EFFECT OF FARMYARD MANURE ON SOIL SURFACE SEALING AND CRUSTING OF DISTURBED TOPSOILS - A CASE STUDY OF WEST POKOT, KENYA.

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DEDICATION.

I dedicate this thesis to my late Father and late Mother who were great educationists and to my wife Lydia and the children; Mwanangombe, Chiti (Jr) and Inonge for the love and the patience during the period of my absence from home.

DECLARATION

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

.... 1st JULY 1992

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This thesis has been submitted for examination with our approval as University Supervisors.

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ZOBISCH, M.A. DATE

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LIST OF ABBREVIATIONS

ACZ	Agro-climatic zone
ASAL	Arid and semi arid areas
cm	Centimetre
ESP	Exchangeable Sodium percentage
g	Gramme
h	Hour
ha	Hectare
J	Joules
kg	Kilogramme
kJ	Kilojoules
kPa	Kilopascal
m	Metre
mg	Milligramme
Mg	Magnesium
min	Minute
ml	Millilitre
mm	Millimetre
r	Correlation Coefficient
r^2	Coefficient of determination
s	Second
t	Metric tonne
y	Year
Zn	Zinc
µm	Micrometer
°C	Degree Celsius

ABSTRACT

The effects of two farmyard manure application rates (5 and 10 t ha^{-1}) on infiltration, runoff, soil loss and soil crust strength of four disturbed topsoil samples from luvisols (FAO/UNESCO, 1974 classification) were investigated under laboratory conditions for 60 days. The experiment was conducted in three experimental phases of 20 days each.

The four topsoil samples were packed in soil trays and subjected to simulated rainfall of a constant intensity of 360 mm h^{-1} for three minutes on four consecutive days.

Each of the three treatments of 0, 5 and 10 t ha^{-1} manure application rates was replicated three times and was subjected to similar experimental procedures as other replicates.

The investigations on the topsoil samples were confined to the top 5 cm layers from which time to runoff, infiltration capacity, runoff and soil loss were measured on each day of rainfall simulation. Crust strength and moisture contents were monitored over a period of two weeks after the last simulation day of each experimental phase. Crust organic matter content and the degree of soil aggregation were determined after each experimental phase.

Results show that soil aggregation changed slightly with time and with manure application. There were increases of between 2 and 14.4 % in the percentage of aggregates of sizes less than 250 µm and those greater than 2 mm. Aggregates of sizes ranging between 250 µm and 2 mm were generally reduced with a maximum decrease reaching 10.5 %.

Crust organic matter content decreased by the end of the 60 day period of study between 0.36 % and 1.17 % for all the four topsoil samples. The 5 t ha^{-1} treatment gained in organic matter content between 0.12 % to 0.46 % while the 10 t ha^{-1} treatment gained between 0.50 % to 0.86 %.

At 0.05 probability level, time to runoff and the amount of surface runoff were significantly influenced by the day of simulation, topsoil type and soil surface conditions. Time to runoff decreased with time while differences in the amount of runoff between treatments were insignificant.

There were significant increases in soil loss (at 95 % confidence level) with the addition of manure to the topsoil samples from chromic and plinthic luvisols especially during the first experimental phase.

Influences of topsoil type on soil loss were noted with the clay loam topsoil sample from orthic luvisol (sample D) having significantly more soil loss than other topsoil samples. Least soil losses were from the sandy clay loam topsoil sample from orthic luvisol (sample B) and the sandy loam topsoil sample from chromic luvisols (sample A).

The moisture content of crusts varied with topsoil type. Clay loam topsoil from orthic luvisol showed some significant crust moisture increase with manure application rate.

Crust strength increased significantly when the crust moisture content was below 4 %. Thus, there was a decrease in crust strength with any increase in moisture content as was expected.

The investigations showed that adding 10 t ha^{-1} farmyard manure to the four topsoil samples of the luvisols studied increased soil loss. This could be attributed to improved soil aggregation and lowered soil bulk density due to the significant increase in soil organic matter content. Generally, there was an increase in crust moisture content, improved soil aggregation and decreased crust strength with the increase in farmyard manure application. Surface runoff and infiltration capacities were not significantly affected by the treatments at 95 % confidence level.

CHAPTER I

1. INTRODUCTION

1.1. General Background.

The great diversity in topography, climate and soils significantly influence both agricultural potential and agricultural production in Kenya.

Of Kenya's total land area, about 80 % is classified as arid and semi arid land (ASAL). ASAL areas fall under agro-climatic zones (ACZs) V, VI and VII (Jaetzold and Schmidt, 1982; Sombroek et al., 1982). Table 1.1 gives more characteristics of these agro-climatic zones.

Mean annual rainfall in these areas ranges from 200 mm (ACZ VI) to 1000 mm (ACZ IV). The rainfall pattern is either unimodal or bimodal and is characterized by very high intensities of short duration. These rains are highly erosive and often contribute to high amounts of runoff.

Soils of ASAL areas are characterized as having a fairly low organic matter, an unstable structure, a propensity to forming surface seals and crusts and a high erodibility.

Table 1.1. Summary of the Characteristics of Agro-climatic Zones IV, V and VI in ASAL (After Jaetzold and Schmidt, 1982; Sombroek et al., 1982).

Characteristic		Agro-climatic zone IV	V	VI
r/E_o ratio		0.4 - 0.5	0.25 - 0.4	0.15 - 0.25
Climatic designation		Temperate/warm transitional	Temperate to hot, semi-arid	Temperate to hot, arid
Vegetation		Dry woodland and bushland	Bushland	Bushland and scrubland
Seasonal probability that $r<0.67E_o$ (%)	(West. Kenya)	20 - 65	65 - 90	90 - 97
	(East. Kenya)	7 - 20	20 - 70	70 - 92
Average growing days		180 - 235	110 - 180	75 - 110
Potential annual production (kg dm ha^{-1})		7,000 - 12,000	3,000 - 7,000	1,000 - 3,000
Carrying capacity (SU ha^{-1})		1 - 2	0.25 - 1	0.05 - 0.25
Main activity		Ranching/livestock millet/cotton/maize	Ranching/livestock/ millet	Ranching
Limitations to maximum production		Husbandry, rainfall soil fertility	Rainfall, husbandry soil fertility	Rainfall soil fertility

r = Average annual rainfall; E_o = Average annual potential evaporation.
SU = Stock unit assumed to weigh 300 kg with dry matter intake of 3,000 kg per year.

Most ASAL soils are associated with high incidence of salinity and /or sodicity. Infiltration rates for these soils are generally low thus compounding to the major problem of inadequate soil moisture to sustain prolonged vigorous plant growth.

The inherent properties of surface sealing and crusting soils are enhanced by the high intensity, short duration rainfall of these

ASAL areas. Surface sealing and crusting problems are therefore quite extensive.

Once formed, surface seals and crusts significantly decrease infiltration rates of rainwater and consequently increase runoff. Increased and concentrated runoff along drainage ways and animal tracks is a major cause of soil degradation and loss of soil productivity.

Very strong crusts (i.e. with high crust strength) are known to impede seedling emergence and consequently leading to decreased crop yields.

1.2. Relevance of Study.

The development of rainfed agriculture that is suited to ASAL, as well as sustaining agricultural productivity, requires some good understanding of the ecological system as well as proper management.

In Kaibon, the subsoil horizons of luvisols and acrisols (FAO/UNESCO, 1974 classification) which are the dominant soils (Gicheru, 1990), have dispersive properties and their exposure to concentrated runoff causes severe rill and gully erosion. The management of these soils therefore requires minimum disturbance of subsoil horizons and improved rainwater penetration.

in order to develop appropriate and effective soil and water management practices, it is important to determine the status of infiltration, soil crusting, soil loss and runoff.

This study attempts to evaluate the effects of farmyard manure, in terms of surface sealing and crusting, infiltration, surface runoff and soil loss for disturbed topsoil layers of luvisols.

It is anticipated that manure would reduce the inherent surface sealing and crusting properties of the topsoils from luvisols and hence improve rainwater penetration into the soil and increase soil moisture storage.

1.3. Objectives and Scope of Study

1.3.1. Objectives

Overall Objective:

To study the effects of rainfall and soil properties on soil surface crusting, infiltration, runoff and soil loss of disturbed topsoils from Luvisols.

Specific Objectives:

1. To relate crust strength to some soil properties (moisture content, aggregation, organic matter content) and rainfall properties (rainfall intensity, amount and kinetic energy).

2. To monitor changes in crust strength and some soil properties for different manure application rates.

3. To monitor infiltration, runoff and soil loss.

1.3.2. Scope of Study

This study attempts to evaluate the effects of different farmyard manure application rates (5 and 10 t ha^{-1}) on soil surface sealing and crusting and soil moisture of topsoil samples from luvisols in Kaibon Catchment, West Pokot District, Kenya.

The topsoils were studied under laboratory conditions using soil trays of dimensions 25 x 25 cm and were subjected to a constant rainfall intensity of 360 mm h^{-1}. This was equivalent to 18 mm of rainfall with a total kinetic energy of 637.2 Joules.

The investigations in this study were confined to the top 5 cm of the topsoils since this is the most critical soil depth prone to crusting (Tarchitzky et al., 1984; Evans and Buol, 1968).

This study, therefore, looks at rainfall properties (amount, intensity and kinetic energy) and some soil properties (moisture, organic matter and aggregation), with a view to evaluating crust strength, infiltration, runoff and soil loss for the different manure application rates.

1.4. Research Study Area.

The topsoils used in this research study were obtained from Kaibon Catchment, West Pokot District, Kenya. The Catchment extends from longitude 35°01'E to 35°08'E and latitude 1°31'N to 1°31'N and covers an area of 165 km^2 (Biamah, 1990). The elevation ranges from 1280 m to 2200 m.

The climate of this area is semi arid and a sizeable portion of the Catchment falls within ACZs IV and V. These ACZs are livestock-millet zones. Rainfall is low and erratic rendering the zones to have low potential for crop production. The crop growing season is short making the Catchment suitable for extensive livestock grazing (see table 1.1).

Rainfall is one of the important climatic elements relevant to agriculture in the study area. Annual rainfall ranges from 800 to 1000 mm with an annual mean of 955 mm for a 26 year period. This rainfall is bimodal, intense and of short duration.

Long rains occur between March and August and they account for 65 % of the total rainfall while Short rains occur from September to November.

Plate 1.1. Panoramic view of Kaibon Catchment.

Table 1.2. Rainfall data for Kongelai Station, West Pokot District, Kenya. (Hendrix, 1985)

Altitude:	1280 m											
Years of record:	26 (1953-1979)											
Mean annual rainfall:	955 mm											
Month:	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall:	26	34	51	96	138	85	148	150	87	62	51	27

Mean annual maximum temperatures vary from 23 to 29°C while the annual minimum temperature ranges between 11 and 17°C. The mean annual potential evaporation is estimated to range from 1650 mm to 1950 mm.

According to Gicheru (1990), dominant soils are luvisols, acrisols and fluvisols (FAO/UNESCO, 1974 classification). These soils are well drained, deep and exhibit moderate to strong surface sealing and crusting properties. Organic matter content of the soils is generally low. However, the silt/clay ratio is more than 0.4 while the flocculation index is low.

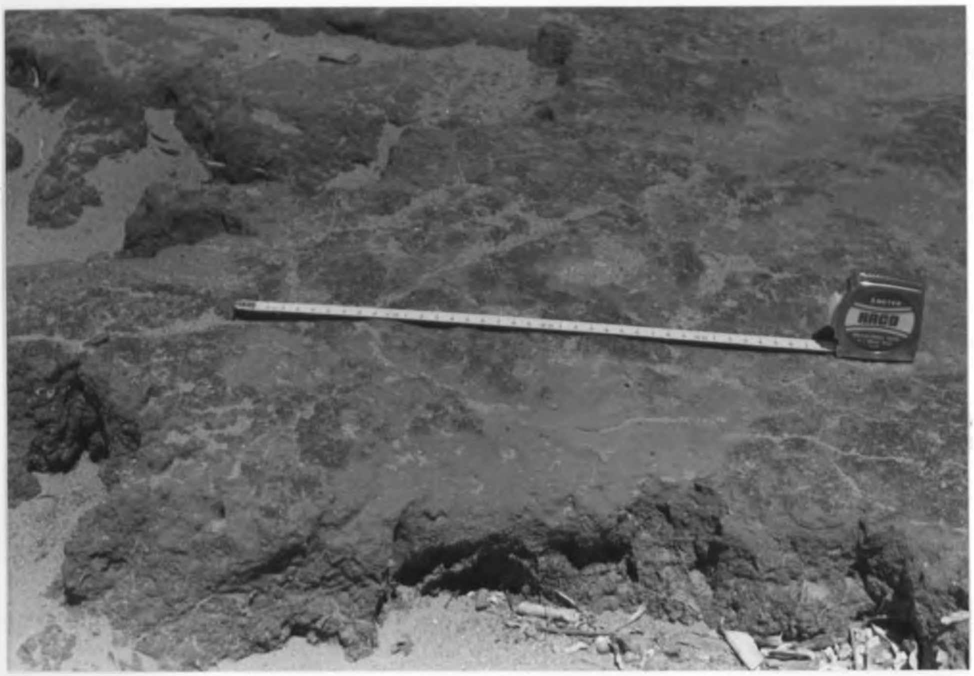

Plate 1.2. Structural Crusting in Kaibon Catchment.

Infiltration rates are low hence high surface runoff (Biamah, 1990). Clay content ranges between 10 and 20 % with Kaolinite and illite clays dominating.

Concentrated runoff flows along tracks and natural drainage ways have often broken the surface seals exposing the unstable subsoils.

Plate 1.3. Depositional Crusting in Kaibon Catchment.

Plate 1.4. Gully Erosion in Kaibon Catchment

This has resulted in accelerated soil erosion. Due to the large size of the catchment (165 km^2), the estimated sediment yield range of 14 to 27 t ha^{-1} (1.0 to 1.9 mm y^{-1}) is relatively low (Biamah, 1990). The sediment from the Catchment has a high silt/sand content and is carried by runoff water.

Because of the low flocculation index, such soils have relatively unstable aggregates while a high silt/clay ratio is characteristic of crusting soils.

The Catchment has an open woodland intermixed with scrubland. Ground cover is scanty for most of the year mainly due to overgrazing and limited moisture (see plate 1.5).

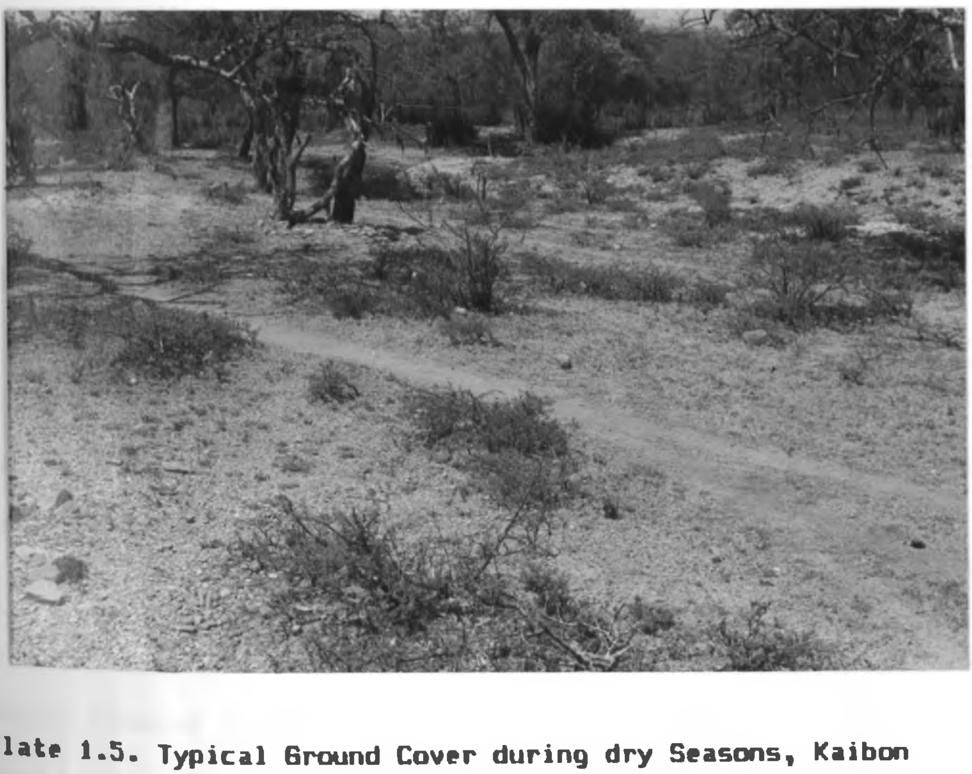

Plate 1.5. Typical Ground Cover during dry Seasons, Kaibon Catchment.

CHAPTER II

2. REVIEW OF LITERATURE

2.1. Soil Surface Sealing and Crusting

During rainstorms, raindrops disperse, compact and transport soil particles. Often, a seal develops on the surface and where soils, such as luvisols, have crusting properties, crusts form.

Chen et al. (1980) attributed the formation of a seal to fine soil particles that adhere to coarse soil particles. During a rainstorm, the coarse soil particles are exposed at the soil surface and subsequently, these are washed away leaving a skin seal. Norton (1987) suggests that deposition of fine soil particles leads to the formation of a seal.

A soil surface seal is therefore a thin layer of fine soil particles and clay colloidal particles on the soil surface that are bound together by surface tensional forces.

A soil surface crust, on the other hand, is a surface layer on soils, ranging in thickness from a few millimetres to perhaps as much as 3 cm, that is much more compact, hard, and brittle when dry than the material immediately beneath it (Brady, 1984).

Soil surface crusting is therefore a special phenomenon of physical soil degradation. It results from non soil loss processes such as soil compaction, breakdown and dispersion of soil aggregates and physical translocation of fine soil particles. Its significance however, has been obscured by more conspicuous soil loss processes such as interrill erosion, rill erosion, gully erosion and mass movements.

2.1.1. Types of Crusts

Classification of crusts can be based on numerous criteria. Chen et al. (1980) used the mechanism of formation to distinguish between crusts. Crusts formed mainly from the raindrop impact have been classified as structural crusts while those resulting from the translocation and deposition of fines have been referred to as depositional crusts.

Crust thickness is sometimes used to distinguish different crusts. Hoogmoed (1987) applied this criterion and differentiated thick crusts as the easily visible large crusts with a thickness of a few millimetres. Small crusts are hardly noticeable with an effective thickness of less than 0.10 mm.

Through micromorphological analysis, Kooistra and Siderius (1985) identify four types of crusts related to the processes of formation. The first type is similar to structural crusts while the other three fall into the class of depositional crusts.

2.1.2. Conditions for Soil Crusting.

Soil crusting phenomena are prevalent in hot dry regions which include arid and semi-arid areas (Mullins et al., 1987; Valentin, 1985; Evans and Buols, 1968). Climatic factors (rainfall and temperature) and soil properties significantly influence crusting.

Rainfall is significant in terms of the intensity, amount, duration and frequency, the compactive force that it exerts (Hergarty and Royle, 1978; Kooistra and Siderius, 1985; Le Bissonnais, 1990) and the intensity of the resulting slaking forces (Painuli and Abrol, 1986). Rainfall augments the formation of crusts through raindrop detachment and aggregate dispersion. High intensity, but short duration rainfall is highly conducive to surface sealing and subsequent crust formation during dry spells.

Kemper et al. (1975) recognized that the wetting and drying cycles are important for crust strength. They state that the disoriented aggregates are consolidated by the first wetting and drying cycle in which the wetting tends to weaken the aggregates while drying stabilizes the configuration resulting in a strong hard soil. The slower the drying rate, the greater the crust strength and vice versa, particulary in soils containing divalent ions (Gerard, 1965).

Soils that are light textured, high in silt content or fine sand are highly prone to crusting (Mullins et al., 1987; Kemper et al., 1975; Hadas and Stibbe, 1977; Lemos and Lutz, 1957). Texture of the top soil in this respect is important in determining the degree of crusting (Kooistra and Siderius, 1985). Norton (1987) points out that primary particle size of the soil was a poor indicator of soil susceptibility to sealing. On the other hand, water dispersible particle size, especially the silt size distribution, was a good indicator. Thus poor aggregation enhances chances of sealing and crusting.

Other conditions shown to influence crusts are; soil moisture content, type and amount of clay and organic matter content (Hanks and Thorp, 1957; Hergarty and Royle, 1978; Debicki and Wontroba, 1985; Painuli and Abrol, 1986). Other factors influencing crusting include percentage of exchangeable sodium (ESP), electrolyte concentration of percolating water and the content of calcium carbonate (Morin et al., 1989; Hadas and Stibbe, 1977; Painuli and Abrol, 1986).

Cultural practices such as tilling the soil to a fine tilth, grazing management and cover crop management also influence the formation of crusts (Hadas and Stibbe, 1977; Mullins et al., 1980).

2.1.3. Formation of Crusts

Raindrop impact on a bare soil surface disperses the finer soil particles (silt and clay) from soil aggregates or clods (Bisal, 1960). The particles are then washed and compacted into pore spaces to form a dense surface layer. When the soil dries, it becomes hard (Hoogmoed, 1987; Kooistra and Siderius, 1985; Farres, 1985; Epstein and Grant, 1973).

High rainsplash rates, at the beginning of a storm, are instrumental in the formation of crusts (Farres, 1985). Boiffin (1985) identified two stages in the formation of crusts. The first stage leads to the development of structural crusts, while the second stage leads to depositional crusts and is marked by puddling and the development of runoff. He also observed that the rate of expansion and thickening of crusts was controlled by initial soil surface morphology.

When exposed to continuous cultivation, soils that have a low structural stability tend to crust easily (Valentin, 1985). Raindrop impact on alkaline soils disperses (deflocculates) colloidal clay particles (Agassi et al., 1981) which, subsequently, inhibit air and water movement down the soil profile. This results in surface sealing and crusting.

Crust hardness increases with an increase in clay content and with a decrease in organic matter and moisture contents (Painuli and Abrol, 1986; Sharma, 1985; Hegarty and Royle, 1978; Lemos and Lutz, 1957; Debicki and Wontroba, 1985). High organic matter content in a soil increases the stability of the peds in water and reduces the formation and the strength of surface crusts (Tisdall and Oades, 1982; Deploey, 1980).

2.1.3.1. Mechanics of Crust Formation

Various studies have established that raindrop impact is paramount in initiating the formation of crusts. The raindrop provides the energy required to breakdown and dislodge soil aggregates (Poesen and Govers, 1985; Moldenhauer and Kemper, 1969; Quansah, 1981; Farmer, 1973; Tarchitzky et al., 1976; Rose, 1960).

The breakdown of soil aggregates and the dispersion of fine particles (clays and silts) are characteristics of the mechanics of crust formation (Shainberg and Singer, 1985; Morin et al., 1989; Tarchitzky et al., 1984; Onofiok and Singer, 1984).

Shainberg and Singer (1985), Epstein and Grant (1973), Morgan (1986) and McIntyre (1958b) have cited soil compaction by the raindrop impact as another cause of surface sealing and crusting.

Tarchitzky et al. (1984), Onofiok and Singer (1984) as well as Morgan (1986) and McIntyre (1958b) established that slaking is also contributory to the formation of crusts. Le Bissonnais (1990) elaborates on aggregate breakdown mechanisms that lead to surface sealing and crusting.

Morin et al. (1987) recognized aggregate breakdown by raindrop impact, compaction, chemical dispersion of clays and transportation of fine soil particles as being characteristic of the mechanics of surface crusting. Shainberg and Singer (1985) emphasized physicochemical dispersion of clay, soil removal and the concentration of sediment of clay and silt particles as being crucial in crust formation. Adsorbed cations and electrolyte concentration in water, also significantly influence crust formation.

2.1.3.2. Processes of Crust Formation.

Numerous propositions of processes of crust formation have been advanced (McIntyre, 1958b; Luk, et al., 1990; Le Bissonnais, 1990; Sharma, 1985; Tarchitzky et al., 1984; Onofiok and Singer, 1984; Chen et al., 1980). These commonly point out to the mechanism of aggregate breakdown as the initial step to crusting followed by transportation. The major differences in the assertions arise in the actual manner in which the breakdown of aggregates and their subsequent transportation is achieved. McIntyre (1958b), for instance, indicates four successive processes as occurring at the soil surface as a result of rapid variation in splash rates. Kemper et al. (1975) attributed crust formation to the processes of wetting and drying. Wetting weakens clods while drying stabilizes the contact to end up with a hard soil surface. This explanation is similar to that given by Tarchitzky et al. (1984). Sharma (1985) recognised that after the breakdown and dispersion of the aggregates, a soil suspension is formed and is followed by segregation of the soil particles during sedimentation and drying.

Chen et al. (1980) differentiated between the processes involved in the formation of structural crusts and depositional crusts. For structural crusts, they emphasize the adherence of fine particles to coarse particles and subsequent exposure and removal of coarse sand particles to leave a skin layer. Depositional crusts form when turbid water infiltrates into the soil. In the initial stages, soil particles are uniformly distributed but later, coarse particles are exposed at the surface and these are washed away leaving a skin seal.

Norton (1987) agrees in principle to the processes as expounded by other Scientists except on the formation of a skin seal.

Valentin (1985) identified stages of formation as; the collapse of crumbs, detachment, sorting, translocation of clays and filling in by clays. Farres (1985) however grouped the processes into three, highlighting the role of rainsplash erosion.

From the studies cited, the general sequence of the processes of crust formation is as indicated here below:

1. Breakdown of soil aggregates.
2. Transportation or translocation of fine particles.
3. Deposition or sedimentation of the fines.
4. Compaction or consolidation.

2.1.4. Characteristics of Soil Crusts

Extensive work has been carried out regarding the characteristics of soil crusts. A common finding is that two layers exist in a crust. McIntyre (1958a) identified the two layers as the top layer, a skin seal of about 0.1 mm thick and the underlying layer, a zone of fine washed in materials. Morgan (1986) has similar observations to McIntyre's findings. Whilst recognizing the two layers as being similar to McIntyre (1958a) and to Onofiok and Singer (1984), Norton (1984), further identified what he terms a 'washed out zone'. This is a region where colloids within 0.5 mm of the surface are removed and where the silt size grains are closely packed.

To the contrary, Tarchitzky et al. (1984) did not detect any wash in zone although a skin seal of 0.1 mm thickness and another layer of 2 to 3 mm thick, were observed. The absence of a wash in zone is also reported by Chen et al. (1980).

Other prominent features of crusts include a high bulk density (Hadas and Stibbe, 1977; Lemos and Lutz, 1957; sharma, 1985), particular orientation of fine soil particles (Evans and Buols, 1968; Onofiok and Singer, 1984), and a high content of water dispersible silt/clay and destroyed aggregates (Sharma, 1985; Tarchitzky et al., 1984; Mullins et al., 1987). Ahmad and Roblin (1971) similarly found characteristic bulk density, particle orientation and destroyed aggregates although the orientation of particles was poorly developed in this case. Probably because of segregation of particles, the dominant particle size in crusts, according to Lemos and Lutz (1957), is less than 0.1 mm in diameter.

Römkens et al. (1985) and Onofiok and Singer (1984) observed that micromorphological features of crusts are variable. Thus, Onofiok and Singer (1984) grouped the characteristics of crusts into two, to form the early and late stage features.

2.2. Factors Influencing Crusting

2.2.1. Rainfall Properties

Relating rainfall properties to the mechanics of soil aggregate destruction gives a better understanding of the influence of rainfall on surface sealing and crusting. This is achieved by analyzing the erosivity of the rainfall. Erosivity is expressed in terms of raindrop size, intensity (I), kinetic energy (KE) or momentum and amount of rainfall (A) (Lal, 1984; Hudson, 1984; Morgan, 1986). Erosivity is therefore the capacity of rainfall to detach and splash soil particles. The interaction of rainfall and soil properties influences the formation, strength and properties of surface seals and crusts.

Soil detachment involves energy transfers in the soil-water system (Lal, 1984; Kinnel, 1981; Morgan, 1986; Bisal, 1960). Indices such as, rainfall energy multiplied by the maximum 30 minute rainfall intensity (EI_{30}), in the Universal Soil Loss Equation (USLE), the kinetic energy that is greater than a specific intensity (KE>I) for Zimbabwe and the amount of rainfall multiplied by the rainfall intensity (AI) for West Africa have been developed (Lal, 1984; Hudson, 1984). Lal (1984) points out that it is still not very clear as to which parameter is most indicative of the detachment power of rainfall due to geographical and rainfall variations. Kilewe (1987), worked out some correlations and found EI_{30} to be a good erosivity factor for the Machakos Area, Kenya, as rainfall amount ($r = 0.57$), Kinetic energy ($r = 0.63$) and the product of energy and rainfall amount (EA) were poor indicators.

Studies in Zimbabwe (Lal, 1984) indicate little difference between momentum, energy and rainfall depth as predictors of soil loss.

Kinnel (1973) on the other hand points out that rain type has a significant influence on the relationships between rainfall intensity, momentum, kinetic energy and drop size.

Raindrops provide the force for detachment (Farmer 1973). This is achieved through momentum, kinetic energy, rainfall amount and raindrop size. The result is either movement or breakdown of soil clods or both (Bisal, 1960). Primary particles are generally detached with the first raindrops while aggregates and clods require more raindrops to disperse first and then detach (Mazurak and Mosher, 1970). As the water infiltrates, the entrapped air ahead may cause breakdown of the aggregates resulting in slaking (Yariv, 1976)

Drop size is important since the horizontal area determines the amount of soil that would sustain the drop impact. This is supported by Epstein and Grant (1967) who found that soil in raindrop splash increased with drop size and drop velocity. Bubenzer and Jones (1971) report that splash was proportional to the drop size and that smaller drops produced significantly less splash than larger ones, although kinetic energy, total rainfall mass and impact velocity were almost constant.

Further effects of drop size are given by Epstein and Grant (1973), Rose (1960) and Lal (1984). However, Rose did not find strong evidence on the role of drop size in detachment and impact velocity. Lal (1984) on the other hand, states that it is difficult to establish direct relationship between median drop size (D_{50}) and rainfall intensity and that the median drop size and the mean rainfall intensity when calculated for the duration of a storm event, are not necessarily related.

Amount and duration of rainfall are not often used as effective properties of rainfall. This is because other parameters (kinetic energy and intensity) can be derived using momentum and drop size. Rose (1960) argues that detachment and splash are related more to momentum of rainfall since momentum is a measure of pressure exerted by the rainfall. Other Scientists feel that kinetic energy is more closely related to rainfall's capacity to cause splash than to momentum. Thus, kinetic energy is often estimated using the relationship between intensity and kinetic energy per unit quantity of rain (Kinnel, 1981). The work by Farmer (1973), Mazurak and Mosher (1970), Bubenzer and Jones (1971) and Quansah (1981) support this.

Kinetic energy and intensity of rainfall therefore become important when considering aggregate detachment. Literature review given by Bubenzer and Jones (1971) clearly shows that splash is related to kinetic energy and intensity of rainfall. Kinnel (1981) related two forms of kinetic energy to rainfall intensity and gave their relationship. He also pointed out the dangers of relating kinetic energy to intensity.

Kinnel (1981) found that the rate of expenditure of kinetic energy was highly correlated with rainfall intensity when drops were travelling at or close to their terminal velocity. Farmer (1973) cites studies where it was reported that the rate of detachment was directly related to rainfall intensity. He however found unpronounced effect of rainfall intensity although low intensity rainfall rarely detached particles greater than 3,000 µm and high intensity rainfall detached particles as large as 5,000 µm. Similar findings are reported by Mazurak and Mosher (1970), Quansah (1981) and Watson and Laflen (1986).

One of the prerequisites for surface sealing and crusting is adequate raindrop impact. The raindrop impact provides the force for detachment. As energy transfer takes place, particles are splashed and consolidated leading to compaction, sealing and crusting. The force also disrupts the aggregates and it imparts velocity to some particles and so sets them in motion (Kilewe, 1987; Epstein and Grant, 1973; Morgan, 1986). It would be expected that this force would be greatest where a film of water develops on the surface, according to the findings of Ghadiri and Payne (1977), Farmer (1973) and Epstein and Grant (1973). Ghadiri and Payne (1977) concluded that the stress on the soil due to raindrop impact is greatest in an annulus of diameter larger than that of raindrops.

The resulting dispersion, slaking, detachment, splashing and compaction greatly influence the formation of a seal or crust (Watson and Laflen, 1986; Hadas and Stibbe, 1977). Epstein and Grant (1967) found that the rate of splash decreased with crust formation. They also found that crust compactness occurred very rapidly during the first few minutes. This is in agreement with the idea that the first raindrops are critical for crust formation and it is also in agreement with the conclusion by Hadas and Stibbe (1977) that hardness of the crust can be affected by the rainfall amounts and the impact of the first rain storm.

Continuous splashing, according to Bisal (1960), causes separation and orientation of soil particles. These influence the formation and strength of a crust. This is similar to what Watson and Laflen (1986), Hadas and Stibbe (1977) and Farres (1985) have reported. The former found that soil detachment by single raindrop splash was related to soil strength while Hadas and Stibbe (1977) indicate an increase in crust resistance with an increase in rainfall.

Some of the observations made by Epstein and Grant (1973) summarize the influence of rainfall properties on surface sealing and crusting. The most relevant are that increasing raindrop size markedly decreased porosity; increasing intensity decreased pore space slightly in the 0 - 4 mm zone but increased slightly in the 4 - 6 mm zone; there was a slight decrease in pore space at low intensity and that crust strength and porosity had a closer relationship to drop size or drop impact than to total kinetic energy of the storm. Kooistra and Siderius (1985) however, attribute the presence of separated grains and a coating in crusts to a higher kinetic energy of rainfall.

Raindrop impact therefore, evokes a number of responses when the soil is exposed to it. Farres (1985) points out three such responses regarding surface sealing and crusting. The first one is rainsplash erosion. This encompasses removal of micro-aggregates and discrete particles. Second is in-situ surface processes such as the breakdown of structured units, surface particle sorting and surface compaction. The third response is removal of fine particles into the soil mass.

2.2.2. Soil Properties

Major soil properties that significantly influence soil surface sealing and crusting include soil aggregation, soil organic matter, soil moisture, soil texture, clay mineralogy and soil chemical composition.

2.2.2.1. Soil Aggregation

Crumb structure modifies the effects of raindrops on soil aggregates (Rose, 1960). Quansah (1981) indicates that soil type influences soil detachment and DePloey (1980) found that stable and well aggregated A_p horizons were more sensitive to detachment by splash than unstable top soil. Dispersion, detachment, slaking and translocation of soil particles will consequently depend on the nature of the soil structure. Formation of either a structural or a depositional crust therefore partly depends on the soil type.

According to Harris et al. (1966), few soils possess sufficient stable structure at their surface to withstand degradation forces of heavy storms. The nature of soil aggregates and the amount of water dispersible aggregates contribute to the formation of surface sealing and crusting and are thus a good indicator of the propensity of soil to crusting (Norton, 1987).

The degree of soil aggregation is important for crusting phenomena, particularly water stable aggregates and the size of aggregates. Falayi and Lal (1979) found that time to incipient runoff increased with an increase in aggregate size. Crust strength was also highest for the medium aggregate size.

The rate of dispersion or breakdown of aggregates determines the time to sealing and ponding. Thus, the size, percentage of water stable aggregates and the general cohesiveness will either accelerate or slow surface sealing and so affect the formation and strength of a crust. Aggregate stability is therefore crucial in controlling the availability of both splash and crusting materials (Farres, 1985).

2.2.2.2. Soil Organic Matter

Soil organic matter has many desirable physical, chemical and biological properties. The effects of organic matter vary from soil to soil and depend on the abundance of organic matter (Im, 1982). According to Allison (1973), organic matter content under ordinary conditions is between 1 and 2 %.

The effectiveness of the source of organic matter depends on the isohumic factor (Morgan, 1986). This is the quantity of humus produced per unit of organic matter. Humus is therefore important especially for aggregate stability. Humus content of 3 to 6 % is common in most well developed grasslands (Allison, 1973). Im (1982) cites studies that showed that the critical level of effective humus was approximately 2 - 2.5 % and that aggregation of soils seemed to be approaching maximum levels at about 1.7 - 2.0 % carbon.

At the significance level of 0.1 %, Chaney and Swift (1984) found highly significant correlations for the relationship between aggregate stability and organic matter. They observed that organic matter levels can be used diagnostically to identify soils which may show problems of structural instability.

Research has shown that soils improve in aggregation when amended with organic materials. Gomah (1982) states that maximum effects of organic materials were observed after 1 - 2 weeks of incubation. Nevertheless, it should be noted that aggregation effectiveness of organic materials depends on the amount of readily decomposable constituents they contain. The more rapidly the materials decompose, the greater the bonding effect. Harris et al. (1966) indicated that the effect of readily decomposable organic material on aggregation increases within a few days, reaches maximum and then starts to decrease gradually. Those materials that are slow in decomposition take longer to become effective but their effects also last longer.

Mechanisms of aggregation have been extensively expounded by Harris et al. (1966), Gomah (1982), Haynes and Swift (1990) and Tisdall and Oades (1982). These studies indicate that aggregation is achieved through three main processes namely: organic cementing substances found in the applied materials or formed during decomposition; the mechanical binding by microbial filaments or cells and mucigels and organic binding compounds synthesized by soil micro-organisms.

Other processes such as cropping systems, rooting systems and temperature also influence soil aggregation. Harris et al. (1966) for instance, found that temperature increased the rate but not the degree of aggregate stabilization by fungi. Aggregate stability was maintained for 84 days at 15°C, for 14 days at 25°C and for 4 days at 35°C.

Work by Hamblin and Davies (1977) show that organic matter is effective in the soil-water system as seen in the amount of water retained at each suction. The difference from low organic matter soils was however, noted at low suction. Those soils with low organic matter had lower total porosity. These trends are also reported by Nuttall (1970), Haynes and Swift (1990) and Im (1982).

