

**SOIL AND WATER CONSERVATION UNDER SOME  
IMPROVED FALLOW PLANT SPECIES IN VIHIGA  
DISTRICT, KENYA.**

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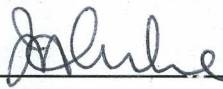
## DECLARATION

This thesis is my original work and has not been presented for a degree in any other university or any other award.

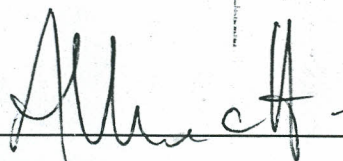
  
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## DEDICATION

*To Orindi family*

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## ABSTRACT

Soils in parts of western Kenya are degraded due to continuous cultivation thus contributing to low crop yields. Alternative farming systems involving the use of short-term tree legume fallows are being encouraged instead of the conventional system where land is left under natural fallow after crop harvest.

This study was carried out over a nine-month period to assess the effect of improved fallows on soil erosion and soil water conservation in a subhumid area in Western Kenya. Soil erosion was assessed in the field using a rainfall simulator. The following treatments were considered: (a) Continuous maize (b) Natural fallow cover (c) Improved fallow cover of *Tephrosia candida*, (d) Improved fallow no cover, (e) Natural fallow no cover tilled, and (e) Improved fallow no cover tilled. Soil moisture storage was assessed on a weekly basis using a 10-cm interval up to a depth of 60 cm under: (a) Continuous maize, (b) Natural fallow, (c) *Tephrosia candida*, (d) *Tephrosia candida* + *Macroptilium atropurpureum*, (e) *Crotalaria grahamiana*, and (f) *Crotalaria paulina*. Runoff intensity, turbidity and soil losses were higher under natural fallow no cover tilled (47.6 mm h<sup>-1</sup>, 10.87 g L<sup>-1</sup>, 3.02 t ha<sup>-1</sup>) compared to the improved fallows no cover tilled (42.4 mm h<sup>-1</sup>, 4.92 g L<sup>-1</sup>, 1.31 t ha<sup>-1</sup>). There was no significant difference (p= 0.05) in terms of aggregate stability in the top 10-cm soil between the treatments. Fluctuations in soil moisture content were greater in the upper soil layers and reduced with depth but the variation among treatments increased with depth. There was a faster recharge of water stocks

but a gradual decrease under the improved fallows compared to conventional farming practices. Rainfall events of less than 10 mm had very limited effect under the treatments where the cover was over 70%. Improved fallows performed better in improving soil physical conditions as shown by the decrease in soil detachability. Improved fallows offer better opportunity for controlling soil erosion and conserving soil moisture.

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## LIST OF ABBREVIATIONS

<i>Cg</i>	<i>Crotalaria grahamiana</i>
CM	Continuous maize
CMca	Continuous maize cover phase1
<i>Cp</i>	<i>Crotalaria paulina</i>
FAO	Food and Agriculture Organization
FEWS	Famine early warning systems
ICRAF	International Centre for Research in Agroforestry
IF	Improved fallow
IFca	Improved fallow cover phase 1
IFcb	Improved fallow cover phase 2
IFncb	Improved fallow no cover phase 2
IFncbt	Improved fallow no cover tilled phase 2
NF	Natural fallow
NF2	Natural fallow 2
NF2cb	Natural fallow cover phase 2
NF2nctb	Natural fallow no cover tilled phase 2
PAR	Photosynthetic active radiation
R1D1	Replicate 1 day 1
R1D2	Replicate 1 day 2
R2D1	Replicate 2 day 1
R2D2	Replicate 2 day 2
R3D1	Replicate 3 day 1

R3D2	Replicate 3 day 2
SOM	Soil Organic Matter
Tc	<i>Tephrosia candida</i>
Tc+M	<i>Tephrosia candida</i> + <i>Macroptilium autropurpureum</i>
W	Week

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background of the problem

Peasant farmers in Western Kenya are faced with food insecurity (Sanchez *et al.*, 1997). Food insecurity as used in this thesis refers to food scarcity and inability to purchase it. Conventionally, the needed increase in agricultural production is met by expanding land under cultivation through such systems like shifting cultivation. However, this is no longer a viable option in high potential areas where population densities are comparatively higher (Rocheleau *et al.*, 1988; Rao *et al.*, 1998a; Sanchez, 1999). In Kenya, geographic regions with favourable climatic conditions for cereal production are limited (Hudgens, 1996) and the rapid population growth at a rate of 2.9% (Republic of Kenya, 2000) has resulted in more intensive land use patterns. The bulk of an increase in food production will therefore have to be achieved by improving the use of land already under cultivation. The need is not only to increase productivity per unit area, but also to prevent more land going out of production due to degradation (Douglas, 1994). One of the most promising techniques of improving land productivity is use of improved fallows.

