear strength tended to be highest under ZT as opposed to CT, 5 FYM and 10 FYM.

Though seasonal variation in soil shear strengths were observed, they were less pronounced when compared to variations in bulk density and soil moisture content.
Bulk density and soil shear strength tended to follow a similar trend, bulk density increasing when soil shear strength was increasing and vice versa.

4.5.6 Seasonal Variation in Soil Crust Strength

Given the low aggregate stability of the soils, surface sealing and subsequent crusting may have developed especially so after high energy storms. A storm of 46 mm received on 13/3/93 nearly destroyed all the clods in the treatments. The break down in soil macro structure resulted in surface sealing and crusting.

Resistance to penetration was found to be highest under zero tillage followed by conventional tillage, 5FYM and least under 10FYM during the study period (see Fig 4.11). Penetration resistance was influenced by soil moisture. The first penetrometer readings were taken on 2/4/93 after a storm of 12.3mm on 1/4/93. It was at this time that the lowest resistance to penetration was recorded. Penetration resistance increased steadily and peaked on 12/4/93 for all treatments. On 18/4/93, a decline in resistance to penetration was observed for all treatments. This could have been a consequence of the 2.5 mm and 19.5 mm of rainfall received on 16/4 and 17/4/93 respectively.

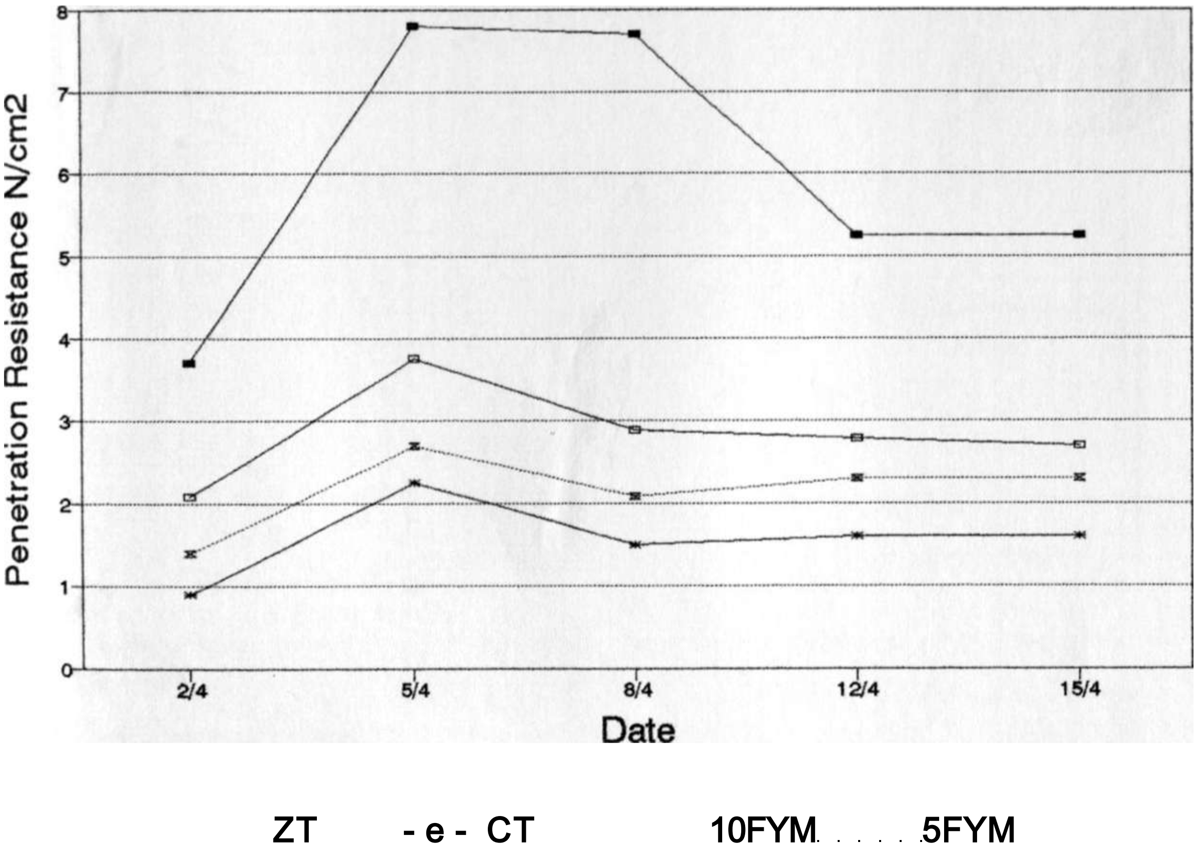

Fig 4.11 Treatment differences in Penetration Resistance, 1992/93

4.5.7 Seasonal Variation in Soil Organic Matter Content

Soil organic matter under all treatments was very low. This could have been the cause of the low stability of aggregates observed. As expected, the highest amount of organic matter (1.71%) was found in the soil where 10 tonnes of farmyard manure had been applied followed by 5FYM (1.62%). CT (1.56%) and ZT (1.54%) did not differ significantly in organic matter content (Table 4.11).

By the end of the season, organic matter under all treatments had reduced, the highest decline being under the conventional tillage treatment. The decline in organic matter under CT was largely attributed to the high quantities of top soil that were lost during the study period. The high temperatures at the study area could have also contributed to loss of organic matter through mineralisation.

Table 4.11 Seasonal Treatment Differences in Soil Organic Matter Conntent, 1992/93

Treatment	Initial Organic matter (%)	Final Organic matter (%)	% Reduction in Organic matter
10FYM	1.71	1.59	0.12
5FYM	1.62	1.52	0.10
CT	1.56	1.40	0.32
ZT	1.54	1.39	0.16

The percentage of stable aggregates ranged from 25.91% (10FYM) to 11.17% (CT). The percentage of stable aggregates under 5FYM was 19.89% while that under ZT was 11.81% (See Table 4.12)

Table 4.12 Seasonal Treatment Differences in Stable Aggregates, 1992/93

Treatment	Beginning of season	End of season	% Change
10FYM	25.91	18.61	-7.50
5FYM	19.89	14.15	-5.70
CT	11.81	13.76	+ 1.95
ZT	11.17	7.03	-4.14

Under all treatments, the stability of aggregates was low thus making the soil more susceptible to erosion. By the end of the experimental period, aggregates stability had declined under all treatments except in the zero tillage treatment where there was an increase by 1.95%.

The low stability of aggregates was attributed to the low organic matter content of the soil observed at the site. The other possible cause of low aggregate stability could have been high sodium content but the analysis of the soil samples revealed that the sodium content was low (See appendix 1). The relatively higher aggregate stability under 10FYM and 5FYM was attributed to the addition of farmyard manure which led to increased soil organic matter content. An increase in farmyard manure did not result in a correspongidng increase in the percentage of stable aggregates. Similarly an increase in farmyard manure never resulted in a corresponding increase in soil organic matter content.

If soil aggregation is improved, the breakdown of soil clods can be reduced. In this way a rough surface can be maintained especially during the initial stages of the season. This would then facilitate depressional storage thus increasing the infiltration opportunity time. In this way, runoff and soil loss can be significantly reduced.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Surface Runoff

Farmyard manure was able to significantly reduce runoff and soil loss when compared to conventional tillage with no manure and zero tillage. At the beginning of the season, the initial cloddy surfaces due to soil tillage enhanced depression storage and hence the absence of runoff'and soil loss. Surface runoff was greatly influenced by rainfall amount under all treatments. Soil sealing, crusting, and compaction resulted in increased runoff.

Farmyard manure application led to an increase in water holding capacity of the soil and a reduction in soil surface sealing, indirectly reducing surface runoff.

Storm runoff was influenced by rainfall intensity, rainfall amount, antecedent moisture content and storm duration. Under high antecedent soil moisture conditions, storms of less than 5 mm caused runoff while under initial dry conditions (onset of rains), storms greater than 15 mm never caused runoff. There was no significant difference in runoff between CT and ZT but the two treatments resulted in much higher runoff'as compared to treatments with farmyard manure. Differences in runoff were less marked for small storms.

Compaction due to raindrop impact coupled with the inherent low organic matter content contributed to the high runoff volume observed under zero tillage.

Runoff expressed as a percentage of seasonal rainfall was 43%, 48% (ZT), 37%, 37% (CT), 29%, 31% (5FYM) and 27%, 28% (10FYM) during the short rains and long rains period respectively.

The differences in soil moisture between treatments (0-10 cm) were not significant at the onset when infiltrability was enhanced by depressional storage and the end of the season when treatment effects were reducing.

5.1.2 Storm and Seasonal Rainfall

The first storms were small in magnitude, spread over long time durations and of low intensities and consequently could no cause runoff and soil loss. The most erosive storm was 46 mm received on 13/3/1993 and resulted in soil loss of 2.70 kg/m^{2} (CT), 2.17 kg/m^{2} (ZT), 1.52 kg/m^{2} (5FYM) 1.46 kg/m^{2} (10 FYM) and runoff of 87% (ZT), 68% (CT), 56%(5FYM) and 49% (10FYM). During the short rains the most erosive storm of 84 mm (28-1/12/92) resulted in a soil loss of 3.3 kg/m^{2} (CT), 1.73 KG/m^{2} (ZT), 1.45kg/m^{2} (5FYM), 1.37 Kg/m^{2} (5FYM) and runoff of 75% (ZT), 64% (CT), 40% (5FYM) and 37% (10FYM).

The short rains of 1992/93 were longer than usual and peaked in January 1993 with 35% of the seasonal rainall. Runoff during this month was 43% (ZT), 37% (CT), 28% (10FYM) and 31% (5FYM) of the rainfall received in January. Longterm data shows that the peak of the short rains is usually in November. April, which is usually the peak of the long rains, received only 38 mm of rainfall far below the monthly mean of 147 mm.

The Seasonal rainfall of 767 mm for the short rains was much higher than the longterm average of 378 mm. During the long rains, eleven storms were received, eight of them below 9 mm. This resulted in poor crop performance and thus the long rains were a complete failure. Farmers did not harvest any crop. In comparison, the short rains which received 64 storms, 20 erosive and 25 above 9 mm and well and evenly distributed led to a bumper harvest.

There was a strong correlation between storm Kinetic energy, runoff and soil loss. High erosivity led to increased soil erosion. Rainfall of low amount spread over long duration never caused runoff while high rainfall over short durations caused alot of destruction.

5.1.3 Soil Loss

This was highly variable at the onset of the season even with the same treatment. More soil was lost during the short rains 9518gm"^{2} (ZT), 14770 grrf^{2} (CT), 10038 gm"^{2} (5FYM) and 9346 gm"^{2} (10FYM) as compared to the long rains period 4478 gm"^{2} (ZT), 3974 gm*^{2} (CT), 2373 gm"^{2} (5FYM) and 2162 gm"^{2} (10FYM). Soil loss was influenced by rainfall characteristics, degree of soil aggregation and antecedent soil moisture. High runoff volumes often resulted in increased soil loss while low runoff volumes gave little soil loss at the onset of the season. However later in the season soil loss tended to decrease even when runoff increased. Soil loss decreased in the order of ZT, CT, 5FYM and 10 FYM over the experimental period.