In as much as it is acknowledged that organic matter is effective in improving aggregation, it is not easy to predict the type of influence, its extent and significance for an individual soil (Hamblin and Davies, 1977). Furthermore, organic matter alone is not sufficient to explain differences in aggregate stability due to water. Tisdall and Oades (1982) in their correlations of water stable aggregates and organic carbon have implicitly given the same observation.

From the foregoing, it becomes clear that soils with low organic matter may have poor aggregation and low moisture content. These conditions are conducive to crusting as dispersion and detachment by raindrop impact becomes easier. Low moisture content allows more air entry into the soil but since air drying decreases aggregate stability in soils low in organic matter (Haynes and Swift, 1990), slaking is easily achieved.

By applying organic matter as a soil amendment, crust strength is generally reduced (Nuttall, 1970; Haynes and Swift, 1990; Debicki and Wontroba, 1985; Amhad and Roblin, 1971). DePloey (1980) found that 5.2 % organic matter content in soil inhibited crusting.

2.2.2.3. Soil Moisture Content

The presence or absence of soil moisture and its interaction with aggregates depend on many factors (Panabokke and Quirk, 1957). Among these factors are; organic matter content, vegetative cover, moisture retention characteristics of the soil, soil texture and soil management practices. The effects of soil moisture content on crusting are manifested through aggregation, time to ponding, runoff, hydraulic conductivity of the crust and crust strength.

The wetting and drying cycles allow consolidation of clods and aggregates and later, the weakening of the same. Kemper et al. (1975) observed that the wetting and drying cycles enable gravitational forces and surface tension forces to squash aggregates into closer contact. Drying also stabilizes the resulting configuration. Once aggregates and pore spaces are broken down, the soil ends up in a structureless mass which upon drying results in a strong hard soil. According to Sharma (1985), the resulting smaller particles, after breakdown, have sufficient particle to particle contact to form bonds when the soil dries and forms a hard crust.

The degree of air entrapment and slaking depends on the initial moisture content. Soil aggregates are also easily destroyed by raindrops as the initial moisture content decreases (Cermuda et al., 1954).

Aggregate stability is strongly correlated with moisture content as established by Haynes and Swift (1990). Different soil management practices affect soil moisture content differently (Busscher and Sojka, 1987) and so is the effect on aggregation. Panabokke and Quirk (1957) however, show that generally, virgin soil aggregates are stronger for a wide range of soil moisture contents. They also observe that the failure of aggregates is prompted by rapid wetting at low moisture tensions. Their results have shown that, stability of aggregates in equilibrium with tensions less than 100 cm, depends on the transfer rate of water to the aggregates.

If a crust already exists, its strength, as determined by the modulus of rupture or cone index methods, will partly depend on the moisture content of the crust (Busscher, 1990; Mirreh and Ketcheson, 1972; Busscher and Sojka, 1987). Ayers and Perumpral (1982) observed that moisture content that produces maximum dry density does not give maximum cone index. The results show that at low moisture content, cone index values increased exponentially with a high dry density. At a high moisture content, cone index values increased linearly. However, the rate of increase of cone index with dry density decreased significantly at higher moisture content.

Govers and Poesen (1985) got similar results to Ayers and Perumpral (1982). They found that shear strength of soil surface was primarily controlled by moisture content. Many more studies support the findings among them the classical works of Lemos and Lutz (1957) and Hanks and Thorp (1957). Others who have had similar observation are Kemper et al. (1975), Chaudhri et al. (1976), Painuli and Abrol (1986) and Hegarty and Royle (1978).

2.2.2.4. Soil Texture

Particle size distribution is one of the aspects of texture that directly influence surface sealing and crusting.

Research has established that soils made up of very fine sand (45 - 65 %) and/or silt (25 - 30 %) are prone to crusting (Hadas and Stibbe, 1977). Probably because of textural characteristics, Lemos and Lutz (1957) found a high percentage of particles less than 0.10 mm in diameter in natural crusts with silt being the highest. Similarly, Sharma (1985) found a higher content of clay, silt and water dispersible silt and clay in the crust. Modulus of rupture correlation with clay gave r = 0.70; with silt, r = 0.68; with silt plus clay, r = 0.82; with fine sand, r = -0.81. Multiple linear regression showed that clay plus silt and exchangeable sodium percentage (ESP) accounted for 84 % of variation in modulus of rupture.

Higher clay content tends to increase water stable aggregates (Moldenhauer and Kemper, 1969). Mullins et al. (1987) observed that, hard setting soils contain very little clay to shrink and crack on drying but this clay content is sufficient to bridge between sand grains.

Aggregation of light textured soils with a high content of fine particles is usually not very good and in most cases, organic matter may have little effect on their aggregation (Harris et al., 1966). This allows easier dispersion and detachment, which are pre-requisites for sealing and crusting (Onofiok and Singer, 1984; Morin et al., 1989; Tarchitzky et al., 1984). Since the packing of fine particles gives little room for bigger pore spaces, this encourages rapid time to ponding and washing away of yet other fine particles. These two processes are important in initiating surface sealing and crusting (Valentin, 1985; Norton, 1987; Chen et al., 1980).

2.2.2.5. <u>Other Soil Properties</u>

Clay mineralogy and chemical composition of the soil do contribute to problems of sealing and crusting. These are linked to the rate and degree of swelling as well as to the rate and degree of deflocculation of clay minerals (Agassi et al., 1981; Lemos and

Lutz, 1957; Panabokke and Quirk, 1957). Mullins et al. (1987) and Lemos and Lutz (1957) point out that kaolinite is dominant for hard setting soils since it does not swell as do montmorillonite and can therefore be contained within the soil matrix without structural cracks developing. All these indicate that if clay mineralogy is such that the lattice bonding is easily weakened by moisture content, it would easily disperse and so would reinforce cementation when a crust forms.

Quirk and Schofield (1955) and Shainberg and Singer (1985) established that permeability of soil and clay dispersion depend on exchangeable sodium and salt concentration of the percolating solution. Through deflocculation and failure of aggregates, the pores get clogged resulting in ponding and consequently crust formation. The presence of calcium carbonate, sodium chloride and exchangeable sodium especially at the top soil layer equally promotes crusting (Hadas and Stibbe, 1957; Gerard, 1965; Sharma, 1985; Painuli and Abrol, 1986).

2.2.3. Soil Management Practices

Soil management practices are expected to provide favourable soil conditions for crop growth. A number of practices are employed to improve either organic matter status, infiltration rates, aeration, structure or other soil properties.

Since soil surface sealing and crusting are initiated by dispersion and detachment of soil aggregates, its control depends on the stability of soil aggregates under both mechanical treatments and in water. This has led to the development of many techniques for enhancing soil cohesion and aggregation in order to counter the effects of crusting (Chaudhri et al., 1976; Robbins et al., 1972; Bilbro and Wanjura, 1982). These techniques include mechanical disruption and chemical and bio-physical amendments. Bio-physical measures have proved to be the most effective (Chaudhri et al. 1976).

Mechanical disruptions involve breaking up the crust using implements. This is therefore not a long term solution but rather an immediate remedial measure. The time of breaking the crust has to coincide with the emergence of seedlings. This is not easy to achieve especially under natural conditions as repeated effects of rainfall on structurally unstable crusting soils would soon mask the effect of the treatment by forming a new crust. Additional operational costs further make this technique unpopular especially to small scale farmers. Bilbro and Wanjura (1982) found the technique satisfactory but they point out that it is not always effective due to incomplete breakup of crusts and/or due to the destruction of too many seedlings. Similar observations were made by Chaudhri et al. (1976) who also stated that the operation is often accomplished too late.

Chemical amendments have been widely tested but they are more favoured in developed countries. Their high cost implications and the large volumes required, limit their applicability in developing countries.

Three main groups of chemical amendments can be identified namely: (a) soil conditioners (Allison and Moore, 1956; Shaviv et al., 1986). (b) Surface active agents (Robbin et al., 1972; Oades, 1976; Page and Quirk, 1979). (c) Soil fracturing agents (Chaudhri et al., 1976).

Bio-physical amendments vary according to the method of application in the field. Materials that are applied in bands in or above seed furrows include asphalt emulsions, sand, sawdust, coke and vinyl resin. Studies on these and other materials have been conducted with varied success levels (Qashu and Evans, 1967; McGregor et al., 1990).

Two other groups under bio-physical amendments involve mulches. Mulches can either be applied on the surface or they can be incorporated into bulk soil. The first group involves a wide spectrum of materials. The commonly applied ones include organic manure, crop residues, stones and petroleum mulch (Lattanzi et al., 1974; Singer et al., 1981).

The primary objective of applying these measures is to modify the physical properties of soil such that crust strength and soil compactability are decreased while improving aggregate stability.

2.2.3.1. Soil Amendments

The use of farmyard manure in crop production is an old method used to improve soil structure and fertility. Different types of manure are found depending on the kind of livestock being reared.

Limited research has been conducted regarding the use of farmyard manure in reducing crusting. Most of the work has concentrated on the use of organic matter. Because of its high organic matter content, farmyard manure can equally be used in controlling surface sealing and crusting by either applying it on the surface or incorporating it into the soil.

Farmyard manure as a soil amendment has been investigated and results indicate that it serves both as a fertilizer and as a soil conditioner (Gati, 1982; Im, 1982; Williams and Cooke, 1961). Increased crop yields and improvements in soil particle aggregation, moisture content and aeration have been reported (Williams and Cooke, 1961; McIntosh and Varney,1972; Mathers and Stewart, 1984; Gomah, 1982). Guttay et al. (1956) reported that 80.4 % of aggregates of treated soil remained in aggregation of greater than 0.10 mm in size while the untreated soil had 65.3 % of aggregates.

Organic matter status is effectively increased through the application of farmyard manure (Vidyarthy and Misra, 1982; Moustafa, 1982). The effect of farmyard manure however depends on the amount incorporated into the soil and on soil moisture content (Chaudhri et al., 1976).

Morgan (1986) points out that, to build up adequate organic matter in the soil, the increase should be within a range of 1 - 2 %, before any effect in stability can be observed. He further cites a study where 1 kg m^{-2} of farmyard manure was only sufficient to maintain the existing organic matter content level.

A 2 year interval for farmyard manure application produced the greatest effects in the study conducted by Guttay et al. (1956). Marked benefits were, however, noted shortly or one year after applying manure.

Im (1982) indicates that the effect of farmyard manure on aggregation varies with the soil conditions. It is more pronounce on soils that are low in organic matter and soils which are poorly aggregated.

As a soil amendment, farmyard manure improves the structure. This is achieved through improved permeability (Williams and Cooke, 1961), improved aggregation and water stability (Mathers and Stewart, 1984), decreased particle density and bulk density

(Tiarks et al., 1974) and decreased evaporation and improved water holding capacity (Mathers and Stewart, 1984). Tiarks et al. (1974) reported that geometric mean diameter of water stable aggregates increased exponentially while Mazurak et al. (1975) found an increase in soil aggregation in large diameter classes and a reduction in the amount of aggregates detached.

Just as it is effective on a short term basis, farmyard manure is equally beneficial on a long term basis. Moustafa (1982) found that prolonged use of farmyard manure significantly increased organic matter content in the soil and slightly affected soil permeability and ESP. However, there were no distinct changes in particle size distribution.

Among the many long term effects reported is the weakening of clods (Williams and Cooke, 1961); improved hydraulic conductivity and infiltration (Mathers and Stewart, 1984; Mazurak et al., 1975); lowered matric suction and increased moisture content at field capacity (FC) and permanent wilting point (PWP) (Salter et al., 1967; Nuttall, 1970). Cross and Fischbach (1973) reported an increase in the initial and the basic water intake rates but comparing the two, there was a decrease in the basic water intake rate.

One of the biggest issues in farmyard manure application is the rate of application. Contradictory results have been reported on the effects of different application rates. For instance, Mathers and Stewart (1984) reported that higher rates of farmyard manure application can reduce crop yields while Mazurak et al. (1975) concluded that heavy application rates did not have adverse effects on crop yields.

Numerous studies on application rates of farmyard manure indicate that heavy application rates adversely affect physical conditions of the soil while moderate and low application rates are good (Guttay et al., 1956; Mathers and Stewart, 1971; Cross and Fischbach, 1973). Tiarks et al. (1974) and Mazurak et al. (1975) however, give comprehensive findings on both detrimental and beneficial effects of heavy manure applications.

Generally, moderate and low application rates of farmyard manure are more favourable for crops than high rates. The conclusion as to the effects of farmyard manure application rates therefore lies in whether one is concerned with crop performance and yields or with soil physical conditions.

Encouraging results have been reported concerning the use of farmyard manure to prevent and/or limit crusting. Chaudhri et al. (1976) reported that the effect of manure on crusting was related to the amount of manure incorporated into the soil and to the moisture content. In their experiment, seedling impedance was reduced as cracks opened up. Mazurak et al. (1975) reported crust strengths of 36 kg cm^{-2} and 4.4 kg cm^{-2} for unmanured plots and plots that received 360 t ha^{-1} y^{-1} respectively. Similarly, Tiarks et al. (1974) reported a decrease in modulus of rupture from 0.60 bars to 0.08 bars when farmyard manure was applied. Nuttall (1970) has also reported reduction in crust strength due to farmyard manure application.

2.2.4. Vegetative Cover

The role of vegetative cover in intercepting raindrops is well documented. Hudson (1984) cites an experiment he conducted earlier, on the use of mosquito gauze to demonstrate how raindrop interception affects erosion processes. In the process of intercepting raindrops, vegetation arrests and dissipates the raindrop energy (Elwell and Stocking, 1976; Hudson, 1984; Morgan, 1986; Okigbo and Lal, 1977). Further proof of the importance of vegetative cover lies in the predictive models of soil loss where reduced soil loss rates are predicted once the value of the cover factor is increased.

When kinetic energy of falling raindrops is intercepted and dissipated, the process of aggregate dispersion and breakdown is likewise decreased. Morgan (1982) observed that crop cover significantly reduced splash detachment. The relationship obtained between the rates of splash detachment under the crop and the kinetic energy of rainfall above the canopy was negative. Finney

(1984) had similar results and concluded that plant cover can obscure an expected relationship between detachment and rainfall energy.

Percentage cover, plant density, height and size of the canopy determine how effective the interception would be. The degree of protection that vegetative cover gives to the soil varies with percentage cover. Any rapid increase in soil loss and runoff does not occur until total vegetal cover falls below a certain percentage. Elwell and Stocking (1976) found the value of 30 % to be critical. In slightly different experiments (Othieno, 1975; Othieno and Laycock, 1977), percentage cover is shown to be vital in soil erosion. These experiments established that 30 % vegetal cover is about the most critical value although a cover of 60 % and greater gave very significant protection. Other studies, such as those conducted by Hussein and Laflen (1982), Laflen and Colvin (1981) and Mutchler and McDowell (1990), highlight the role of vegetal cover in controlling rainsplash.

Contrary to conventional expectations that the protective effect of vegetal cover would be greatest at low rainfall intensities, Morgan (1986), shows plant cover to be more effective in protecting the soil in higher energy storms rather than low energy storms.

Plant density adds to total percentage cover and to the continuity of the canopy just as plant litter does (Morgan, 1986). Finney (1984) established that percentage interception area increases while the volume of throughfall decreases and volumes of stemflow and leaf drip increase with plant growth. The kinetic energy under plant canopy, though low, tends to increase as the canopy area increases.

The height of the canopy influences the coalescence and hence the terminal velocity and drop size of falling raindrops. At low heights, these drops do not often break (Finney, 1984). Morgan (1986) indicated that waterdrops falling from 7 m high may actually attain over 90 % of their terminal velocity.

The interception of raindrops reduces raindrop impact on aggregate breakdown and so reduces rainsplash and detachment. Consequently, surface sealing and crusting is minimized while infiltration is enhanced. Because of the low soil and air temperatures associated with good vegetative cover, evaporative soil water losses are reduced and consequently soil moisture content is raised.

Any organic matter increase encourages biological activity in the soil and so inhibits soil surface sealing and crusting.

2.2.5. Slope

The influence of slope on surface sealing and crusting has not been widely researched. Slope affects surface sealing and crusting by influencing splash detachment and subsequent runoff (Lal, 1984; Morgan, 1986; Hudson, 1984).

Studies that have looked at the influence of slope on splash detachment and runoff indicate that at gentle slopes interrill erosion is dominant. As slope steepness increases, the process becomes rainfall detachment limited (McIsaac et al., 1987). This means rainsplash detachment is more dominant on gentle slopes than on steep slopes.

As slope steepness increases, more splash detachment takes place possibly because of the effective downward movement of particles (Quansah, 1981; Hudson, 1984) and probably because of the velocity that is imparted to other particles by the splashed ones (Kilewe, 1987). Quansah (1981) reports that splash detachment is a power function of kinetic energy and slope and that these are interdependent. He found that these two parameters accounted for 79 - 90 % of the variation in the amounts of soil detached. He therefore developed an equation of the form:

$$Q = a(KE)^b (S)^c \ldots\ldots\ldots\ldots [1]$$

Where, Q = Splash detachment (kg m^{-2}).

a,b,c = Empirically determined constants.

S = Slope percentage.

KE = Kinetic energy (J m^{-2}).

The significance of slope to surface sealing and crusting lies in the influence that it exerts on the mechanism of crust formation. McIntyre (1958b) and Epstein and Grant (1967), indicated least crusting where there was more splashing. On the other hand, due to continuous splashing and dispersion, a thin structural crust would form (Bisal, 1960; Farres, 1985; Watson and Laflen, 1986; Hadas and Stibbe, 1977). Where there is a slope break from steep to gentle, runoff velocity is reduced to allow more infiltration. Here, a depositional crust would form from soil materials carried down the slope (Chen et al., 1980; Kooistra and Siderius, 1985).

2.3. Effects of Soil Crusting

Crusting becomes a problem when the soil surface dries thus increasing the crust strength (Chaudhri et al., 1976;). This increase in crust strength creates conditions that adversely affect soil productivity. When the crust develops cracks, its adverse effects on seedling emergence and infiltration are somewhat reduced (Ahmad and Roblin, 1971).

Effects resulting from soil crusting include impedance of seedling emergence, creation of anaerobic conditions, reduction in infiltration and conductivity at the surface, increased runoff, impedance of gas diffusion and occurrence of rill erosion. On the whole, more research has been conducted on the effect of crusting on seedling emergence and infiltration.

2.3.1. Effect on Infiltration.

Skaggs (1982) has made a concise summary of some results on the effect of crusting on infiltration. In his earlier study that he has cited, he found that there was a dramatic reduction of infiltration on a crusted surface during the first few minutes. After eight minutes, infiltration was reduced to about 2 cm h^{-1} from about 6.4 cm h^{-1}. Other studies have confirmed that infiltration rates and hydraulic conductivity are reduced when a crust develops on a soil surface. For instance, Morgan (1986) cites reductions of about 90 % during studies in Israel and Mali. Ben-Hur et al. (1987), when comparing measurements of flood and sprinkler infiltrometers found values of 8.6 mm h^{-1} and 57 mm h^{-1} for the sprinkler infiltrometer and the flood infiltrometer respectively. The variability of the steady-state infiltration rates of the two methods also reflected the effect of crusting (41.8 % for the flood infiltrometer as opposed to 14.7 % for the sprinkler infiltrometer).

Edwards and Larson (1969) found that after 1 hour of soil exposure to raindrops, infiltration dropped by more than 50 %. In this study, saturated hydraulic conductivities for seals at 0.5, 1.0 and 1.0 hours were 0.7, 0.3 and 0.2 cm h^{-1} while infiltration values were 1.5, 1.05 and 0.94 cm h^{-1} respectively. This increasing disparity between saturated hydraulic conductivity and infiltration at increasing times indicate that the suction gradient through the seal was increasing with time. Hillel and Gardner (1969) attributed the reduction in porosity, infiltration and conductivity to hydraulic properties of both the crust and the sublayer soil. Bradford et al. (1987) also reported reduced infiltration rates that ranged from 1.2 to 36.0 mm h^{-1}.

2.3.2. Effect on Runoff and Sediment yield

Soil surface sealing and crusting are results of a combination of factors among them, soil properties. The effects of soil surface sealing and crusting on runoff and sediment yield will therefore depend on the rate of formation of a surface seal and crust.

Soil surface sealing and crusting enhance surface runoff and rill erosion in certain cases while they decrease sediment yields in other cases. Results from a study by Poesen and Govers (1985) show that sealing and compaction decrease the amount of raindrop detached material, sediment concentration in interrill runoff and soil loss. They also indicate that there was more detachment by raindrop on cultivated plots than on sealed plots although sealed plots lost more soil due to rill runoff.

Barber et al. (1979) observed similar patterns on a crusting soil. An initial increase in runoff was noted. Similarly, soil loss reached a peak early in the storm and then decreased. Likewise, infiltration rates were reduced. These reductions were attributed to changes in the soil surface.

Epstein and Grant (1967) found that splash had more soil loss than runoff water while water loss percentage highly correlated with soil loss in runoff water (r^2 = 0.90). Splash loss had r^2 of 0.03. They further noted that soil loss increased to maximum during the first 10 minutes then it decreased whereas the runoff rate remained constant after sometime. They attributed these changes in runoff and soil loss to crusting.

Cai et al. (1985) also made observations regarding soil loss, runoff and crusting. After maximum crust formation they found rainsplash transport rate to have reduced to as much as 70 % while rainwash and rill erosion were greatly enhanced. This increased runoff and sediment delivery rates by 6 - 25 times and 15 - 50 times respectively.

The phases of erosion, namely; aggregate breakdown, splash detachment, surface runoff turbulence and surface runoff scour, hinge on detachment and transport capacities of the system. Thus the amount of soil loss or sediment concentration is dependent on whether the system is transport limited or detachment limited and/or vice versa. The quantity and velocity of runoff therefore initiate detachment and transportation as well (Rose, 1960). Meyer and Monke (1965) are in agreement with Rose (1960) but they include runoff concentration as another determinant of the erosivity of runoff.

Poesen and Govers (1985) state that soil degradation increases surface runoff volume and rill erosion potential while Lal (1984) indicates that soil detachment and splash are directly proportional to the soil surface exposed. Meyer and Monke (1965) concluded that the propensity of a soil to erosion depends on infiltration characteristics, detachability and transportability.

Poesen and Govers (1985) and Epstein and Grant (1967) found patterns of soil loss where the initial phase was marked by increasing soil loss and sediment concentration. The later phase was of decreased soil loss and sediment concentration.

2.3.3. Effect on Gas Diffusion

Gas diffusion in soil is significantly affected by the formation of crusts. Ahmad and Roblin (1971) show lowered gaseous diffusion due to crust formation. When the soil samples were crusted and wet, gaseous diffusion fell to 11 and 6 % from 23 and 16 % respectively. Hanks and Thorp (1956) also recorded lowered oxygen diffusion. Stepniewski (1985) states that surface sealing might impede gas diffusion through the surface up to a moisture tension of 20 kPa and that, the coefficient of gas diffusion could be lowered below 0.5 % of that of the atmospheric coefficient, at soil moisture tensions of up to 100 kPa, when soil surface sealing (bulk density of 154 mg m^{-3}) occurs.

2.3.4. Effect on Seedling Emergence

Successful emergence of seedlings contributes to better yields. This has prompted research into the effect of soil crusts on seedling emergence and consequently leading to the conclusion that formation of a crust on a soil surface adversely affects seedling emergence.

Hadas and Stibbe (1977) studied the emergence of wheat seedlings. They reported that when the crust resistance was less than 4 - 6 bars, there was no emergence problem with wheat. Similarly, Hanks and Thorp (1956; 1957) concluded that crust strength greatly affects emergence of wheat seedlings. Seedling emergence decreased more rapidly with unit increase in crust strength (at crust strength below 200 millibars). This trend was pronounced in the drier end of the available moisture range. They also reported that an increase in crust resistance from 108 to 273 millibars decreased emergence of bean seedlings from 100 % to 0 %. Epstein and Grant (1973) have also cited a case which showed that there was no seedling emergence at a penetrometer resistance of 15.5 bars.

Other studies have reported that yields of corn varied inversely as the hardness of the soil with r = 0.77 at $P<0.001$ (Swanson and

Jacobson, 1956). Bilbro and Wanjura (1982) found that the mean emergence date was delayed in a linear manner as the penetrometer resistance increased (r = 0.851) and the emergence percentage declined linearly as the penetrometer resistance increased (r = -0.967). They also report that the emergence rate index declined linearly with an increase in penetrometer resistance (r = -0.979).

By and large, the impedance of gaseous diffusion, creation of anaerobic conditions, occurrence of rill erosion and increased runoff resulting from surface crusting have been based on the fact that reduced infiltration would either encourage more runoff or waterlogging depending on topography. The former would encourage soil loss while the later would favour anaerobic conditions.

2.4. Assessment of Crusting

Several methods of assessing surface crusting have been developed over time and can be categorized as: visual observation, micromorphological studies and indices of crust strength. The last two methods are the most widely applied in scientific studies of crusting phenomena.

2.4.1. Visual Observation

Visual observation is a qualitative and subjective way of assessing surface crusting. It involves the investigation of visible features of a crust (occurrence, form and size). This method is not scientific in approach but rather gives an estimation of the extent of the crusting problem in a given area.

2.4.2. Micromorphological Studies

The advent of electronic equipment for measurements and observations has made micromorphological analysis of crusts easier. Particular features of crusts are easily analyzed and measured to enable characterization. Features usually analyzed include thickness, compactness, porosity and general configuration of crusts.

Many scientists have and are using this approach when analyzing crusts. Onofiok and Singer (1980), Kooistra and Siderius (1985) Luk et al. (1990) and Farres (1985) among others have effectively applied this method to crust analysis.

The method involves slicing a cross-section of a crust and examining it using electronic microscopes. An added advantage of this method is that microphotographs of the cross-section can be made. These photographs give a visual impact of the various features of a crust. However, the disadvantage of this method lies in its inability to measure crust strength.

2.4.3. Indices of Crust Strength

This approach relates the force that was applied when a crust is ruptured, to the strength of the crust. Soil properties such as moisture content, organic matter content, aggregation and clay content are therefore implicitly reflected since they influence the strength of a crust.

The two indices that are widely used are the cone index and the modulus of rupture index. Cone index is used in penetrometer measurements. It is a measure of penetration resistance and is expressed as the force required to produce a given penetration divided by the cross-sectional area of the probe (Ayers and Perumpral, 1982; Waldron and Constantin, 1970). A penetrometer, as defined by Davidson (1965), is any device forced into the soil to measure resistance to vertical penetration.

Modulus of rupture (MOR) is a concept relating to the breaking strength of beams. It is an index of strength of material and is expressed as the maximum stress in the material when fracture occurs in bending (Reeve, 1965). Using a rectangular beam and soil briquets, Reeve gives the following relationships.

$$F = \frac{2bd^2S}{3L} \qquad [2]$$

$$S = \frac{3FL}{Sbd^2} \ldots\ldots\ldots\ldots\ldots\ldots [3]$$

Where S = Crust strength (dyne cm^{-2} or bar).

F = Force applied at centre of beam (dynes).

L = Distance between briquet and support (cm).

b = Width of briquet (cm).

d = Depth or thickness of briquet (cm).

Kemper et al. (1975) worked with soil cylinders and modified the equation. He gives the relationship as:

$$F = \frac{\Pi}{2} SDL \ldots\ldots\ldots\ldots\ldots\ldots [4]$$

$$S = \frac{2F}{\Pi DL} \ldots\ldots\ldots\ldots\ldots\ldots [5]$$

Where S = Crust strength (g cm^{-2} or bars).

F = Force applied (g).

D = Diameter of sample (cm).

L = Length of sample (cm).

Other less widely used methods of determining crust strength based on modulus of rupture are the shear vane and fishing line methods

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Other less widely used methods of determining crust strength based on modulus of rupture are the shear vane and fishing line methods

(Page and Hole, 1977). Sometimes, seedling emergence is used directly as an indicator of crust strength (Hadas and Stibbe, 1977; Hanks and Thorp, 1956; Hanks and Thorp, 1957; Chaudhri et al., 1976; Swanson and Jacobson, 1956).

Other scientists have conducted measurements of physical parameters such as moisture content, infiltration, bulk density and gas diffusion and have related the parameters to crust properties (Bradford and Ferris, 1987; Ben-Hur et al., 1987; Morin et al., 1989; McIntyre, 1958a).

Using the later method, Hadas and Stibbe (1977), derived the relationship of crust strength to water content. This relationship is given as:

$$S = B \exp^{(-aPw)} \ldots\ldots\ldots\ldots\ldots\ldots [6]$$

Where S = Crust strength (bars)

a = Pure number (bars)

B = Constant (bars)

Pw = Water content of crust (%)

Crust strength as measured by penetrometer resistance varies with a number of factors such as texture (Onofiok and Singer, 1984; Tarchitzky, 1984), soil organic matter (Nuttall, 1970; Haynes and Swift, 1990; DePloey, 1980), bulk density and soil moisture tension (Mirreh and Ketcheson, 1972; Perumpral, 1987; Busscher and

Sojka, 1987).

A number of shortcomings for both penetrometer and modulus of rupture measurements have led to modifications in their applications. Holder and Brown (1974) state that the use of modulus of rupture for seedling emergence studies is unsatisfactory since many factors influence seedling emergence. They developed another approach of using a probe from below.

A comprehensive critique on soil crust measurements is given by Page and Hole (1977). Waldron and Constantin (1970), Ayers and Perumpral (1982) and La et al. (1985) have evaluated penetrometer measurement methods while Debicki and Wontroba (1985) look at both modulus of rupture and penetrometer methods. Perumpral (1987) gives a very comprehensive review of cone penetrometer applications.

The main features that come out regarding methods of assessing crusts are that comparisons between methods are difficult because of differences in designs, methods of measuring and experimental conditions, giving rise to high coefficients of variation. There is therefore, no evidence to the effect that one method is better than the other (Page and Hole, 1977).

CHAPTER III

3. MATERIALS AND METHODS

3.1. Characterization of Soils

All the four soil samples used in this laboratory study were collected from a depth of up to 15 cm of the topsoil layers of luvisols (FAO/UNESCO, 1974 classification). The luvisol types included a plinthic luvisol, a chromic luvisol, and two orthic luvisols.

The four topsoil samples have been designated as indicated here below and have been referred to as such throughout the document.

Sandy loam topsoil from chromic luvisol = Sample A.
Sandy clay loam topsoil from orthic luvisol = Sample B.
Sandy clay loam topsoil from plinthic luvisol = Sample C.
Clay loam topsoil from orthic luvisol = Sample D.

Table 3.1. below gives the percentage of soil separates for the topsoil samples. Sample A has 45 % fine and very fine sand, sample B, 36 %, sample D, 26 % and Sample C, 35 %. Except for sample D, the other samples have overall percentage of sand content of 59 % and over. Silt content is generally low while clay content is

higher than silt content.

The main difference between samples B and D is that sample B is a sandy clay loam with a sand content of 67 % while sample D is a clay loam with 34.5 % sand. The former has 1.1 % fine silt while the latter has 10.1 %.

According to Hadas and Stibbe (1977), the samples fall into the category of soils that have crusting problems.

Prior to applying treatments, sample A had 1.1 % organic matter, sample B, 1.5 %, sample D, 5.6 % and sample C, 1.7 %. Other characteristics are listed in appendix 2.

Table 3.1. Percentage Distribution of Soil Separates for the Topsoil Samples Studied (pipette method).

Particle size classification	Topsoil sample Sample A	Sample B	Sample D	Sample C
Sand, Very coarse	3.9	3.0	0.6	3.2
Coarse	5.5	7.5	1.2	6.3
Medium	22.1	21.6	7.1	15.8
Fine	33.7	26.1	16.0	24.7
Very Fine	11.0	9.5	9.6	9.9
Silt, Coarse	2.3	6.1	5.3	1.5
Medium	1.8	2.1	11.7	4.1
Fine	0.6	1.1	10.1	5.6
Clay	19.1	23.0	38.4	28.9
Texture Class (USDA)	SL	SCL	CL	SCL

(SL = Sandy loam; SCL = Sandy clay loam; CL = Clay loam).

3.2. Farmyard Manure.

Farmyard manure was applied as a soil amendment for all the topsoil samples. This farmyard manure was a mixture of cow dung and grass straws. The chemical composition, based on the wet digestion method and using the atomic absorption spectrophotometry, flame photometry and colorimeter, is given in table 3.2 below.

Table 3.2. Chemical composition of Farmyard manure applied in the Experiment.

Nitrogen (% N)	Phosphorus (% P)	Potassium (% K)	Calcium (% Ca)	Magnesium (% Mg)	Manganese (% Mn)	Sodium (% Na)	Zinc (% Zn)	Copper (% Cu)
2.07	1.25	3.00	0.50	0.10	0.30	1.75	0.03	Trace

(Analysed by the Kenya Agricultural Research Institute - KARI)

3.3. Rainfall Simulator

A rainfall simulator described by Kamphorst (1987) was used in simulating the rainfall (see table 3.3, fig. 3.1 and plate 3.1). The simulator consists of the following components.

A sprinkler (A) with a built in pressure regulator based on the Mariotte bottle principle for the production of a standard rain shower.

A support (B) for the sprinkler which also functions as a wind shield.

The sprinkler has a calibrated cylindrical water reservoir (a) with a capacity of 2000 ml. Water is discharged from the sprinkling head (b) through 49 capillaries (c). The discharge rate is determined by the length and inner diameter of the capillaries.

The pressure head on the capillaries can be adjusted by moving the aeration tube (d) upward or downward. Lower ends of the capillaries have a short piece of tubing (e) whose inner diameter controls the drop size and frequency.

After filling the cylinder with water, the cork is replaced on the opening (f) and the sprinkler placed on the support frame (B). The removal and replacement of the cork (g) from the aeration tube initiates and stops sprinkling respectively.

In this study, the frame was fitted into the soil tray (C). The latter fitted into the percolate collector (D). The soil tray and the percolate collector were designed to fit with the rainfall simulator (plates 3.1 and 3.2 and appendix 9).

The soil trays were 25.2 cm wide, 26.2 cm long and 10 cm deep with a surface area of 0.0625 m^2. At the bottom of each tray was a 4 mm wire mesh which was supported by a welded mesh to prevent sagging due to the soil mass. A non absorbent cloth was laid over the wire mesh to stop the soil from falling through to the percolate collector below. The complete assembly is shown in plate 3.2.

Table 3.3. Specifications of the Rainfall Simulator (Kamphorst, 1987).

Magnitude of shower	18 mm
Duration of rainshower	3 min
Intensity of rainshower	6 mm/min
Average fall height of drops	400 mm
Diameter of drops	5.9 mm
Mass of drops	0.106 g
Number of capillary tubes	49
Kinetic energy	35.4 J/mm
Surface area of trays	0.0625 m^2

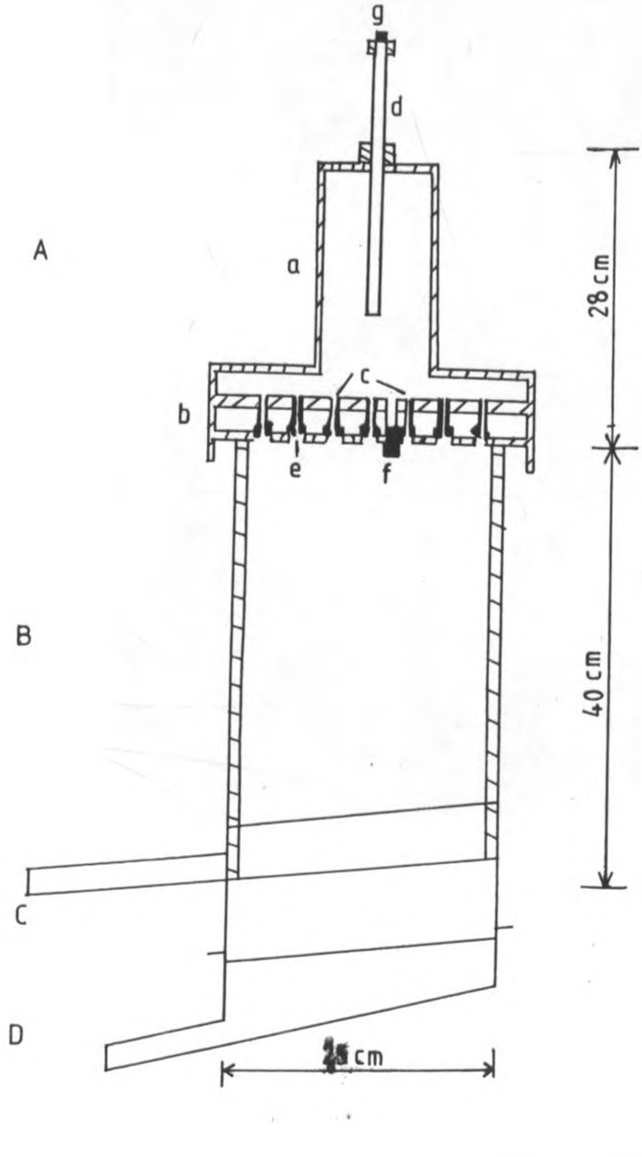

Fig. 3.1. Cross-section of the Rainfall Simulator with a soil tray and Percolate collector.