Improved fallow is defined as a targeted use of plant species in order to achieve one or more of the aims of natural fallow within a short time or on a small land area (Prinz, 1986). A natural fallow is aimed at improving the

chemical and physical conditions of a soil after a phase of use, controlling weeds, diseases and pests, and supplying useful by products such as firewood, medicinal herbs or animal feeds (Prinz, 1986). Improved fallows involve the growing of trees/shrubs such as *Crotalaria*, *Sesbania*, and *Tephrosia* in rotation with staple crops such as maize (Rao *et al.*, 1998a). Preferred species in the improved fallow system are legumes that fix nitrogen from air through symbiotic association with rhizobium bacteria and transfer it to soils when the plant biomass is incorporated (Rocheleau *et al.*, 1988). They also prevent soil loss and conserve water through the improvement of soil physical conditions leading to relatively higher infiltration rates and less runoff (ICRAF, 1999). In high potential areas of Kenya, farms can only be left fallow for very short periods due to increasing population and competing land uses. This has led to the introduction into farming systems of trees and shrubs that facilitate soil recovery (Sanchez, 1999). Species used are those that enhance soil fertility and establish rapid ground cover (Rao *et al.*, 1998a; ICRAF, 1999).

Improved fallows are largely being used in western Kenya highland to restore soil fertility (Rao *et al.*, 1998a). These areas are characterised by high population pressure with densities ranging from 500 to 1200 persons/km<sup>2</sup>. Farm sizes vary between 0.5 and 2.0 hectares with soils of very low fertility (ICRAF, 1997). Relatively higher soil nitrogen (N) and phosphorous (P) levels have been observed under improved fallows than in natural fallows (Kwesiga *et al.*, 1999). *T. candida* and *C. grahamiana*, have been identified as potential

species for improved fallows because of their fast growth, ease of propagation, comparatively higher biomass production and nitrogen fixing properties (ICRAF, 1999).

The biomass produced may also help in improving soil physical conditions thus reducing erodibility. Soil erodibility is the integrated effect of processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport (Lal and Elliot, 1994). Soil properties such as particle size distribution, structural stability, organic matter content, nature of clay minerals and chemical constituents affect these processes (Landon, 1991; Morgan, 1995). Soil physical characteristics are dynamic, being altered over time and under different land uses, soil surface management and cropping systems. Hence soil erodibility also changes over time (Lal, 1992). Cropping systems involving improved fallows may result in the improvement of soil physical properties and therefore reduced erodibility and soil moisture storage capacity.

Hillel (1971), Omwega (1989) and Morgan (1995) have argued that strategies for soil and water conservation in subhumid areas should be based on soil surface cover to protect it from raindrop impact, improving soil aggregate stability, increasing infiltration capacity thereby reducing runoff and overall soil loss. The strategies should aim at establishing and maintaining good ground cover and the feasibility of this is determined by what crops are being

grown and how quickly under the local climate and soil conditions they can attain a preferred 40-50 percent canopy cover. According to Hudson (1981), small differences in cover can cause big differences in soil and water loss.

Improvement in infiltration and aggregate stability may be achieved through the maintenance or addition of organic matter from the plant biomass (Allison, 1973; Priyono *et al.*, 1996). A high infiltration rate is associated with the presence of stable aggregates and pores between them (Le Bissonnais, 1996; Amézqueta, 1999). Organic matter acts as mulch on soil surface reducing direct evaporation rates, runoff, soil loss but increasing infiltration and biological activity (Papendick, 1992). It is therefore important that an adequate amount of organic matter is maintained.

## **1.2 Statement of the problem**

The sustainable use of both soil and water is essential for continued plant production. Kenya is basically an agricultural country and the areas that experience the highest erosion risks are the most productive in the country (Denga *et al.*, 2000). In parts of Vihiga District where the land is steep (reaching a maximum of 40%) (Rao *et al.*, 1999), a considerable amount of precipitation and soil are likely to be lost through runoff. In some humid regions, loss by runoff may be as high as 50 or 60% of the annual precipitation (Brady and Weil, 1999). The topsoil that is lost contains much of the nutrients that plants need for their growth and development.