At low bulk density and low soil shear strength, storms of low intensity and low magnitude caused little soil loss as a result of their low erosivity. However, high intensity storms resulted in alot of runoff and soil loss due to their high erosivity. Under low bulk densities soil particles were easily detached while under high bulk densities and high rainfall intensities the increased runoff led to increased soil detachment and thus increased soil loss and increased runoff at the onset of the season. Later in the season after the soil had settled, high rainfall intensities led to increased runoff but reduced soil loss due to soil surface sealing.

Farmyard manure application significantly reduced soil loss and runoff. FYM led to improved soil aggregation, reduction of bulk density and reduction of soil shear strength. This led to reduced soil loss especially under low intensity rainfall. Conventional tillage without any soil amendment leads to a lot of soil and runoff water losses for this structurally unstable soil while zero tillage alone leads to high runoff volumes. Conventional tillage alone therefore reduces aggregate stability and promotes soil loss.

5.1.4 Soil Infiltrability

The soil at the study area exhibited some moderate infiltration. The progressive seasonal decrease in infiltration observed was attributed to surface sealing and subsequent crusting of the top soil which resulted in high volumes of surface runoff.

The soil had a low percentage of stable aggregates and hence this made the soil prone to surface sealing and crusting. Infiltration was initially high but soon after tillage, the soil clods were broken down by the very high energy of falling rain drops which resulted in the sealing of the soil surface especially under CT and ZT.

The improvement in soil aggregation due to an increase in organic matter content from the FYM treatments increased the stability of the aggregates and hence provided favourable conditions for better infiltration. Besides, the maintenance of a cloddy soil macrostructure helped to impound runoff in depression storage and hence enhanced infiltration.

The topsoil layer controls infiltration and therefore any incorporation of farmyard manure will lead to higher infiltration

5.1.5 Soil Moisture

Soil moisture kept on fluctuating as a result of wetting (rainfall) and drying during the dry spells. The variation was more pronounced in the 0-10 cm depth as compared to the 0-100 cm depth. The highest soil moisture was observed under 10FYM followed by 5FYM, CT and ZT implying that FYM was effective in enhancing soil moisture storage. Under all treatments, field capacity moisture conditions were never reached during the experimental period. If there had been a crop on the plots, runoff would have been reduced due to soil cover and thus soil moisture in the profile would have been more than that observed on the bare plots.

5.1.6 Soil Aggregation

Addition of farmyard manure was effective in increasing soil aggregation though the organic matter levels were generally low for all treatments.

At the end of the short rains, a reduction in soil aggregation was recorded for all treatments. The highest decrease was in CT and ZT. Therefore regular application of farmyard manure is essential for sustained soil productivity. A decline in soil organic matter content was observed and it was attributed to the top soil losses and organic matter oxidation as a result of high temperatures at the experimental site. From the results obtained in this study, the top soil layers were richer in organic matter content than the underlying horizons (see Table 4.1).

Farmyard manure was found to be effective in reducing runoff and soil loss during the duration of the study. The differences between 10FYM and 5FYM were not significant. Therefore it was not the amount of farmyard manure that was critical but its application. The conservation and use of farmyard manure warrants much attention and is essential to the development of sustainable farming systems.

5.1.7 Soil Bulk Density, Shear Strength and Resistance to Penetration.

Soil bulk density was highest under ZT and CT but least under the farmyard manure treatments. Bulk density was low when soil moisture was high and high under low soil moisture conditions.

Soil shear strength was highest at the beginning of the season when the profile was still dry. The highest values were recorded under ZT indicating a need for soil loosening and tilling the soil just after harvest when there is still some residual soil moisture. Penetration resistance was least under the Farmyard manure treatments.

5.2 Recommendations

The organic matter content of the soil needs to be steadily increased. This seems to be the only way in which soil physical structure can be improved and the rate of infiltration increased. Application of farmyard manure as a farm management practice is recommended. This is applicable since most farmers in Machakos keep some animals. The combined effect of improved crop growth and improved soil conditions as a result of farmyard manure application can be expected to lead to substantial reductions in soil and water losses and a more sustainable system of farming.

In case the farmyard manure is in short supply, it is recommended that only the strip to be planted should be cultivated and the little farmyard manure available applied in this strip (strip tillage). A rate of 5 tons/ha could be applied since the difference between 5FYM and 10FYM gave more or less the same results. This will lead to a suitable micro climate for the crop consequently quick establishment thus an early cover during the early part of the season when the land is bare.

Zero tillage is not suitable for this soil because it leads to alot of runoff due to soil sealing and crusting. Furthermore the high bulk density observed under zero tillage may impede root development and thus poor crop performance.

Zero tillage is recommended on medium textured soils with high biological activity and on self structuring, cracking clay soils. Zero tillage is also favourable where the top soil is shallow, stable, of high organic matter content and underlain by structurally unstable soils such as plinthite.

Conventional tillage without any farmyard manure leads to a lot of soil loss for structurally unstable soils because of the low aggregate stability of the soil. In the absence of farmyard manure and crop residues mechanical measures such as ridging are recommended in order to conserve as much runoff as possible in situ.

Further research is needed to verify the long term effects of the four treatments in terms of soil fertility and crop performance.

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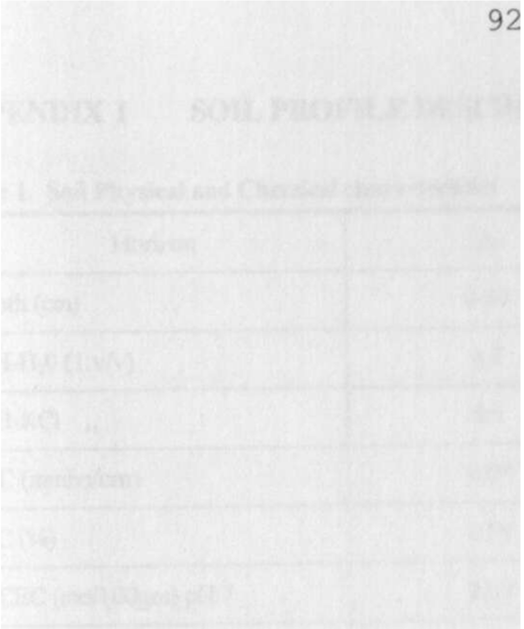

APPENDICES

APPENDIX 1 SOIL PROFILE DESCRIPTION AND ANALYTICAL DATA

Table I. Soil Physical and Chemical characteristics

Horizon	**A**	**BC**	**C**
Depth (cm)	**0-14**	**14-60**	**60-90**
***pH-$H_2$0(l:v/v)**	**6.3**	**5.6**	**5.6**
***pH-KCl „**	**5.5**	**4.9**	**4.8**
***EC (mmho/cm)**	**0.09**	**0.06**	**0.05**
****C (%)**	**0.58**	**0.31**	**0.27**
****CEC (me/lOOgm) pH 7**	**23.9**	**19.8**	**13.4**
****Exch. Ca (me/lOOg)**	**4.5**	**5.2**	**5.0**
****» Mg "**	**3.7**	**4.8**	**4.9**
#* » H	**0.94**	**0.65**	**0.4**
* « Na «	**0.29**	**0.27**	**0.15**
****Sum of cations**	**9.43**	**10.92**	**10.45**
••Base sat. % pH 7	**58**	**55**	**53**

*** Data from Gicheru and Ita, 1987.**

**** Data from Soil Science Dept analysis of project samples**

General Site Information

Agroclimatic zone	IV-4
Location/altitude	Machakos district, 1600m
Parent material	Undifferentiated quartzo-feldspathic gneiss
Drainage class	Well drained
Relief	Undulating
Slope gradient	8%
Vegetation/land use	Grazing, bushed grass land
Surface sealing	Moderate

Profile Description

A 0-14cm: Yellowish red (5 YR 4/6 dry) to dark reddish brown (5 YR 3/3 moist); sandy clay; weak, coarse, sub-angular blocky; slightly hard when dry; friable when moist, slightly sticky and slightly plastic when wet; many micro and macro pores; many very fine, fine to few medium and common coarse roots; gradual and smooth transition to :

14-60: Red (2.5 YR 4/6 dry) to dark red 2.5 YR 3/6 moist); clay; weak, coarse sub-angular blocky; slightly hard when dry, friable when moist, sticky and plastic when wet; many micro and macro pores; many very fine to fine common medium and few coarse roots:

60+: Stone line. This was highly variable.

APPENDIX 2 CALIBRATION OF NEUTRON PROBE

Table 2 Neutron probe calibration (20-60 cm) Depth

Depth	Mean	% Vol. Soil	COUNT RATIO	
(cm)	count	moisture	Measured	Expccted
20.0	116.77	9.30	0.15	0.15
40.0	207.67	14.01	0.27	0.17
60.0	239.33	20.43	0.31	0.18
20.0	140.40	9.50	0.18	0.20
40.0	156.16	11.90	0.20	0.21
60.0	179.58	13.20	0.23	0.23
20.0	163.97	12.50	0.21	0.24
40.0	164.00	14.00	0.24	0.27
60.0	132.74	9.40	0.17	0.28
20.0	259.50	21.53	0.33	0.31
40.0	265.50	22.68	0.34	0.32
60.0	262.00	22.71	0.34	0.33
20.0	220.00	15.25	0.28	0.33
40.0	279.00	24.74	0.36	0.34
60.0	261.00	23.30	0.34	0.34
20.0	272.00	24.07	0.35	0.34
40.0	288.00	25.43	0.37	0.35
60.0	297.50	25.50	0.38	0.35
20.0	305.50	25.90	0.39	0.36
40.0	304.00	26.20	0.39	0.37
60.0	291.50	25.48	0.37	0.37
20.0	273.50	24.17	0.35	0.38
40.0	258.50	21.78	0.33	0.39
60.0	247.00	20.99	0.32	0.39

CALIBRATION (80-120 cm)

80.0	194.63	17.00	0.25	0.25
100.0	233.55	19.70	0.30	0.30
120.0	249.12	21.20	0.32	0.32
80.0	272.00	23.18	0.35	0.34
100.0	300.00	25.98	0.39	0.34
80.0	264.00	27.03	0.34	0.35
100.0	298.50	27.08	0.38	0.35
120.0	320.50	27.91	0.41	0.36
80.0	268.00	23.18	0.34	0.37
100.0	280.00	24.98	0.36	0.38
120.0	310.00	25.09	0.40	0.38
80.0	298.50	26.35	0.38	0.39
100.0	330.50	28.01	0.42	0.40
80.0	286.50	18.60	0.37	0.40
100.0	314.00	19.88	0.40	0.41
120.0	321.50	23.29	0.41	0.41
80.0	275.50	23.29	0.35	0.42
100.0	342.00	26.60	0.44	0.44
120.0	118.00	10.80	0.15	0.15