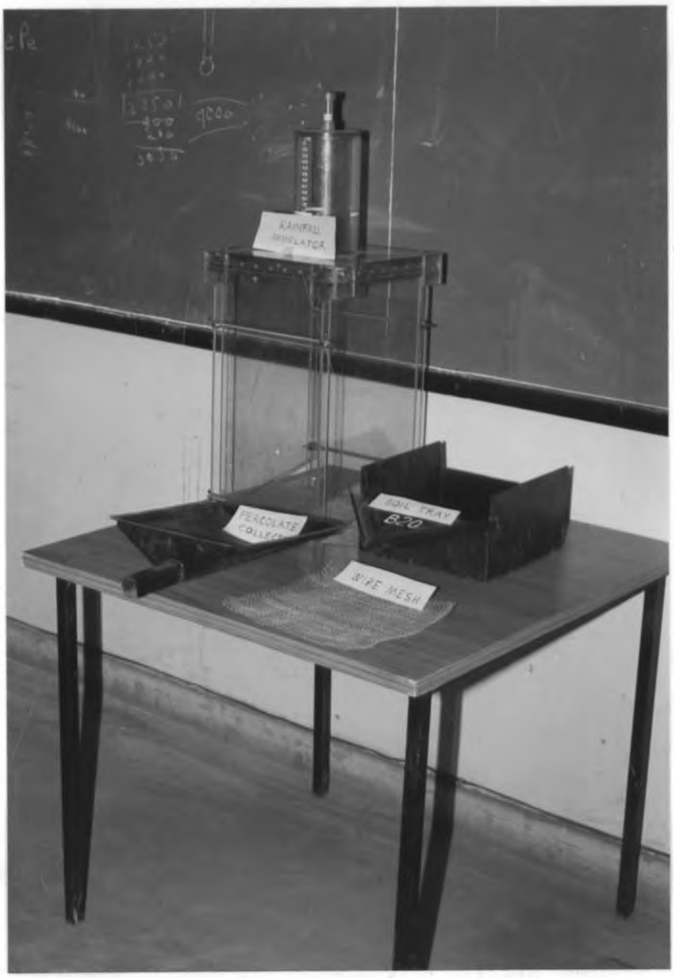

Plate 3.1. Rainfall Simulation Equipment.

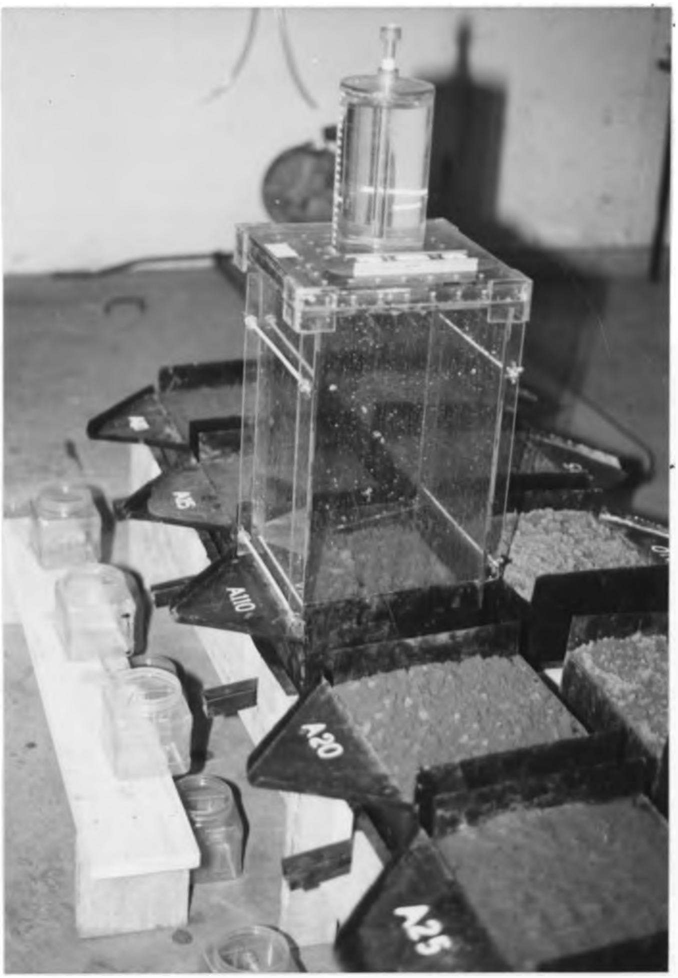

Plate 3.2. Experimental set up of Rainfall Simulation Equipment.

3.4. Cone Penetrometer

A hand held cone penetrometer for top soil layers (type 1B, Eijkelkamp Equipment) was used in this study (plate 3.3). This instrument measures the penetration resistance by means of a compression spring.

There are two cone types (0.25 cm^2 and 0.5 cm^2) 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.

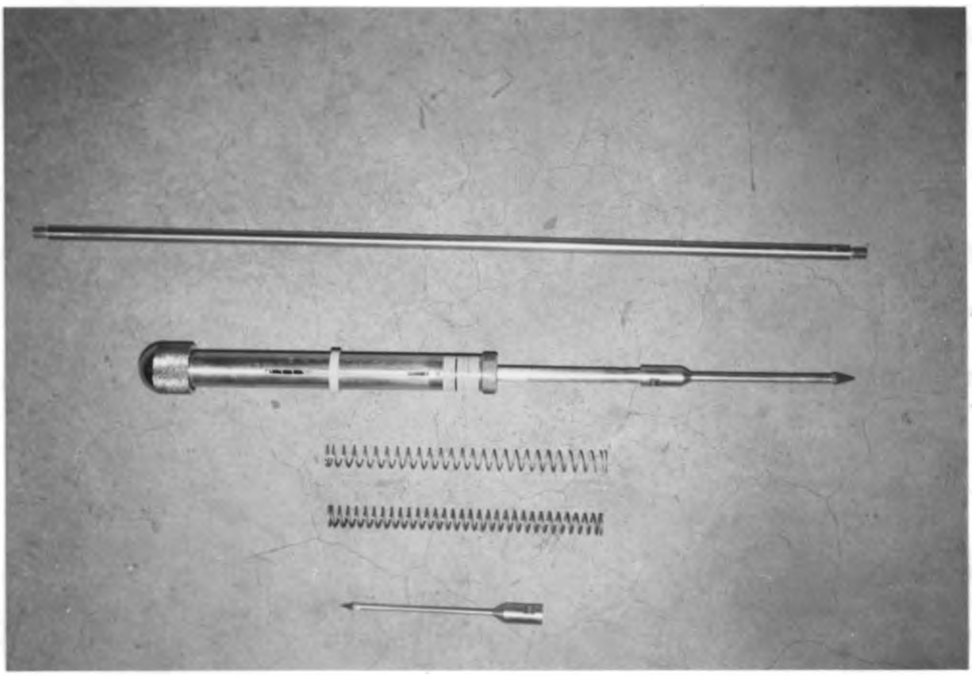

Plate 3.3. Cone Penetrometer and additional Components.

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.

3.5. Experimental Design

The experiment was based on a completely randomised design but for data analysis, the randomized block design model was used as well. Each block represented a particular topsoil type and consisted of nine trays which were made up of three treatments, each replicated three times.

3.6. Treatments

Two farmyard manure application rates of 5 t ha^{-1} and 10 t ha^{-1} and a control (no manure applied) were investigated. Before application, farmyard manure was ground so as to reduce the crumb sizes. This was later sieved through a 4 mm sieve.

Prior to packing the soil, a 2 cm thick layer of river sand that passed through a 4 mm sieve was packed at the base of the trays. The soil was then overlain on the sand. From a height of 5 cm, the trays were dropped to the floor. This was repeated five times. The soil trays were then refilled to the brim again. The dropping of the soil trays enabled uniform compaction and packing in the initial stage.

Pre-wetting was conducted with 1600 ml of water allowing no splashing and runoff. A day later, the soil surfaces were broken up and farmyard manure was incorporated to a depth of 5 cm in required proportions.

3.7. Experimental Procedure

The effective total period of the experiment was 60 days divided into three experimental phases of 20 days each. Each phase involved rainfall simulation for four consecutive days, drying in the sun for five hours for four days and measuring penetration resistance and sampling for moisture content and organic matter content.

A day after breaking soil surfaces and applying farmyard manure, rainfall simulation was initiated. Prior to simulation, the simulator was calibrated such that water discharge was 375 ml per minute. During simulations, sprinkling was conducted for 3 minutes giving a total of 1125 ml of discharged water. This is equivalent to 18 mm of rainfall at an intensity of 360 mm h^{-1} with a total kinetic energy of 637.2 Joules. During rainfall simulations, the sprinkling head was moved sideways in all horizontal directions to enable random distribution of drops over the soil surface.

The soil trays were on a slope of 5 % so the simulator frame had to be adjusted such that the top, where the sprinkler rests was horizontal.

After the fourth day of simulation, the soil trays were taken out in the sun for five hours. This was repeated for the following three days after which the soil trays were kept in the laboratory where sampling for moisture content and organic matter content and measuring penetration resistance were conducted.

Run-off and soil loss were collected during and after every rainfall simulation.

Sampling for penetration resistance and moisture content were based on a grid system where the cells to be sampled were predetermined using random numbers. Three cells were selected per tray per each sampling day. Sampling was carried out a day after the fourth rainfall simulation and every fifth day thereafter up to the sixteenth day. Samples for organic matter and aggregate stability analyses were collected on the sixteenth day after the fourth simulation.

On every seventeenth day after the fourth simulation, the soil surfaces were again broken up and simulations continued as before.

3.8. Collection of Data

3.8.1. Crust Strength

A hand held cone penetrometer was pushed into the soil at a constant rate (approx. 2 cm s^{-1}) and the following formula employed to calculate penetration resistance.

$$CR = I * \frac{C_s}{A_c} \ldots\ldots\ldots\ldots\ldots\ldots [7]$$

where CR = Cone resistance (N cm^{-2})

I = Impression on the scale (cm)

C_s = Spring constant (N cm^{-1})

A_c = Area of cone (cm^2)

Multiplying the result by 0.1 gives cone penetration resistance in kg cm^{-2}.

3.8.2. Runoff and Soil Loss

Runoff and soil loss were determined by weighing and oven drying eroded sediment at 105°C for 24 hours. Immediately after collecting runoff and the sediment, the bowls together with runoff and the sediment were weighed. Aluminium hydrate [$AlK(SO_4)_2.12H_2O$] was added as a flocculant. The bowls were left to settle for 24 hours after which water was carefully decanted. The various components were discerned as follows.

$$RS = M_t - T \ldots\ldots\ldots\ldots\ldots\ldots [8]$$

Where RS = Runoff plus sediment yield (g)

M_t = Weight of bowl plus runoff plus sediment (g)

T = Weight of bowl (g)

$$SL = [S_d + T] - T \ldots\ldots\ldots\ldots\ldots\ldots [9]$$

Where SL = soil loss (g)

S_d = weight of oven dried soil (g)

T = weight of bowl (g)

$$R = RS - SL \ldots\ldots\ldots\ldots\ldots\ldots [10]$$

Where R = collected runoff (g)

SL = Soil loss (g)

RS = Runoff plus sediment yield (g)

The weight of runoff (g) was directly read as runoff in millilitres since 1 g of water at 20°C is equivalent to 1 ml.

3.8.3. Crust Moisture Content

Three samples from the three preselected cells were mixed to make a composite sample, weighed then oven dried at 105°C for 24 hours. Moisture content on a dry weight basis was then determined using the equation:

$$WC = \frac{[S_w + T] - [S_d + T]}{[S_d + T] - T} * 100 \ldots\ldots\ldots\ldots [11]$$

Where WC = Moisture content (%).

S_w = Weight of wet soil (g)

S_d = Weight of oven dried soil (g)

T = Weight of bowl (g)

3.8.4. Crust Organic Matter Content

Variations in organic matter content (with time and with manure application rates) among the soil samples were monitored during the experimental period. The Walkley-Black Method was used to determine the organic carbon content of each sample. To get the percentage organic matter content, organic carbon was multiplied by a conversion factor of 1.73.

3.8.5. Degree of Aggregation

Air dried soil was passed through a 5 mm sieve from which three 25 g samples were taken. These were added to a set of 2, 1, 0.5, 0.25 and 0.18 mm sieves on a sieve shaker. After shaking for 10 minutes, the remaining soil on each sieve was weighed to the nearest 0.01 g and expressed as a percentage of the total soil sample.

3.9. Analysis of Data

Three methods of data analysis were employed, namely analysis of variance (ANOVA), regression and correlation analyses. All these were based on a 5 % level of significance.

Through ANOVA, the main tests carried out covered the variations in the data for each tray, between trays and between the topsoil types (blocks). Both completely randomized and randomized block designs were thus employed. The variables analyzed included treatment, topsoil type, phase and simulation/sampling day effects.

Multiple comparison test, in this case the Duncan's Multiple range Test (Miller and Freund, 1985), was employed to compare the range of sample means with least significant ranges.

CHAPTER IV

4. RESULTS AND DISCUSSION

4.1. Soil Properties

4.1.1. Degree of Soil Aggregation

Dry sieving test on the degree of aggregation showed that sample A had 83 % of aggregates that were less than 500 µm in stable aggregation, sample B had 65 %, sample D had 53 % and sample C 68 % of the aggregates. This is indicative of high friability of these topsoils when they are dry. Soil aggregation remained stable only when the aggregates were less than 500 µm in size.

Duncan's Multiple Range Test (0.05 probability level) indicates that sample A had much more aggregates that were less than 180 µm (35.5 %) than other size category. Sample B had more aggregates in the 250 - 500 µm and the <180 µm size categories while samples C and D had the largest percentages in the 250 - 500 µm category. Generally, sample D had more bigger aggregates than the other topsoil samples (see figures 4.1 to 4.6).

Samples A, B and C had increased percentages of aggregates less than 250 µm after 60 days for all treatments. The increases for $10\ t\ ha^{-1}$ treatments were not as high as for other treatments.

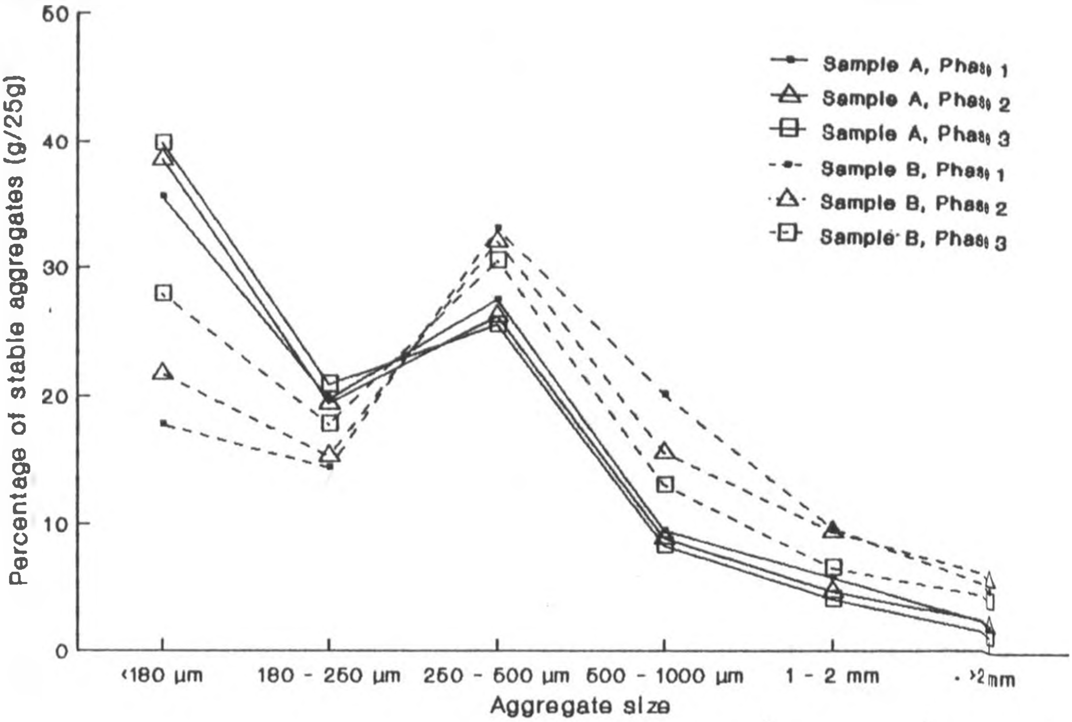

Fig. 4.1. Percentage of Aggregates in each Aggregate Size Category for Samples A and B (controls).

There was a decrease in the percentage of aggregates between 250 µm and 2 mm and an increase in aggregates greater than 2 mm for $10\ t\ ha^{-1}$ treatments for samples A and B.

Sample C had increased aggregates of less than 250 µm in all the treatments (figures 4.7 and 4.8). Sample D had slight increases in aggregates that were less than 500 µm but significant changes were manifested in aggregate sizes that were greater than 1 mm.

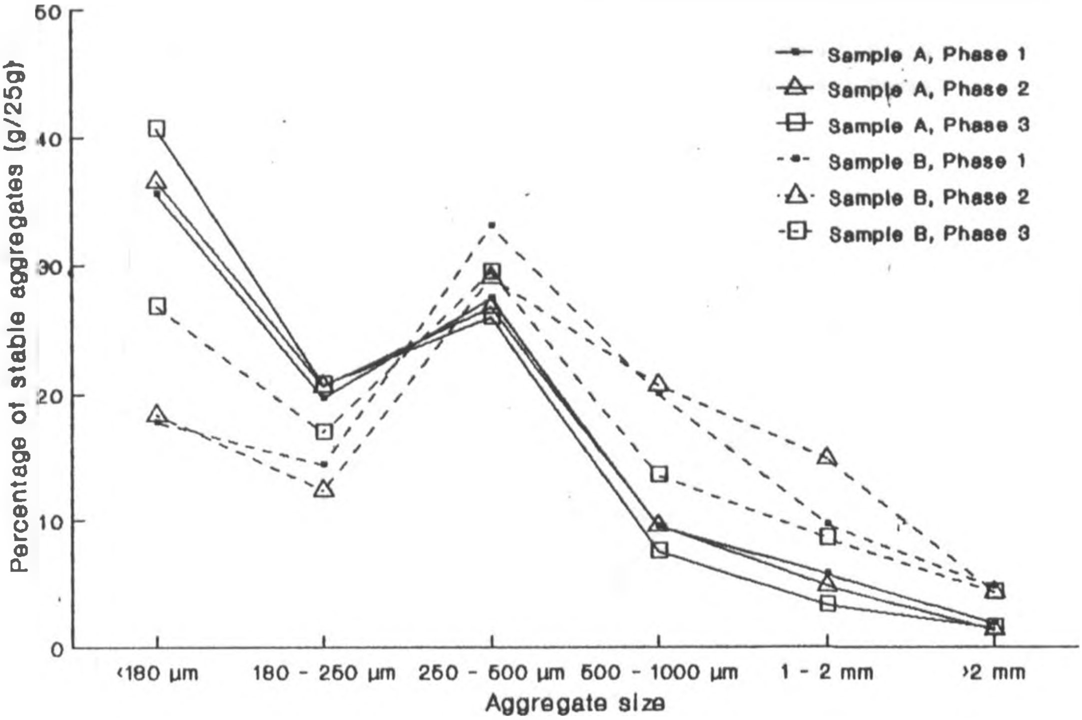

Fig. 4.2. Percentage of Aggregates in each Aggregate Size Category for Samples A and B (5 t ha^{-1} treatment).

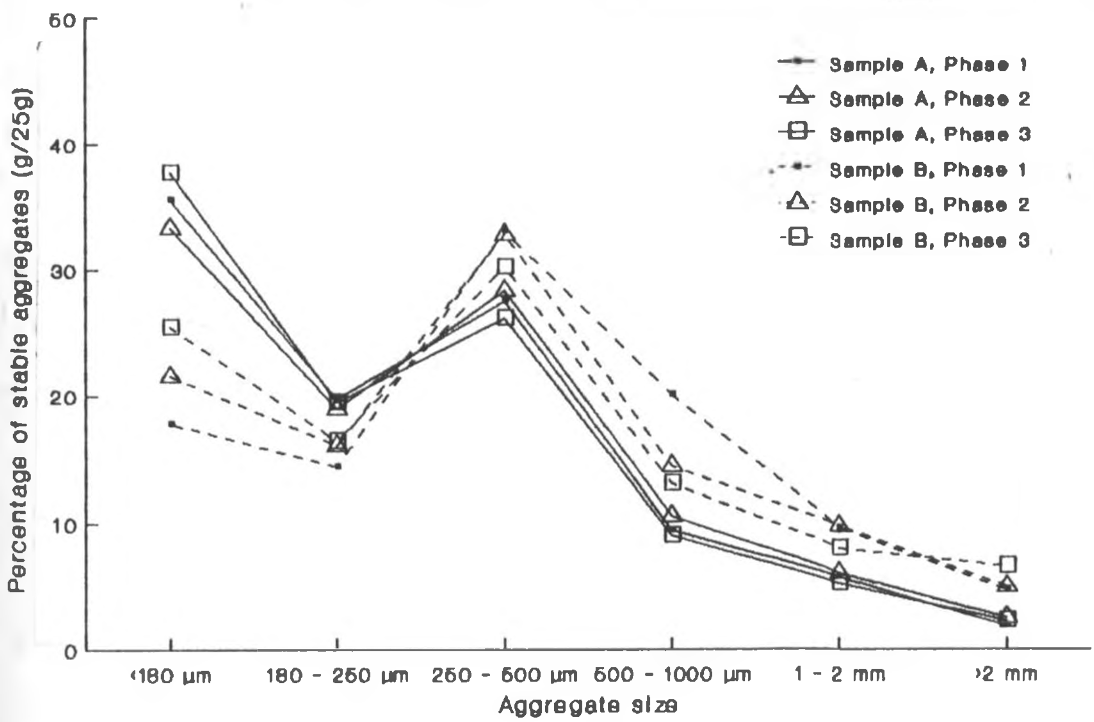

Fig. 4.3. Percentage of Aggregates in each Aggregate Size Category for Samples A and B (10 t ha^{-1} treatment).

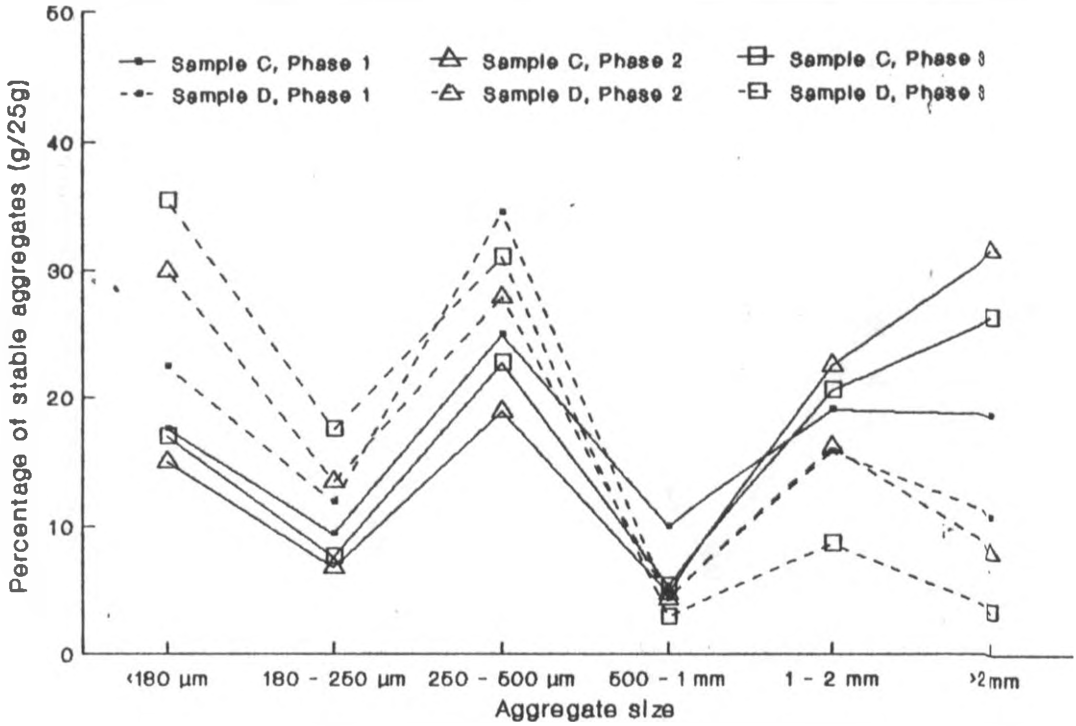

Fig. 4.4. Percentage of Aggregates in each Aggregate Size Category for Samples C and D (controls).

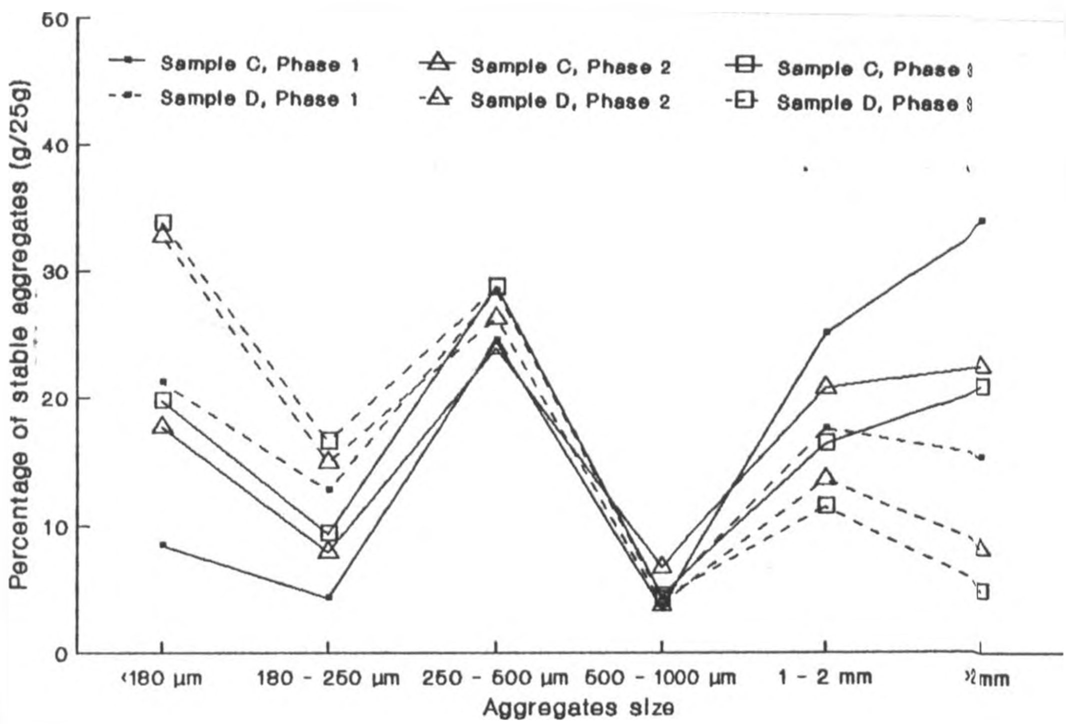

Fig. 4.5. Percentage of Aggregates in each Aggregate Size Category for Samples C and D (5 t ha^{-1} treatment).

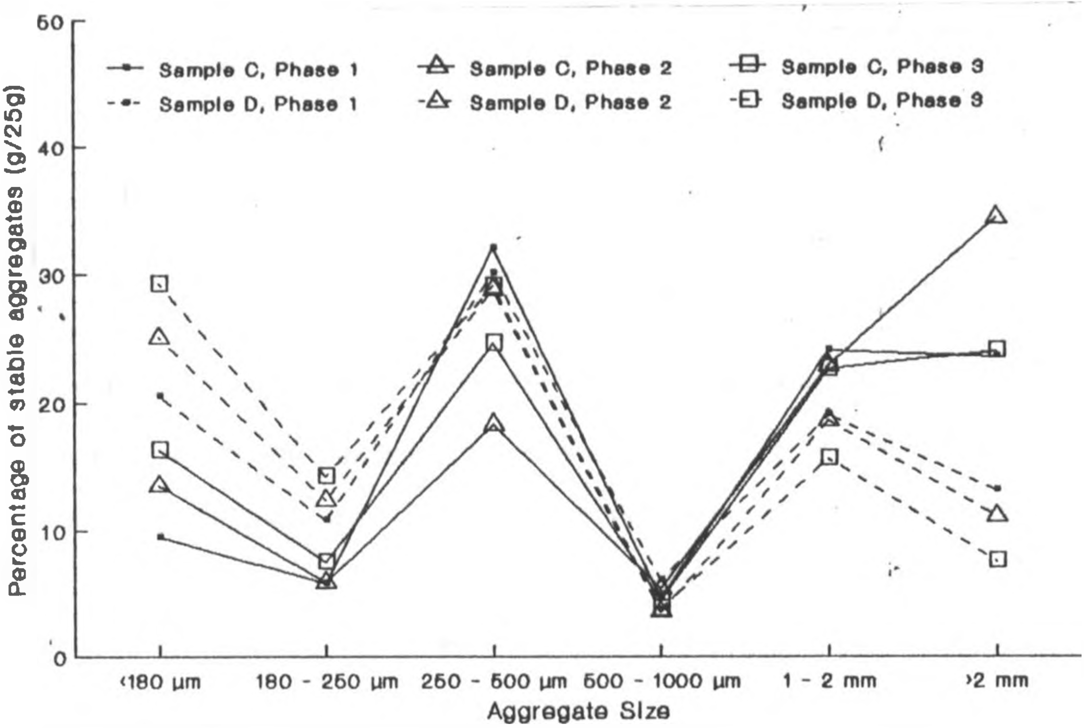

Fig. 4.6. Percentage of Aggregates in each Aggregate Size Category for Samples C and D (10 t ha^{-1} treatment).

The general trend for sample A was that with time, more aggregates became stable when they had a size of 250 µm or less. This trend did not change with the application of 5 t ha^{-1} manure. However, 10 t ha^{-1} manure had an effect in that stable aggregates of sizes greater than 2 mm increased by 0.4 % by the end of 60 days.

The control and 5 t ha^{-1} treatment for sample A had a higher increase in stable aggregates (4.4 % and 5.2 %) of less than 250 µm in size than 10 t ha^{-1} treatment (2.3 %). The highest increase in aggregates was for 5 t ha^{-1} treatment with 5.2 %.

With sample B, the control and 5 t ha^{-1} treatments more stable aggregates that were less than 250 μm in size. The control had the highest increase of 10.1 %. 10 t ha^{-1} treatment also raised the percentage of aggregates that were greater than 2 mm in size by 1.9 %.

Five tonnes per hectare treatment for sample D showed an increased percentage of aggregates less than 500 μm in size. The highest aggregate increase of 3.53 % was for the 250 - 500 μm size range. The control and 10 t ha^{-1} treatment reduced the peroentage of aggregates less than 1 mm. For all treatments, there was a significant gain in aggregation for all sizes greater than 1 mm. The highest gain was in aggregates greater than 2 mm. The control had the highest (9.62 %) followed by 10 t ha^{-1} treatment (7.24 %) and then 5 t ha^{-1} (4.19 %).

Sample C had the highest increase (in the control) for aggregate sizes of less than 250 μm (14.35 %). The 5 and 10 t ha^{-1} treatments also gained (12.62 and 8.16 % respectively) but not as much as the control. The losses in the percentage of aggregates greater than 500 μm go up to as high as 10.54 % for 5 t ha^{-1} treatment. This is indicative of easily dispersible aggregates.

Generally, data on soil aggregation suggest that the application of manure increased the degree of aggregation in most aggregate size categories. Applying 10 t ha-1 manure increased aggregation in samples A and B.

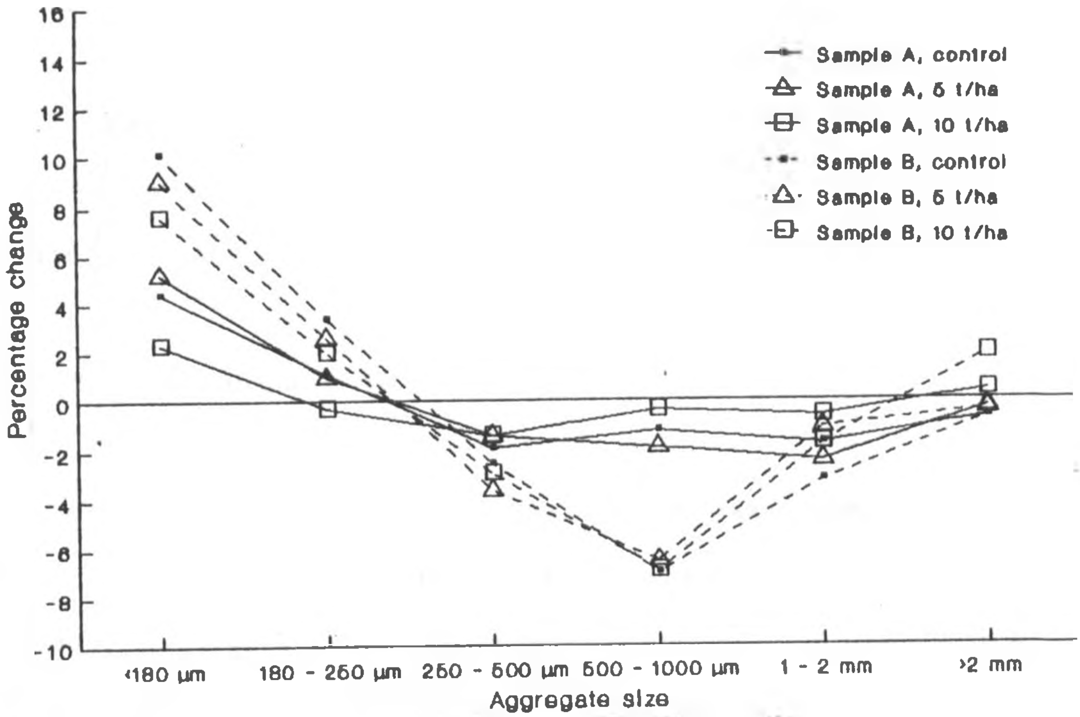

Fig. 4.7. Percentage Change in Aggregates in each Particle size Category after 60 days (samples A and B).

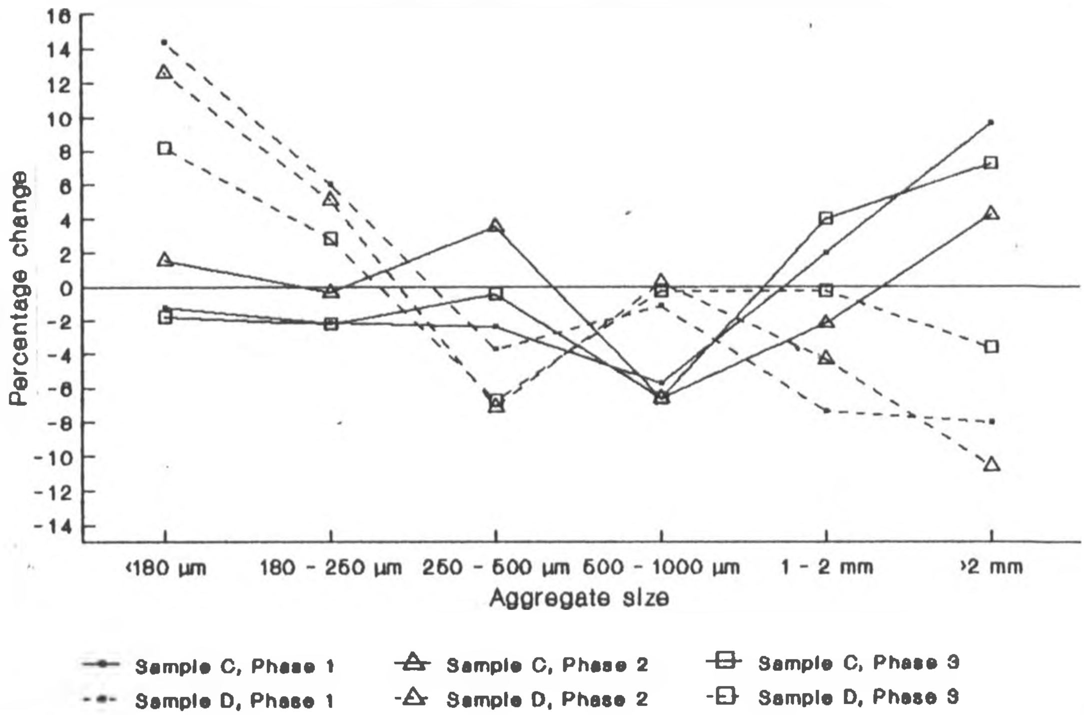

Fig. 4.8. Percentage Changes in Aggregates in each Particle size Category after 60 days (samples C and D).

For sample C and sample D, the former gained in aggregates of sizes greater than 1 mm while the latter gained in aggregates of sizes less than 250 µm but lost in those sizes greater than 500 µm. An increase in the percentage of aggregates of very small sizes shows the ease with which crumbs were broken down.

4.1.2. Crust Organic Matter

Organic matter content in the topsoils increased when farmyard manure was added but after the first and second experimental phases, there were decreases in organic matter. The highest and lowest losses occurred where 10 t ha^{-1} manure was applied. Sample C gave the highest losses of 1.2 and 1.7 % during phases 1 and 2 respectively. The lowest losses were for sample B after phase 1 and for sample A after phase 2.

Table 4.1. Percentage increase in Organic Matter content after applying Treatments.

Topsoil sample	Treatment 5 t ha^{-1}	10 t ha^{-1}
Sample A	0.12	0.50
Sample B	0.46	0.53
Sample C	0.12	0.88
Sample D	0.35	0.74

Table 4.1 indicates the respective increases in organic matter content after applying farmyard manure. With 5 t ha^{-1} manure application, sample B had the highest increase of 0.46 % followed by sample D with 0.35 %. For 10 t ha^{-1} application rate, sample C

had the highest increase (0.88 %) followed by sample B (0.74 %).

The addition of farmyard manure raised the organic matter content such that even after phase 2 of the experiment, trays with manure maintained a higher percentage of organic matter. Figures 4.9 and 4.10 also reveal the effect of time lapse. All the topsoil samples and their treatments showed a gradual decrease in organic matter content over time. Table 4.2 gives the overall decrease in organic matter content of the topsoil samples after 60 days.