An adequate and balanced supply of moisture is essential for plant growth. Moisture is constantly being taken up by plants together with nutrients and is lost by transpiration and therefore a steady supply is necessary if growing plants are to remain alive (Fitzpatrick, 1986). Soil management should therefore include strategies that reduce runoff but promote rapid infiltration leading to maximum storage of rainwater and minimum soil loss.

Most studies involving improved fallows have focussed on nitrogen fixing qualities of plants (Giller and Wilson, 1991; Arnaud, 1995; Giller and Cadisch, 1995; Hartemink *et al.*, 1996; Giller *et al.*, 1997; Kwesiga *et al.*, 1999; Mafongoya and Dzowela, 1999; Szott *et al.*, 1999) but not the non-nutrient benefits. Apart from nutrient deficiency, it is possible that other factors such as poor soil physical conditions and inadequate soil moisture may contribute to decline in crop yields. This study, therefore, evaluated some effects of variation in amount of soil cover between *Tephrosia candida*, *Macroptilium atropurpureum*, *Crotalaria grahamiana*, *Crotalaria paulina*, natural fallow and continuous maize, on soil loss and water retention.

### **1.3 Research questions.**

The following questions constituting the problem of the study were formulated:

1. Do short term improved fallows provide better soil cover than continuous maize and natural fallows?
2. What effects do short term-improved fallows have on aggregate stability, runoff, soil loss and soil moisture storage compared to continuous maize and natural fallows?

#### **1.4 Study objectives**

The aim of this study was to investigate the effect of short term improved fallows on soil erosion control and soil water conservation. To answer the above questions, the study was guided by the following specific objectives:

1. To monitor soil cover changes under natural and improved fallow conditions, and maize crop.
2. To determine the influence of improved fallows on aggregate stability, infiltration and soil loss.
3. To determine soil moisture changes under different land use systems:
  - i) Continuous maize
  - ii) Natural fallow
  - iii) Improved fallows

#### **1.5 Significance of the study**

This study examined some roles of improved fallows in soil and water conservation through provision of soil cover on arable land in Vihiga, a sub-humid area in western Kenya. This is considered as a contribution to the

assessment of soil moisture availability and soil erosion hazards on agricultural land in areas of high population density. Soil erosion is largely an irreversible process that leads to the loss of the fertile topsoil and reduced crop yields. The data generated is useful in evaluating soil and water conservation strategies. Reducing the rate of soil erosion will boost food production in these areas.

Increased soil moisture availability due to improved soil physical conditions may reduce the risk of crop failure during long rains thus improving food availability. Dry spells may occur during the growing cycle particularly at critical growth stages. Optimum soil physical conditions together with adequate amount of soil moisture at planting time will lead to sufficient root development when the crop is very young. Such crops are able to explore a wider area hence, may not be affected as much as those grown on soils with poor physical conditions. In addition, the improved conditions encourage relatively higher infiltration and the cover or mulch on the soil surface conserves the moisture. Rotating annual crops with leguminous trees and shrubs can reduce the incidence of crop pests and diseases through breaking their life cycles.

### **1.6 Study area and study justification**

This study was carried out at Ochinga, Vihiga district. The area is characterised by intensive cultivation due to high population density common

to high potential areas of Kenya (Republic of Kenya, 1997). Ochinga area was chosen because it is faced with the problem of declining crop yields resulting from soil degradation (ICRAF, 1999; Rao *et al.*, 1999). Improved fallows have been introduced in the area and found to improve soil fertility in a relatively short time. Its influence on water infiltration, runoff, soil loss and soil water storage through cover provision has received relatively less attention.

## 2.2 Rainfall erosivity

Erosivity refers to the ability of rainfall to cause soil erosion. It is a function of the intensity and duration of rainfall events. The erosivity index is a measure of the potential for soil erosion by water. It is calculated as the product of the maximum 30-minute rainfall intensity and the duration of the rainfall event. The erosivity index is a function of the rainfall intensity and duration. The erosivity index is a function of the rainfall intensity and duration. The erosivity index is a function of the rainfall intensity and duration. (Madsen, 1981)

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Introduction

Rainfall erosion results from an interaction of rain and soil, and amount of erosion that occurs in any given circumstances are influenced by both rain and soil (Hudson, 1981) together with the use or management under which land has been put. Rain ability to cause erosion and the soils' vulnerability to erosion are influenced by a number of factors that can be explained by theories of erosion- erosivity and erodibility.