Regression 0utput:(20-60)

Constant	-4.57
R Squared	0.92
X Cocflicient(s)	79.68
Vol. Moisture Content =	(79.68 xCR)- 4.57

Regression 0utput:(80-

Constant	0.68
R Squared	0.98
X CoefTicient(s)	63.82
Vol. Moisture content =	(63.82 xCR) +0.68

APPENDIX 3 VOLUMETRIC SOIL MOISTURE DATA AS DETERMINED BY A NEUTRON PROBE, SHORT RAINS PERIOD, 1992/93

Conventional Tillage Block A

Date

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	16.15	19.52	18 44	19.93	18.42	19.23	22.18	16.56	19.03	20.51	18.71	14.76	13.64	12.10	14.15	11.88	11.35	10.21	07.87	09.78	10.13	11.27	07.25
40.00	15.35	20.76	20.65	18.34	19.79	24.29	22.61	19.58	21.09	20.53	20.68	18.79	18 19	16.68	16.52	15.98	15.54	15.05	13.38	13.21	11.11	12.14	11.61
60.00	10.57	19.26	20.87	18.81	19.51	22.33	23.02	21.32	21.55	20.89	21.89	20.83	19.36	18.23	17.74	17.21	16.62	15.89	1448	13.44	13.46	13.92	12.33
80.00	15.13	15.52	22.25	21.75	21.33	24.53	25.75	25.25	25.79	25.47	26.38	25.21	24.53	22.17	22.86	22.02	20.86	19.92	18.67	17 89	18.01	16.78	16.66
100.00	14.44	16.51	21.33	23.39	23.39	24.08	24.77	25.46	26.75	26.96	27.51	27.37	25.85	25.46	24.44	22 81	22.09	21.32	19.26	18.57	17.89	17.20	17.20

Conventional Tillage Block B

Date

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	17.14	21.37	18.42	19.76	18.45	21.29	22.69	17.22	19.21	20.41	18.30	15.37	14.25	14.26	16.17	13.54	13.01	12.32	10.45	12.12	10.88	8.06	9.55
40.00	17.33	20.63	20.28	18.75	19.06	23.13	21.87	19.47	20.41	19.64	19.69	18.38	16.41	17.41	18.10	16.87	16.54	15.79	15.59	14.70	14.10	14.05	13.18
60.00	12.68	21.60	21.56	20.61	19.31	25.29	23.12	21.93	21.85	21.09	21.64	21.28	20.12	20.39	19.32	18.71	18.18	17.50	17.49	15.27	15.70	15.10	14.55
80.00	15.76	21.53	23.60	24.22	23.21	28.55	26.86	25.73	25.65	25.62	25.63	25.30	23.74	24.24	23.72	22.92	22.07	21.81	21.02	19.89	19.24	18.30	18 51
100.00	16.70	22.70	24.08	24.77	24.77	28.21	26.83	27.28	26.83	26.61	27.86	26.93	26.02	24.72	24.93	24.09	23.81	21.68	21.87	21.94	21.93	19.26	19.26

Conventional Tillage Block C

Depth	Date																						
	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	11.32	23.26	20.89	24.51	22.64	25.71	23.59	20.22	21.75	21.93	20.93	19.09	16.28	15.63	17.80	16.42	15.72	11.59	13.74	13.78	12.50	12.34	12.77
40.00	10.28	22.54	22.75	23.16	24.26	25.17	24.97	22.54	22.87	21.93	22.27	20.90	20.35	19.12	19.55	19.75	18.71	15.31	17.80	16.41	16.63	16.11	15.89
60.00	09.75	18.49	22.93	22.04	23.93	24.53	22.64	21.75	21.83	20.92	21.36	20.62	19.89	19.55	18.94	18.99	18.66	18.11	17.31	16.54	16.37	15.65	16.28
80.00	09.89	20.30	23.71	22.95	25.11	25.50	24.27	24.30	23.70	23.42	23.54	21.95	22.82	21.91	21.52	20.90	20.61	19.26	19.71	18.42	18.37	18.16	18.35
100.00	09.02	16.44	16.13	16.95	20.68	25.28	24.64	24.63	24.56	24.63	24.75	22.01	23.39	23.40	22.64	22.15	21.61	19.70	21.16	19.89	20.33	19.46	19.33

Zero Tillage Block A

Depth	Date																						
	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	17.74	20.80	19.05	18.87	20.06	21.58	21.84	16.94	19.44	20.02	18.33	15.14	13.51	12.17	12.09	10.51	10.56	10.16	09.26	11.20	11.96	07.98	06.25
40.00	17.74	20.95	21.13	19.75	20.19	23.35	22.77	22.68	21.12	19.64	20.43	19.09	18.16	17.29	17.39	16.34	16.08	16.53	15.07	14.91	15.50	13.04	12.95
60.00	13.76	20.56	22.11	22.08	21.44	23.99	23.02	23.26	22.24	21.60	22.50	21.54	20.63	20.29	19.78	19.57	17.67	19.23	17.16	16.28	16.86	14 49	14.44
80.00	17.20	23.96	23.20	24.77	24.33	26.69	27.16	26.25	26.14	26.15	26.11	26.01	25.50	24.74	24.46	24.06	23.35	22.95	21.60	21.05	19.88	18.12	18 86
100.00	16.34	23.39	22.70	24.08	24.77	24.75	26.77	26.75	28.16	27.34	27.32	27.57	27.10	25.91	25.67	25.16	24.57	24.58	23.02	23.37	21.69	20.26	20.17

Zero Tillage Block B

	Date																					
	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
Depth																							
25.00	15.66	21.40	17.39	18.39	18.15	20.96	22.36	19.53	20.43	20.69	19.49	17.28	15.98	13.39	14.56	12.98	13.12	12.86	10.21	09.40	10.08	06.59	06.59
40.00	17.74	20.37	18.90	19.94	18.66	22.35	22.64	20.11	21.14	21.14	20.98	19.32	18 16	17.54	16.90	16.77	15.93	15.18	15.66	13.04	13.41	09.81	10.43
60.00	14.24	20.68	20.82	20.33	20.88	24.69	24.20	23.64	20.69	22.60	23.34	21.72	21.49	20.57	20.01	17.08	21.01	18.16	18.18	13.84	15.37	13.32	13.33
80.00	15.03	22.41	22.13	21.18	24.68	26.84	26.79	26.99	25.29	25.69	25.81	23.55	23.17	20.11	22.73	20.13	22.14	21.79	21.64	16.99	19.12	16.07	16.76
100.00	16.34	19.12	18.14	21.23	22.44	25.25	24.03	24.45	24.56	23.22	23.10	22.88	22.47	20.42	20.61	19.95	21.25	23.22	19.78	19.00	19.35	17.32	17.59
120.00	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34	16.34

Zero Tillage Block C

	Date																					
	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
Depth																							
25.00	13.59	17.60	17.46	18.14	17.08	17.53	17.95	15.74	15.96	16.61	15.09	12.74	12.06	12.30	11.33	10.58	10.28	13.39	08 85	09.03	08.84	08.18	08.18
40.00	15.26	18.95	18.39	20.69	18.59	20.46	20.31	19.58	19.31	18.88	18.96	17.23	13.74	16.40	14.79	14.10	13.50	16.30	12.81	12.15	11.94	10.41	10.12
60.00	13.46	21.64	21.59	20.79	21.86	25.02	22.13	23.47	23.58	22.39	22.20	21.08	19.69	19.50	15.81	17.08	16.39	20.30	15.90	13.91	13.12	11.59	12.74
80.00																							
100.00																							

10FYM Block A

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	21.25	24.29	25.25	23.71	23.49	25.93	24.89	23.29	23.15	24.08	22.42	18.96	17.02	15.63	17.64	15.78	14.70	14.80	13.09	14.83	14.31	11.64	12.67
40.00	21.25	24.62	26.21	21.80	23.03	25.86	24.79	23.41	23.53	22.50	23.16	21.57	20.78	19.58	19.78	19.19	19.10	18.44	17.18	17.65	17.48	16.89	17.10
60.00	15.63	22.77	25.17	23.42	22.77	26.07	24.94	28.15	23.68	24.64	24.07	22.89	22.61	21.36	20.70	21.00	20.50	20.61	18.44	18.21	19.44	17.45	17.46
80.00	17.68	23.89	28.93	26.15	25.40	27.44	27.83	30.95	27.34	26.21	27.08	26.86	25.72	25.51	24.27	24.57	24.23	23.79	22.58	21.99	22.45	20.66	20.31
100.00	17.27	25.29	28 79	26.78	26.25	28.49	29.15	30.62	28.73	28.61	28.28	28.60	27.45	26.72	25.96	25.80	25.49	24.01	23.62	23.26	22.91	21.09	21.55
120.00	17.27	19.73	23.48	24.52	24.07	27.55	31.25	30.51	30.70	30.22	29.23	29.79	29.10	28.77	27.35	27.43	27.30	25.20	25.20	24.30	24.47	23.96	22.01

10FYM Block B

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	17.49	22.28	17.72	19.99	20.74	21.66	19.80	16.74	18.42	16.56	16.88	14.43	13.26	12.48	16.55	13.44	12.48	11.87	11.42	11.48	11.78	08.29	08.85
40.00	17.46	21.75	19.95	20.66	21.23	24.85	21.15	18 96	20.76	19.39	19.34	18.71	17.30	17.49	18.66	17.03	16.29	16.15	14 89	14.68	13.38	13.87	13.44
60.00	15.86	21.86	21.43	21.51	21.98	25.31	21.46	21.44	22.13	20.64	20.91	20.90	19.84	20.09	19.27	18.84	18.66	18.16	18.18	17.31	16.29	16.50	15.97
80.00	18.24	22.59	23.81	24.12	24.40	28.66	24.87	24.41	24.69	23.84	24.06	24.16	22.95	22.83	22.86	22.35	22.20	21.94	22.11	20.43	20.53	19.50	19.77
100.00	17.89	19.92	24.42	24.86	25.77	28.20	25.86	25.49	27.04	25.42	24.60	25.41	24.90	24 15	24.24	23.58	22.87	22.80	23.00	21.25	21.57	20.39	20.84
120.00	17.90	15.56	24.29	25.79	25.77	28.46	28.84	28.83	29.34	27.05	27.73	26.12	25.41	26.09	25.45	24.46	23.88	24.43	23.95	22.34	22.06	21.49	23.52