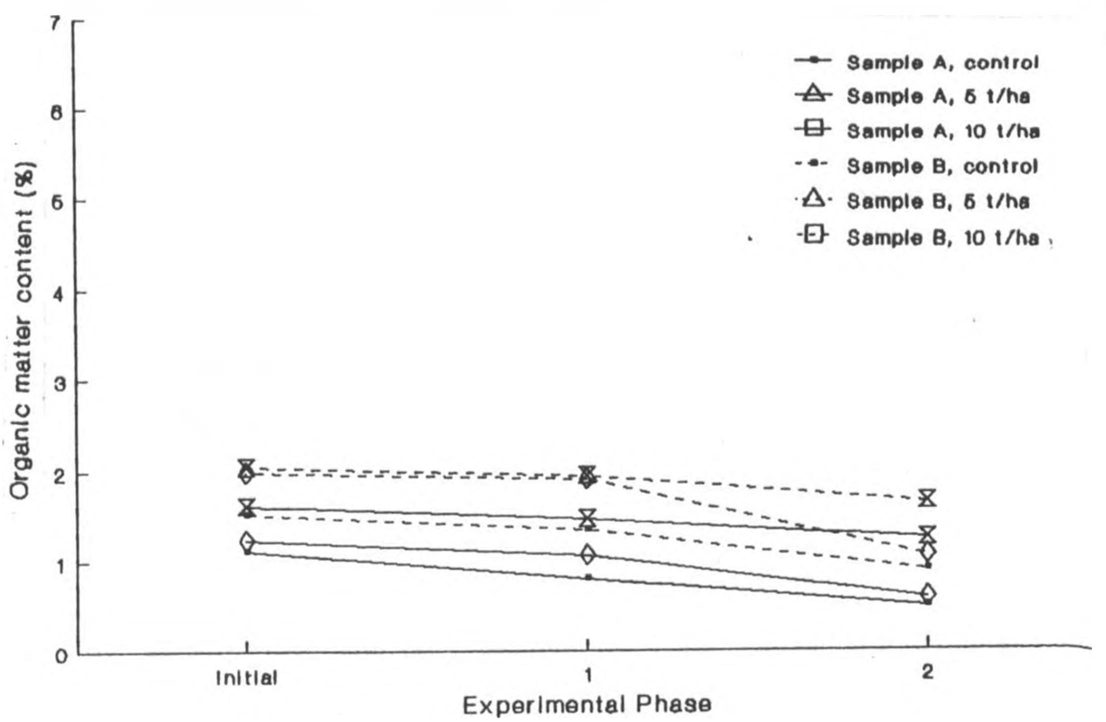

Fig. 4.9. Changes in Organic Matter Content for Samples A and B.

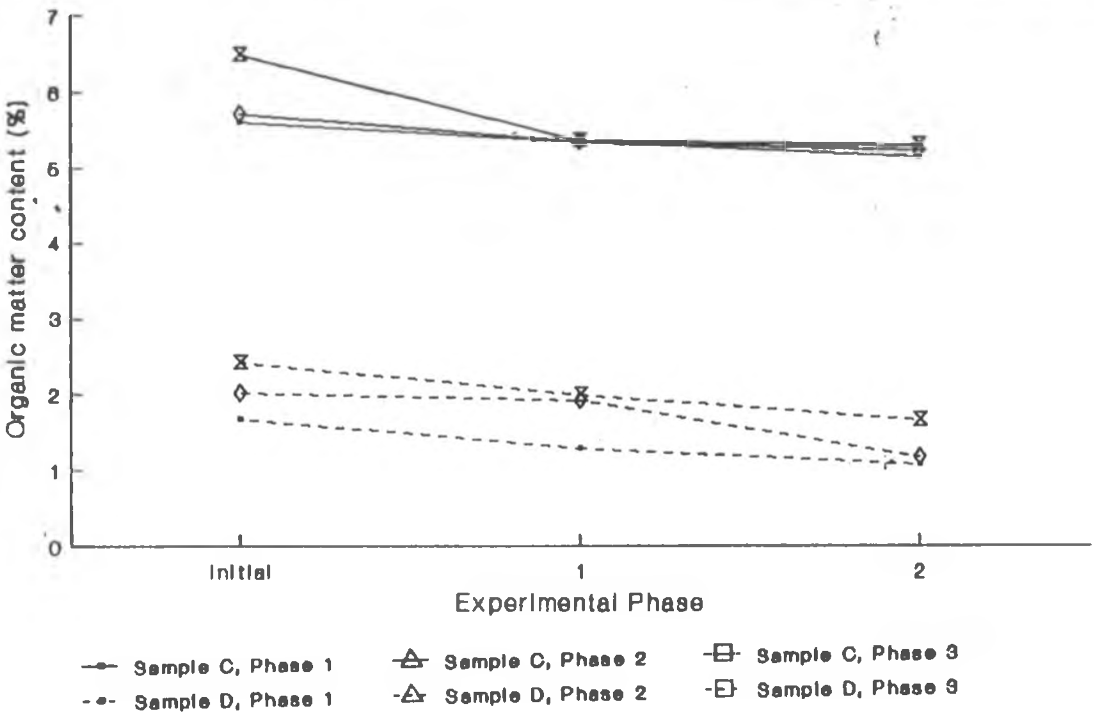

Fig. 4.10. Changes in Organic Matter Content for Samples C and D.

Table 4.2. Percentage decrease in Organic Matter Content of the Topsoil Samples after 60 days.

Topsoil sample	Control	Treatment 5 t ha^{-1}	10 t ha^{-1}
Sample A	0.62	0.64	0.36
Sample A	0.61	0.91	0.39
Sample C	0.46	0.48	1.17
Sample D	0.60	0.85	0.75

The 5 t ha^{-1} treatments gave the highest decrease in organic matter except for sample C where 10 t ha^{-1} gave the highest. Lowest decreases were for 10 t ha^{-1} treatment in samples A and B while for sample D and sample C, the controls had the lowest decreases.

This behaviour is not easy to explain unless individual topsoil samples are studied particularly to determine physical and chemical reactions. Considering that there was no crop grown and that the incubation period was short, the decline in organic matter could partly be due to loss as wash load as well as decomposition.

4.2. Soil Surface Sealing and Crusting.

The degree of soil surface sealing was not measured but as pointed out by Bradford et al. (1987), surface sealing causes increased runoff. Moldenhauer and Kemper (1969) and Epstein and Grant (1967) also attribute lowered infiltration rates and peaking effect to the development of a surface seal and crust. Even for this experiment, the fast rate of reduction in time to runoff for every subsequent rainfall simulation was indicative of soil surface sealing.

At such a low gradient (5 %), the observation by Römkens et al. (1985) that at incipient puddling, surface seals are more fully developed for storms with low than with high intensities may not apply. This experiment involved very high intensities but then the system was transport limited and so runoff would not have significantly destroyed the seals and crusts.

Surface sealing and subsequent crusting may have developed at a fast rate given that the topsoil samples, except sample D, had most of the initial crumbs of about 15 cm in diameter broken down during the first rainfall simulation (see plate 4.1).

This agrees with data on aggregate stability which indicate that aggregate stability is significant in the lower aggregate scales of less than 500 µm.

The breakdown of crumbs and aggregates provides the materials for both surface sealing and sediment yield (Moldenhauer and Koswara, 1968). The sealing and compaction processes are therefore attained much faster if the rate of breakdown is high as was the case in this experiment.

Crusts of up to 2 cm thick were observed in all the topsoil samples. These crusts were characterized by a more compacted top layer. As the cone penetrometer was pushed into the soil, maximum resistance was attained from this top layer.

The differences in penetration resistance were more distinct when moisture content in the crust fell below 4 %. This reflected the influence of moisture content.

Before simulation

After first simulation

After second simulation

After fourth simulation

Plate 4.1. Disintegration of soil crumbs during consecutive rainfall simulation on Sample C.

4.3. Infiltration.

All the topsoil samples together with the treatments showed infiltration trends that decayed with time. The highest total infiltrated water was recorded on the first day while the lowest was on the fourth day of simulation.

No significant treatment and phase effects were revealed through statistical analyses. There were however, significant topsoil type effects during phases 2 and 3. Sample B had the highest total infiltration throughout the experiment (see figure 4.11). During phases 2 and 3, this sample generated no runoff on the first day of simulation giving the highest infiltration value of 18 mm. Sample D had the lowest infiltration throughout the simulation.

Skaggs (1982) and Kilewe (1987) indicated that soil properties, initial water content, rainfall intensities and surface sealing and crusting significantly influenced infiltration. During this experiment, the differences due to soil properties were distinct.

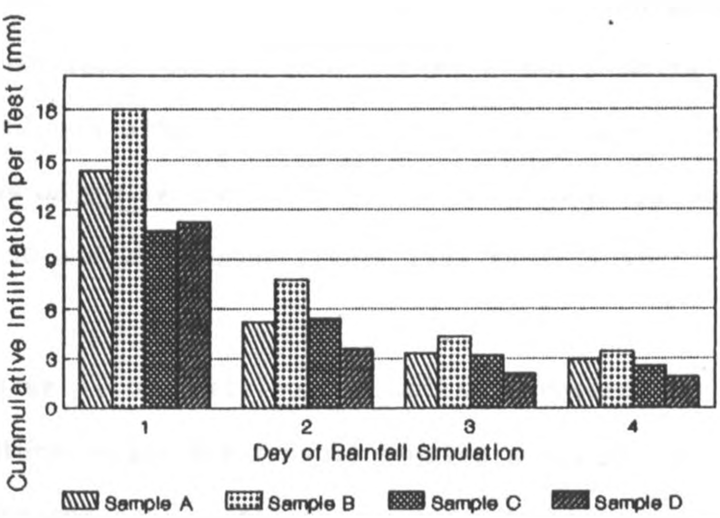

Fig. 4.11. Mean Infiltration Capacities for each Topsoil Sample during Rainfall Simulations.

Rainfall characteristics directly contributed to the pattern of infiltration curves by quickly reducing the infiltration capacity to below the rainfall rate. This was particularly so because the rainfall rate of 360 mm h^{-1} that was applied could have been greater than the saturated conductivities of the soils (Skaggs, 1982). The large size of raindrops easily disintegrated the aggregates and formed small craters. These caused surface sealing and puddling and consequently reduced infiltration. By the fourth day of simulation, the soil type effects were weakened by the effect of rainfall hence the reduced soil type effects on infiltration on this day.

Antecedent soil moisture also influenced infiltration. Table 4.3 shows that day 1 of phase 1 had less infiltrated water (8.3 to 10.9 mm) than on the same day during phases 2 and 3 which had between 10.1 and 18 mm. Similarly, all the simulation days in phase 1 had lower values than phases 2 and 3 while subsequent simulation days after day 1 also had lower values. Infiltration capacities on the second and fourth day of simulation were reduced to about 50 and 25 % respectively (see table 4.3).

During phase 1, pre-wetting the soils increased the antecedent soil moisture in all the topsoil samples while phases 2 and 3 had less antecedent soil moisture compared with phase 1 since no pre-wetting was conducted (see table 4.4).

Likewise, the first and each subsequent simulation increased the antecedent soil moisture. Consequently, infiltration capacities of the topsoil samples were reduced with increases in antecedent soil moisture.

Table 4.3. Ranges of Infiltration Capacities for all the Topsoil Samples during the Experiment.

Simulation day	Infiltration capacity (mm) Phase 1	Phase 2	Phase 3
1	8.3 - 10.9	10.1 - 18.0	11.8 - 18.0
2	2.1 - 5.3	3.6 - 9.9	4.0 - 9.8
3	1.7 - 3.5	1.8 - 5.1	1.9 - 5.7
4	1.5 - 3.6	1.6 - 4.1	1.7 - 3.5

Table 4.4. Antecedent Soil Moisture of Crusts on day 1 of each Phase (Gravimetric).

Topsoil sample	Moisture Content (%) Phase 1	Phase 2	Phase 3
Sample A	12.7	1.7	1.9
Sample B	14.2	1.5	1.6
Sample D	30.4	19.3	8.1
Sample C	15.6	7.2	4.4

4.4. Time to Runoff.

All the four topsoils investigated gave similar curves that decayed with time until they stabilized. The ranges in time to runoff for all the topsoil samples during each experimental phase are given in table 4.5 (see also appendix 1.1).

The first days gave significantly longer times at 95 %

significance level of the Duncan's Multiple Range Test. The longest time to runoff during phase 1 was 93 s on day 1 while on the same simulation day, phases 2 and 3 did not generate runoff.

Phases 2 and 3 gave the longest time to runoff (>180 s) on day 1. This was because the topsoils were not pre-wetted prior to rainfall simulation unlike phase 1. As simulation progressed, the time dropped to between 10 and 28 s (see appendix 6). These results are expected due to the influence of antecedent soil moisture and initial soil surface conditions (Falayi and Lal,1979).

Table 4.5. Ranges in Time to Runoff for all Topsoil Samples (s).

Simulation day	Phase 1	Phase 2	Phase 3
1	52 - 93	59 - >180	103 - >180
2	13 - 29	13 - 55	25 - 57
3	11 - 29	11 - 27	15 - 34
4	12 - 20	10 - 28	15 - 27

The topsoil samples did not show any significant difference between the same treatments and phases. However the treatment effect on the same day of rainfall simulation was significant at 95 % level on day 4 for sample A, and on day 1 for sample B during phase 1.

Five tons per hectare treatment in sample A took longer to generate runoff than other treatments on day 1. This was however short lived as on subsequent days, the control was higher than both 5 and 10 t/ha. For sample B, 10 t/ha treatment took longer to runoff on day 1.

Analysis of Variance (ANOVA) shows that the differences in time to runoff on these days were just slightly significant at 95 % significance level (see appendix 3.2). Duncan's Multiple Range Test ranks the control for sample A as taking significantly longer (22.7 s) than both 5 and 10 t ha^{-1} treatments with 17.7 and 17.3 s respectively. Similarly, 10 t ha^{-1} treatment in sample B took longer than 5 t ha^{-1} and the control with 67.7 s, 59.3 s and 55.3 s respectively.

The control in sample A took longer to generate runoff probably due to lower organic matter content since incorporating farmyard manure into the soil increased organic matter content for 5 and 10 t ha^{-1} treatments (see table 4.2).

Generally, organic matter improves water holding capacity of the soil (Im, 1982). Considering that this was the fourth day of simulation, trays with farmyard manure accumulated more water in the topsoil layer than the control. Consequently, infiltration rates were lowered and the topsoil became saturated quickly. This led to early runoff. 5 and 10 t ha^{-1} treatments therefore took a shorter time to runoff than the control.

Sample B gave a reversed situation where 10 t ha^{-1} treatment had a longer time to runoff on day 1. This could be explained by the fast rate and extent of seal and crust formation in the early stages for trays with little organic matter (Epstein and Grant, 1967). Similarly, the explanation by Moldenhauer and Kemper (1969) can be applied. The hydraulic pressure gradient pushing the water through the disintegrated top layer is lowered by the lower layer with larger pore spaces in the control and 5 t ha^{-1} treatment. Consequently the infiltration rates were lowered.

For 10 t ha^{-1} treatment the rate of seal and crust development was slower than the control and 5 t ha^{-1} treatment indicating the slower structural degradation processes. The formation of a compacted layer was also hampered. Unlike 10 t ha^{-1}, the control and 5 t ha^{-1} treatments may have developed the seals and crusts faster. This would have reduced saturation time and so quickened runoff generation due to early puddling.

Soil type effects on each simulation day were highly significant on the first days of phases 2 and 3. The rest of the days for all phases had slight soil type effects. On the first day in phase 1 there were slight significant differences in all treatments due to pre-wetting. In phases 2 and 3, the soils were air-dry on the first days. Soil characteristics were therefore more influential during phases 2 and 3 than phase 1.

There was a general trend of decreasing time to runoff between treatments and topsoil samples in each of the phases during the simulations. After the second day of simulation, all the topsoils yielded similar times to runoff regardless of the treatment. In this case, surface sealing and crusting became dominant as all topsoil samples should have developed seals and crusts.

Regression analyses show that only a small percentage of variation in time to runoff is explained by organic matter content (less than 10 % for all samples). Kinetic energy on the other hand explained over 70 % of the variation in time to runoff. A combination of Kinetic energy and organic matter gave lowered coefficients of determination (see appendix 5.3). The best fit regression equations for time to runoff are as follows.

$$TRO_a = 53.52X^{(-0.36)} \qquad [12]$$

$$TRO_b = 72.24X^{(-1.51)} \qquad [13]$$

$$TRO_c = 40.85X^{(-1.01)} \qquad [14]$$

$$TRO_d = 37.71X^{(-1.49)} \qquad [15]$$

Where

TRO_a = Time to runoff for sample A (s)

TRO_b = Time to runoff for sample B (s)

TRO_c = Time to runoff for sample C (s)

TRO_d = Time to runoff for sample D (s)

X = Kinetic energy (kJ)

4.5. Surface Runoff.

The highest and lowest maximum amounts of runoff recorded for individual rain storms were 16.4 mm (91 %) and 14.4 mm (80 %) respectively on the fourth day of rainfall simulation. The lowest and highest minimum records were 0 and 9.7 mm (54 %) on the first day.

There was a steady increase in runoff from day 1 up to day 3 when runoff started to stabilize. Stabilization started when runoff reached about 70 % to 80 % of the total rainfall input (see figure 4.12).

The highest mean percentage of runoff recorded was 82 % for sample D while the lowest was 50 % for sample B (See appendices 1.4 to 1.6 for more details).

In most cases, the day of simulation significantly influenced the amount of surface runoff. These effects could be attributed to changes in antecedent soil moisture and soil surface conditions (Barber et al., 1979; Cai et al., 1985; Poesen and Govers, 1985).

Statistical analysis using the Duncan's Multiple Range Test (0.05 probability level) shows the first days of each phase as having the lowest percentage runoff. This trend is more pronounced and distinct in phases 2 and 3 than in phase 1. The largest amounts of surface runoff were observed on days 3 and 4 of all phases.

Statistically, no significant differences were shown between treatments and phases. Farmyard manure therefore, did not have any effect on surface runoff. This could have been due to the high intensity of the rainfall (360 mm h^{-1}) and the large size of the raindrops (5.9 mm in diameter).

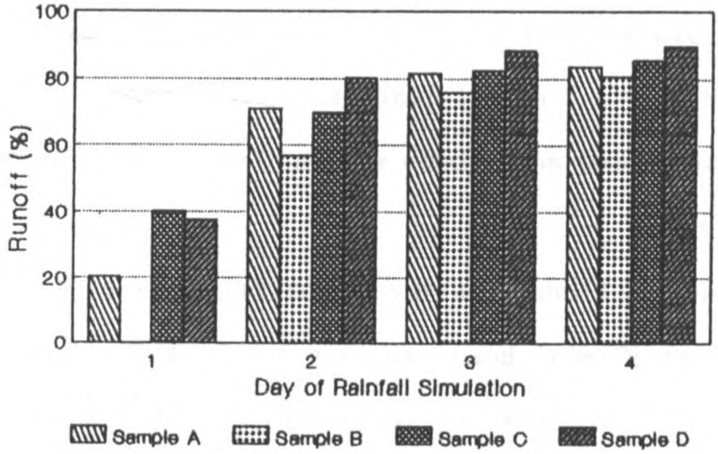

Fig. 4.12. Typical Surface Runoff Patterns for each Topsoil Sample during the Experiment.

More runoff was expected from the controls than the 5 and 10 t ha^{-1} treatments since the latter two had farmyard manure which improved aggregation. However, rainfall characteristics and the inherent properties of the topsoils necessitated easy aggregate breakdown for all treatments. Consequently, there was no great differences in the resulting runoff for all the treatments.

Surface sealing and crusting were encouraged leading to lowered infiltration rates as surface soil conditions and internal soil mass characteristics changed (Kilewe, 1987; Skaggs, 1982).

There were more distinct soil type effects on runoff in phase 2 and 3 than in phase 1. These effects also influenced the amount of runoff on each simulation day.

Generally, there were significant increases in amounts of runoff from the first to the fourth day of simulation. During the fourth day of rainfall simulation, all the samples had about the same amounts of runoff (see appendices 1.4 to 1.6). On this day, runoff responded more to soil surface conditions than to soil properties.

Coefficients of variation for surface runoff were low. They ranged from 4.4 to 25 % (day 1 excluded) and from 21 to 67 % when day 1 of each phase was included (see table 4.6).

The coefficients show high variations on the first day of simulation due to antecedent soil moisture, soil surface conditions and the development of a surface seal and crust.

Table 4.6. Coefficients of Variation in Surface Runoff for each Treatment in each Experimental Phase.

Topsoil sample	Treatment	Phase 1 a	Phase 1 b	Phase 2 a	Phase 2 b	Phase 3 a	Phase 3 b
	Control	-	8.1	43.3	10.7	41.5	11.0
Sample A	5 t/ha	-	8.9	41.2	9.1	44.5	11.7
	10 t/ha	-	4.4	41.1	9.6	43.2	8.8
	Control	-	7.4	65.0	21.4	66.7	25.0
Sample B	5 t/ha	-	8.7	63.8	18.3	64.8	20.9
	10 t/ha	-	11.3	66.9	25.4	63.1	16.3
	Control	28.6	10.8	27.6	10.7	34.9	14.1
Sample C	5 t/ha	22.5	5.4	21.1	9.8	31.6	11.9
	10 t/ha	37.4	9.5	23.6	9.8	32.6	10.7
	Control	25.3	7.6	31.4	10.4	40.4	7.6
Sample D	5 t/ha	23.3	5.2	26.7	7.8	41.0	6.7
	10 t/ha	21.9	6.8	30.5	7.0	41.3	7.1

(a = day 1 included. b = day 1 excluded)

Regression analyses showed that Kinetic energy and time to runoff greatly influenced runoff (see appendix 5.4). Kinetic energy accounted for over 72 % of the variation in runoff for all the topsoil samples while organic matter did for less than 0.5 %. Time to runoff explained over 90 % of the variation.

Regression equations for predicting surface runoff for the four topsoil samples are as follows:

$$RO_a = 109.95\ e^{(-0.01X)} \ldots\ldots\ldots\ldots\ldots [16]$$

$$RO_b = 156.02\ e^{(-0.03X)} \ldots\ldots\ldots\ldots\ldots [17]$$

$$RO_c = 102.00\ e^{(-0.01X)} \ldots\ldots\ldots\ldots\ldots [18]$$

$$RO_d = 102.51\ e^{(-0.01X)} \ldots\ldots\ldots\ldots\ldots [19]$$

Where

RO_a = Runoff for sample A (%)

RO_b = Runoff for sample B (%)

RO_c = Runoff for sample C (%)

RO_d = Runoff for sample D (%)

X = Time to runoff (s)

4.6. Soil loss.

The results obtained from this simulation study show phase variations in soil loss. Figures 4.19 to 4.22 clearly show the patterns followed by each treatment and each topsoil sample. The general trend in each phase (phases 2 and 3) shows a gradual increase in soil loss up to a maximum on the second day of simulation. Thereafter, there is some gradual decrease in soil loss.

The pattern in soil loss of all the four samples in phase 1, showed a gradual decrease from day 1 to day 4 (see Fig. 4.13 and 4.14). The only exception is with sample A which shows some decrease up to the third day of simulation and then peaks again up to the fourth day of simulation.

In phase 1, the high soil loss experienced on day 1 was due to the disintegration of soil particles by the beating action of raindrops. During this period the samples had high infiltration rates. On subsequent simulation days, the soil surfaces sealed and hence there was a gradual decrease in soil loss with increasing runoff.

Soil loss pattern during phases 2 and 3 is similar to that of runoff where there is an increase up to a maximum. The soil loss reaches the maximum on day 2 whereas the runoff peaks on day 4. The increase in soil loss from day 1 to day 2 could be attributed to the low initial soil moisture and the slow disintegration and detachment of soil particles. The subsequent gradual decrease in soil loss could be due to increased surface sealing.

Soil loss patterns agree with the sequence of soil surface evolution suggested by Le Bissonnais (1990). Initially, Phases 2 and 3 had dry aggregates. The high rainfall intensity during rainfall simulation induced slaking which quickly closed up the soil surface. Macroaggregates were therefore quickly disintegrated, detached and transported by runoff.

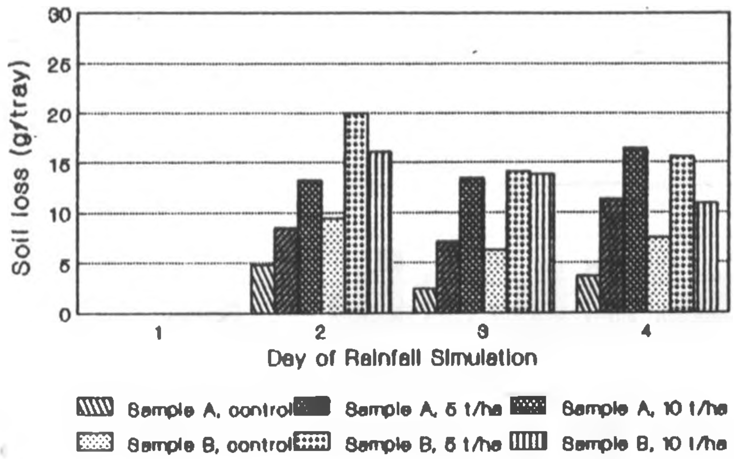

Fig. 4.13. Soil loss from Samples A and B during phase 1.

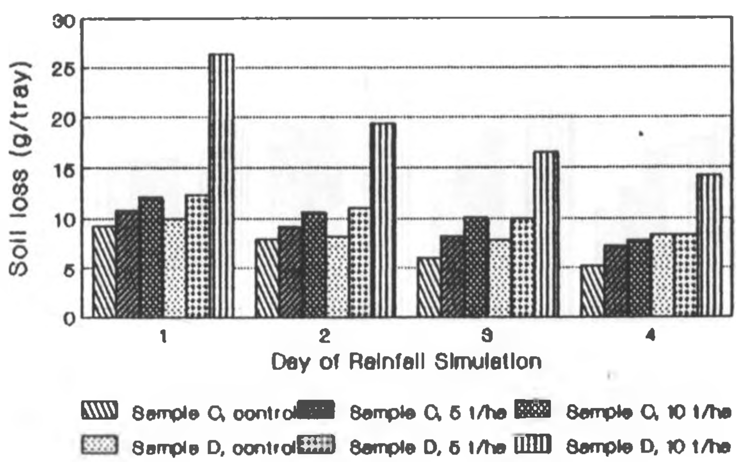

Fig. 4.14. Soil loss from Samples C and D during phase 1.

Phase 1 had initially saturated aggregates due to pre-wetting and so mechanical breakdown was dominant (Le Bissonnais, 1990). Some large quantity of rainfall was required to seal the soil surface.

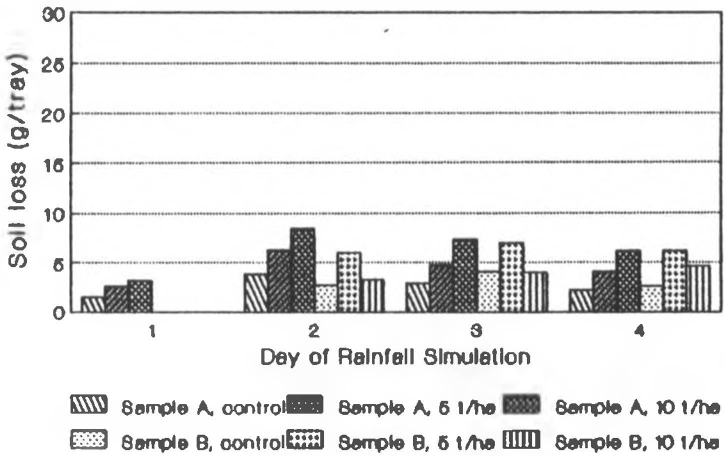

Fig. 4.15. Soil loss from Samples A and B during phase 2.

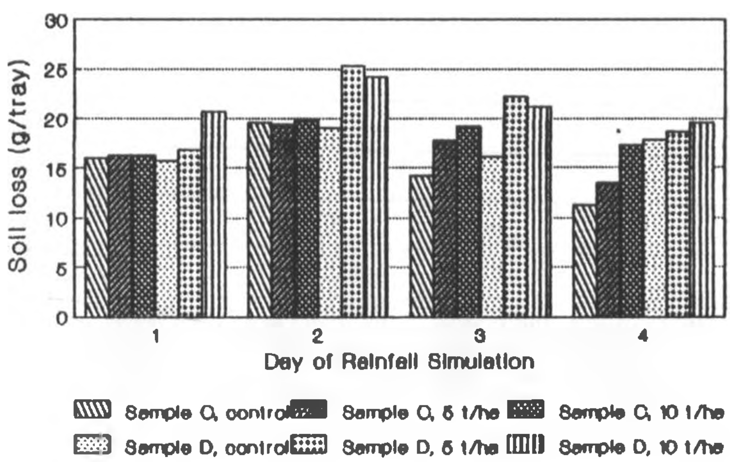

Fig. 4.16. Soil loss from Samples C and D during phase 2.

The initial soil loss would therefore be high due to the cloddy surface conditions and rainfall properties but would decrease subsequently when macroaggregates are disintegrated and there is increased surface sealing.

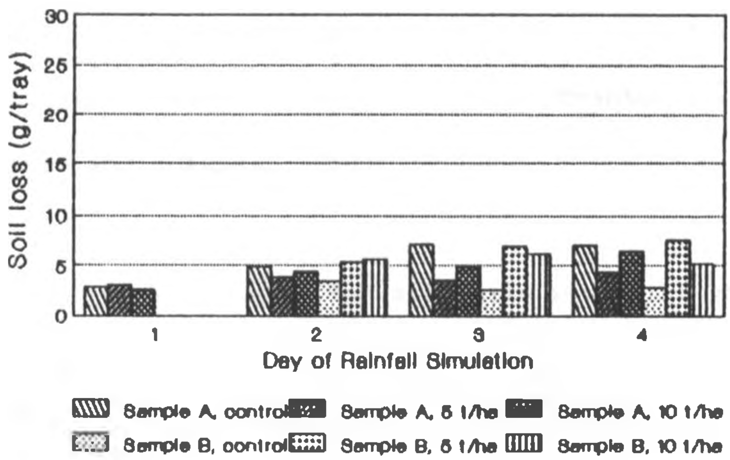

Fig. 4.17. Soil loss from Samples A and B during phase 3.

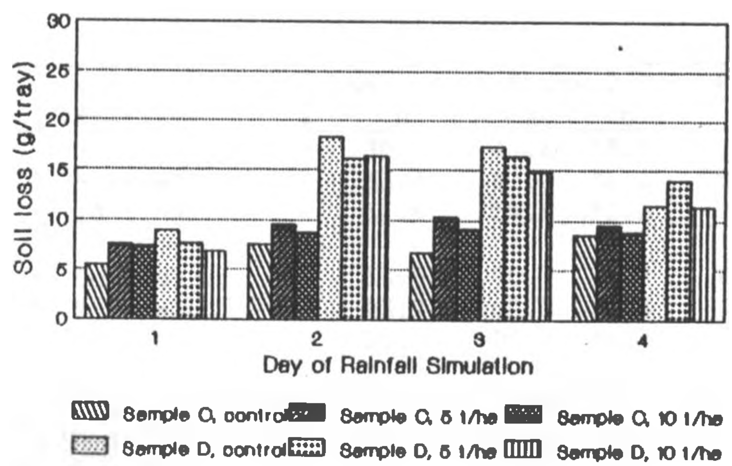

Fig. 4.18. Soil loss from Samples C and D during phase 3.

The behaviour of sample A could be attributed to the delayed breakdown of microaggregates which require more rainfall and time. Initially, the infiltration rate was high but with high intensity rainfall, clods were broken down. The products then filled up the pore spaces and so reduced the water intake rate. Soil erosion was delayed due to the slow breakdown of microaggregates until the soil particles became small enough to be transported by runoff (Moldenhauer and Koswara, 1968).

Soil loss was very variable for all soils investigated. This was similar to Barber et al. (1979) who indicated a common variance of 50 % in soil loss for the luvisol they studied. Variability in soil loss cannot therefore be avoided since many variables influence soil loss (Bryan and Luk, 1981).

Table 4.7. Coefficients of Variation in Soil Loss for each Treatment in each Experimental Phase.

Topsoil sample	Treatment	Phase 1		Phase 2		Phase 3	
		a	b	a	b	a	b
	Control	-	30.7	41.6	33.5	38.3	24.2
Sample A	5 t/ha	-	33.4	51.3	46.1	21.1	19.5
	10 t/ha	-	31.9	59.8	52.6	37.6	25.5
	Control	-	33.5	90.7	59.7	80.9	47.3
Sample B	5 t/ha	-	43.7	105.7	76.3	89.9	58.6
	10 t/ha	-	21.7	80.4	46.7	71.0	33.0
	Control	27.7	21.6	38.0	28.3	22.9	20.0
Sample C	5 t/ha	24.1	22.7	31.1	30.8	46.0	43.3
	10 t/ha	47.4	42.6	27.0	27.3	17.6	14.3
	Control	30.6	33.6	33.7	32.7	33.4	26.2
Sample D	5 t/ha	47.5	51.2	53.7	53.8	57.4	49.3
	10 t/ha	5.0	67.9	37.4	27.4	46.2	39.4

(a = day 1 included. b = day 1 excluded)

Table 4.7 shows that for sample A, coefficients of variation went over 50 % in certain instances. Sample B reached about 100 % while for sample D and sample C the coefficients reached 68 and 47 % respectively. This high variation accounted for the significant differences between some replicates as well.

Differential changes in soil properties during rainfall events bring about variations in soil loss as expounded by Bradford et al. (1987), Le Bissonnais (1990) and Farres (1985). Similar changes were observed in this study.

The highest total sediment yield was obtained from the sample D during phase 2 (85.7 g). The lowest sediment yield for the same topsoil was 34 g during phase 1. Sample C ranked second with 72 g in phase 2 but it had a minimum value of 28 g during phase 1. Sample B was the third having 49.7 g in phase 1. Sample A had the lowest maximum sediment yield of 43 g in phase 1. The lowest minimum sediment yield of 9 g was obtained from sample B during phase 3.

4.6.1. Treatment Effects.

Variables that were investigated during the analysis of variance (treatment, time factor and soil type) influenced soil loss. Treatment effects in each phase were significant in phases 1 and 2 for sample A. 10 t ha^{-1} treatments gave higher soil loss (43 g in phase 1 and 41 g in phase 2) than the 5 t ha^{-1} and the control (see appendices 1.4 to 1.6 and appendix 4.8) although in phase 1, 5 t ha^{-1} treatments were still higher than the control while in phase 2 the two were similar.

Both samples B and D showed treatment effects in phase 1 only. Sample B showed that 5 and 10 t ha^{-1} treatments had statistically higher soil loss (50 and 41 g respectively) than the control which had 23 g. 5 and 10 t ha^{-1} treatments were however not significantly different. Sample C had the 10 t ha^{-1} treatment yielding higher sediment (79 g) than both 5 t ha^{-1} and the control (42 and 34 g respectively). These results are depicted in Fig. 4.14 where the graphs for 10 t ha^{-1} treatment lie well above those of 5 t ha^{-1} and the control.

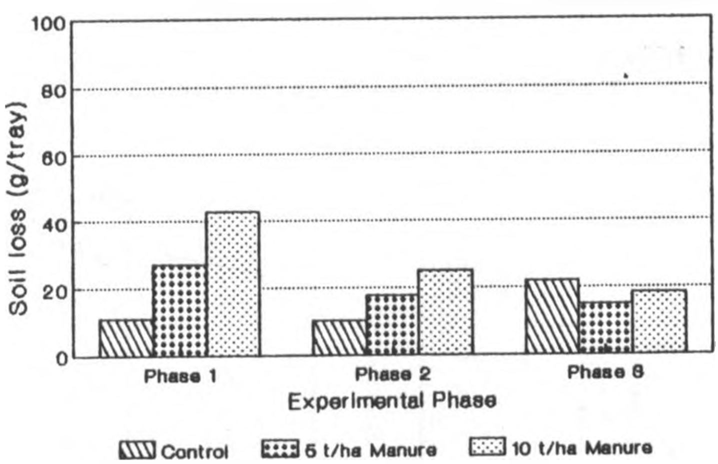

Fig. 4.19. Total Soil loss from each Treatment during each Experimental Phase for Sample A.

Treatment effects on soil loss during the same day were indicated in all phases for sample A. In phases 1 and 2, 10 t ha^{-1} treatments ranked highest in soil loss on days 3 and 4 with 13.4 and 16.5 g respectively.

The controls ranked lowest with 2.4 g of soil on day 3 and 3.7 g on day 4. Sample D had 5 and 10 t ha^{-1} treatments yielding higher soil loss than the control on day 4.

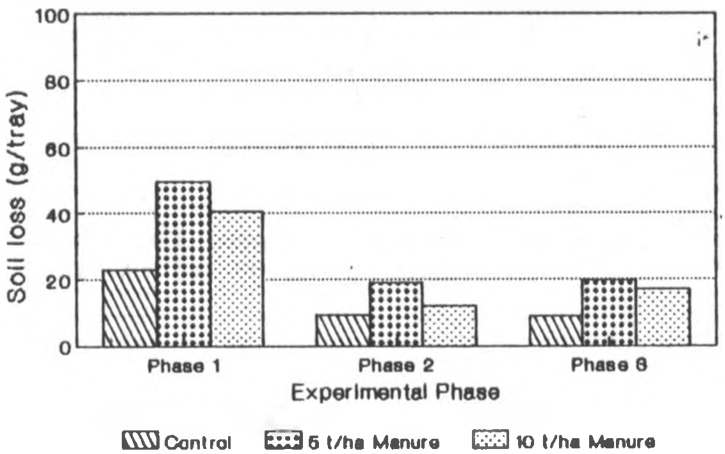

Fig. 4.20. **Total Soil loss from each Treatment during each Experimental Phase for Sample B.**

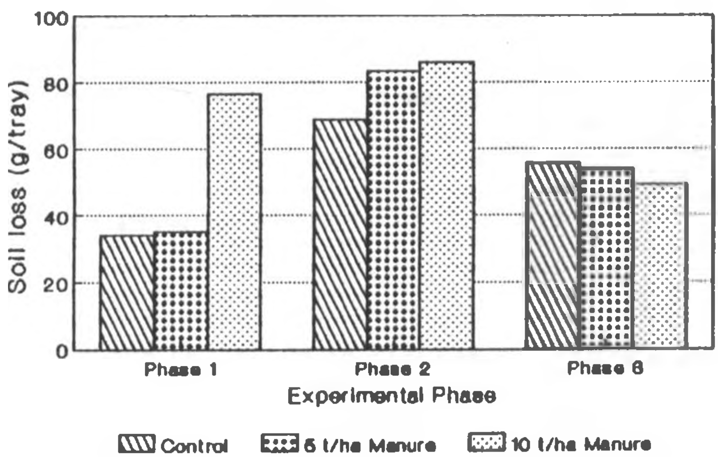

Fig. 4.21. **Total Soil loss from each Treatment during each Experimental Phase for Sample D.**

During phase 3, the control had significantly higher soil loss (7.2 g) than the 5 and 10 t ha^{-1} treatments on day 3 for sample A.