#### 2.2 Rainfall erosivity

Erosivity refers to the ability of rainfall to cause detachment and transport of soil (Morgan, 1995). Erosivity is due to direct raindrop impact and to the runoff generated. The ability of rain to cause soil erosion is attributed to its rate and drop size distribution, both of which affect its energy (Hudson, 1981). Larger raindrops fall faster, reaching a terminal velocity of about  $8.3 \text{ m s}^{-1}$  (Brady and Weil, 1999). As the speeding raindrops impact the soil with explosive force, they transfer their kinetic energy to the soil particles, detaching soil, destroying soil granules and splashing which under certain conditions, cause an appreciable transportation of soil.

The maximum range of raindrop sizes in many different types of tropical rainfall is about 5 mm in diameter and drops bigger than this break up into a

number of smaller drops (Hudson, 1981; Bradford and Huang, 1996). Drops are said to be stable up to 4.6 mm diameter, and unstable above 5.4 mm diameter but may not disintegrate in between this range (Hudson, 1981). Low intensity rain that can last for days is made up of small drops whereas a high intensity rain has at least some drops, which are much bigger. The terminal velocity of falling raindrops depends upon the size and shape of the raindrops. Terminal velocity of raindrops increases as the size increases, with the largest drops of about 5 mm diameter having a terminal velocity of about  $9 \text{ m s}^{-1}$  (Hudson, 1981).

Rainfall erosivity takes into consideration the total rainfall, intensity and seasonal distribution (Brady and Weil, 1999). Rainfall intensity is important because intense rains have large drop size, which result in much greater kinetic energy being available to detach soil particles and higher rate of rainfall may lead to more runoff providing the means to detach soil particles. Gentle rains of low intensity may cause less erosion, even if total annual precipitation is high but the reverse is true for a few torrential down pours. The presence of improved fallows cover may ameliorate the effect of raindrops on soil by intercepting and disintegrating them into tiny droplets.

### ***2.2.1 Transport phase in erosion process***

Runoff water plays a major role in the transportation of soil particles. The soil particles detached by raindrop impact are carried down slope by runoff so long

as the water is flowing smoothly in a thin layer where it has little power to detach soil. But where it concentrates in channels, it increases both velocity and turbulence (Morgan, 1995). The channelized flow then carries along soil splashed by raindrops and begins to detach particles as it cuts into the soil mass.

Three types of water erosion are therefore recognised: interill, rill and gully erosion (Hudson, 1981; Morgan, 1995; Bradford and Huang, 1996). Interill erosion is the detachment and transport of soil by raindrop impact and shallow overland flow (Lal and Elliot, 1994). It occurs when splashed soil is removed more or less uniformly except that tiny columns of soil often remain where pebbles intercept the raindrops (Bradford and Huang, 1996; Brady and Weil, 1999). As the flow is concentrated into tiny channels (rills), rill erosion results. Rill erosion is the process of detachment and transport of soil particles by concentrated flow (Lal and Elliot, 1994). Rills are common on newly planted bare land and small enough to be smoothed over by normal tillage. Where runoff becomes concentrated, the volume increases cutting deeper into the soil, deepening and coalescing rills into larger channels termed as gullies (Morgan, 1995).

### **2.3 Soil erodibility**

Erodibility is a soil's inherent susceptibility or vulnerability to erosion (Hudson, 1981; Morgan, 1995; Shainberg and Levy, 1996). Although this

resistance depends in part on topographic position, slope steepness and the amount of disturbance, the properties of the soil are the most important (Le Bissonnais, 1996). Included are soil texture, aggregate stability, shear strength, infiltration capacity, organic and the chemical content (Morgan, 1995; Le Bissonnais, 1996). The integration of improved fallows into farming systems may reduce soil erodibility through addition of organic matter into the soil, which may improve aggregation, infiltration capacity in addition to covering the soil surface (Buckles and Triomphe, 1999). The modification of these properties also modifies soil erodibility.

Soil texture refers to the relative proportions of clay, silt and sand in a sample of soil with the dominant size fraction used to describe texture (FitzPatrick, 1986; Wild, 1993). It influences erodibility in that it determines the infiltration and runoff rates. According to Lal and Elliot (1994), sandy soils have lower runoff rates, are more easily detached but less easily transported than silt soils. On the other hand, clayey soils though not easily detached, have lower infiltration rates that may lead to greater runoff and increased erosion. Silty soils tend to have the greatest erodibilities because they are easily detached and transported (Lal and Elliot 1994).