10FYM Block C

Date

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	22.01	28.47	23.20	21.54	21.61	22.60	25.12	22.39	22.87	24.25	21.97	17.51	16.74	15.68	20.11	17.13	14.68	14.69	14.71	14.47	18.71	10.28	13.59
40.00	23.55	29.62	25.59	25.32	25.10	25.91	26.35	23.82	24.19	25.20	24.17	21.54	21.32	21.59	22.28	21.56	20.86	18.26	20.09	18.89	16.91	15.13	15.66
60.00	15.45	24.75	23.29	23.62	23.42	24.04	24.25	23.64	21.65	22.75	21.74	22.18	21.67	20.95	20.47	20.64	19.63	18.95	18.31	17.75	17.48	16.24	16.22
80.00	14.86	24.30	22.52	23.72	23.56	23.65	23.21	23.19	22.67	22.43	22.62	21.87	22.47	20.85	20.88	21.23	20.35	21.50	19.53	18.33	19.21	18.83	19.33
100.00	16.70	19.61	17.54	24.10	23.93	23.82	24.75	25.25	24.51	24.23	23.80	22.88	25.63	22.59	22.62	22.35	21.81	22.07	23.78	21.67	21.66	20.66	20.22

5FYM Block A

Date

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	20.54	22.77	20.48	21.81	21.47	25.54	24.69	20.93	21.91	22.67	21.69	17.36	16.13	15.81	17.92	15.40	14.96	14.08	13.40	14.29	13.33	09.94	12.05
40.00	21.24	24.07	21.94	20.55	22.20	24.56	23.89	22.72	22.49	21.83	23.26	20.55	19.79	18.94	19.50	18.63	18.31	17.52	17.03	16.18	15.62	14.82	14.75
60.00	14.73	22.08	23.45	21.71	22.59	26.11	24.30	24.28	23.25	22.80	24.40	22.51	22.08	20.85	20.90	19 80	19.63	17.93	18.39	17.52	14.26	15.67	14.77
80.00	16.91	21.87	25.43	25.15	24.97	26.16	26.63	28.25	26.53	25.99	29.61	25.26	25.10	24.59	23.91	23.56	22.18	22.73	21 87	20.20	19.66	*19 41*	*Mil*
100.00	16.95	16.99	24.90	26.24	25.55	28.06	28.14	28.12	27.50	27.31	28 56	28.03	26.38	25.78	25.28	24.26	24.08	24.29	23.02	22 43	21.66	20 35	20.31

5FYM Block B

Date

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	19.03	24.46	19.87	21.27	23.61	23.12	23.33	18.96	20.36	21.78	20.10	15.65	14.78	14 64	16.60	13.67	12.81	11.00	10.06	10.81	09.69	08.49	09.37
40.00	21.51	24.44	22.01	20.50	23.28	24.14	23.82	21.21	22.67	21.37	21.79	20.21	19.28	19.12	19.45	18.25	18.18	16.86	16.20	15.74	14.82	13.89	13.90
60.00	15.45	22.84	22.90	20.93	22.28	25.74	23.94	22.77	22.79	21.71	22.80	21.74	20.63	21.56	20.67	19.70	19.23	18.26	17.98	1687	15.78	14.36	14.50
80.00	16.52	23.69	24.79	23.91	25.02	27 49	25 95	26.24	26.03	25.80	25.85	25.37	24.97	24.68	24.38	23.49	23.24	22.05	21.47	20.47	19.35	17.70	17.55
100.00	16.57	24.12	25.03	25.36	24.20	26.22	26.59	27.37	27.06	26.57	27.84	26.51	26.95	24.72	25.39	24.53	24.32	23.66	23.15	22.39	20.77	17.76	18.31

5FYM Block C

Date

Depth	18/11	14/12	21/12	28/12	5/1	11/1	18/1	25/1	1/2	8/2	15/2	22/2	1/3	8/3	15/3	22/3	29/3	5/4	12/4	19/4	1/5	10/5	17/5
25.00	08.92	21.97	20.25	19.33	18.90	18.97	18.08	14.84	16.72	17.68	16.30	13.58	12.39	11.41	14.08	12.67	12.20	14.95	11.24	11.81	11.21	09.40	08.48
40.00	10.72	21.44	22.37	21.99	20.31	20.10	18.95	17.71	17.69	17.73	16.91	15.19	15.11	15.10	15.40	14.89	14.47	16.73	14.05	13.11	14.80	12.91	12.56
60.00	10.65	22.32	24.00	22.23	22.47	25.52	20.41	19.17	19.42	17.96	18.86	17.69	16.15	17.11	17.34	16.85	16.49	17.62	18.60	15.17	16.29	14.61	14.44
80.00	13.76	23.86	26.09	25.24	24.40	27.26	23.98	23.81	23.22	22.32	23.10	22.06	21.15	21.69	21.30	21.75	20.11	20.58	19.84	19.29	20.77	18.90	18.88
100.00	12.45	22.84	26.14	24.98	24.45	27.16	25.40	23.79	24.60	23.97	24.00	24.49	24.60	22.99	22.40	22.28	22.16	21.68	22.09	21.14	20.91	20.55	20.17
120.00	13.07	24.08	26.14	25.46	24.77	26.14	27.74	24.77	27.63	26.39	27.08	26.49	25.54	23.71	24.79	24 88	24.48	22.29	23.73	23.63	21.35	22.00	22.00

Table 3 Volumetric Water Content (0-10cm)

	Treatment			
Date	CT	10FYM	5FYM	ZT
18/11	13.23	14.17	13.82	11.71
14/12	13.82	15.75	15.40	13.18
21/12	8.93	10.67	9.94	7.36
28/12	15.37	17.38	15.56	14.50
5/1	6.46	12.10	12.00	6.39
11/1	12.51	13.77	13.20	11.94
18/1	18.26	21.54	20.80	17.80
25/1	11.64	13.91	12.61	11.09
1/2	11.48	12.61	12.09	11.69
15/2	7.87	9.24	8.36	7.94
22/2	3.71	4.12	3.91	3.54
1/3	6.27	6.74	6.39	5.97
22/3	6.53	7.56	7.47	4.79
29/3	4.44	4.93	4.87	4.06
5/4	5.80	7.12	6.49	5.57
12/4	13.15	13.91	13.42	12.31
19/4	5.94	7.49	6.29	5.81
1/5	5.90	7.35	6.19	5.80
Total	171.31	200.36	188.81	171.08

APPENDIX 4 RAINFALL DATA FOR KATUMANI, SHORT RAINS PERIOD, 1992/93

Table 4 Daily Rainfall Data

	Month							
Date	Oct	Nov	Dec	Jan	Feb	Mar	April	May
1		01.60	04.35	06.40	02.00		12.3	
2				05.05				
3		15.20						
4		05.70						
5		06.30						
6		10.40		02.40				08.75
7			03.50	23.50				
8				10.60	28.50			
9			06.50	00.75	21.70			
10				11.25	01.40			
11		02.90	67.25		30.10			
12		16.00	07.40		02.50			03.90
13		01.50		13.10		45.75		
1		07.20	07.20	16.80	01.20			
15		16.60		00.50	05.90	02.30		
16				36.95			02.5	
17		00.75	58.65	03.45			19.5	
18			16.70	10.50				
19			05.25	02.30		02.00	03.8	
20				38.10				
21				01.35				
22								
23		02.55		10.40		03.70		
24		04.80				03.60		
25		02.40						
26				04.20				
27				05.00				
28	10.90	70.00	03.95	09.50				
29	08.40	03.55	01.35	03.40				
30	08.95	05.75	03.90	52.25				
31			16.90	01.50				
Total 92/93	28.25	173.20	202.90	269.25	93.30	57.35	38.10	12.65
Monthly Means	35.00	164.00	84.00	50.00	45.00	89.00	147.00	65.00

Table 5 Mean Monthly Rainfall in mm and 27 year recorded extremes at Katumani, Machakos (Stewart and Faught, 1984)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Mean	38	158	90	50	43	86	144	67	9	5	4	8
Low	0	27	12	0	0	0	20	4	0	0	0	0
High	183	487	267	203	177	229	315	151	35	37	20	43

Table 6 Rainfall Characteristics

Date	Day No.	lRainfall Mm	K.E (J/m2)	130	EI30	Duration Hrs
28/10/92	1	10.90	88.87	6.80	604.32	2.50
29/10/92	2	08.40	37.57	6.80	255.48	3.00
30/10/92	3	08.95	122.82	10.08	1238.03	2.90
1/11/92	4	01.60	0.00	0.80	0.00	0.40
3/11/92	7	15.20	126.44	8.30	1049.45	4.00
4/11/92	8	05.70	0.00	3.40	0.00	2.00
5/11/92	9	06.30	17.03	5.20	88.56	4.17
6/11/92	10	10.40	63.22	8.00	505.76	3.60
11/11/92	15	02.90	7.82	5.80	45.36	0.50
12/11/92	16	16.00	279.59	18.00	5032.62	1.50
13/11/92	17	01.50	0.00	3.00	0.00	0.30
14/11/92	18	07.20	81.10	8.00	648.80	1.20
15/11/92	19	16.60	300.45	18.20	5468.19	1.20
17/11/92	21	00.75	0.00	1.50	0.00	0.10
23/11/92	27	02.55	0.00	2.40	0.00	2.50
24/11/92	28	04.80	0.00	2.80	0.00	0.60
25/11/92	29	02.40	0.00	1.60	0.00	0.60
28-01/12	34	83.65	1360.27	36.20	49241.77	7.30
07/12/92	41	03.50	0.00	1.60	0.00	1.80
9/12/92	43	06.50	112.07	11.80	1322.43	1.10
11/12/92	45	67.25	1108.14	19.70	21830.36	5.20
12/12/92	46	07.40	89.02	8.80	783.38	1.60
14/12/92	48	07.20	62.73	8.40	526.93	2.40
17-18/12/'	52	75.35	909.76	18.30	16648.61	8.10
19/12/92	53	05.25	25.62	6.00	153.72	0.90
28/12/92	62	03.95	53.96	7.00	377.72	0.60
29/12/92	63	01.35	0.00	0.60	0.00	0.10
30/12/92	64	03.90	19.69	5.60	110.26	1.40
31/12/92	65	16.90	211.05	16.00	3376.80	5.20

Table 6. Cont.