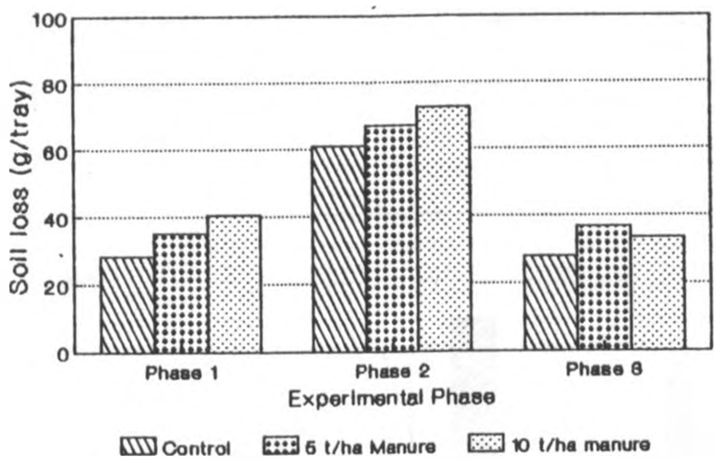

Fig. 4.22. Total Soil loss from each Treatment during each Experimental Phase for Sample C.

These results agree with those of other studies (Mazurak et al., 1975; Cross et al., 1973; Tiarks et al., 1974) which showed that manure application increases sediment yield mainly due to changes in particle density of the whole soil. Subsequently, there is increased detachment of soil particles during a rainstorm event.

4.6.2. Soil Type Effects

Soil type effects are reflected in figures 4.23 to 4.25 (see also appendices 1.4 to 1.6 and 4). Figure 4.24 shows that for 5 t ha^{-1} treatments, sample B had the highest soil loss of 49.7 g in phase 1. For the same treatment during phase 2, sample D and sample C had higher soil losses than both sample B and sample A. However, these soil losses were not significantly different. When soil type effects in phase 3 are compared, sample D had the highest for all the treatments. There were no significant differences between the rest of the topsoil samples.

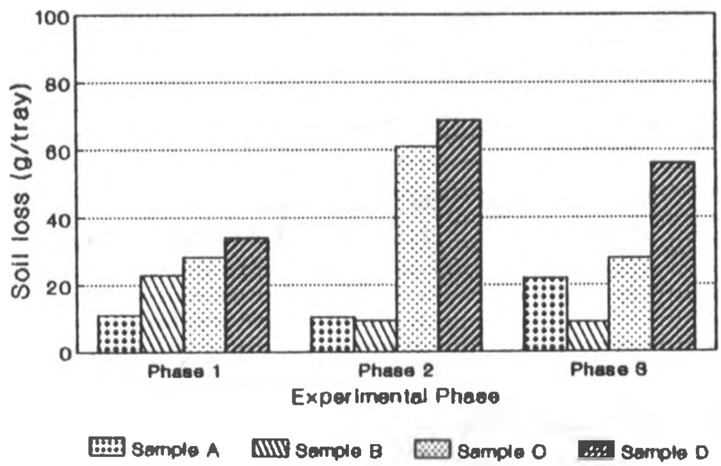

Fig. 4.23. **Total Soil loss for each Topsoil Sample during each Experimental Phase (Controls).**

Generally, the sample D had higher soil loss during all phases for the 10 t ha^{-1} treatments than all the other samples. Sample B had the lowest soil loss. During phase 1, sample D had the highest soil loss followed by sample A.

Phase 2 had a clearly defined rank order where sample D was the highest followed by sample C, sample A and lastly sample B.

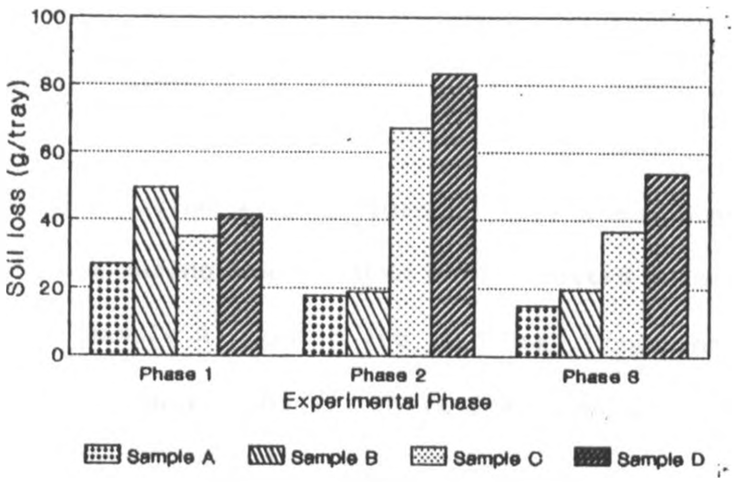

Fig. 4.24. Total Soil loss for each Topsoil Sample during each Experimental Phase (5 t ha^{-1} treatments).

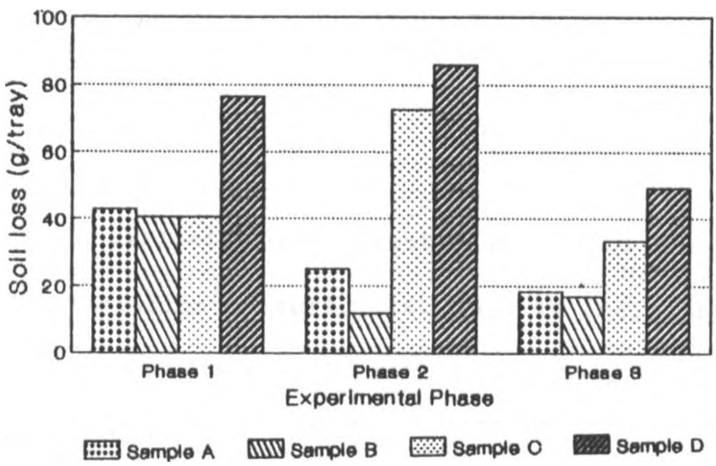

Fig. 4.25. Total Soil loss for each Topsoil Sample during each Experimental Phase (10 t ha^{-1} treatments).

Soil type effects explained some of the variations in soil loss between the different topsoil samples investigated. It showed how the different soil properties influenced soil loss and how each topsoil reacted to rainfall properties. The treatments however, modified the soil type effects.

4.6.3. Time Effects.

The time of simulation also influenced soil loss. Sample A had higher soil loss during phase 3 than during phases 2 and 1 for the controls. For sample A, both 5 and 10 t ha^{-1} treatments had the highest soil loss during phase 1 while during phases 2 and 3 soil losses were low.

All treatments in sample B had higher soil losses during phase 1 while sample D had the highest soil loss during phase 2 for all treatments. Sample C had variable soil losses with the highest in phase 2.

Individual soil variables investigated accounted for very low percentage in variation of soil loss. This is indicative of the complex interactions of the factors that determine the amount and rates of soil loss.

Other soil variables, presumably, clay content, silt content, degree of aggregation and stability of water stable aggregates, also influenced soil loss.

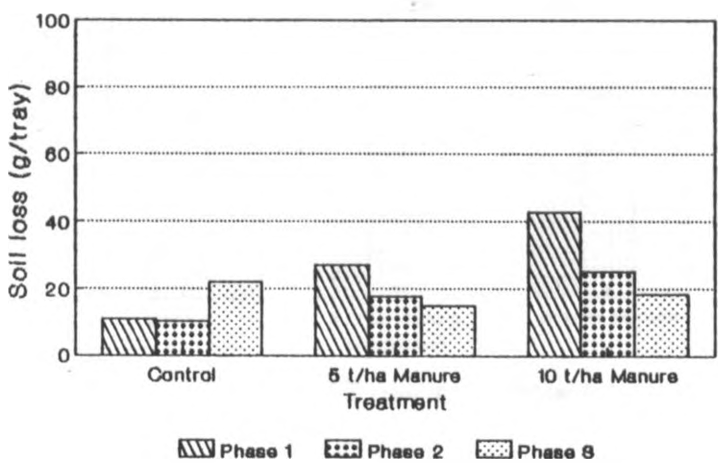

Fig. 4.26. Total Soil loss from each Treatment during different Experimental Phases (Sample A).

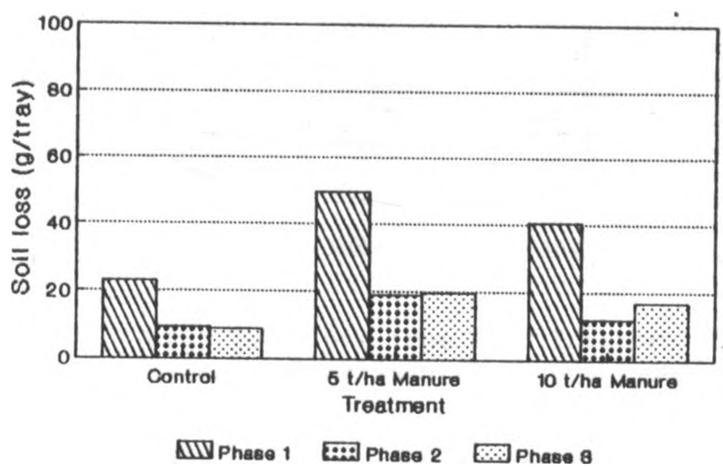

Fig. 4.27. Total Soil loss from each Treatment during different Experimental Phases (sample B).

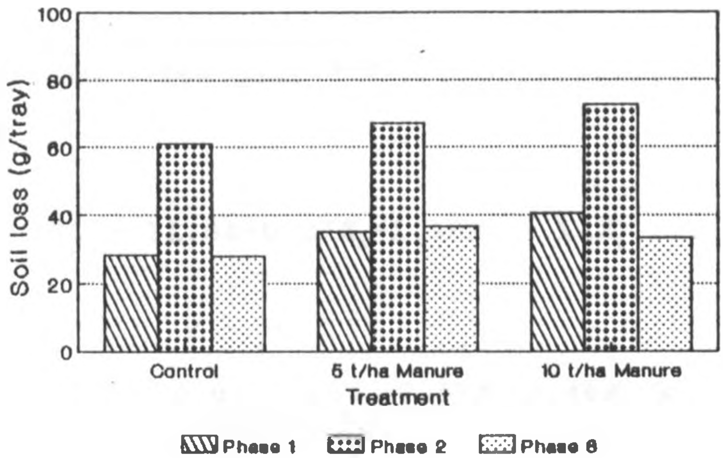

Fig. 4.28. Total Soil loss from each Treatment during different Experimental Phases (sample D).

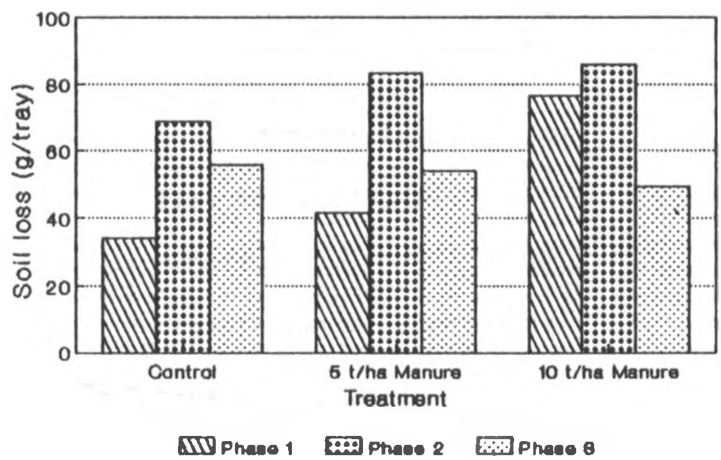

Fig. 4.29. Total Soil loss from each Treatment during different Experimental Phases (sample C).

Multiple linear regressions improved the percentage variation except in sample B (see appendix 5.5). The following regression equations for determining soil loss were derived.

$$SL_a = 33.38-0.25X_1-0.40X_2+6.37X_3+2.05X_4 \ldots\ldots [20]$$

$$SL_b = 162.39X_1^{(-0.98)} \ldots\ldots [21]$$

$$SL_c = 11.84+0.27X_2-1.48X_3-7.11X_4 \ldots\ldots [22]$$

$$SL_d = 50.83-0.28X_1-0.35X_2+2.44X_3-2.45X_4 \ldots\ldots [23]$$

Where

SL_a = Soil loss for sample A (g)

SL_b = Soil loss for sample B (g)

SL_c = Soil loss for sample C (g)

SL_d = Soil loss for sample D (g)

X_1 = Time to runoff (s)

X_2 = Runoff (%)

X_3 = Organic matter content (%)

X_4 = Kinetic energy (kJ)

4.7. Crust Moisture.

The crust moisture content (gravimetric moisture content) for all topsoil samples decayed with time. The moisture content for sample A and sample B decreased sharply five days after rainfall simulation. For sample D and sample C the decrease was gradual.

This gradual decrease was attributable to the weather than to soil properties.

These trends were expected since the longer the soil stays without moisture replenishment, the drier it becomes. No phase effects were observed. Day effects were very highly significant on the 6th day after rainfall simulation.

Soil types had some differences which were masked by weather influences. All the same, sample D had more moisture in the crusts for all treatments. This was followed by sample C and lastly by sample A and sample B (see figs. 4.30 to 4.35).

From analytical data for the topsoil samples, sample D had more clay and silt than the other samples. Clay retains more moisture than sand. The significant difference in moisture content can therefore be attributed to fine particle distribution.

Significant treatment effects were observed on days 1 and 6 during phase 1 for sample D. On these days, 5 and 10 t ha^{-1} treatments had more moisture content in the crusts than the control (see fig. 4.30). This was probably due to organic matter content which improves water retention (Im, 1982; Hamblin and Davies, 1977; Nuttall, 1970) although organic matter does not explain a significant proportion of variation in moisture content during this experiment.

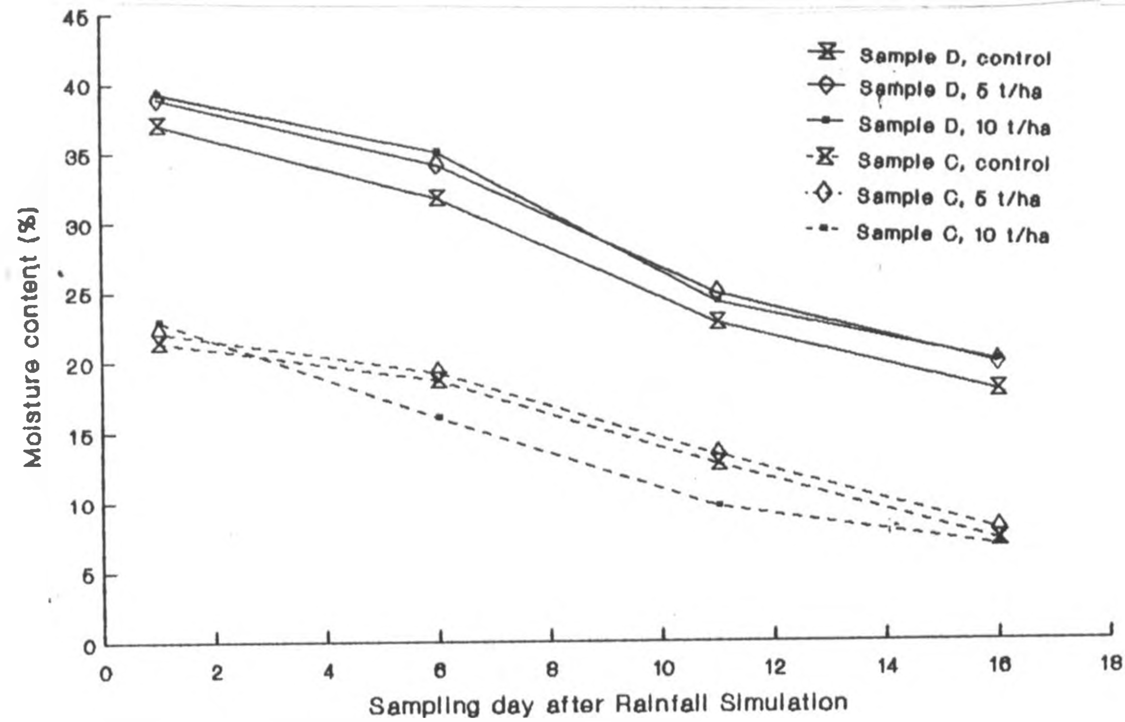

Fig. 4.30. Gravimetric Moisture Content of Crusts for Samples C and D during Experimental Phase 1.

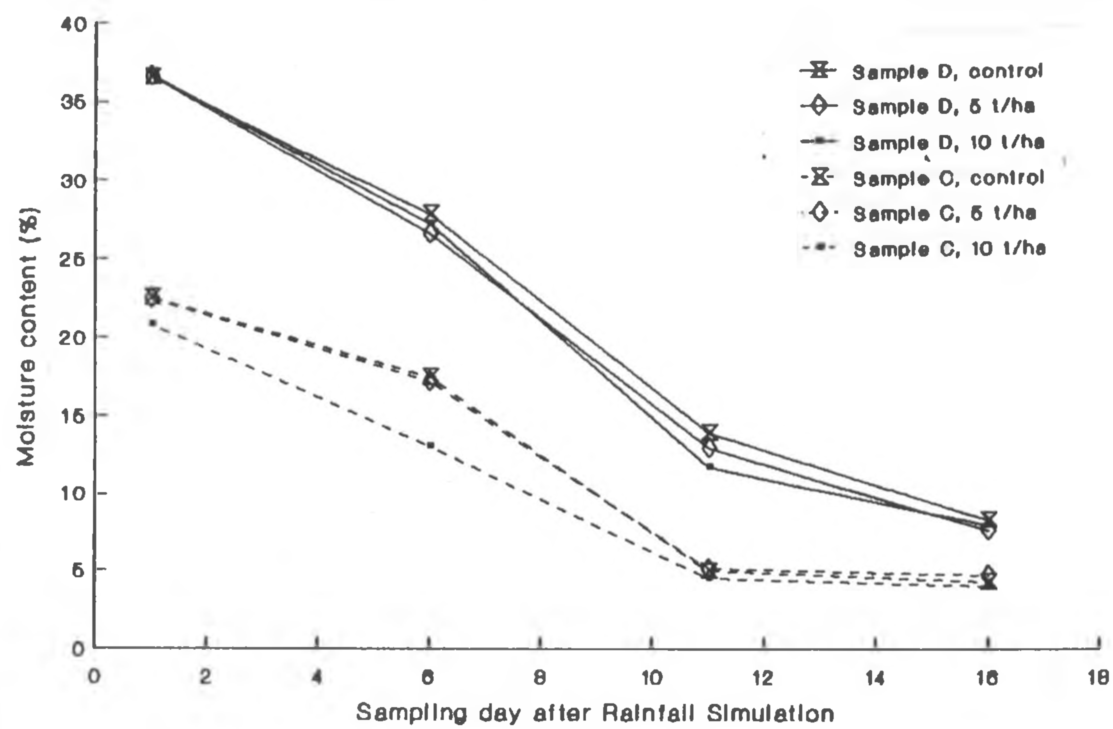

Fig. 4.31. Gravimetric Moisture Content of Crusts for Samples C and D during Experimental Phase 2.

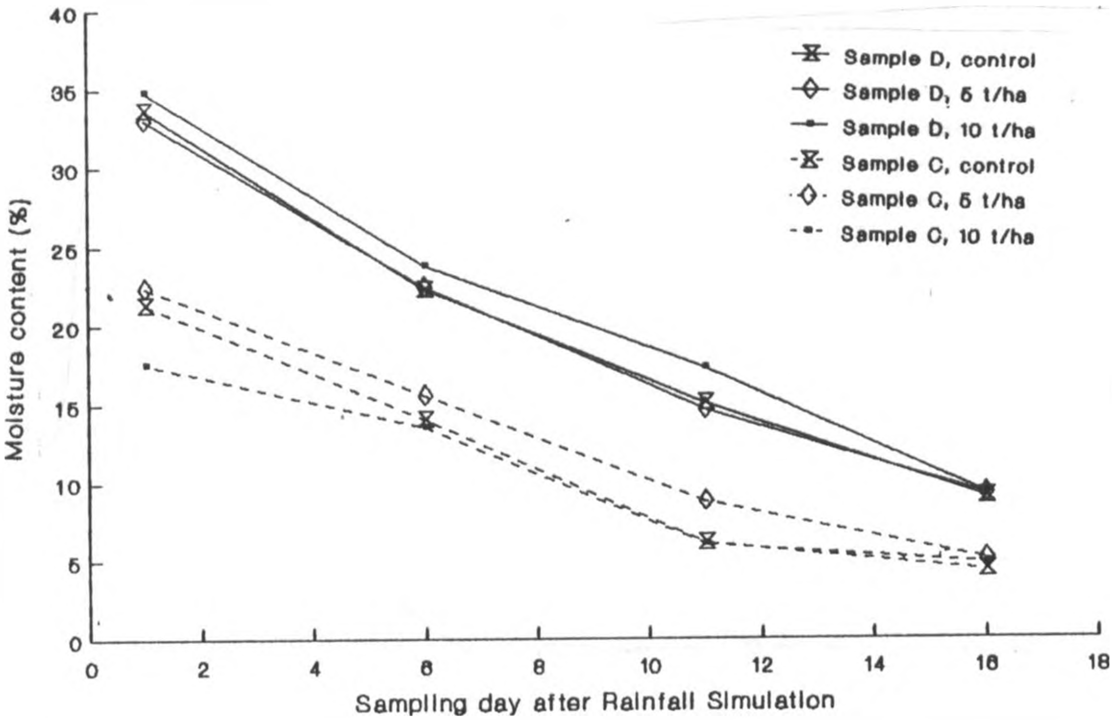

Fig. 4.32. Gravimetric Moisture Content of Crusts for Samples C and D during Experimental Phase 3.

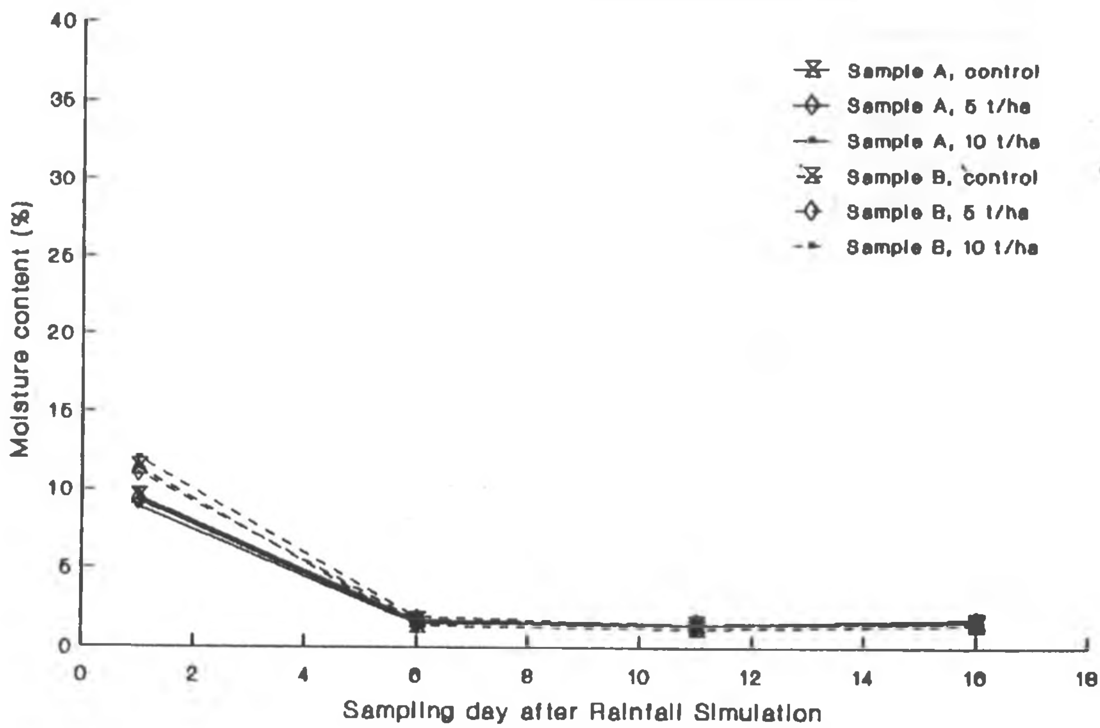

Fig. 4.33. Gravimetric Moisture Content of Crusts for Samples A and B during Experimental Phase 1.

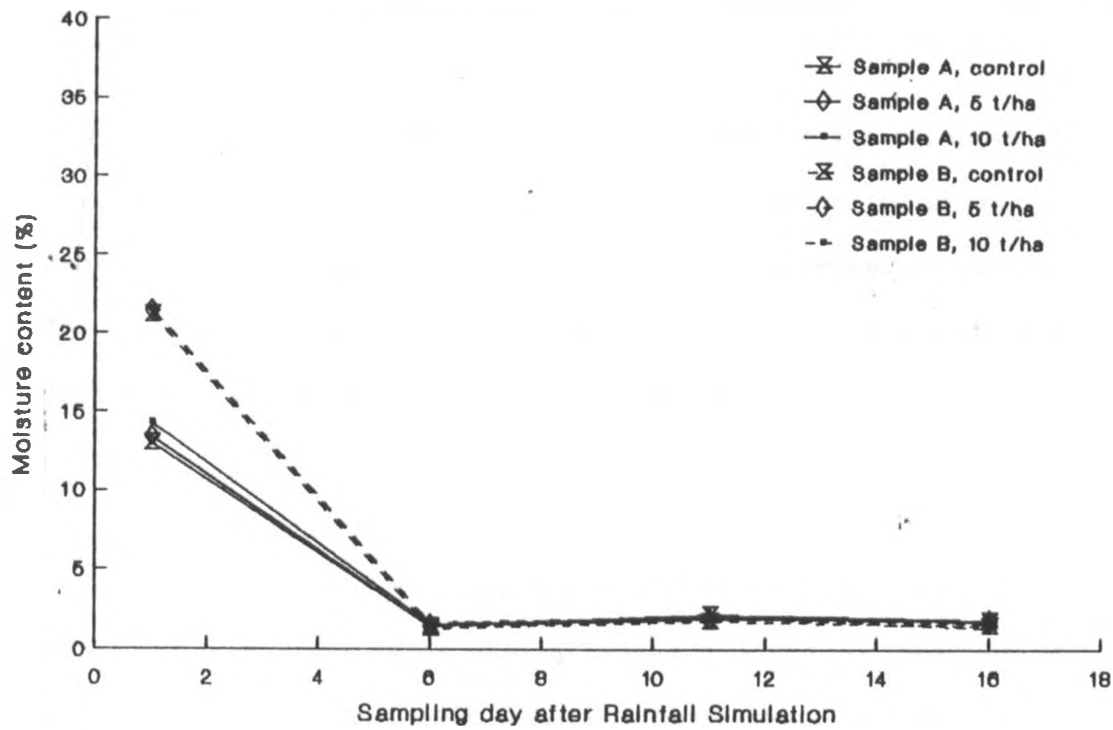

Fig. 4.34. Gravimetric Moisture Content of Crusts for Samples A and B during Experimental Phase 2.

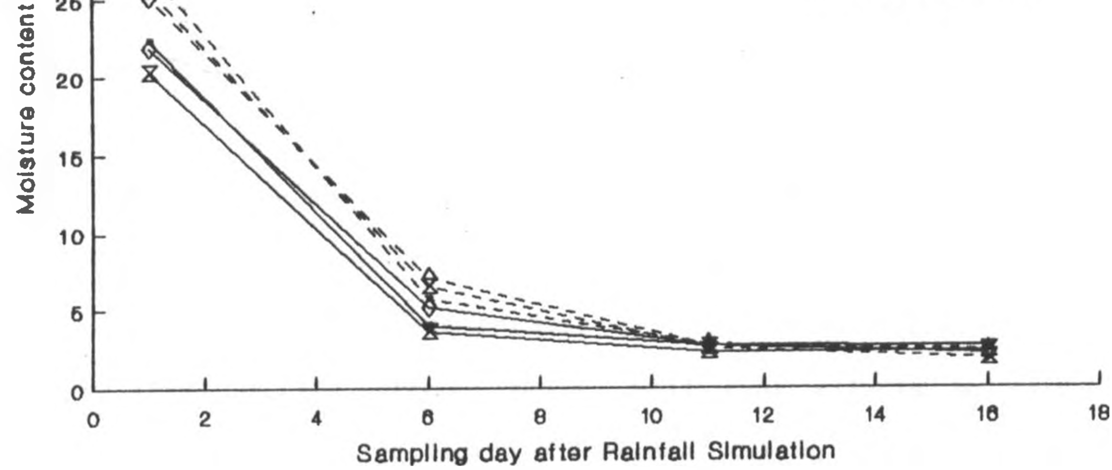

Fig. 4.35. Gravimetric Moisture Content of Crusts for Samples A and B during Experimental Phase 3.

4.8. Penetration Resistance.

Cone penetration resistance was used to determine the strength of crusts. The higher the resistance value the stronger the crust is. Generally, soil properties significantly influenced soil crusting. The penetration resistance observed showed the influence of soil properties and moisture content hence the differences in the graphs.

Sample B had asymptotic curves during all the phases while sample A reached a maximum value during phases 2 and 3 but not during phase 1. Sample C and sample D did not reach their maxima even on day 16 after simulation. This was due to high humidity during the experiment.

The maximum resistance in sample A, samples B and D were lower than in sample C (range of 3.5 to 6.0 kg cm^{-2} for the former compared to 15 to 25 kg cm^{-2} for the latter). During phase 2, the differences became greater after day 6 (see fig. 4.36 to 4.41).

By day 6, samples A and B had attained penetration resistance values of over 3 kg cm^{-2} unlike samples C and D which had less than 3 kg cm^{-2}. This was because of high humidity during the experiment in the latter sample. Soil type effects on each sampling day gave significant differences during all the phases except on day 1 of phase 3.

Maximum penetration resistance for all the four topsoil samples was attained during phase 3. The highest maximum value was for sample C which had attained 31 kg cm^{-2} on day 16. This was followed by sample A (14 kg cm^{-2}) on day 11, then sample D with 11 kg cm^{-2} on day 11 and lastly the sample B with 8 kg cm^{-2} on day 16.

Samples A and B reached maximum values at the time when moisture content was not at the lowest unlike samples C and D that had a gradual increase in penetration resistance with moisture depletion.

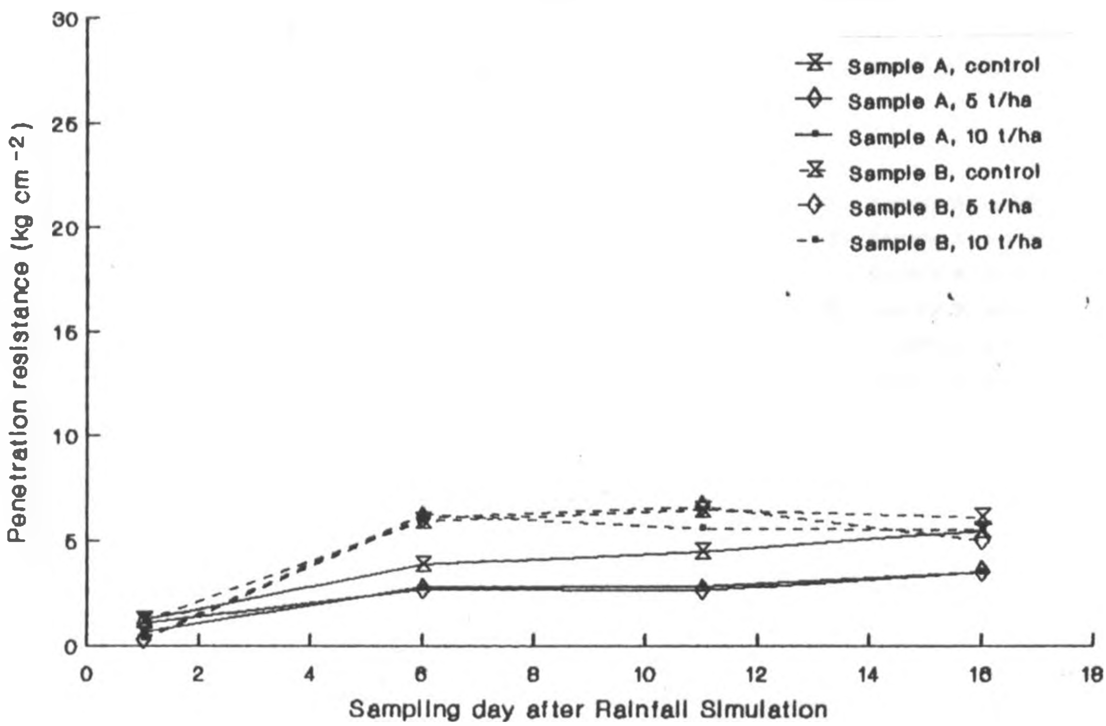

Fig. 4.36. Penetration Resistance for Samples A and B during phase 1.

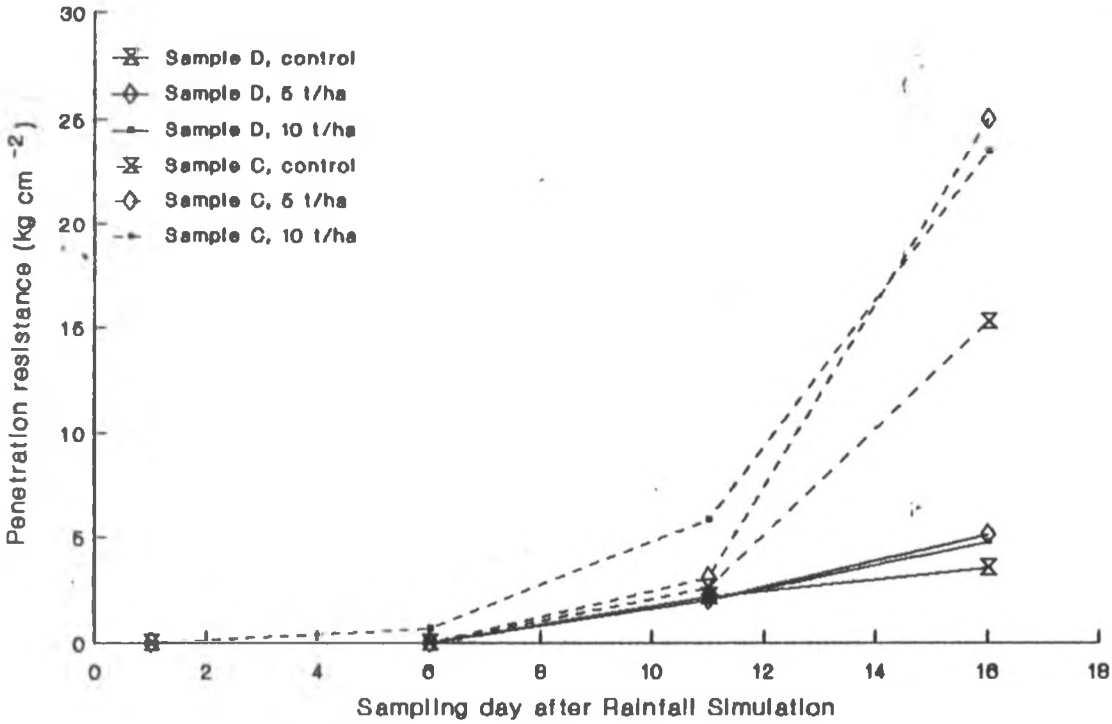

Fig. 4.37. Penetration Resistance for Samples C and D during phase 1.

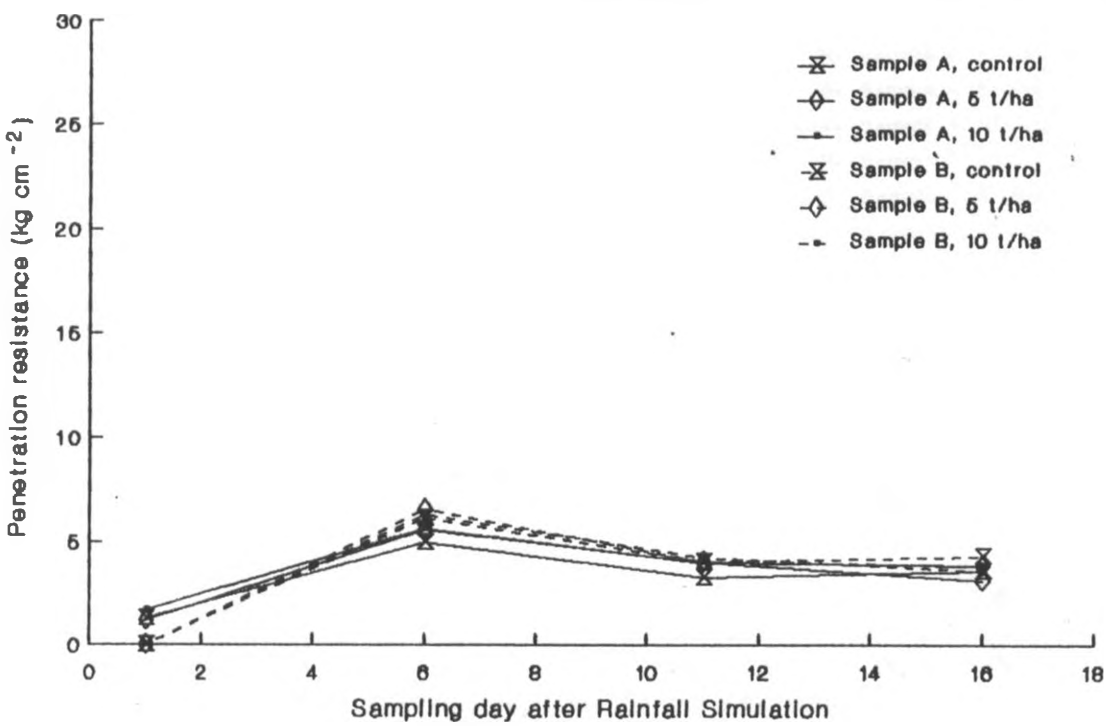

Fig. 4.38. Penetration Resistance for Samples A and B during phase 2.