Date	Day No.	Rainfall Mm	K.E (J/m2)	130	EI30	Duration Hrs
1/1/93	66	6.40	13.73	5.20	71.40	1.50
2/1/93	67	5.05	**0.00**	1.30	**0.00**	1.90
6/1/93	71	2.40	**0.00**	4.00	**0.00**	2.00
7/1/93	72	23.50	115.69	8.00	925.52	10.80
8/1/93	73	10.60	63.71	6.40	407.74	5.00
9/1/93	74	0.75	**0.00**	**1.00**	**0.00**	0.10
10/1/93	75	11.25	152.62	7.60	1159.91	1.70
13/1/93	78	13.10	**0.00**	2.80	**0.00**	7.00
14/1/93	79	16.80	329.08	**11.00**	3619.88	5.90
15/1/93	80	0.50	**0.00**	0.50	**0.00**	**0.00**
16/1/93	81	36.95	686.68	22.20	15244.30	3.80
17/1/93	82	3.45	39.06	7.40	289.04	0.50
18/1/93	83	10.50	240.21	20.40	4900.28	3.10
19/1/93	84	2.30	1.81	4.40	7.96	1.40
20/1/93	85	38.10	594.30	38.00	22583.40	3.50
21/1/93	86	0.70	**0.00**	0.80	**0.00**	1.10
26/1/93	91	4.20	10.75	5.00	53.75	1.10
27/1/93	92	5.00	**0.00**	2.80	**0.00**	0.90
28/1/93	93	9.50	53.11	6.00	318.66	3.20
29/1/93	94	3.40	**0.00**	2.40	**0.00**	0.60
30/1/93	95	52.25	621.55	12.00	7458.60	6.80
31/1/93	96	1.50	**0.00**	3.00	**0.00**	0.30
1/2/93	97	2.00	**0.00**	2.40	**0.00**	0.50
8-9/2/93	105	50.20	450.48	12.50	5631.00	10.70
10/2/93	106	1.40	**0.00**	1.60	**0.00**	0.20
11/2/93	107	30.10	422.10	**11.00**	4643.10	3.30
12/2/93	108	2.50	**0.00**	**1.00**	**0.00**	2.70
14/2/93	110	1.20	**0.00**	0.80	**0.00**	0.10
13/3/93	140	45.75	1235.85	45.75	56540.14	**1.00**
15/3/93	142	2.30	**0.00**	2.10	**0.00**	0.10
19/3/93	146	2.00	**0.00**	2.40	**0.00**	0.40
23/3/93	150	3.70	**0.00**	4.00	**0.00**	0.80
24/3/93	151	3.60	**0.00**	2.50	**0.00**	**1.00**
1/4/93	159	12.30	95.14	8.60	818.20	1.30
16/4/93	174	2.50	**0.00**	1.20	**0.00**	1.10
17/4/93	175	19.50	182.42	14.70	2681.57	3.90
19/4/93	177	3.80	7.77	4.80	37.30	1.10
6/5/93	194	8.75	51.30	6.48	332.42	3.50
12/5/93	200	3.90	**0.00**	4.10	**0.00**	0.10

APPENDIX 5 SEASONAL RUNOFF AND SOIL LOSS DATA, SHORT RAINS PERIOD, 1992/93

Table 7 Seasonal Runoff Volume (mm)

		Treatment			
Date	Day	CT	10FYM	5FYM	ZT
28/10/92	1	**0.00**	**0.00**	**0.00**	**0.00**
29/10/92	2	**0.00**	**0.00**	**0.00**	**0.00**
30/10/92	3	**0.00**	**0.00**	**0.00**	**0.00**
1/11/92	4	**0.00**	**0.00**	**0.00**	**0.00**
3/11/92	7	**0.00**	**0.00**	**0.00**	**0.00**
4/11/92	8	**0.00**	**0.00**	**0.00**	**0.00**
5/11/92	9	**0.00**	**0.00**	**0.00**	**0.00**
6/11/92	10	**0.00**	**0.00**	**0.00**	**0.00**
11/11/92	15	**0.00**	**0.00**	**0.00**	**0.00**
12/11/92	16	7.30	0.56	0.93	5.34
13/11/92	17	**0.00**	**0.00**	**0.00**	**0.00**
14/11/92	18	**0.00**	**0.00**	**0.00**	**0.00**
15/11/92	19	7.52	1.78	2.56	5.84
17/11/92	21	**0.00**	**0.00**	**0.00**	**0.00**
23/11/92	27	**0.00**	**0.00**	**0.00**	**0.00**
24/11/92	28	**0.00**	**0.00**	**0.00**	**0.00**
25/11/92	29	**0.00**	**0.00**	**0.00**	**0.00**
28-30/12	34	53.40	31.00	33.42	62.76
01/12/92	35	**0.00**	**0.00**	**0.00**	**0.00**
07/12/92	41	**0.00**	**0.00**	**0.00**	**0.00**
9/12/92	43	0.89	0.40	0.50	0.97
11/12/92	45	47.08	41.35	42.93	50.56
12/12/92	46	1.23	0.96	1.02	1.50
14/12/92	48	**0.00**	**0.00**	**0.00**	**0.00**
17-18/12/	52	47.90	35.37	37.21	50.14
19/12/92	53	3.04	2.42	2.45	3.34
28/12/92	62	**0.00**	**0.00**	**0.00**	**0.00**
29/12/92	63	**0.00**	**0.00**	**0.00**	**0.00**
30/12/92	64	**0.00**	**0.00**	**0.00**	**0.00**
31/12/92	65	4.25	2.58	2.97	5.25
1/1/93	66	**0.00**	**0.00**	**0.00**	**0.00**
2/1/93	67	**0.00**	**0.00**	**0.00**	**0.00**
6/1/93	71	**0.00**	**0.00**	**0.00**	**0.00**
7/1/93	72	10.40	7.38	8.03	10.28
8/1/93	73	**0.00**	**0.00**	**0.00**	**0.00**
9/1/93	74	**0.00**	**0.00**	**0.00**	**0.00**
10/1/93	75	4.11	1.43	1.67	7.26
13/1/93	78	**0.00**	**0.00**	**0.00**	**0.00**
14/1/93	79	3.09	2.36	2.48	5.43
15/1/93	80	**0.00**	**0.00**	**0.00**	**0.00**

Table 7 cont Seasonal Runoff Volume (mm)

Date	Day	Treatment CT	 10FYM	 5FYM	 ZT
16/1/93	82	0.62	0.36	0.41	0.71
18/1/93	83	1.71	1.20	1.18	2.74
19/1/93	84	**0.00**	**0.00**	**0.00**	**0.00**
20/1/93	85	22.99	0.28	20.84	25.45
21/1/93	86	**0.00**	**0.00**	**0.00**	**0.00**
26/1/93	91	**0.00**	**0.00**	**0.00**	**0.00**
27/1/93	92	**0.00**	**0.00**	**0.00**	**0.00**
28/1/93	93	3.85	2.31	2.44	4.64
29/1/93	94	**0.00**	**0.00**	**0.00**	**0.00**
30/1/93	95	33.98	29.23	32.91	38.11
31/1/93	96	**0.00**	**0.00**	**0.00**	**0.00**
1/2/93	97	**0.00**	**0.00**	**0.00**	**0.00**
8-9/2/93	105	14.01	9.65	10.31	16.19
10/2/93	106	**0.00**	**0.00**	**0.00**	**0.00**
11/2/93	107	14.18	11.82	11.49	15.78
12/2/93	108	**0.00**	**0.00**	**0.00**	**0.00**
14/2/93	110	**0.00**	**0.00**	**0.00**	**0.00**
13/3/93	140	31.20	22.28	25.55	39.95
15/3/93	142	**0.00**	**0.00**	**0.00**	**0.00**
19/3/93	146	**0.00**	**0.00**	**0.00**	**0.00**
23/3/93	150	**0.00**	**0.00**	**0.00**	**0.00**
24/3/93	151	**0.00**	**0.00**	**0.00**	**0.00**
1/4/93	159	3.16	2.92	2.82	5.08
16/4/93	174	**0.00**	**0.00**	**0.00**	**0.00**
17/4/93	175	5.98	5.54	5.40	6.68
19/4/93	177	**0.00**	**0.00**	**0.00**	**0.00**
6/5/93	194	**0.00**	**0.00**	**0.00**	**0.00**
12/5/93	200	**0.00**	**0.00**	**0.00**	**0.00**

Table 8 Seasonal Soil Loss Data, Short Rains Period, 1992/93

		Soil loss g/m2			
Date	Day	CT	10FYM	5FYM	ZT
5/10/92	1	**0.00**	**0.00**	**0.00**	**0.00**
29/10/92	2	**0.00**	**0.00**	**0.00**	**0.00**
30/10/92	3	**0.00**	**0.00**	**0.00**	**0.00**
1/11/92	4	**0.00**	**0.00**	**0.00**	**0.00**
3/11/92	7	**0.00**	**0.00**	**0.00**	**0.00**
4/11/92	8	**0.00**	**0.00**	**0.00**	**0.00**
5/11/92	9	**0.00**	**0.00**	**0.00**	**0.00**
6/11/92	10	**0.00**	**0.00**	**0.00**	**0.00**
11/11/92	15	**0.00**	**0.00**	**0.00**	**0.00**
12/11/92	16	106.33	1.83	4.06	79.86
13/11/92	17	**0.00**	**0.00**	**0.00**	**0.00**
14/11/92	18	**0.00**	**0.00**	**0.00**	**0.00**
15/11/92	19	251.64	21.62	25.01	177.52
17/11/92	21	**0.00**	**0.00**	**0.00**	**0.00**
23/11/92	27	**0.00**	**0.00**	**0.00**	**0.00**
24/11/92	28	**0.00**	**0.00**	**0.00**	**0.00**
25/11/92	29	**0.00**	**0.00**	**0.00**	**0.00**
28-30/11	34	3335.79	1368.44	1448.31	1731.96
01/12/92	35	**0.00**	**0.00**	**0.00**	**0.00**
07/12/92	41	**0.00**	**0.00**	**0.00**	**0.00**
9/12/92	43	4.50	0.45	0.94	2.10
11/12/92	45	1980.12	1469.32	1512.41	502.57
12/12/92	46	17.13	5.32	5.49	2.24
14/12/92	48	**0.00**	**0.00**	**0.00**	**0.00**
17-18/12/	52	1514.25	910.00	1152.14	814.58
19/12/92	53	149.63	49.42	58.68	78.59
28/12/92	62	**0.00**	**0.00**	**0.00**	**0.00**
29/12/92	63	**0.00**	**0.00**	**0.00**	**0.00**
30/12/92	64	**0.00**	**0.00**	**0.00**	**0.00**
31/12/92	65	106.12	85.81	89.63	103.48
1/1/93	66	**0.00**	**0.00**	**0.00**	**0.00**
2/1/93	67	**0.00**	**0.00**	**0.00**	**0.00**
6/1/93	71	**0.00**	**0.00**	**0.00**	**0.00**
7/1/93	72	119.96	9.78	17.50	112.37
8/1/93	73	**0.00**	**0.00**	**0.00**	**0.00**
9/1/93	74	**0.00**	**0.00**	**0.00**	**0.00**
10/1/93	75	81.01	19.48	13.57	10.40
13/1/93	78	**0.00**	**0.00**	**0.00**	**0.00**
14/1/93	79	257.02	160.27	192.50	196.81
15/1/93	80	**0.00**	**0.00**	**0.00**	**0.00**
16/1/93	81	2130.78	1802.12	1898.04	1695.68
17/1/93	82	19.87	12.23	12.77	12.85
18/1/93	83	101.37	83.76	84.57	65.55
19/1/93	84	**0.00**	**0.00**	**0.00**	**0.00**

Table 8 Continued..