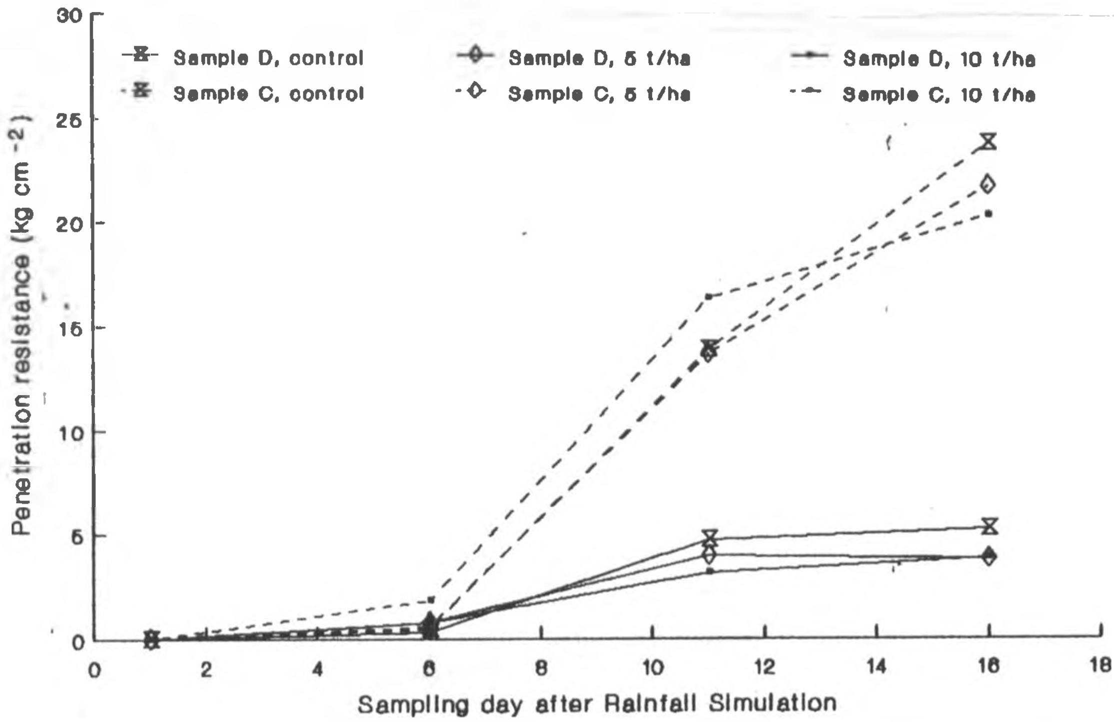

Fig. 4.39. Penetration Resistance for Samples C and D during phase 2.

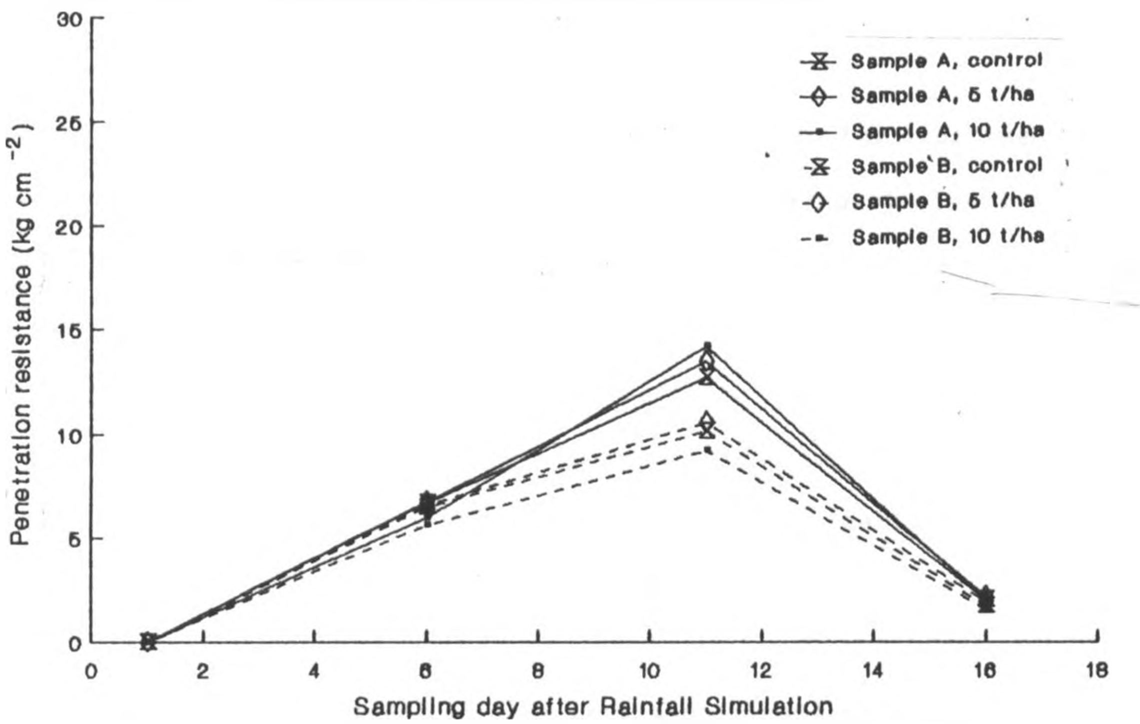

Fig. 4.40. Penetration Resistance for Samples A and B during Experimental phase 3.

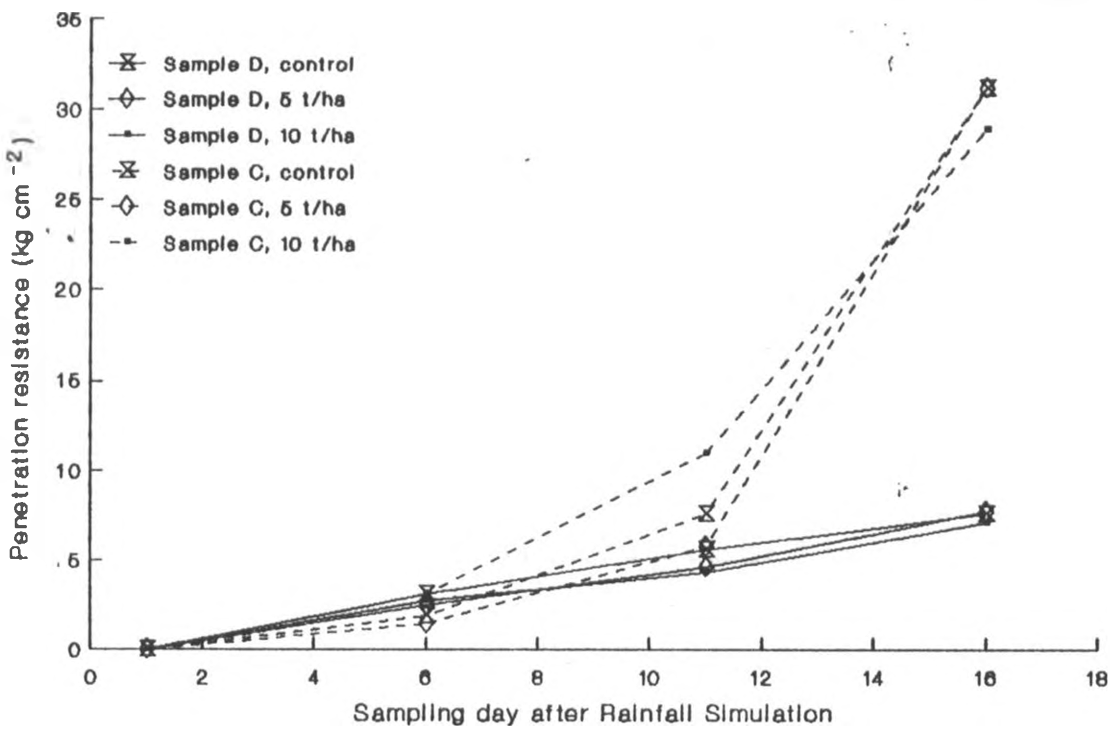

Fig. 4.41. Penetration Resistance for Samples C and D during Experimental phase 3.

Similar trends were shown during phases 1 and 2 of the experiment and suggest that cohesion of aggregates and soil particles were attained at different moisture contents depending on the topsoil.

Differences in organic matter and particle size were closely associated with the differences in penetration resistance. This is similar to Sharma (1985) who observed that particle size distribution influenced penetration resistance.

During phase 1, treatment effects were significant on days 11 and 16 for sample A and on day 1 for sample B where the controls had

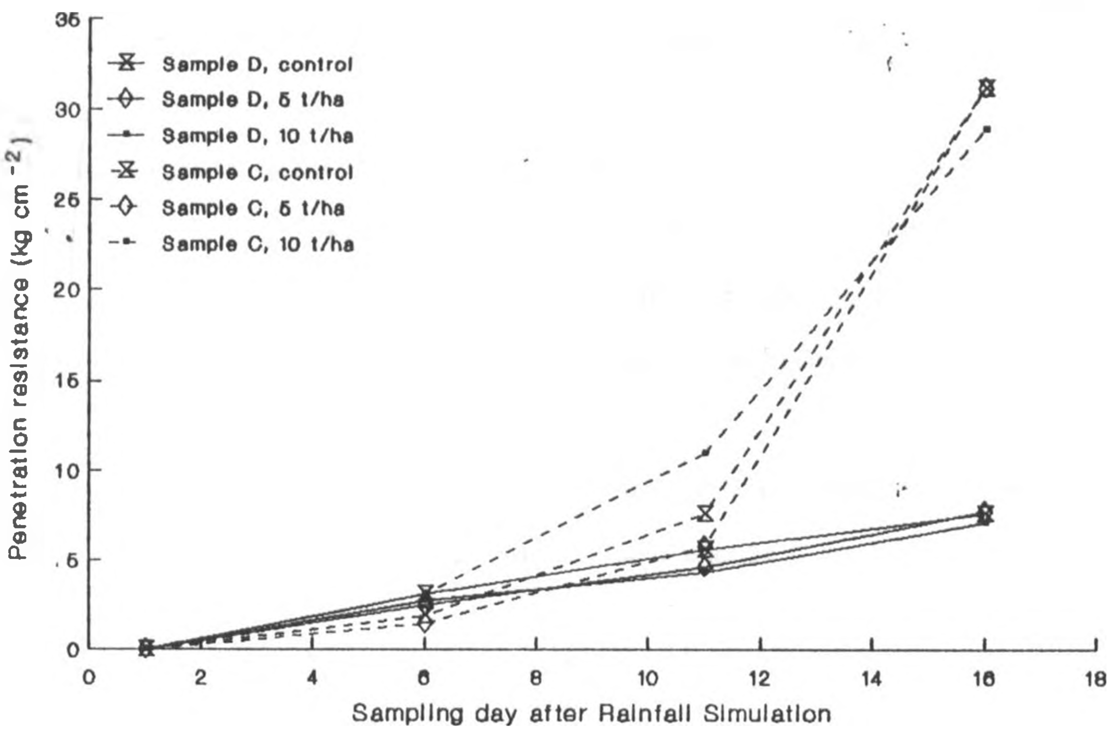

Fig. 4.41. Penetration Resistance for Samples C and D during Experimental phase 3.

Similar trends were shown during phases 1 and 2 of the experiment and suggest that cohesion of aggregates and soil particles were attained at different moisture contents depending on the topsoil.

Differences in organic matter and particle size were closely associated with the differences in penetration resistance. This is similar to Sharma (1985) who observed that particle size distribution influenced penetration resistance.

During phase 1, treatment effects were significant on days 11 and 16 for sample A and on day 1 for sample B where the controls had higher penetration resistance (4.5, 5.5 and 1.2 kg cm^{-2}) than both the 5 and 10 t ha^{-1} treatments. These treatment effects tie in with organic matter content of the soils. The controls with the lowest organic matter had higher penetration resistance than the 5 and 10 t ha^{-1} treatments. Moisture content of the crusts were not significantly different and so could not have significantly influenced penetration resistance on these particular days.

Employing linear regression analyses, sample D and sample A showed exponential decay functions. Sample B and sample C followed power functions.

Sample B and sample C therefore, had the following general prediction equation.

$$PR = A.X^{b} \quad \ldots\ldots\ldots\ldots\ldots\ldots [24]$$

Where PR = Cone penetration resistance (kg cm^{-2}).

A = Constant.

b = Constant.

X = Moisture content (%)

Samples D and A had exponential functions of the following general form:

$$PR = A\, e^{(b.x)} \ldots\ldots\ldots\ldots\ldots\ldots [25]$$

Where PR = Cone penetration resistance ($kg\ cm^{-2}$).

A = Constant

b = constant

e = Exponential

x = Moisture content (%).

Characteristic regression curves for controls and 5 and 10 t ha^{-1} treatments are given in appendix 9. In all cases, there was a negative relationship between moisture content and Cone penetration resistance. This was expected since depletion of soil moisture leads to hardening of the soil as also indicated by other studies (Luk et al.,1990; Hadas and Stibbe, 1977).

The results from regressions showed that application of manure modified the behaviour of regression equation parameters (see appendix 5.1). Both 5 and 10 t ha^{-1} manure decreased the percentage in variation explained by moisture content. This implies that some other factor(s), presumably organic matter and bulk density, were influential.

The scatter in data points intensified with more manure applied except for sample B. This was indicated by the increase in the standard errors of the estimated cone penetration resistance from the control to 10 t ha^{-1}. Scatter was equally reflected in the data points in the regression curves (see appendix 9).

The highest percentage of variation in cone penetration resistance due to moisture content was found in control treatments for all the soils except for sample D. The highest value of 95 % variation was obtained from the control in sample C while the lowest was 38 % for 10 t ha^{-1} treatment in sample A. Organic matter content gave very insignificant correlations.

Confidence limits and T-tests at 95 % significance level with 34 degrees of freedom showed that the calculated parameter values in regression equations lie within the expected limits (see appendix 5.2). The intervals tend to become bigger with more manure applied. This is also indicative of the weakening influence of soil moisture content as other factors are introduced.

4.9. Other Observations.

An increase in kinetic energy exerted by the rainfall led to increased cumulative runoff and soil loss for all treatments on topsoil samples. Cumulative runoff however stabilized with time.

During phase 1, cumulative runoff stabilized for all samples while during phases 2 and 3, the quantity of runoff was still increasing. This was because of pre-wetting prior to rainfall simulation during phase 1.

Cumulative soil loss, on the other hand, increased with increasing kinetic energy. This could have been due to macroaggregates and microaggregates breakdown (Le Bissonnais, 1990) and to continuous destruction and formation of washed in layers (Luk et al., 1990).

Figures 4.42 to 4.50 show changes that occurred in the control treatments. During phase 1, there was a gentle gradient in the graphs for cumulative soil loss that changed during phases 2 and 3. Samples C and D started with high soil loss which continued to increase sharply.

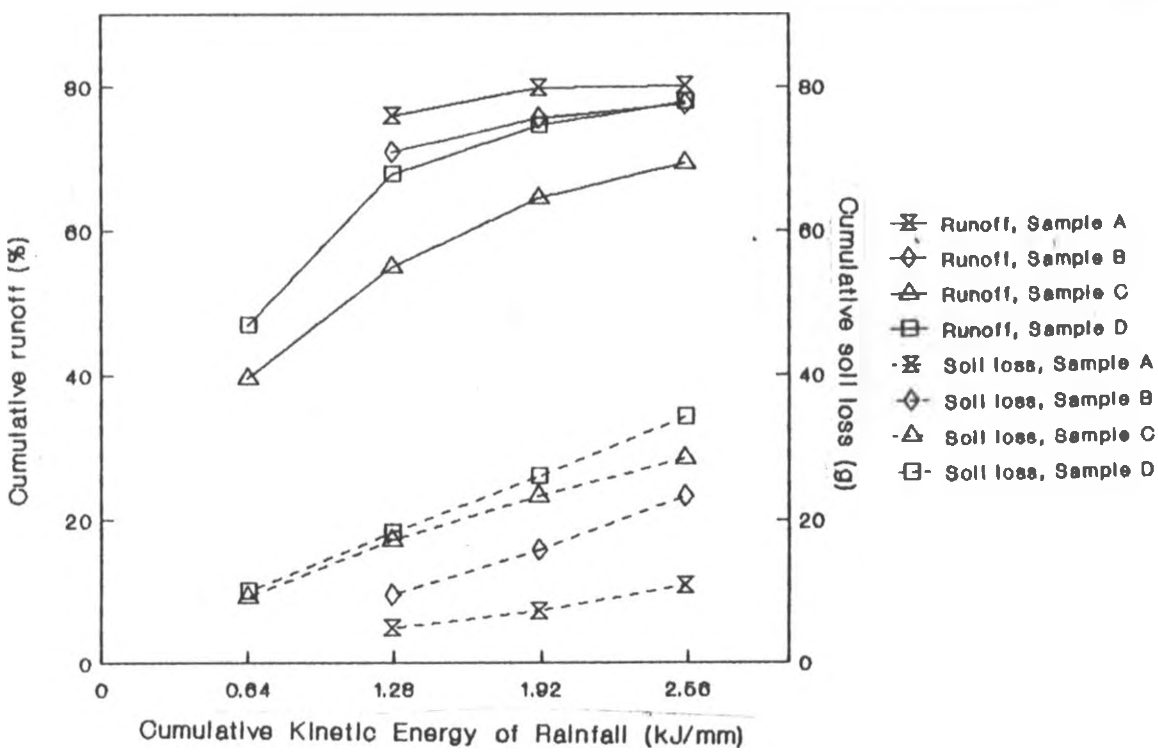

Fig. 4.42. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 1 (controls).

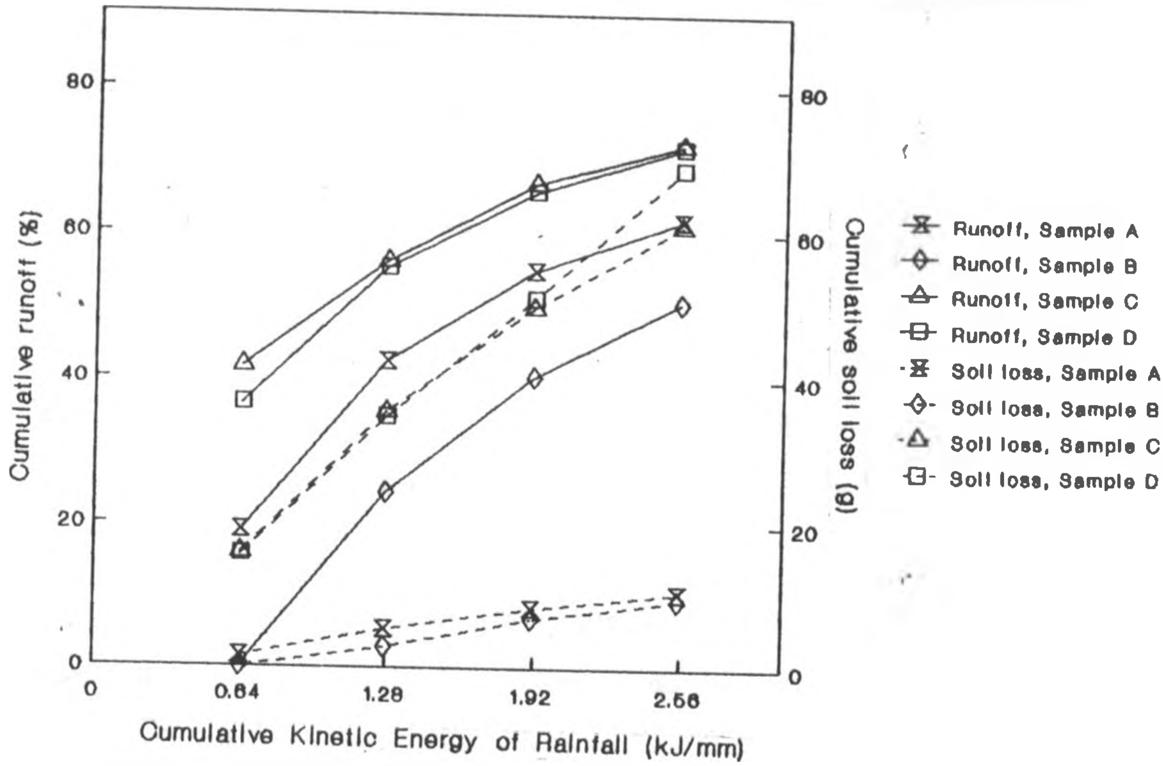

Fig. 4.43. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 2 (controls).

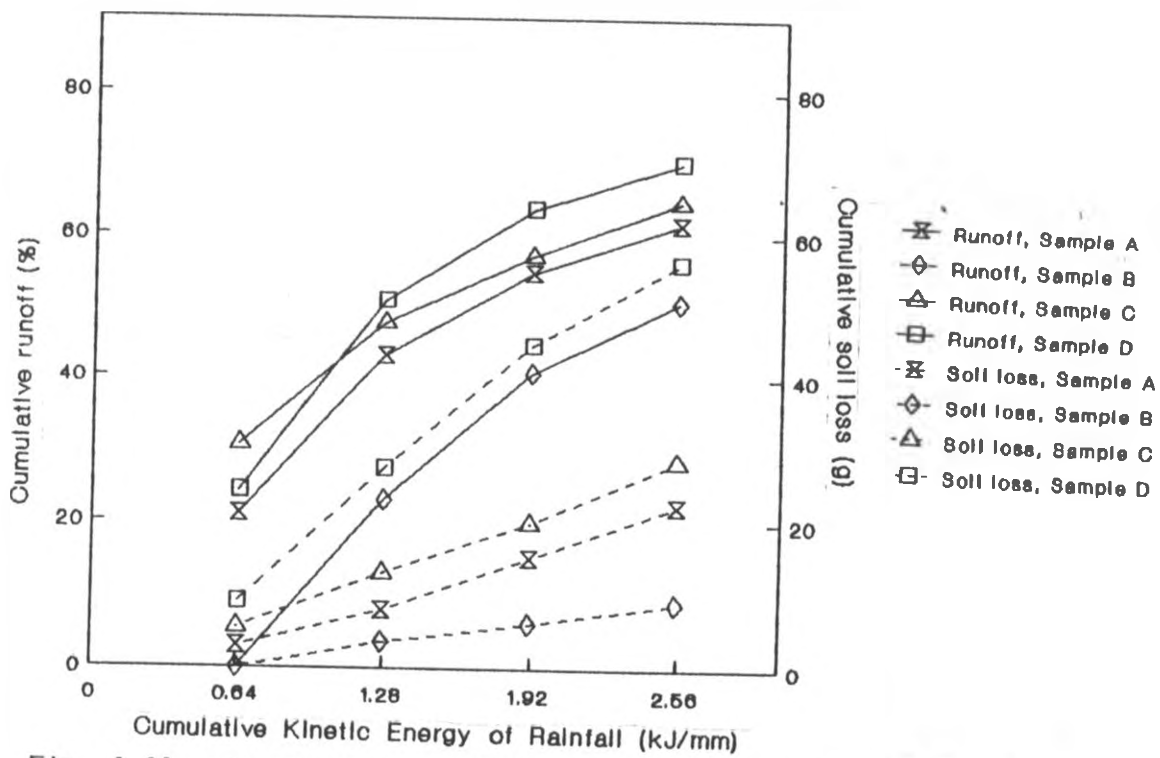

Fig. 4.44. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 3 (controls).

Sample B and sample A cluster together just as samples C and D do. There was no more clustering of graphs during phase 3 and the gradients became similar to the ones obtained during phase 1. Only sample D maintained a steep gradient.

During phase 1, sample A had a lower cumulative soil loss. During phase 2, both samples A and B had almost the same yields. During phase 3, sample B had the lowest cumulative soil loss throughout.

In phase 1, sample A had the highest cumulative runoff while sample C had the lowest. This changed during subsequent phases. Samples C and D yielded the highest values and sample B the lowest during phase 2. Sample D had the highest cumulative runoff during phase 3.

5 t ha^{-1} treatments depicted similar trends for cumulative runoff to that of the controls. In figures 4.45 to 4.47, the gradients for cumulative soil loss are steeper. This suggests more soil loss during this phase than the previous phase. Sample A had the lowest values during phase 1 but it clustered with sample B during phases 2 and 3.

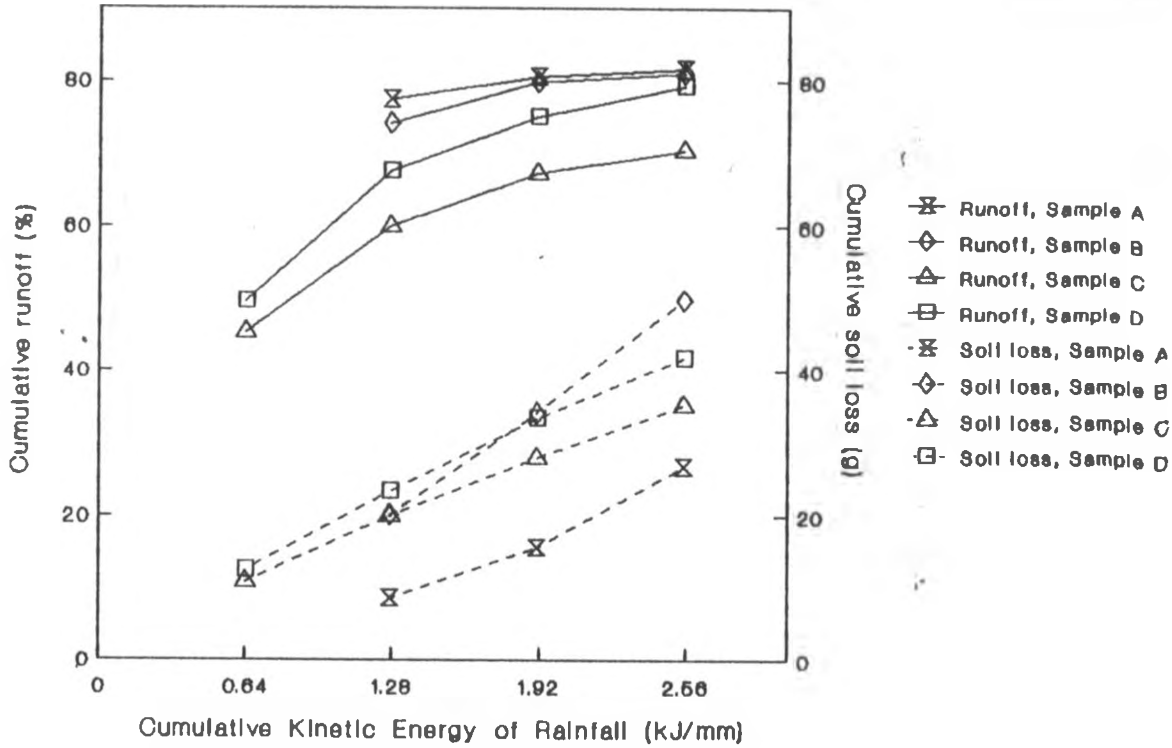

Fig. 4.45. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 1 (5 t ha^{-1} treatment).

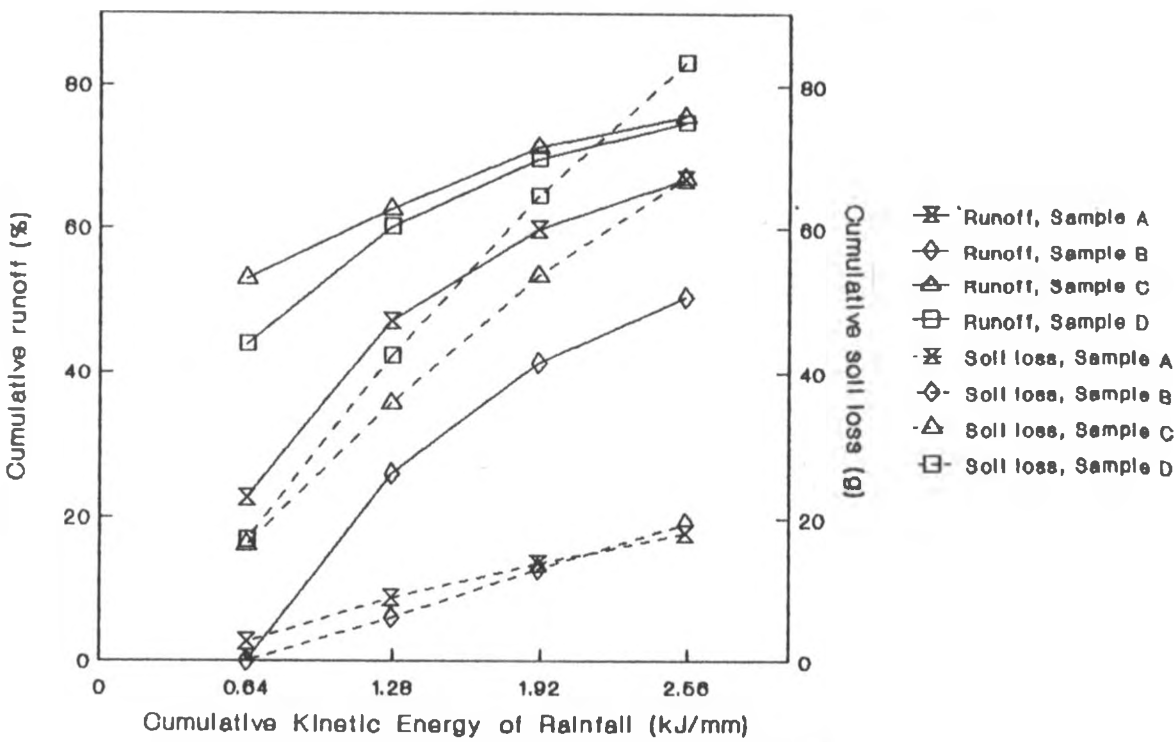

Fig. 4.46. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 2 (5 t ha^{-1} treatment).

Except for sample A, the other samples clustered together during phase 1 for 5 t ha^{-1} treatment. They separated during subsequent phases. During phase 2, cumulative soil loss values, towards the end of rainfall simulation (2.56 kJ/mm), were higher than phase 1. Phase 3 had lower values.

The 10 t ha^{-1} treatments gave slightly different graphs. For cumulative runoff, sample D had the lowest during phase 1. During phases 2 and 3, it was sample B which had the lowest cumulative runoff. Phase 3 showed all samples clustering together except sample B (see figures 4.42 to 4.44).

Cumulative soil loss from sample A, sample B and sample D were the same value during phase 1. The gradients of the graphs are still steep with sample B having the highest values.

Similar trends to 5 t ha^{-1} treatments are maintained by 10 t ha^{-1} treatments although during phase 2, sample A and sample B separate (see figures 4.48 to 4.50).

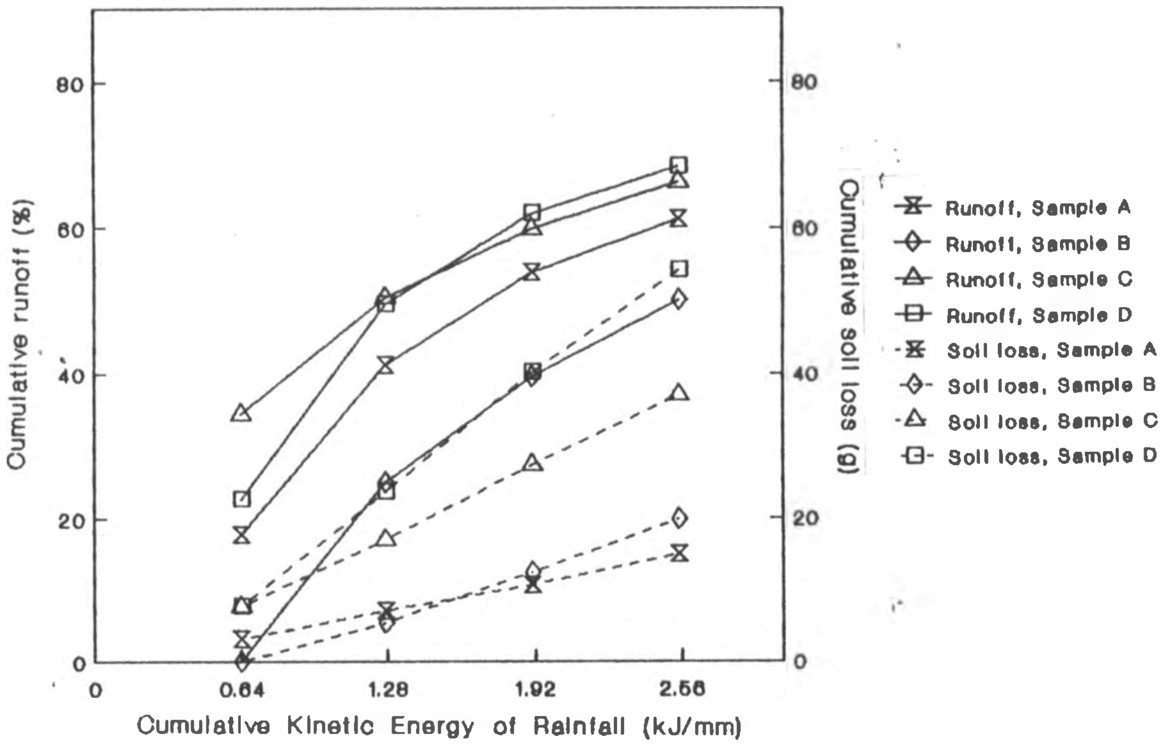

Fig. 4.47. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 3 (5 t ha^{-1} treatment).

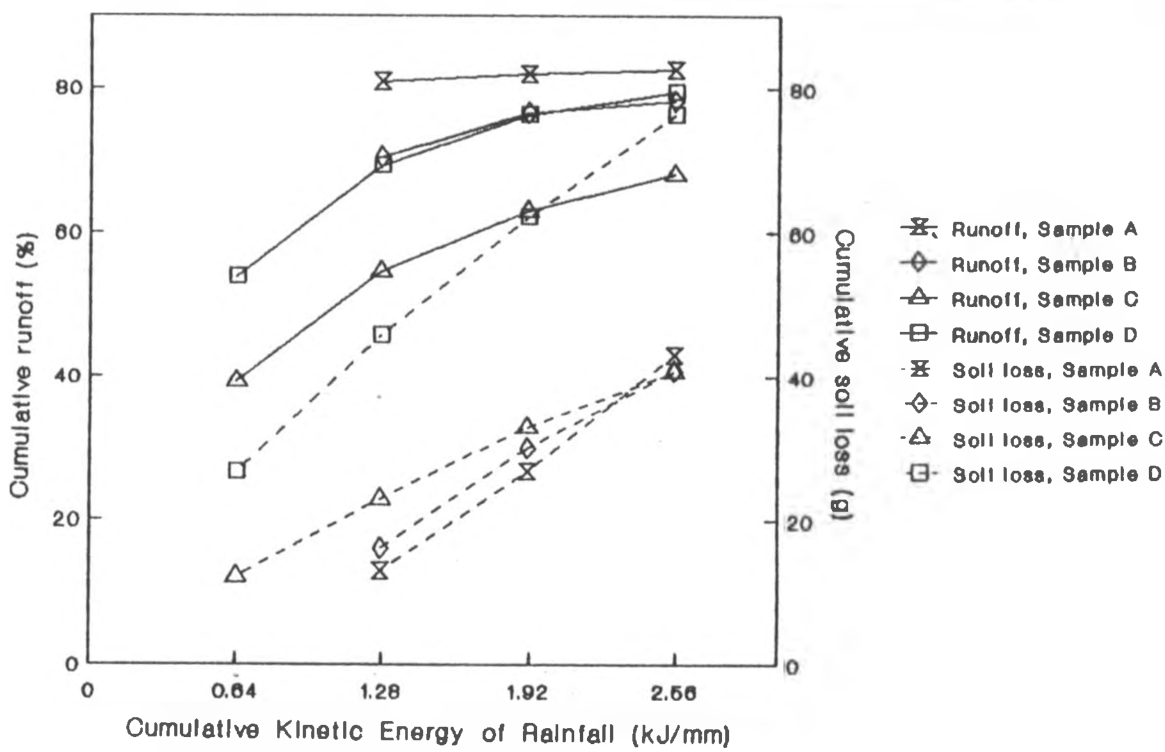

Fig. 4.48. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 1 (10 t ha^{-1} treatment).