		Soil loss g/m2			
Date	Dav	CT	10FYM	5FYM	ZT
20/1/93	85	1834.73	1635.22	1636.67	970.27
21/1/93	86	**0.00**	**0.00**	**0.00**	**0.00**
26/1/93	91	**0.00**	**0.00**	**0.00**	**0.00**
27/1/93	92	**0.00**	**0.00**	**0.00**	**0.00**
28/1/93	93	475.56	108.25	136.62	62.18
29/1/93	94	**0.00**	**0.00**	**0.00**	**0.00**
30/1/93	95	1127.97	931.73	932.12	910.42
31/1/93	96	**0.00**	**0.00**	**0.00**	**0.00**
1/2/93	97	**0.00**	**0.00**	**0.00**	**0.00**
8-9/2/93	105	720.25	583.32	633.92	581.24
10/2/93	106	**0.00**	**0.00**	**0.00**	**0.00**
11/2/93	107	436.64	191.95	187.12	196.56
12/2/93	108	**0.00**	**0.00**	**0.00**	**0.00**
14/2/93	110	**0.00**	**0.00**	**0.00**	**0.00**
13/3/93	140	2697.07	1460.23	1521.30	2174.61
15/3/93	142	**0.00**	**0.00**	**0.00**	**0.00**
19/3/93	146	**0.00**	**0.00**	**0.00**	**0.00**
23/3/93	150	**0.00**	**0.00**	**0.00**	**0.00**
24/3/93	151	**0.00**	**0.00**	**0.00**	**0.00**
1/4/93	159	261.76	86.68	213.09	610.59
16/4/93	174	**0.00**	**0.00**	**0.00**	**0.00**
17/4/93	175	914.84	615.07	638.51	1693.26
19/4/93	177	**0.00**	**0.00**	**0.00**	**0.00**
6/05/93	194	**0.00**	**0.00**	**0.00**	**0.00**
12/5/93	200	**0.00**	**0.00**	**0.00**	**0.00**

Table 9 Rain Water Infiltration Data, Short Rains Period, 1992/93

		Infiltration (mm)			
Date	Day No	CT	10FYM	5FYM	ZT
28/10/92	1	10.90	10.90	10.90	10.90
29/10/92	2	8.40	8.40	8.40	8.40
30/10/92	3	8.95	8.95	8.95	8.95
1/11/92	4	1.60	1.60	1.60	1.60
3/11/92	7	15.20	15.20	15.20	15.20
4/11/92	8	5.70	5.70	5.70	5.70
5/11/92	9	6.30	6.30	6.30	6.30
6/11/92	10	10.40	10.40	10.40	10.40
11/11/92	15	2.90	2.90	2.90	2.90
12/11/92	16	8.70	15.44	15.07	10.66
13/11/92	17	1.50	1.50	1.50	1.50
14/11/92	18	7.20	7.20	7.20	7.20
15/11/92	19	9.08	14.82	14.04	10.76
17/11/92	21	0.75	0.75	0.75	0.75
23/11/92	27	2.55	2.55	2.55	2.55
24/11/92	28	4.80	4.80	4.80	4.80
25/11/92	29	2.40	2.40	2.40	2.40
28-30/12	34	30.25	52.66	50.23	20.90
01/12/92	35	4.35	4.35	4.35	4.35
07/12/92	41	3.50	3.50	3.50	3.50
9/12/92	43	5.61	6.10	6.00	5.54
11/12/92	45	20.17	25.90	24.32	16.69
12/12/92	46	6.17	6.44	6.38	5.90
14/12/92	48	**0.00**	**0.00**	**0.00**	**0.00**
17-18/12	52	27.45	39.98	38.14	25.21
19/12/92	53	2.21	2.83	2.80	1.91
28/12/92	62	3.95	3.95	3.95	3.95
29/12/92	63	1.35	1.35	1.35	1.35
30/12/92	64	3.90	3.90	3.90	3.90
31/12/92	65	12.65	14.32	13.93	11.65
1/1/93	66	6.40	6.40	6.40	6.40
2/1/93	67	5.05	5.05	5.05	5.05
6/1/93	71	**0.00**	**0.00**	**0.00**	**0.00**
7/1/93	72	13.10	16.12	15.47	13.22
8/1/93	73	**0.00**	**0.00**	**0.00**	**0.00**
9/1/93	74	0.75	0.75	0.75	0.75
10/1/93	75	7.14	9.82	9.58	3.99
13/1/93	78	**0.00**	**0.00**	**0.00**	**0.00**
14/1/93	79	13.71	14.44	14.32	11.37
15/1/93	80	**0.00**	10.75	10.75	10.75
16/1/93	81	19.00	25.20	23.93	16.08
17/1/93	82	2.83	3.09	3.04	2.74
18/1/93	83	8.79	9.30	9.32	7.76

Table 9 Cont. Rain Water Infiltration Data, Short Rains Period, 1992/93

Date	Day No.	Infiltration (mm) CT	10FYM	5FYM	ZT
19/1/93	84	2.30	2.30	2.30	2.30
20/1/93	85	15.11	17.82	17.26	12.65
21/1/93	86	0.70	0.70	0.70	0.70
26/1/93	91	4.20	4.20	4.20	4.20
27/1/93	92	5.00	5.00	5.00	4.86
29/1/93	94	3.40	3.40	3.40	3.40
30/1/93	95	18.27	23.02	19.34	14.14
31/1/93	96	1.50	1.50	1.50	1.50
1/2/93	97	2.00	2.00	2.00	2.00
8-9/2/93	105	36.10	40.55	39.89	34.01
10/2/93	106	1.40	1.40	1.40	1.40
11/2/93	107	15.92	18.28	18.61	14.32
12/2/93	108	2.50	2.50	2.50	2.50
14/2/93	110	1.20	1.20	1.20	1.20
13/3/93	140	14.55	23.47	20.20	2.30
19/3/93	146	2.00	2.00	2.00	2.00
23/3/93	150	3.70	3.70	3.70	3.70
24/3/93	151	3.60	3.60	3.60	3.60
1/4/93	159	9.14	9.38	9.49	7.22
16/4/93	174	2.50	2.50	2.50	2.50
17/4/93	175	13.52	13.96	14.10	12.82
19/4/93	177	3.80	3.80	3.80	3.80
6/5/93	194	8.75	8.75	8.75	8.75
12/5/93	200	3.90	3.90	3.90	3.90

APPENDIX 6 STATISTICAL ANALYSIS OF SOIL AND RUNOFF DATA, 1992/93

ANALYSIS OF VARIANCE OF SOIL LOSS AND RUNOFF

Analysis of Variance Procedure
Class Level Information

Class	Levels	Values
BLOCK	3	A B C
TREAT	4	10FYM 5FYMCTZT

Number of observations in data set = 12
Alpha= 0.05
Critical Value of T= 2.45
Means with the same letter are not significantly different.

12/11/92
Dependent Variable: RUNOFF

R^2	c.v.	V *MSE*	
0.94	28.36	1.00	LSD-2.0

Treatment:	CT	ZT	5 FYM	10 FYM
Mean :	7.30	5.34	0.93	0.56
Grouping	A	A	B	B

Dependent Variable: SEDIMENT

R^2	c.v.	V *MSE*	
0.81	66.09	31.74	LSD= 63.41

Treatment:	CT	ZT	5 FYM	10 FYM
Mean	106.33	79.86	4.06	1.83
	A	A	B	B

15/11/92
Dependent Variable: RUNOFF

R^2	C.V	*J MSE*	
0.91	24.98	1.11	LSD=2.21

Treatment	CT	ZT	5 FYM	10 FYM
Mean:	7.52	5.84	2.56	1 78
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

R^2	c.v.	V *MSE*	
0.77	85.66	101.89	LSD= 153.56

Treatment:	CT	ZT	5 FYM	10 FYM
Mean:	251.65	177.52	25.01	21.62
Grouping:	A	A	B	B

28-1/12/92
Dependent Variable: RUNOFF

r^2	c.v.	V *MSE*	
0.76	6.15	11.80	LSD=23.59

Treatment:	CT	ZT	5 FYM	10 FYM
Mean:	53.4	62.76	33.42	31.008
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

r^2	c.v.	V *MSE*	
0.90	29.94	396.86	LSD=792.88

Treatment:	CT	ZT	5 FYM	10 FYM
Mean:	2507.8	11784	8204	795.5
Grouping:	A	B	B	B

9/12/92
Dependent Variable: RUNOFF

r^2	c.v.	*-J MSE*	
0.88	21.66	0.15	LSD= 0.30

Treatment.	ZT	CT	5 FYM	10 FYM
Mean:	0.97	0 89	0.5	0.40
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

R^2	c.v.	yj MSE	
0.99	12.0	0.23	LSD= 0.47

Treatment:	CT	ZT	5FYM	10FYM
Mean:	4.23	2.23	0.83	0.48
Grouping:	A	B	C	C

11/12/92

Dependent Variable: RUNOFF

R^2	c.v.	J MSE	
0.91	4.0	1.82	LSD= 3.64

Treatment:	ZT	CT	5 FYM	10FYM
Mean:	50.56	47.08	42.93	41.35
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

R^2	c.v.	J MSE	
0.86	19.25	237.11	LSD= 473.71

Treatment:	CT	ZT	5FYM	10FYM
Mean:	1759.1	1021.6	1041.2	1105.6
Grouping:	A	B	B	B

12/12/92

Dependent Variable: RUNOFF

R^2	c.v.	J MSE	
0.80	13.65	0.16	LSD- 0.32

Treatment:	ZT	CT	5 FYM	10 FYM
Mean:	1.5	1.23	1.02	0.965
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

R^2	CV	J MSE	
0.82	49.95	2.69	LSD- 5.37

Treatment:	CT	ZT	5FYM	10FYM
Mean:	11.79	3.90	2.98	2.84
Grouping:	A	B	B	B

17-18/12/92

Dependent Variable: RUNOFF

R^2	c.v.	J MSE	
0.90	7.93	43.38	LSD-6.76

Treatment:	ZT	CT	5 FYM	10 FYM
Mean:	50.14	47.90	37.21	35.37
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.97	6.44	63.32	LSD= 126.52

Treatment:	CT	ZT	5FYM	10FYM
Mean :	1336.17	767.28	986.64	841.26
Grouping:	A	C	B	C

19/12/92

Dependent Variable: RUNOFF

r^2	c.v.	V MSE	
0.88	12.44	0.35	LSD=0.7

Treatment:	ZT	CT	5 FYM	10 FYM
Mean:	3.34	3.04	2.45	2.42
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.89	39.16	17.83	LSD- 35.62