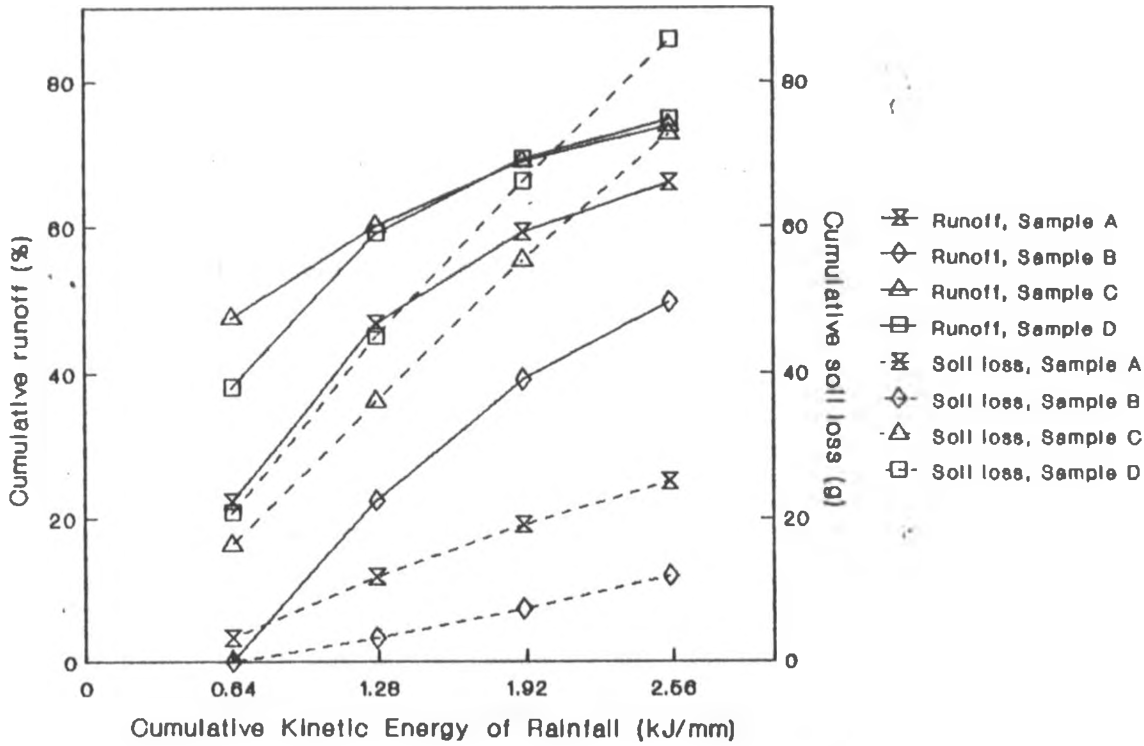

Fig. 4.49. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 2 (10 t ha^{-1} treatment).

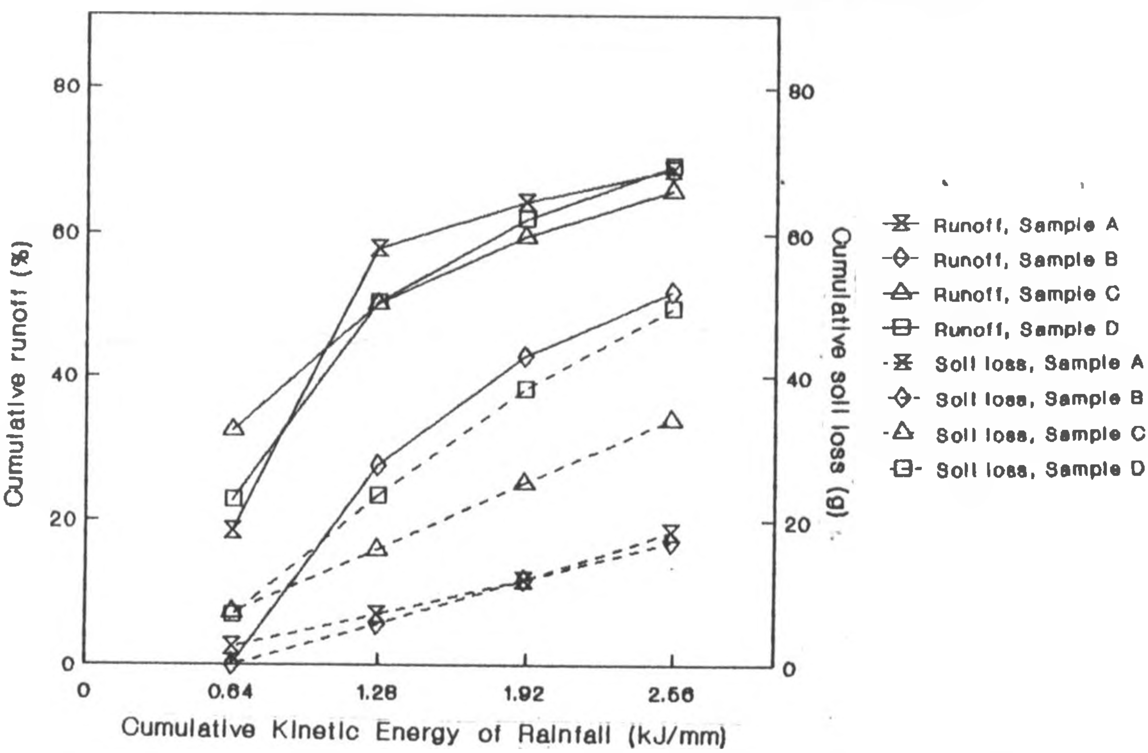

Fig. 4.50. Cumulative Runoff and Soil loss for Topsoil Samples during Experimental phase 3 (10 t ha^{-1} treatment).

CHAPTER V

5. CONCLUSIONS AND RECOMMENDATIONS.

5.1. Conclusions.

5.1.1. Degree of Soil Aggregation.

With time, there was an increase in the percentage of aggregates less than 250 µm and a decrease in those aggregates greater than 250 µm. The addition of farmyard manure lowered the increase in the percentage of aggregates less than 250 µm with 10 t ha^{-1} treatments having the greatest effect. 10 t ha^{-1} treatments also increased aggregation in the size category of greater than 2 mm.

Farmyard manure slightly improved soil aggregation but this was not sufficient to enable the topsoils to withstand the destructive force of raindrops. For the period of this study therefore, the aggregation in the soil samples did not result in reduced soil loss, runoff and soil surface crusting. Penetration resistance (crust strength) was however reduced.

5.1.2. Soil Organic Matter Content.

Larger increases in soil organic matter were recorded for samples B, C and D which had higher initial organic matter content than the sample A which had a lower initial organic matter content.

At the end of 60 days, all topsoil samples recorded decreased organic matter content. Sample D and sample C had higher losses where manure was applied while lowest losses were from the controls.

Sample A and sample B lost more organic matter from 5 t ha^{-1} treatments while 10 t ha^{-1} treatments recorded lower losses.

In spite of the losses in organic matter, soil aggregation improved slightly. Losses in organic matter to levels that did not surpass the initial organic matter content did not adversely affect soil aggregation.

5.1.3. Time to Runoff.

Time to runoff for sample A and sample B responded to farmyard manure. Manure application to topsoils from luvisols can therefore either increase or decrease the time to runoff depending on the properties of the topsoil.

During the first days of the simulation, there were longer times to runoff mainly due to cloddy soil surface conditions, higher porosity and the lower antecedent moisture content.

Cumulative kinetic energy of the rainstorm, with coefficients of determination (r^2) of over 70 %, accounted more for the variation in the time to runoff than organic matter content (r^2 of less than 10 %) at 95 % confidence level (see appendix 5.3).

5.1.4. Surface Runoff

Application of manure did not significantly influence the amount of runoff. Regression analyses indicate that cumulative kinetic energy explained a greater percentage of the variation in runoff (over 70 %) compared to organic matter (less than 5 %) while the time to runoff accounted for over 90 % at the probability level of 0.05.

Initial cloddy surfaces due to soil preparations enhanced surface depressional storage while smooth and sealed surfaces led to more runoff.

Soil surface sealing and crusting led to increased surface runoff. All the samples reached runoff rates of over 60 % on the last rainfall simulation day.

On bare and exposed surfaces of the topsoil samples studied, runoff reached high rates over a short time regardless of the treatments. Rainfall characteristics could have played a significant role in the process of runoff generation considering that the disintegration of soil clods was easily achieved. This could have led to compaction, lower porosity and quick topsoil layer saturation.

5.1.5. Soil loss.

A number of variables affected soil loss leading to high variability. Individually, time to runoff, runoff, organic matter and kinetic energy of the rainfall did not adequately explain the variation in soil loss.

High rainfall intensity and drop size were effectively instrumental in aggregate breakdown and quick soil saturation hence increased runoff. Soil type was dominant in determining soil loss as particle size distribution and degree of aggregation could have been influential.

Increasing farmyard manure in the topsoil samples increased soil loss predominantly during the first phase. This suggests that more soil is apt to be lost during the first rainfall events if farmyard manure had just been applied. Given the short incubation period for manure, the physical and chemical reactions might not have had maximum effects. Where soil aggregation had improved soil loss might have been more in the form of whole aggregates than discrete soil particles.

5.1.6. Crust Moisture.

The results obtained showed that soil properties were influential in determining soil moisture that was retained. Sample D which had the highest clay content responded positively to treatments. Addition of farmyard manure to sample D helped to increase moisture content unlike the other samples which did not show significant differences in moisture content with manure application.

The increase in moisture content of the crust in sample D was a result of the interaction of organic matter with other soil properties such as clay content, silt content and the amount and size of pore spaces.

5.1.7. Penetration Resistance.

Penetration resistance depended on the soil moisture content as was expected but each topsoil sample had its own moisture content level at which maximum penetration resistance were reached. Samples A and B for instance, attained maximum penetration resistance before the minimum moisture contents were reached thus depicting asymptotic trends. Samples C and D had increasing penetration resistance with decreasing moisture content and did not reach asymptote points.

The highest penetration resistance was recorded from the controls during phase 3. This links with organic matter content and shows that organic matter content was important in reducing penetration resistance. Less organic matter content led to higher penetration resistance just as the controls had the highest penetration resistance but with lowest organic matter content.

The general observation is that both soil moisture and organic matter content influenced the penetration resistance in all the four topsoil samples that were studied.

All the four topsoil samples investigated developed structural crusts whose thickness ranged between 0.5 to 2 cm. The highest penetration resistance did not exceed 32 kg cm^{-2}

5.2. Recommendations.

The study of soil surface sealing and crusting in Kenya is relatively new. It is therefore crucial that behavioral patterns of each topsoil sample are studied and determined to necessitate proper remedial measures.

It is recommended that only one topsoil sample at a time should be studied to enable detailed investigation of the various aspects that influence the behaviour.

Any future experiments of this nature, should be conducted both in the field and in the laboratory to enable a comparative study. It is recommended that both simulated and natural rainstorms be monitored.

In view of the fact that time to runoff and surface runoff depend more on antecedent moisture and soil surface conditions, it is important that these are monitored and quantified for each sample.

Both field and laboratory experiments should be undertaken to determine rates of change in soil surface clods and aggregates, infiltration rates and hydraulic conductivities for each of the topsoil sample at different rainfall intensities and kinetic energy.

Considering that soil loss increases with increasing farmyard manure for some soils, investigations into other measures that may reduce soil loss and crust strength but increase moisture content should be undertaken. Straw mulching, both surface and incorporated, is one such measure.

Field studies on soil loss due to manure application should be conducted to determine critical levels for both soil loss and manure application rates for each topsoil sample.

More detailed investigations on variables such as aggregation and particle size distribution should be conducted to determine their influence on soil loss particularly for sample D and sample C. The particle and aggregate sizes that are carried away in runoff should also be investigated.

Considering that the Cone penetrometer used in this study was only very sensitive when soil moisture content fell below a certain amount, similar future experiments should employ more precise and more sensitive penetrometer.

Furthermore, a rainfall simulator that could produce different drop sizes and different rainfall intensities would be more appropriate for comparative field and laboratory studies of this nature.

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APPENDIX 1. SUMMARY TABLES FOR MEASURED PARAMETERS

1.1. Ranges of Mean Values for Time to Runoff (s).

Topsoil sample	Treatment	Experimental phase Phase 1	Phase 2	Phase 3
	Control	22 - 66	23 - 124	18 - 112
Sample A	5 t/ha	18 - 73	21 - 116	19 - 124
	10 t/ha	17 - 59	21 - 123	19 - 127
	Control	20 - 55	31 - >180	26 - >180
Sample B	5 t/ha	17 - 59	22 - >180	21 - >180
	10 t/ha	18 - 68	26 - >180	21 - >180
	Control	12 - 89	10 - 83	25 - 101
Sample C	5 t/ha	12 - 93	11 - 83	23 - 93
	10 t/ha	11 - 69	12 - 78	27 - 103
	Control	17 - 52	16 - 69	15 - 122
Sample D	5 t/ha	15 - 63	13 - 60	15 - 122
	10 t/ha	16 - 64	13 - 59	15 - 113

1.2. Ranges of Mean Values for Gravimetric Moisture content of Crusts (% on dry weight basis).

Topsoil sample	Treatment	Experimental phase Phase 1	Phase 2	Phase 3
	Control	1.5 - 9.5	1.5 - 13.0	2.3 - 20.3
Sample A	5 t/ha	1.5 - 9.3	1.4 - 13.4	2.2 - 21.8
	10 t/ha	1.4 - 8.9	1.6 - 14.3	2.6 - 22.3
	Control	1.2 - 11.3	1.3 - 21.2	1.8 - 25.7
Sample B	5 t/ha	1.4 - 11.1	1.5 - 21.5	2.2 - 25.2
	10 t/ha	1.4 - 11.9	1.4 - 21.5	2.4 - 27.0
	Control	17.9 - 37.1	8.4 - 36.5	9.1 - 33.7
Sample D	5 t/ha	19.9 - 38.9	7.7 - 36.6	9.3 - 33.1
	10 t/ha	20.1 - 39.3	8.1 - 36.7	9.4 - 34.9
	Control	7.1 - 21.4	4.4 - 22.5	4.4 - 21.3
Sample C	5 t/ha	7.9 - 22.1	4.7 - 22.5	5.2 - 22.4
	10 t/ha	6.7 - 22.9	4.1 - 20.8	4.9 - 17.5

1.3. Ranges of Mean Values for Cone penetration Resistance (kg cm^{-2}).

Topsoil sample	Treatment	Experimental phase Phase 1	Phase 2	Phase 3
	Control	1.23 - 5.48	1.32 - 5.00	0.0 - 12.73
Sample A	5 t/ha	1.09 - 3.51	1.19 - 5.63	0.0 - 13.50
	10 t/ha	0.67 - 3.54	1.70 - 5.67	0.0 - 14.23
	Control	1.20 - 6.44	0.0 - 6.20	0.0 - 10.23
Sample B	5 t/ha	0.33 - 6.63	0.0 - 6.60	0.0 - 10.60
	10 t/ha	0.36 - 6.23	0.0 - 6.37	0.0 - 9.27
	Control	0.0 - 3.87	0.0 - 5.27	0.0 - 7.50
Sample D	5 t/ha	0.0 - 5.10	0.0 - 4.00	0.0 - 7.67
	10 t/ha	0.0 - 4.73	0.0 - 3.90	0.0 - 7.07
	Control	0.0 - 15.37	0.0 - 23.73	0.0 - 31.13
Sample C	5 t/ha	0.0 - 25.00	0.0 - 21.67	0.0 - 31.13
	10 t/ha	0.0 - 23.47	0.0 - 15.47	0.0 - 28.87

1.4. Percentage Runoff and Total Soil loss during the First Experimental Phase .

Topsoil sample	Treatment	Runoff (mm)	Runoff (%)	Soil loss (g)
	Control	14.4	80	11.0
Sample A	5 t/ha	14.8	82	27.1
	10 t/ha	14.8	82	43.1
	Control	14.0	78	23.0
Sample B	5 t/ha	14.6	81	49.7
	10 t/ha	14.0	78	40.8
	Control	14.0	78	28.4
Sample C	5 t/ha	14.2	79	35.2
	10 t/ha	14.2	79	40.7
	Control	12.6	70	34.2
Sample D	5 t/ha	12.8	71	41.6
	10 t/ha	12.2	68	76.4

1.5. Percentage Runoff and Total Soil loss during the Second Experimental Phase.

Topsoil sample	Treatment	Runoff (mm)	Runoff (%)	Soil loss (g)
	Control	11.2	62	10.5
Sample A	5 t/ha	12.1	67	17.9
	10 t/ha	11.9	66	25.3
	Control	9.2	51	9.6
Sample B	5 t/ha	9.2	51	19.2
	10 t/ha	9.0	50	12.0
	Control	13.0	72	61.0
Sample C	5 t/ha	13.5	75	67.0
	10 t/ha	13.5	75	72.7
	Control	13.0	72	68.8
Sample D	5 t/ha	13.7	76	83.2
	10 t/ha	13.3	74	85.7

1.6. Percentage Runoff and Total Soil loss during the Third Experimental Phase.

Topsoil sample	Treatment	Runoff (mm)	Runoff (%)	Soil loss (g)
	Control	11.2	62	22.1
Sample A	5 t/ha	11.2	62	15.0
	10 t/ha	11.0	61	18.4
	Control	9.2	51	9.0
Sample B	5 t/ha	9.0	50	19.9
	10 t/ha	9.4	52	17.0
	Control	11.7	65	28.3
Sample C	5 t/ha	11.9	66	37.0
	10 t/ha	11.9	66	33.8
	Control	12.6	70	56.0
Sample D	5 t/ha	12.4	69	54.1
	10 t/ha	12.6	70	49.4

APPENDIX 2. ANALYTICAL DATA FOR THE TOPSOIL SAMPLES.

2.1. Properties of the Topsoil Samples used in the Experiment.

Soil parameter	Topsoil sample Sample A	Sample B	Sample D	Sample C
pH	6.40	6.80	6.70	6.60
EC (mS/cm)	0.04	0.04	0.08	0.04
CEC (me/100 g)	9.36	6.00	39.12	12.48
Mg (me/100 g)	1.17	0.22	3.07	2.2
K (me/100 g)	0.72	0.27	0.48	0.66
Na (me/100 g)	2.70	0.45	1.25	1.05
Exch. Ca (me/100 g)	1.80	1.00	0.70	5.30
Base sat. %	68.30	32.30	14.10	74.40

(Analysed by Kenya Agricultural Research Institute)

2.2. Organic Matter Content in the Soil Crusts after each Experimental Phase (%).

Topsoil sample	Treatment	Initial	After Phase 1	After Phase 2
Sample A	Control	1.12	0.81	0.50
	5 t/ha	1.24	1.07	0.60
	10 t/ha	1.62	1.48	1.26
Sample B	Control	1.52	1.36	0.91
	5 t/ha	1.98	1.91	1.07
	10 t/ha	2.05	1.95	1.66
Sample D	Control	5.60	5.34	5.14
	5 t/ha	5.72	5.34	5.24
	10 t/ha	6.48	5.36	5.31
Sample C	Control	1.67	1.29	1.07
	5 t/ha	2.02	1.91	1.17
	10 t/ha	2.41	1.98	1.66

APPENDIX 3. CALCULATED F-VALUES FOR ANALYSIS OF VARIANCE.[1]

3.1. Calculated F-Values for Treatment effects on Soil loss per Topsoil sample during each Experimental Phase.

	Calculated F-Value		
Topsoil sample	Phase 1	Phase 2	Phase 3
Sample A	26.91**	4.91*	1.37
Sample B	9.49*	1.06	1.07
Sample C	3.07	1.02	4.00
Sample D	12.05*	3.04	0.16

($F_{0.05}$ with degrees of freedom of 2,9 is 4.26)

3.2. Calculated F-Values for Treatment effects on Time to Runoff for Rainfall Simulation days during Experimental Phase 1.

	Calculated F-Value			
Topsoil sample	Day 1	Day 2	Day 3	Day 4
Sample A	0.38	3.59	1.49	5.74*
Sample B	14.25*	3.10	1.12	3.08
Sample C	2.16	2.70	0.81	0.13
Sample D	1.09	0.57	0.03	1.02

($F_{0.05}$ with degrees of freedom of 2,6 is 5.14)

3.3. Calculated F-Values for Treatment effects on Soil loss for Rainfall Simulation days during Experimental Phase 1.

	Calculated F-Value			
Topsoil sample	Day 1	Day 2	Day 3	Day 4
Sample A	-	3.35	18.36*	10.97*
Sample B	-	2.47	2.61	3.42
Sample C	0.31	0.37	1.35	61.99*
Sample D	1.30	1.09	0.88	0.58

($F_{0.05}$ with degrees of freedom of 2,6 is 5.14)

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[1] *** = highly significant. ** = Moderately significant. * = Slightly significant.

3.4. Calculated F-Values for Treatment effects on Soil loss for Rainfall Simulation days during Experimental Phase 2.

	Calculated F-Value			
Topsoil sample	Day 1	Day 2	Day 3	Day 4
Sample A	9.89*	1.53	1.78	1.75
Sample B	0.00	2.47	2.61	3.42
Sample C	0.00	1.65	0.68	1.23
Sample D	0.19	0.22	0.45	0.06

($F_{0.05}$ with degrees of freedom of 2,6 is 5.14)

3.5. Calculated F-Values for Treatment effects on Soil loss for Rainfall Simulation days during Phase 3.

	Calculated F-Value			
Topsoil sample	Day 1	Day 2	Day 3	Day 4
Sample A	0.27	1.47	11.13*	3.06
Sample B	0.00	0.70	1.83	1.48
Sample C	0.46	0.35	1.05	0.10
Sample D	0.31	0.11	0.20	0.22

($F_{0.05}$ with degrees of freedom of 2,6 is 5.14)

3.6. Calculated F-Values for Treatment effects on Crust Moisture Content on each Sampling day during Exprimental Phase 3.

	Calculated F-Value			
Topsoil sample	Day 1	Day 6	Day 11	Day 16
Sample A	0.04	1.53	0.08	2.29
Sample B	0.05	1.58	1.95	0.82
Sample D	6.51*	18.69*	1.23	1.47
Sample C	4.92	0.62	1.35	0.29

($F_{0.05}$ with degrees of freedom of 2,6 is 5.14)

3.7. Calculated F-Values for Treatment effects on Cone Penetration Resistance on each Sampling day during Experimental Phase 1.

	Calculated F-Value			
Luviosl type	Day 1	Day 6	Day 11	Day 16
Sample A	1.35	4.93	7.55*	15.80*
Sample B	6.34*	0.07	2.19	1.99
Sample D	0.00	0.00	0.19	0.63
Sample C	0.00	0.00	3.70	0.85

($F_{0.05}$ with degrees of freedom of 2,6 is 5.14)

APPENDIX 4. DUNCAN'S MULTIPLE RANGE TEST.

4.1. Duncan's Least Significant Range for overall Treatment Effect on Soil loss.

Topsoil sample	Phase 1 p^2	Phase 1 p^3	Phase 2 p^2	Phase 2 p^3	Phase 3 p^2	Phase 3 p^3
Sample A	2.91	2.98	2.70	2.77	-	-
Sample B	4.10	4.20	-	-	-	-
Sample C	-	-	-	-	-	-
Sample D	5.19	5.42	-	-	-	

(degrees of freedom of 9 at 95 % significance level)

4.2. Duncan's Least Significant Range for overall Phasing Effect on Soil loss per Treatment.

Topsoil sample	Control p^2	Control p^3	5 t/ha p^2	5 t/ha p^3	10 t/ha p^2	10 t/ha p^3
Sample A	1.85	1.90	2.31	2.37	2.27	2.33
Sample B	1.74	1.78	3.16	3.24	2.56	2.62
Sample C	3.91	4.00	2.99	3.06	2.47	2.53
Sample D	4.59	4.71	5.51	5.64	6.60	6.76

(degrees of freedom of 9 at 95 % significance level)

4.3. Duncan's Least Significant Range for overall Soil type Effect on Soil loss per Treatment.

Experimental Phase	Treatment	Least Significant Range p^2	p^3	p^4
1	Control	2.82	2.92	2.97
	5 t/ha	4.52	4.69	4.77
	10 t/ha	4.05	4.21	4.28
2	Control	3.34	3.50	3.59
	5 t/ha	4.46	4.68	4.79
	10 t/ha	3.06	3.21	3.29
3	Control	4.12	4.32	4.43
	5 t/ha	4.24	4.45	4.56
	10 t/ha	4.16	4.37	4.47

(degrees of freedom of 6, 12 and 12 at 95 % significance level for phases 1, 2 and 3 respectively)

4.4. Duncan's Least Significant Range for Treatment Effect on Time to Runoff.

Experimental Phase	Topsoil sample	Day	p^2	p^3
1	Sample A	4	4.32	4.48
	Sample B	1	5.77	5.98

(degrees of freedom of 6 at 95 % significance level)

4.5. Duncan's Least Significant Range for Treatment Effect on Soil loss.

Experimental Phase	Topsoil sample	Day	p^2	p^3
1	Sample A	3	4.44	4.61
	Sample A	4	0.96	0.99
2	Sample A	1	3.04	3.15
		4	6.73	6.98
3	Sample A	1	1.59	1.65

(degrees of freedom of 6 at 95 % significance level)

4.6. Duncan's Least Significant Range for Treatment Effect on Crust Moisture Content.

Experimental Phase	Topsoil sample	Day	p^2	p^3
1	Sample D	1	1.59	1.65
	Sample D	2	1.35	1.41

(degrees of freedom of 6 at 95 % significance level)

4.7. Duncan's Least Significant Range for Treatment Effect on Cone Penetration Resistance.

Experimental Phase	Topsoil sample	Day	p2	p3
1	Sample A	3	1.29	1.34
		4	0.98	1.02
3	Sample D	3	1.02	1.06

(degrees of freedom of 6 at 95 % significance level)

4.8 Rank Order of Treatment Effects on Soil loss.

Topsoil sample	Treatment ranking Phase 1	Phase 2	Phase 3
Sample A	10>5>0	10>5,0	-
Sample B	10,5>0	-	-
Sample C	10>5,0	-	-

10 = 10 t ha^{-1} treatment
5 = 5 t ha^{-1} treatment
0 = Control

4.9 Rank Order of Soil type Effects on Soil loss.

Treatment	Sample ranking Phase 1	Phase 2	Phase 3
Control	D,C,B>A	D,C>A,B	D>A,B,C
5 t ha^{-1}	B>A,C,D	D,C>A,B	D>C>A (1)
10 t ha^{-1}	D>A>C (2)	D>C>A>B	D>A,B (3)

1. C not different from B and B not different from A.
2. A not different from B and B not different from C.
3. D not different from C and C not different from B.

4.10 Rank Order of Soil type Effects on Moisture Content of the Crust.

Treatment	Sample ranking Phase 1	Phase 2	Phase 3
Control	C>D>A,B	-	-
5 t ha^{-1}	C>D>A,B	-	-
10 t ha^{-1}	C>D>A,B	-	-

4.11 Rank Order of Phase Effect on Soil loss.

Topsoil sample	Experimental phase ranking Control	5 t ha^{-1}	10 t ha^{-1}
Sample A	3>2,1	1>2,3	1>2,3
Sample B	1>2,3	1>2,3	1>2,3
Sample C	2>1,3	2>1,3	2>1,3
Sample D	2,3>1	2>1,3	2,1>3

(3 = phase 3; 2 = phase 2; 1 = phase 1)

4.12 Rank Order of Treatment Effect on Time to Runoff on the Same Simulation day.

Topsoil sample	Simulation Day	Experimental phase Phase 1	Phase 2	Phase 3
Sample A	4	0>5,10	-	-
Sample B	1	10>5,0	-	-

10 = 10 t ha^{-1} treatment
5 = 5 t ha^{-1} treatment
0 = Control

4.13 **Rank Order of Treatment Effect on Soil loss on the same Simulation day.**

Topsoil sample	Simulation Day	Experimental phase Phase 1	Phase 2	Phase 3
Sample A	1	-	10,5>0	-
	3	10>5>0	-	0>5,10
	4	10,5>0	-	-
Sample D	4	10,5>0	-	-

10 = 10 t ha^{-1} treatment
5 = 5 t ha^{-1} treatment
0 = Control

4.14 **Rank order of Treatment Effect on Moisture Content of the Crust on the same Sampling day.**

Lvisol type	Sampling Day	Experimental phase Phase 1	Phase 2	Phase 3
Sample D	1	10,5>0	-	-
	2	10,5>0	-	-

10 = 10 t ha^{-1} treatment
5 = 5 t ha^{-1} treatment
0 = Control

4.15 **Rank order of Treatment Effect on Cone Penetration Resistance on the same Sampling day.**

Topsoil sample	Sampling Day	Experimental phase Phase 1	Phase 2	Phase 3
Sample A	3	0>5,10	-	-
	4	0>5,10	-	-

10 = 10 t ha^{-1} treatment
5 = 5 t ha^{-1} treatment
0 = Control

APPENDIX 5. PARAMETER VALUES FOR REGRESSION EQUATIONS.[2]

5.1. Regression Equation Parameters of Penetration Resistance on Moisture Content for the Different Soils ($n = 36$).

Topsoil sample	Manure	A	b	Standard error Y est.	Standard error X coeff	r^2
Sample A	control	5.37	-0.10	0.50	0.01	0.58
	5 t/ha	4.53	-0.08	0.63	0.02	0.41
	10 t/ha	4.57	-0.08	0.68	0.02	0.38
Sample B	control	6.69	-0.59	0.47	0.07	0.67
	5 t/ha	7.69	-0.80	0.85	0.14	0.51
	10 t/ha	7.24	-0.72	0.66	0.11	0.58
Sample C	control	12.94	-0.08	0.64	0.02	0.62
	5 t/ha	9.97	-0.07	0.54	0.01	0.64
	10 t/ha	8.50	-0.06	0.41	0.01	0.71
Sample D	control	441.42	-2.01	0.31	0.08	0.95
	5 t/ha	678.58	-2.15	0.51	0.14	0.87
	10 t/ha	368.71	-1.99	0.69	0.18	0.78

5.2. Confidence limits for Regression Equation Parameters of Penetration Resistance on Moisture content.

Topsoil sample	Treatment	Regression constant	X Coefficient
Sample A	control	$4.32<A<6.42$	$-0.14<b<-0.06$
	5 t/ha	$3.48<A<5.58$	$-0.12<b<-0.04$
	10 t/ha	$3.48<A<5.66$	$-0.12<b<-0.04$
Sample B	control	$2.56<A<10.82$	$-0.87<b<-0.31$
	5 t/ha	$2.50<A<12.88$	$-1.14<b<-0.46$
	10 t/ha	$2.61<A<11.87$	$-1.06<b<-0.38$
Sample C	control	$12.13<A<13.75$	$-0.11<b<-0.05$
	5 t/ha	$8.92<A<11.02$	$-0.11<b<-0.03$
	10 t/ha	$7.41<A< 9.59$	$-0.10<b<-0.02$
Sample D	control	$437.29<A<445.55$	$-2.29<b<-1.73$
	5 t/ha	$673.39<A<683.77$	$-2.49<b<-1.81$
	10 t/ha	$364.08<A<373.34$	$-2.33<b<-1.65$

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2 The required minimum value of r^2 to give a significant T-test at 95 % confidence level is 0.11 since $n>32$.

APPENDIX 5. PARAMETER VALUES FOR REGRESSION EQUATIONS.[2]

5.1. Regression Equation Parameters of Penetration Resistance on Moisture Content for the Different Soils (n_i= 36).

Topsoil sample	Manure	A	b	Standard error Y est.	Standard error X coeff	r^2
Sample A	control	5.37	-0.10	0.50	0.01	0.58
	5 t/ha	4.53	-0.08	0.63	0.02	0.41
	10 t/ha	4.57	-0.08	0.68	0.02	0.38
Sample B	control	6.69	-0.59	0.47	0.07	0.67
	5 t/ha	7.69	-0.80	0.85	0.14	0.51
	10 t/ha	7.24	-0.72	0.66	0.11	0.58
Sample C	control	12.94	-0.08	0.64	0.02	0.62
	5 t/ha	9.97	-0.07	0.54	0.01	0.64
	10 t/ha	8.50	-0.06	0.41	0.01	0.71
Sample D	control	441.42	-2.01	0.31	0.08	0.95
	5 t/ha	678.58	-2.15	0.51	0.14	0.87
	10 t/ha	368.71	-1.99	0.69	0.18	0.78

5.2. Confidence limits for Regression Equation Parameters of Penetration Resistance on Moisture content.

Topsoil sample	Treatment	Regression constant	X Coefficient
Sample A	control	4.32<A<6.42	-0.14<b<-0.06
	5 t/ha	3.48<A<5.58	-0.12<b<-0.04
	10 t/ha	3.48<A<5.66	-0.12<b<-0.04
Sample B	control	2.56<A<10.82	-0.87<b<-0.31
	5 t/ha	2.50<A<12.88	-1.14<b<-0.46
	10 t/ha	2.61<A<11.87	-1.06<b<-0.38
Sample C	control	12.13<A<13.75	-0.11<b<-0.05
	5 t/ha	8.92<A<11.02	-0.11<b<-0.03
	10 t/ha	7.41<A< 9.59	-0.10<b<-0.02
Sample D	control	437.29<A<445.55	-2.29<b<-1.73
	5 t/ha	673.39<A<683.77	-2.49<b<-1.81
	10 t/ha	364.08<A<373.34	-2.33<b<-1.65

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[2] The required minimum value of r^2 to give a significant T-test at 95 % confidence level is 0.11 since n>32.

5.3. Regression Equation Parameters of Time to Runoff on Organic Matter and cumulative Kinetic energy of Rainfall (n = 33).

Topsoil sample	r^2	A	Std. error of Y est.	Coefficient X_3	X_4
Sample A	0.85	53.52	0.27	-	-0.36
	0.04	46.06	0.68	-1.28	-
	0.61	122.35	24.79	-8.29	-42.91
Sample B	0.84	72.24	0.33	-	-1.51
	0.06	83.10	0.79	-0.49	-
	0.63	194.89	37.64	-15.71	-67.61
Sample C	0.73	40.85	0.33	-	-1.01
	0.06	262.43	0.61	-0.40	-
	0.63	152.70	15.96	-13.53	-26.94
Sample D	0.81	37.71	0.38	-	-1.49
	0.03	39.65	0.87	-0.33	-
	0.62	118.91	23.12	-12.78	-39.29

(X_3 = Organic matter. X_4 = Kinetic energy)

5.4. Regression Equation Parameters of Runoff on Time to Runoff, Organic matter and Cumulative Kinetic Energy of Rainfall (n = 33).

Topsoil sample	r^2	A	Std. error of Y est.	X_1	Coefficient X_3	X_4
Sample A	0.99	109.95	0.05	-0.01	-	-
	0.04	46.06	0.54	-	0.28	-
	0.80	40.45	0.24	-	-	0.99
	0.71	12.11	13.23	-	8.21	28.17
Sample B	0.99	156.02	0.14	-0.03	-	-
	0.02	12.94	1.68	-	0.58	-
	0.79	9.21	0.79	-	-	3.03
	0.77	-17.47	14.90	-	7.91	37.65
Sample C	0.91	102.51	0.10	-0.01	-	-
	0.001	55.70	0.33	-	0.11	-
	0.86	54.60	0.13	-	-	0.57
	0.81	32.61	8.43	-	-0.01	23.22
Sample D	0.94	102.00	0.10	-0.01	-	-
	0.03	50.91	0.42	-	0.18	-
	0.72	54.60	0.23	-	-	0.68
	0.70	19.90	12.62	-	7.71	25.77

(X_1 = Time to runoff. X_3 = Organic matter. X_4 = Kinetic energy.)

5.5. Regression Equation Parameters of Soil loss on Time to Runoff, Runoff, Organic matter and cumulative Kinetic Energy of Rainfall (n = 33).

Topsoil sample	r^2	A	Std. error of Y est	Coefficient X_1	X_2	X_3	X_4
Sample A	0.55	33.38	2.53	-0.25	-0.40	6.37	2.05
	0.52	23.00	2.57	-0.18	-0.23	5.66	-
	0.22	12.46	3.22	-0.07	-0.05	-	-
	0.40	29.67	0.40	-0.52	-	-	-
	0.32	0.44	0.47	-	0.59	-	-
	0.26	2.16	0.49	-	-	0.78	-
	0.20	3.97	0.51	-	-	-	0.52
	0.39	-2.08	2.85	-	-	5.13	1.44
	0.43	-2.75	2.80	-	0.06	4.67	-0.14
	0.22	11.59	3.27	-0.07	-0.04	-	-0.19
Sample B	0.69	-13.36	3.04	0.07	0.36	3.92	-6.94
	0.55	-2.52	3.61	-0.03	0.04	4.83	-
	0.41	4.14	4.07	-0.03	0.06	-	-
	0.79	162.39	0.42	-0.98	-	-	-
	0.69	1.07	0.51	-	0.03	-	-
	0.17	1.08	0.83	-	-	0.90	-
	0.45	2.72	0.68	-	-	-	1.22
	0.33	-6.99	4.33	-	-	5.78	2.35
	0.67	-3.36	3.09	-	0.21	4.13	-5.46
	0.60	-9.70	3.39	0.08	0.42	-	-7.94
Sample C	0.28	7.88	4.00	0.02	0.30	-1.22	-7.36
	0.10	49.48	4.42	-0.16	-0.18	-3.65	-
	0.03	18.30	4.51	-0.07	-0.07	-	-
	0.03	11.36	0.38	-0.002	-	-	-
	0.02	5.53	0.39	-	0.15	-	-
	0.01	16.61	0.39	-	-	-0.08	-
	0.02	11.70	0.39	-	-	-	-0.07
	0.03	20.68	4.50	-	-	-1.48	-0.82
	0.28	11.84	3.94	-	0.27	-1.48	-7.11
	0.28	-4.02	3.96	0.06	0.37	-	-7.88
Sample D	0.33	50.83	4.65	-0.28	-0.35	2.44	-2.45
	0.30	56.45	4.68	-0.32	-0.47	2.93	-
	0.24	61.55	4.78	-0.32	-0.47	-	-
	0.10	15.96	0.36	-0.003	-	-	-
	0.09	4.48	0.36	-	0.27	-	-
	0.05	10.28	0.37	-	-	0.20	-
	0.004	14.15	0.38	-	-	-	0.05
	0.07	10.17	5.29	-	-	3.36	-0.36
	0.18	7.38	5.06	-	0.14	2.28	-3.96
	0.29	53.58	4.69	-0.28	-0.32	-	-3.01

(X_1 = Time to Runoff. X_2 = Runoff.
X_3 = Organic matter. X_4 = Kinetic energy.

APPENDIX 6. GRAPHS FOR TIME TO RUNOFF.