Treatment:	CT	ZT	10FYM	5FYM
Mean:	84.14	40.34	31.09	26.53
Grouping:	A	B	B	B

31/12/92

Dependent Variable: RUNOFF

r^2	c.v	V MSE	
0.94	11.80	0.44	LSD-0.89

Treatment:	ZT	CT	5 FYM	10 FYM
Mean:	5.25	4.25	2.96	2.58
Grouping:	A	B	C	C

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.79	5.37	4.84	LSD= 9.67

Treatment:	CT	ZT	5FYM	10FYM
Mean:	96.41	92.57	86.19	85.19
Grouping:	A	A	B	B

18/1/93

Dependent Variable: RUNOFF

R^2	c.v.	-J MSE	
0.95	4.90	0.44	LSD-0.88

Treatment:	CT	ZT	5 FYM	10 FYM
Mean:	10.40	10.28	8.03	7.38
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

R^2	C.V.	-J MSE	
0.28	98.28	44.54	LSD- 8.89

Treatment:	CT	ZT	5FYM	10FYM
Mean:	62.41	55.89	29.28	33.72
Grouping:	A	A	B	B

10/1/93

Dependent Variable: RUNOFF

R^2	c.v	J MSE	
0.89	32.6	1.18	LSD- 2.36

Treatment	CT	ZT	5 FYM	10 FYM
Mean:	4.11	7.26	1.67	1.43
Grouping:	A	B	C	C

Dependent Variable: SEDIMENT

R^2	c.v.	V MSE	
0.91	29.22	9.58	LSD 19.150

Treatment:	CT	5 FYM	ZT	10FYM
Mean:	70.26	21.25	21.03	18.65
Grouping:	A	B	B	B

14/1/93

Dependent Variable: RUNOFF

R^2	C.V.	yl MSE	
0.94	12.86	0.43	LSD-0.86

Treatment:	ZT	CT	5 FYM	10 FYM
Mean:	5.42	3.09	2.48	2.36
Grouping:	A	B	C	C

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.89	6.99	13.49	LSD= 26.96

Treatment:	CT	ZT	5FYM	10FYM
Mean:	230.74	192.95	190.91	157.98
Grouping:	A	B	B	C

16/1/93

Dependent Variable: RUNOFF

r^2	c.v.	V MSE	
0.90	10.96	1.74	LSD- 3.48

Treatment:	ZT	CT	5 FYM	10 FYM
Mean:	20.87	17.95	13.02	11.75
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.88	13.57	202.26	LSD- 404.11

Treatment:	CT	5FYM	10FYM	ZT
Mean:	1911.4	1474.4	1399.6	1175.0
Grouping:	A	B	B	B

17/1/93

Dependent Variable: RUNOFF

r^2	c.v.	V MSE	
0.94	14.60	0.08	LSD-0.15

Treatment:	ZT	CT	5 FYM	10 FYM
Mean:	0.71	0.62	0.41	0.365
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.95	8.71	1.28	LSD-2.56

Treatment:	CT	ZT	5FYM	10FYM
Mean:	21.16	13.23	12.53	11.97
Grouping:	A	B	B	B

18/1/93

Dependent Variable: RUNOFF

R^2	c.v.	J MSE	
0.83	32.55	0.56	LSD=1.11

Treatment:	ZT	CT	10FYM	5 FYM
Mean:	2.74	1.71	1.2	1.18
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

R^2	C.V.	yjMSE	
0.94	19.47	10.44	LSD- 20.87

Treatment:	CT	5FYM	10FYM	ZT
Mean:	79.13	50.95	47.17	37.35
Grouping:	A	B	B	B

20/1/93

Dependent Variable: RUNOFF

R^2	C.V.	y/ MSE	
0.92	4.02	0.90	LSD= 1.80

Treatment:	ZT	CT	5FYM	10fym
Mean:	25.45	22.99	20.84	20.28
Grouping:	A	B	C	C

Dependent Variable: SEDIMENT

R^2	c.v.	J MSE	
0.96	14.60	143.48	LSD= 286.66

Treatment:	CT	5FYM	10FYM	ZT
Mean:	1282.3	1132.6	898.6	616.4
Grouping:	A	A	C	C

28/1/93

Dependent Variable: RUNOFF

R^2	CV	-J MSE	
0.94	10.40	0.34	LSD= 0 69

Treatment:	ZT	CT	5FYM	10FYM
Mean:	4.64	3.85	2.44	2.31
Grouping:	A	B	C	C

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.88	36.52	61.98	LSD= 123.84

Treatment:	CT	5FYM	10 FYM	ZT
Mean:	364.33	161.11	99.83	53.66
Grouping:	A	B	B	B

30/1/93

Dependent Variable: RUNOFF

r^2	c.v.	V MSE	
0.94	4.33	1.45	LSD= 2.90

Treatment:	ZT	CT	5FYM	10FYM
Mean:	38.11	33.98	32.90	31.07
Grouping:	A	B	B	B

Dependent Variable: SEDIMENT

r^2	c.v	V MSE	
0.98	4.26	34.09	LSD= 68.1

Treatment:	CT	5FYM	10 FYM	ZT
Mean:	904.33	799.14	753.76	745.48
Grouping:	A	B	B	B

8-9/2/93

Dependent Variable: RUNOFF

r^2	c.v.	V MSE	
0.87	12.62	1.58 .	LSD=3.16

Treatment:	ZT	CT	5FYM	10FYM
Mean:	16.18	14.01	10.31	9.65
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

r^2	c.v.	V MSE	
0.74	15.74	95.66	LSD= 191.11

Treatment:	CT	5FYM	10FYM	ZT
Mean:	736.32	617.61	601.03	476.60
Grouping:	A	A	A	B

18/1/93

Dependent Variable: RUNOFF

R^2	C V.	*-J MSE*	
0.77	10.59	1.41	LSD= 2.82

Treatment:	**ZT**	**CT**	**10FYM**	**5FYM**
Mean:	15.78	14.18	11.82	11.491
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

R^2	C V	*y/* A*4SE*	
0.72	29.77	61.454	LSD= 122.76

Treatment:	**CT**	**5FYM**	**ZT**	**10FYM**
Mean:	302.49	207.89	163.82	151.41
Grouping:	A	A	B	B

13/3/93

Dependent Variable: RUNOFF

r^2	c.v	*-V MSE*	
0.92	9.71	2.89	LSD= 5.77

Treatment:	**ZT**	**CT**	**5FYM**	**10FYM**
Mean:	39.95	31.20	25.55	22.28
Grouping:	A	B	B	C

Dependent Variable: SEDIMENT

r^2	c.v	v *MSE*	
0.94	14.46	283.82	LSD= 567.04

Treatment:	**CT**	**ZT**	**5FYM**	**10FYM**
Mean:	2697.0	2174.5	1521.3	1460.2
Grouping:	A	A	B	B

1/4/93

Dependent Variable: RUNOFF

r^2	c.v.	V *MSE*	
0.90	12.75	0.45	LSD= 0.89

Treatment:	**ZT**	**CT**	10fym	**5 FYM**
Mean:	5.08	3.16	2.92	2.82
Grouping:	A	B	B	B

Dependent Variable: SEDIMENT

r^2	C.V.	*y/ MSE*	
0.67	75.94	122.54	LSD= 91.83

Treatment:	**ZT**	**CT**	**10FYM**	**5FYM**
Mean:	290.7	165.0	98.6	96.2
Grouping:	A	B	B	B

17/4/93

Dependent Variable: RUNOFF

r^2	c.v.	v *MSE*	
0.87	6.49	0.38	LSD= 0.77

Treatment:	**ZT**	**CT**	**10FYM**	**5FYM**
Mean:	6.86	5.98	5.54	5.40
Grouping:	A	A	B	B

Dependent Variable: SEDIMENT

r^2	C.V.	*y/MSE*	
0.88	43.73	218.63	LSD= 436.81

Treatment:	**ZT**	**CT**	**5FYM**	**10 FYM**
Mean:	941.3	494.0	298.1	266.3
Grouping:	A	B	B	B

APPENDIX 7 SOIL SHEAR STRENGTH DATA (Kpa), KATUMANI, MACHAKOS (1992/93)

Table 8 Soil Shear Strength (Kpa)

	Treatment			
Date	ZT	CT	10FYM	5FYM
18/11	12.26	10.82	5.95	6.62
14/12	27.06	24.90	10.45	13.17
21/12	12.33	8.62	7.38	7.50
28/12	6.10	4.98	3.80	3.71
5/1	8.87	4.18	3.79	3.86
11/1	9.68	4.13	3.88	4.55
18/1	7.66	8.96	7.63	7.36
25/1	11.20	7.55	6.85	7.30
1/2	10.40	7.73	6.48	7.48
15/2	13.23	9.80	8.90	8.65
22/2	13.01	12.93	11.36	12.06
1/3	19.85	15.17	14.38	14.43
22/3	17.07	8.32	7.90	8.57
29/3	20.43	10.28	9.35	9.67
5/4	21.18	10.20	9.90	9.85
12/4	15.45	9.62	10.05	10.45
19/4	12.82	7.74	7.73	7.65
1/5	16.67	10.15	9.95	10.47

APPENDIX 8 SOIL BULK DENSITY DATA, Katumani, Machakos, 1992/93

Table 8 Variations in Soil Bulk Density

	Bulk Density e/cm^			
Date	CT	10FYM	5FYM	ZT
18/11	1.26	1.21	1.25	1.28
14/12	1.30	1.24	1.24	1.32
21/12	1.29	1.24	1.24	1.30
28/12	1.15	1.14	1.13	1.18
5/1	1.18	1.14	1.13	1.25
11/1	1.14	1.05	1.07	1.18
18/1	1.29	1.22	1.25	1.30
25/1	1.18	1.17	1.18	1.24
1/2	1.11	1.07	1.12	1.17
15/2	1.08	1.05	1.07	1.10
22/2	1.11	1.10	1.11	1.17
1/3	1.29	1.23	1.25	1.34
22/3	1.26	1.18	1.23	1.40
29/3	1.30	1.18	1.24	1.39
5/4	1.31	1.25	1.26	1.38
12/4	1.22	1.21	1.18	1.23
19/4	1.49	1.43	1.44	1.57
1/5	1.48	1.45	1.45	1.58

APPENDIX 9 REGRESSION ANALYSES

RAINFALL - RUNOFF REGRESSIONS

Regression Output:	CT
Constant	-3.10
R Squared	0.93
X Coefficient(s)	0.65

Regression Output:	10FYM
Constant	-2.35
R Squared	0.89
X Coefficient(s)	0.47

Regression Output:	5FYM
Constant	-2.50
R Squared	0.89
X Coefficient(s)	0.51

Regression Output:	ZT
Constant	-3.42
R Squared	0.92
X Coefficient(s)	0.72

RAINFALL - SOIL LOSS REGRESSIONS

Regression Output:	CT
Constant	•146.23
R Squared	0.76
X Coefficient(s)	33.49

Regression Output:	10FYM
Constant	-86.94
R Squared	0.70
X Coefficient(s)	20.52

Regression Output.	5FYM
Constant	-92.75
R Squared	0.73
X Coefficient(s)	21.93

Regression Output:	ZT
Constant	-75.11
R Squared	0.63
X Coefficient(s)	22.11

KINETIC ENERGY-RUNOFF REGRESSIONS

Regression Output:	CT
Constant	-0.76
R Squared	0.90
X Coefficient	0.04

Regression Output:	10FYM
Constant	-0.57
R Squared	0.84
No. of Observations	69.00

Regression Output:	5FYM
Constant	-0.63
R Squared	0.85
X Coefficient(s)	0.03

KINETIC ENERGY-SOIL LOSS REGRESSIONS

Regression Output:	CT
Constant	-54.85
R Squared	0.90
X Coefficient(s)	2.15

Regression Output:	10FYM
Constant	-26.87
R Squared	0.79
No. of Observations	69.00

Regression Output:	5FYM
Constant	-26.59
R Squared	0.80
X Coefficient(s)	1.36

Regression Output:	ZT
Constant	-0.90
R Squared	0.92
X Coefficient(s)	0.04

I30- RUNOFF REGRESSIONS

Regression Output:	CT
Constant	-3.01
R Squared	0.54
X Coefficient(s)	0.99

Regression Output:	10FYM
Constant	-2.03
R Squared	0.48
X Coefficient(s)	0.70

I_{30} - RUNOFF REGRESSIONS

Regression Output:	5FYM
Constant	-2.23
R Squared	0.49
X Coefficients)	0.75

Regression Output:	ZT
Constant	-3.58
R Squared	0.57
X Coefficient(s)	1.14

STORM DURATION-RUNOFF REGRESSIONS

Regression Output:	CT
Constant	-1.32
R Squared	0.31
X Coefficient(s)	2.73

Regression Output:	ZT
Constant	-16.92
R Squared	0.75
X Coefficient(s)	1.43

lao - SOIL LOSS REGRESSIONS

Regression Output:	CT
Constant	-253.42
R Squared	0.72
X Coefficient(s)	65.35

Regression Output:	10FYM
Constant	-151.75
R Squared	0.66
X Coefficient(s)	39.94

I_{30} - SOIL LOSS REGRESSIONS

Regression Output:	5FYM
Constant	-154.77
R Squared	0.65
X Coefficient(s)	41.77

Regression Output:	ZT
Constant	-158.77
R Squared	0.64
X Coefficients)	44.75

STORM DURATION-SOIL LOSS REGRESSIONS

Regression Output:	CT
Constant	-7.35
R Squared	0.19
X Coefficient(s)	121.24

Regression Output:	10FYM
Constant	-1.06
R Squared	0.30
X Coefficient(s)	2.01

Regression Output:	5FYM
Constant	-1.11
R Squared	0.30
X CoefTicient(s)	2.15

Regression Output:	ZT
Constant	-1.34
R Squared	0.30
X Coefficient(s)	3.02

EI3Q-RUNOFF REGRESSIONS

Regression Output:	CT
Constant	1.56
R Squared	0.66
X Coefficient(s)	0.00

Regression Output:	10FYM
Constant	1.20
R Squared	0.57
X Coefficients)	0.00

Regression Output:	5FYM
Constant	1.26
R Squared	0.59
X Coefficient(s)	0.00

Regression Output.	ZT
Constant	1.65
R Squared	0.72
X Coefficients)	0.00

Regression Output:	10FYM
Constant	-6.93
R Squared	0.18
X Coefficients)	76.53

Regression Output:	5FYM
Constant	-9.93
R Squared	0.20
X Coefficient(s)	82.93

Regression Output:	ZT
Constant	16.97
R Squared	0.16
X Coefficients)	79.85

RUNOFF-SOIL LOSS REGRESSIONS

Regression Output:	CT
Constant	15.88
R Squared	0.81
X Coefficient(s)	51.64

Regression Output:	10FYM
Constant	20.53
R Squared	0.73
X Coefficients)	41.62

Regression Output:	5FYM
Constant	22.06
R Squared	0.75
X Coefficients)	41.49

Regression Output:	ZT
Constant	29.97
R Squared	0.68
X Coefficients)	30.45

EIjo - SOIL LOSS REGRESSIONS

Regression Output:	CT
Constant	51.30
R Squared	0.86
X Coefficient(s)	0.06

Regression Output:	10FYM
Constant	44.19
R Squared	0.67
X Coefficient(s)	0.04

Regression Output:	5FYM
Constant	49.67
R Squared	0.68
X Coefficients)	0.04

Regression Output:	ZT
Constant	55.75
R Squared	0.71
X Coefficient(s)	0.04

APPENDIX 10 DESCRIPTIVE STATISTICS

Descriptive statistics

Variable	N	Min	Max	Mean	Std Dev
RAINFALL	276	0.50	79.30	12.44	17.48
KE	276	0.00	1360.27	151.37	295.26
13o	276	0.50	45.75	8.01	8.70
EI30	276	0.00	56540.14	3435.27	9748.21
TIME	276	0.00	10.80	2.29	2.40
RUNOFF	276	0.00	62.76	4.46	10.93
SOILLOSS	276	0.00	3335.79	204.56	518.96

TRT=CT

Variable	N	Min	Max	Mean	Std Dev
RUNOFF	69	0.00	53.40	4.93	11.76
SOILLOSS	69	0.00	3335 79	270.21	673.05

TRT=FYM10

Variable	N	Min	Max	Mean	Std Dev
RUNOFF	69	0.00	41.35	3.55	8.84
SOILLOSS	69	0.00	1802.12	168.29	431.24

TRT=FYM5

Variable	N	Min	Max	Mean	Std Dev
RUNOFF	69	0.00	42.93	3.80	9.44
SOILLOSS	69	0.00	1898.04	179.93	452.26

TRT=ZT

Variable	N	Min	Max	Mean	Std Dev
RUNOFF	69	0.00	62.76	5.58	13.23
SOILLOSS	69	0.00	217461	199.79	489,18

CORRELATION ANALYSIS

Pearson Correlation Coefficients N = 276

	RAINFALL	KE	130	EDO
RAINFALL	LOO	0.94	0.76	0.77
KE	0.94	1.00	0.87	0.92
130	0.76	0.87	1.00	0.88
EI30	0.77	0.91	0.88	1.00
DURATION	0.71	0.51	0.39	0.31
RUNOFF	0.94	0.92	0.71	0.79
SOILLOSS	0.83	0.89	0.80	0.84
INFILT	0.88	0.79	0.67	0.62

	DURATION	RUNOFF	SOILLOSS	INFILT
RAINFALL	0.71	0.94	0.83	088
KE	0.51	0.92	0.89	0.79
130	0.39	0.71	0.80	0.67
EI30	0.31	0.79	0.84	0.62
DURATION	1.00	0.54	0.42	0.72
RUNOFF	0.54	1.00	0.85	0.69
SOILLOSS	0.42	0.85	1.00	0.65
INFILT	0.72	0.69	0.64	1.00

All variables highly significant

Analysis for Treatment CT

CORRELATION ANALYSIS

Pearson Correlation Coefficients

	RAINFALL	KE	130	EI30
RUNOFF	0.96	0.95	0.74	0.82
SOILLOSS	0.87	0.95	0.85	0.93
INFILT	0.89	0.80	0.68	0.60

	DURA TION	RUNOFF	SOILLOSS	INFILT
DURATION	1.00	0.56	0.44	0.76
RUNOFF	0.56	1.00	0.90	0.77
SOILLOSS	0 44	0.90	1.00	0.71

Summary of Stepwise Procedure for Dependent Variable RUNOFF

	Variable	Partial	Model		
Step	Entered	R**2	R**2	F	Prob>F
1	RAINFALL	0.93	0.93	891.28	0.0001
2	DURATION	0.03	0.96	49.68	0.0001
3	130	0.01	0.96	2.80	0.0990
4	EDO	0.01	0.97	11.63	0 0011

Analysis for Treatment FYM 10

CORRELATION ANALYSIS

Pearson Correlation Coefficients

	RAINFALL	KE	130	EI30
RUNOFF	0.94	0.92	0.69	0.76
SOILLOSS	0 84	0.89	0.81	0.82
INFILT	0.94	0.87	0.73	0.72

	DURATION	RUNOFF	SOILLOSS	INFILT
DURATION	1.00	0.55	0.43	0.71
RUNOFF	0.55	1.00	0.85	0.80
SOILLOSS	0.43	0.85	1.00	0.74

Summary of Stepwise Procedure for Dependent Variable RUNOFF

Step	Variable Entered	Partial R**2	Model R**2	F	Prob>F
1	RAINFALL	0.89	0.89	542.4 0	0.0001
2	DURATION	0.03	0.92	22.22	0.0001
3	130	0.01	0.93	6.69	0.0120

Analysis for Treatment FY1M5

Pearson Correlation Coefficients

	RAINFALL	KE	130	EDO
RUNOFF	0.94	0.92	0.70	0.77
SOILLOSS	0.85	0.90	0.81	0.82
INFILT	0.92	0.85	0.72	0.70

	DURATION	RUNOFF	SOILLOSS	INFILT
DURATION	1.00	0.55	0.44	0.72
RUNOFF	0.55	1.00	0.87	0.78
SOILLOSS	0.44	0.87	1.00	0.74
INFILT	0.72	0.78	0.74	1.00

Summary of Stepwise Procedure for Dependent Variable RUNOFF

Step	Variable Entered	Partial R**2	Model R**2	F	Prob>F
1	RAINFALL	0.89	0.89	552.53	0.0001
2	DURATION	0.03	0.92	23.68	0.0001
3	130	0.01	0.93	5.19	0.0260
4	KE	0.00	0.93	3.10	0.0829

Analysis for Treatment ZT

CORRELATION ANALYSIS

Pearson Correlation Coefficients

	RAINFALL	KE	130	EI30
DURATION	0.71	0.51	0.40	0.31
RUNOFF	0.96	0.96	0.76	0.85
SOILLOSS	0.79	0.87	0.80	0.84
INFILT	0.80	0.67	0.56	0.44

	DURATION	RUNOFF	SOILLOSS	INFILT
DURATION	1.00	0.55	0.39	0.76
RUNOFF	0.55	1.00	0.82	0.65
SOILLOSS	0.39	0.82	1.00	0.54
INFILT	0.76	0.65	0.54	1.00

Summary of Stepwise Procedure for Dependent Variable RUNOFF

Step	Variable Entered	Partial R**2	Model R**2	F	Prob>F
1	RAINFALL	0.92	0.92	825.14	0.0001
2	DURATION	0.03	0.96	52.87	0.0001
3	EI30	0.01	0.97	12.66	0.0007
4	130	0.01	0.97	19.72	0.0001