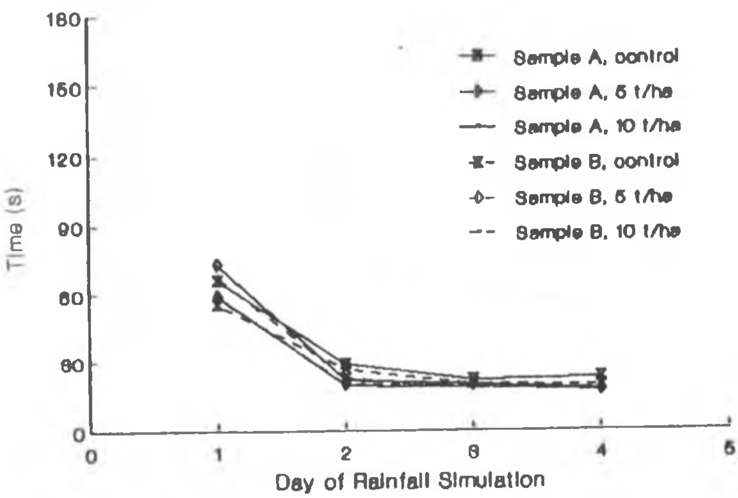


Fig. 6.1. Time to runoff for Samples A and B during Phase 1.

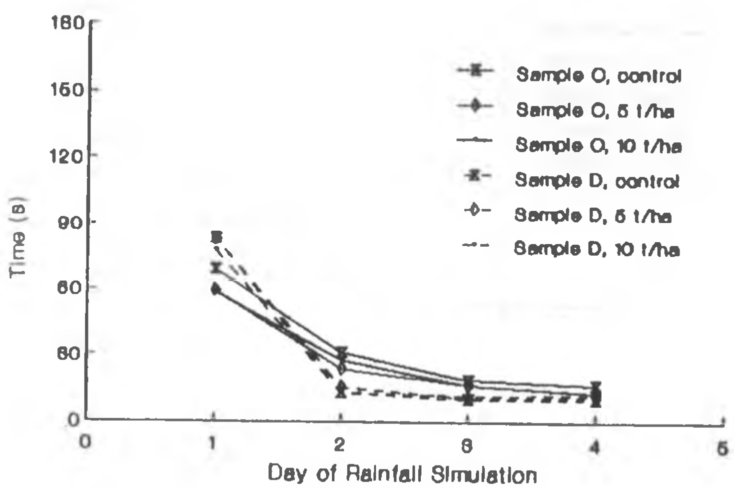


Fig. 6.2. Time to runoff for Samples C and D during Phase 1.

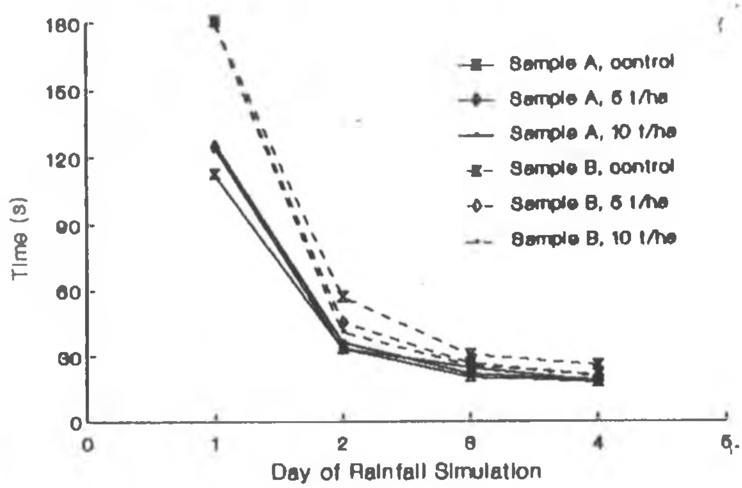


Fig. 6.3. Time to runoff for Samples A and B during Phase 2.

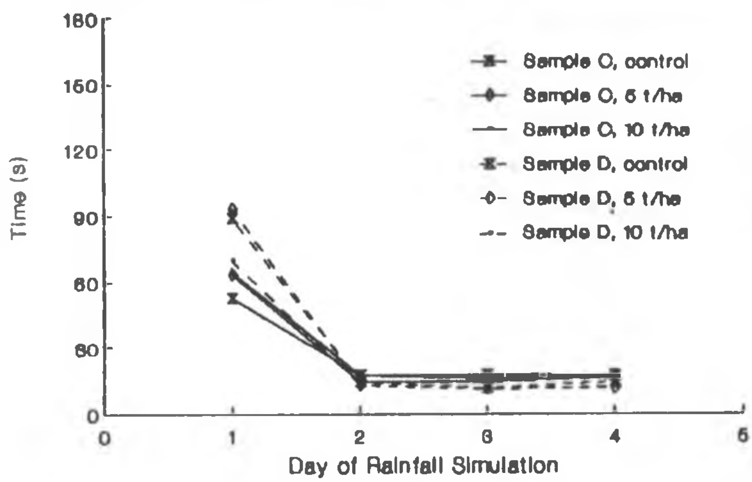


Fig. 6.4. Time to runoff for Samples C and C during Phase 2.

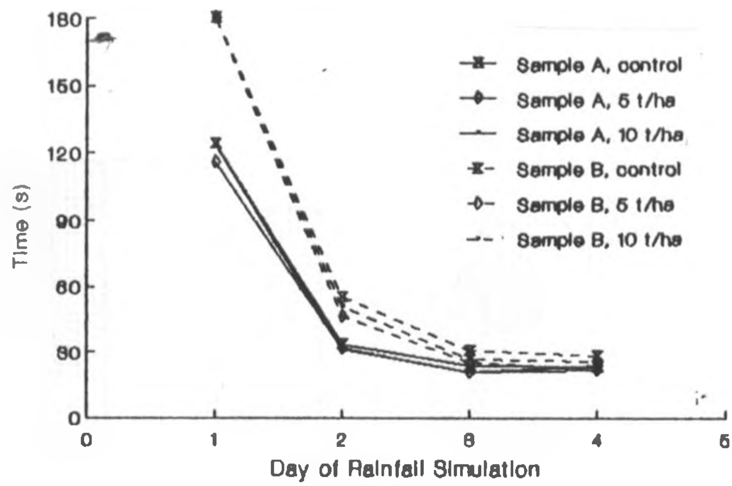


Fig. 6.5. Time to runoff for Samples A and B during Phase 3.

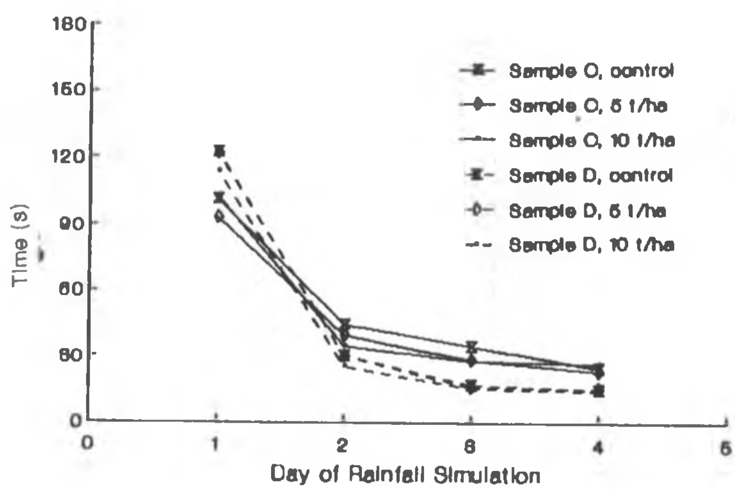


Fig. 6.6. Time to runoff for Samples C and D during Phase 3.

APPENDIX 7. BARGRAPHS FOR SURFACE RUNOFF.

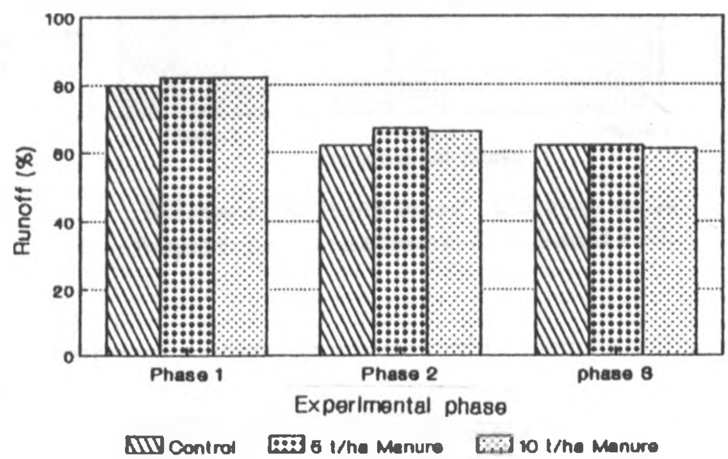


Fig. 7.1. Runoff per Treatment for Sample A.

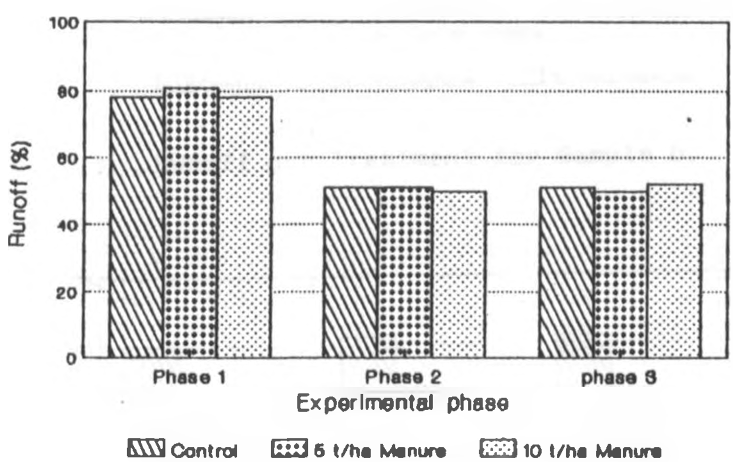


Fig. 7.2. Runoff per Treatment for Sample B.

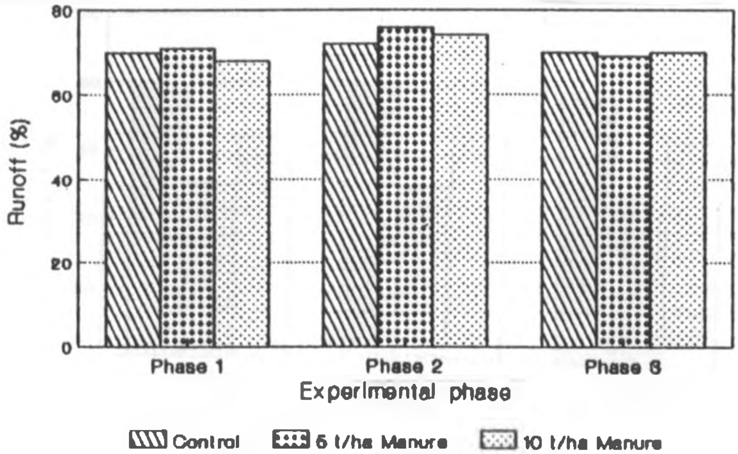


Fig. 7.3. Runoff per Treatment for Sample C.

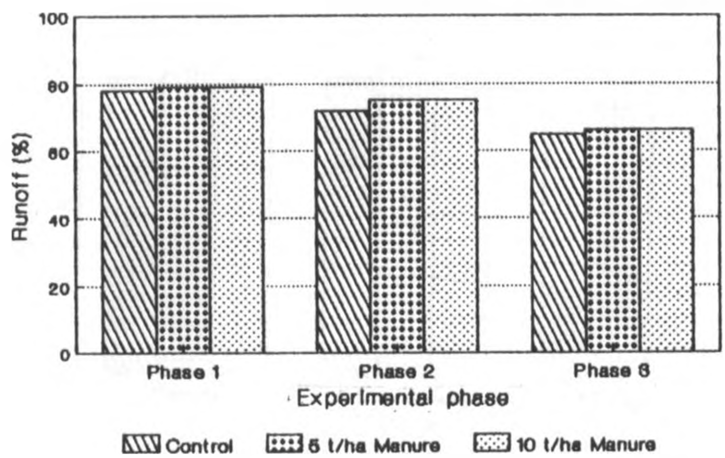


Fig. 7.4. Runoff per Treatment for Sample D.

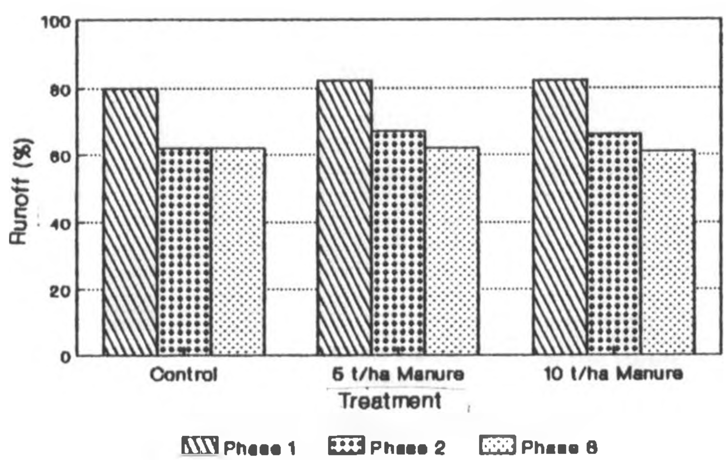


Fig. 7.5. Runoff per Phase for Sample A.

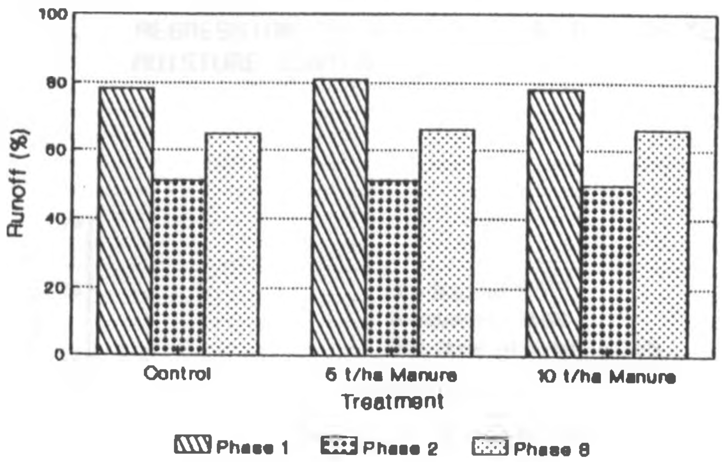


Fig. 7.6. Runoff per Phase for Sample C

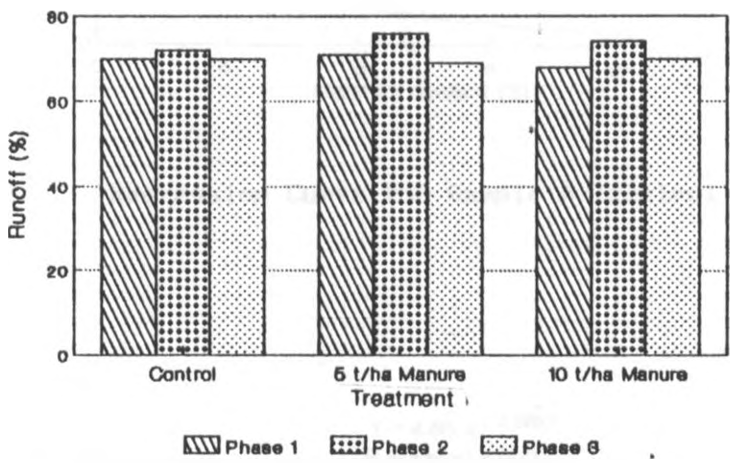


Fig. 7.7. Runoff per Phase for Sample B.

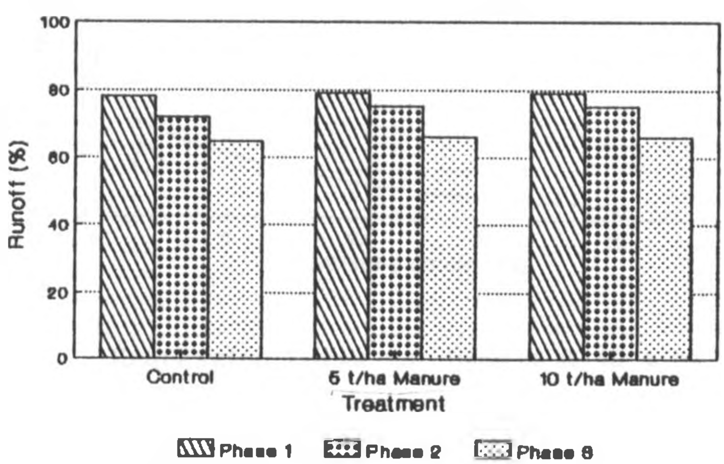


Fig. 7.8. Runoff per Phase for Sample D.

APPENDIX 8. REGRESSION CURVES FOR PENETRATION RESISTANCE AND MOISTURE CONTENT.

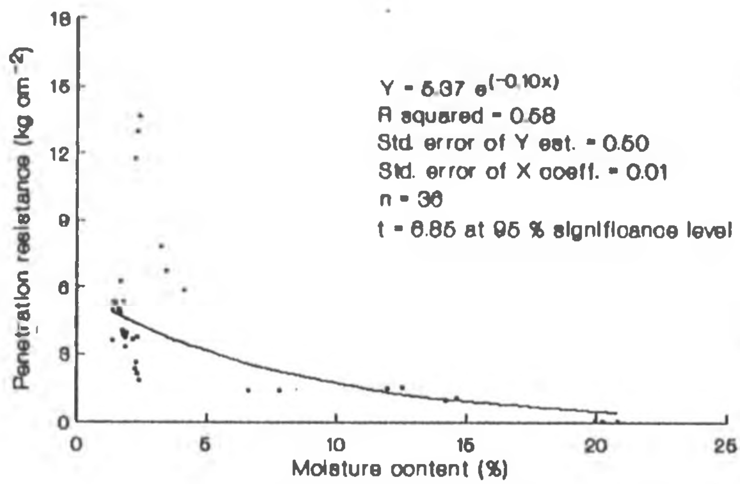


Fig. 8.1. Regression Curve for Sample A (control).

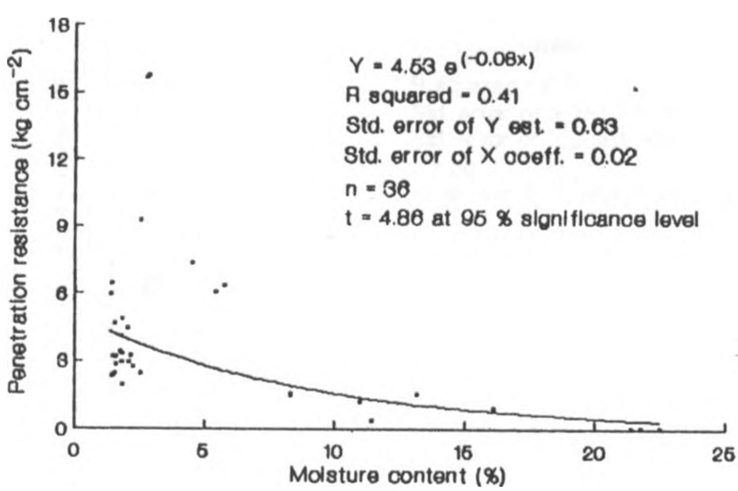


Fig. 8.2. Regression Curve for Sample A (5 t ha^{-1} treatment).

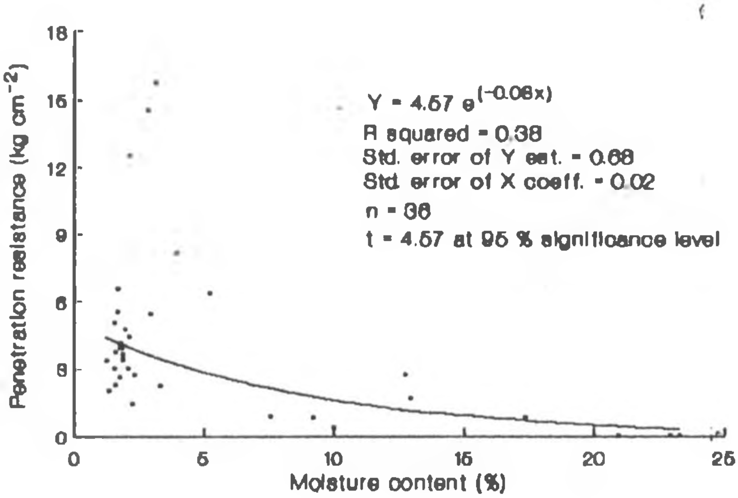


Fig. 8.3. Regression Curve for Sample A (10 t ha^{-1} treatment).

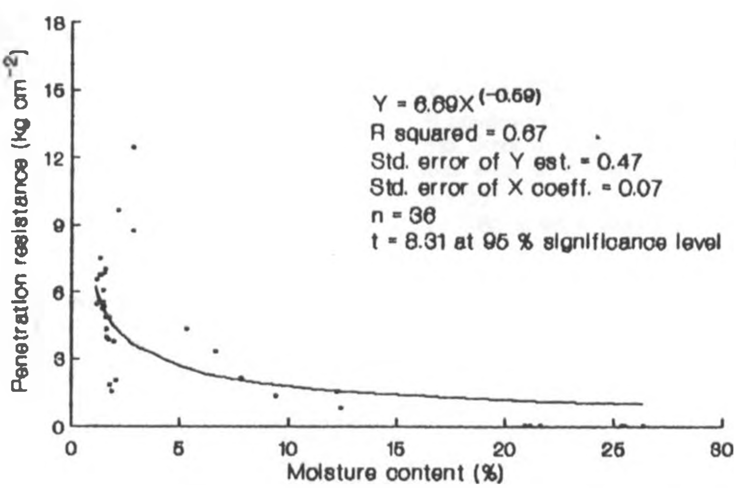


Fig. 8.4. Regression Curve for Sample B (control).

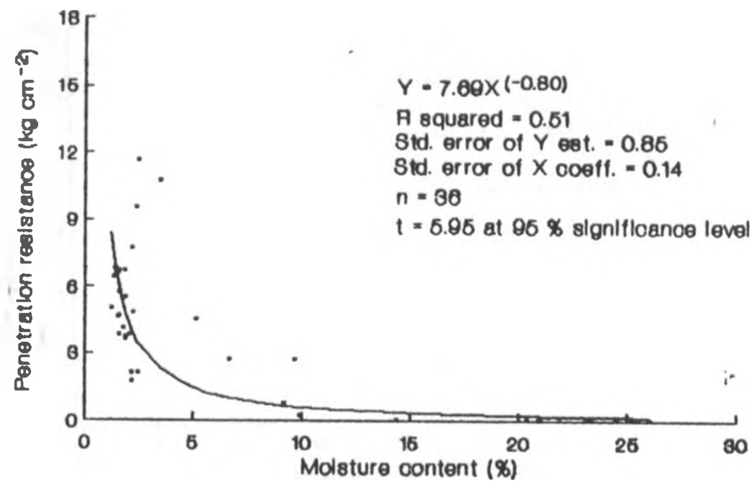


Fig. 8.5. Regression Curve for Sample B (5 t ha^{-1} treatment).

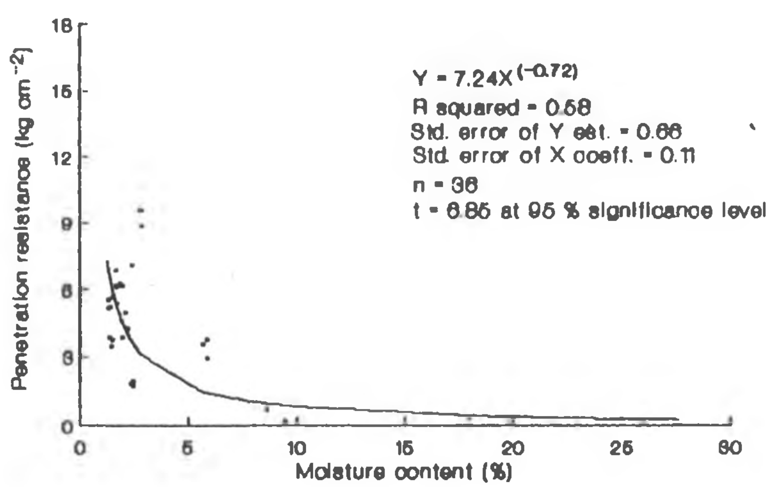


Fig. 8.6. Regression Curve for Sample B (10 t ha^{-1} treatment).

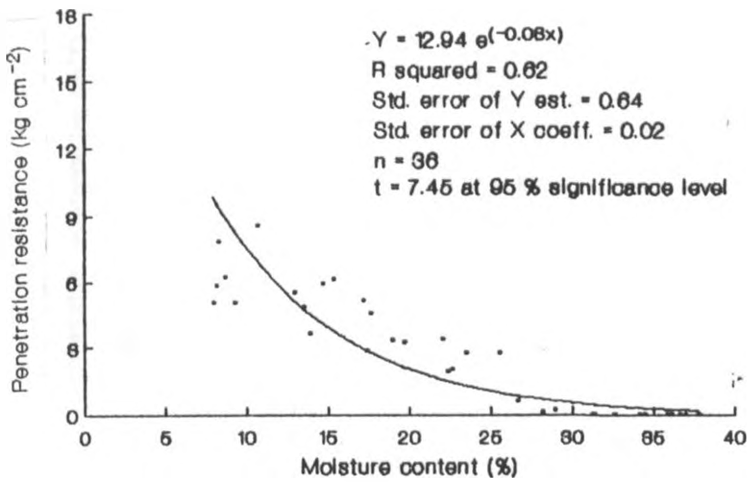


Fig. 8.7. Regression Curve for Sample D (control).

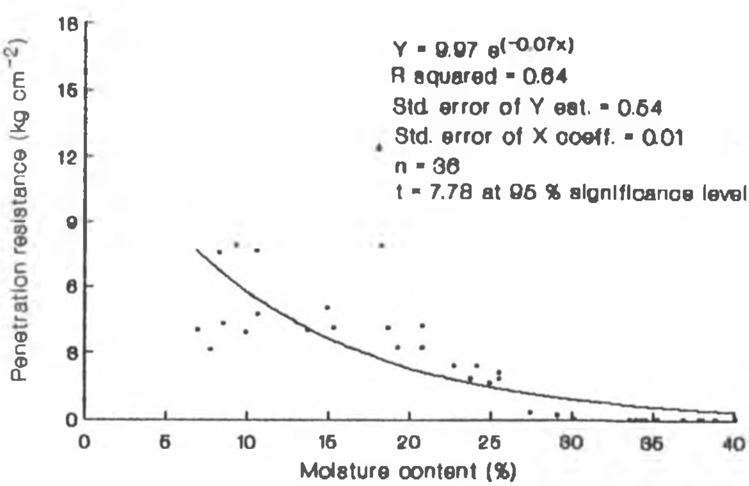


Fig. 8.8. Regression Curve for Sample D (5 t ha^{-1} treatment).

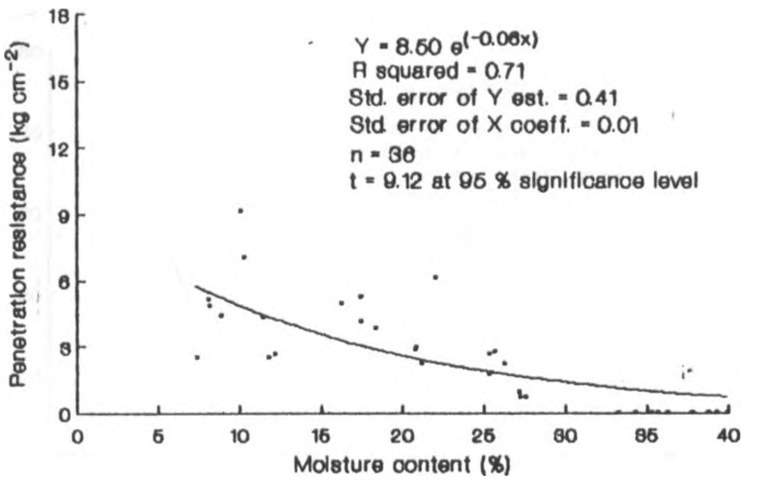


Fig. 8.9. Regression Curve for Sample D (10 t ha^{-1} treatment).

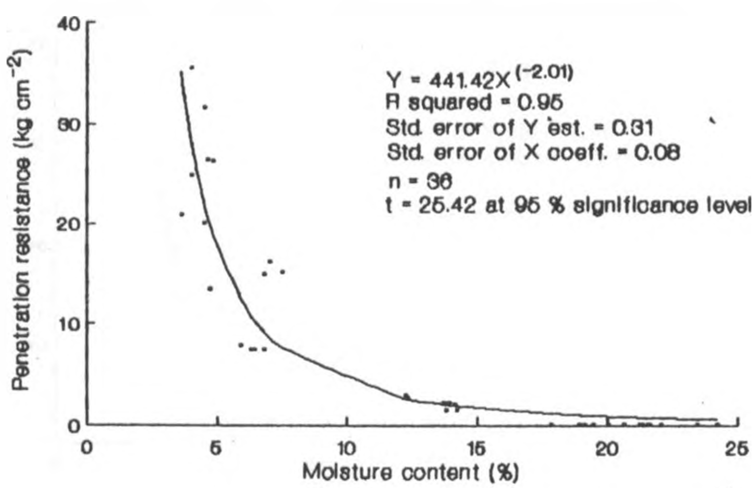


Fig. 8.10. Regression Curve for Sample C (control).

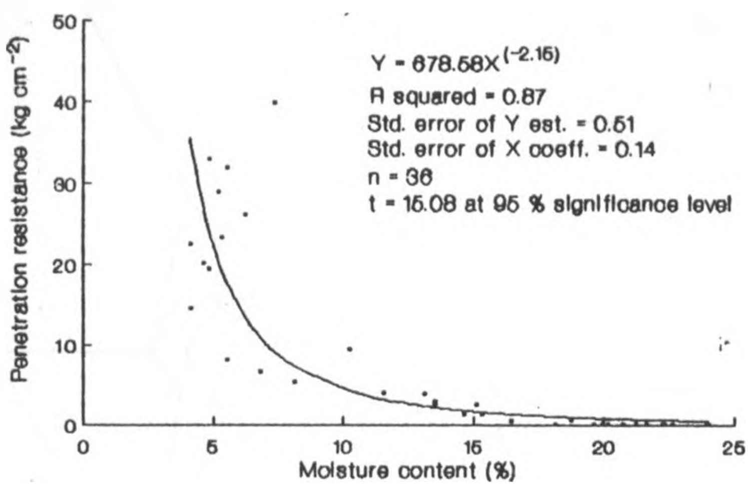


Fig. 8.11. Regression Curve for Sample C (5 t ha^{-1} treatment).

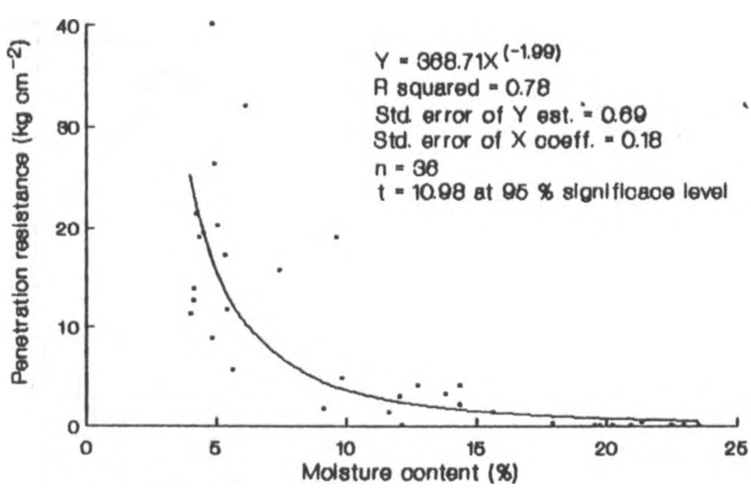
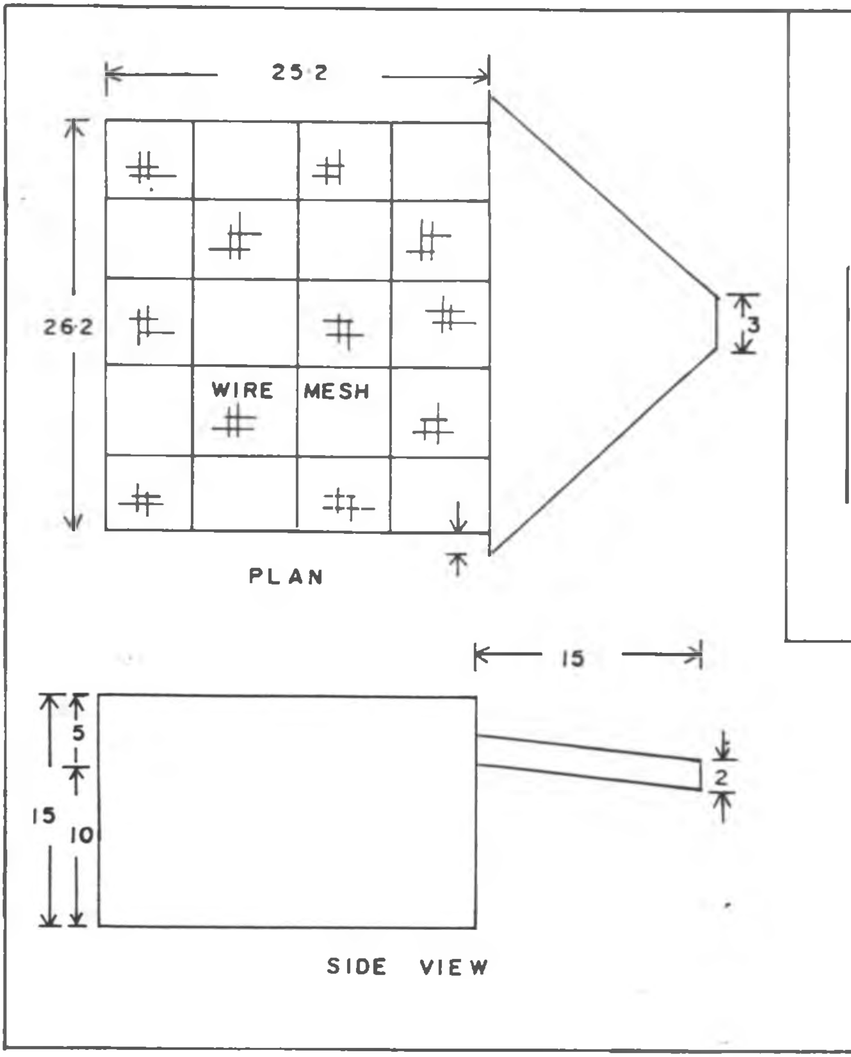
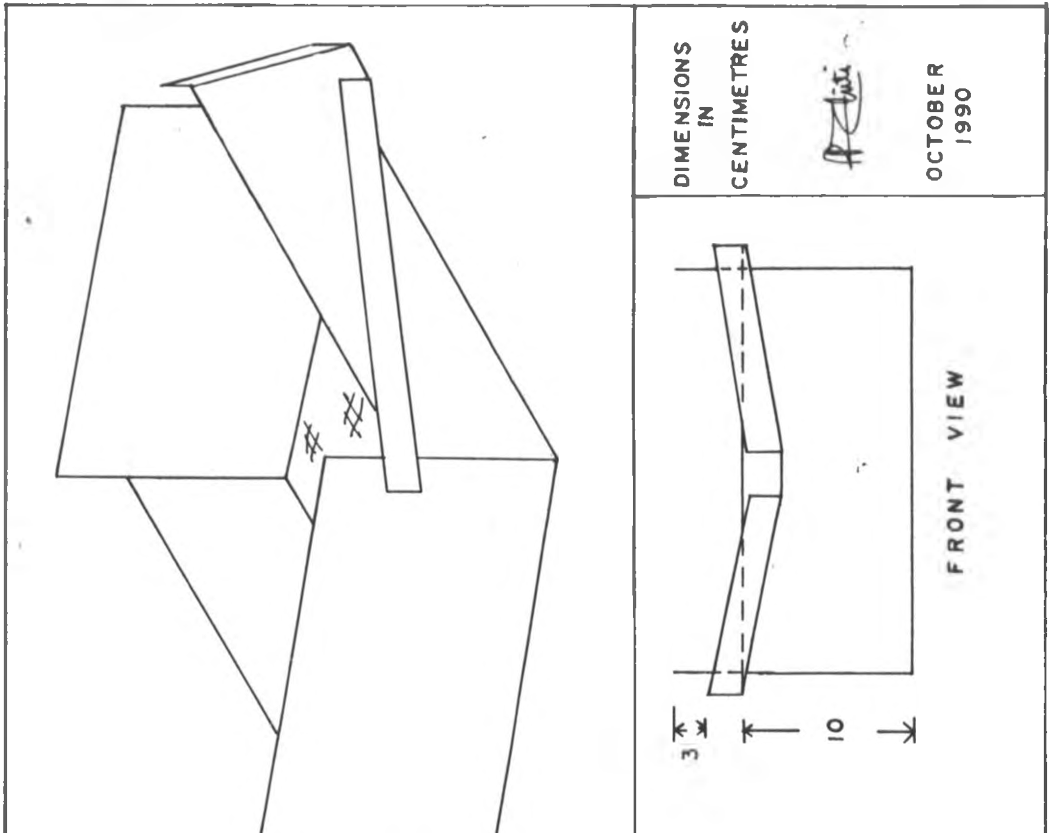


Fig. 8.12. Regression Curve for Sample C (10 t ha^{-1} treatment).


25·2
26·2
WIRE MESH
3
PLAN
15
5
15
10
2
SIDE VIEW

APPENDIX 9. DESIGN OF A SOIL TRAY.



APPENDIX 10. DESIGN OF A PERCOLATE COLLECTOR.