Aggregate stability refers to the resistance soil aggregates offer to the disintegrating influence of water and other mechanical manipulations (Kemper, 1965). It is used as an index of soil structure in the field. The

successful management of soils in the tropics depends on the management of soil structure since the texture cannot be changed over a short period of time by any economical means (Lal, 1989; Feller *et al.*, 1996). Good soil structure is a desirable characteristic for sustaining agricultural productivity. It depends on the presence of stable aggregates. Stability of aggregates and pores between them governs retention and movement of water, soil aeration, erosion, biological activity and growth of crops (Amezketta, 1999). Maintaining high aggregate stability is therefore essential for maintaining soil productivity, minimising soil erosion and degradation (Le Bissonnais, 1996). Good soil structure improves soil aeration and increase infiltration of rainwater, which can then be utilised by plants.

Quantity of organic matter present influences many important soil properties, including absorption and retention of water, reserves of exchangeable bases, the capacity to supply nitrogen, phosphorous and other elements to growing crops, stability of soil structure and adequacy of aeration (Broadbent, 1965, Page *et al.*, 1982). Soil organic matter (SOM) binds soil particles into aggregates that are responsible for good soil structure and porosity distribution, allowing aeration, root penetration and movement and retention of water (Allison, 1973; Papendick, 1992). Soil water retention is improved since soil organic matter increases both infiltration rates and water holding capacity (Lal, 1989; Prijono *et al.*, 1996). Aggregate stability is encouraged especially by the non-humic substances produced during decomposition

(Brady and Weil, 1999). The SOM levels drop following cultivation but the rate of decline depends on the management practices and inputs such as crop rotation, residue management and application of organic amendments (Allison, 1973). The rate of destruction of SOM can be minimised by restricting tillage, controlling erosion and keeping most of the plant residues at or near the soil surface. Tillage accelerates SOM losses due to increased oxidation and by erosion (Brady and Weil, 1999). It should be limited therefore to only those needed to control weed and maintain adequate soil aeration. Minimum tillage practices leave much of the plant residues on or near the soil surface slowing down the rate of residue decay and reduce erosion losses (Barthès *et al.*, 2000). With time, minimum tillage can lead to higher organic matter levels.

Infiltration is the process of water entry into the soil generally by downward flow through all or part of the soil surface (Hillel, 1980). The rate of this process, relative to the rate of water supply, determines how much, if any will run off. Infiltration rate therefore affects water economy of plant communities, surface runoff and its attendant danger of erosion. Infiltration rate depends on soil characteristics such as initial soil water content and suction, texture, SOM structure and roughness of the soil surface (Hillel, 1980; Le Bissonnais, 1996).

The moisture content of topsoil at the start of a rainfall greatly affects the infiltration rate. Lower initial soil moisture content is likely to result in higher infiltration rates at the beginning of rainfall while higher values are likely to

result in higher runoff rates (Uriyo, 1979). Coarse textured soils such as sands and sandy loams have higher infiltration rates than clay soils because of the larger spaces between soil particles. But larger cracks or macropores influence infiltration since they can transmit considerable quantities of water so that clays with well defined structures can have infiltration rates that are much higher than would be expected from their texture alone (Morgan, 1995).

Infiltration rate is high during the early stages of infiltration especially when the soil is initially quite dry but decreases to approach a constant rate asymptotically, due to a decrease in the matric suction gradient which occurs as infiltration proceeds (Shainberg and Levy, 1996). The decrease can also result from gradual deterioration of soil structure, usually caused by the impact energy of water drops leading to the formation of a dense surface seal and from the migration of pore blocking particles (Hillel, 1980; Shainberg and Levy, 1996). Situations where the application rate of the water exceeds the infiltration rate of the soil may also lead to runoff generation. The excess surface water, tends to accumulate over the soil surface collecting in depressions forming puddles contributing to surface storage (Hillel, 1980). Surface storage depends on surface roughness and overall slope of the land. It is when the surface storage is filled and the puddles begin to overflow that actual runoff begin. Surface runoff carries with it considerable amounts of dissolved chemicals and detached soil particles.

Other factors influencing erosion include the slope length and steepness, crop and land management. Doubling of the slope increases erosion by less than 50% (Young, 1997). Along a slope, there is relatively larger build up of the amount of surface runoff, its velocity and depth (Hudson, 1981). Doubling the gradient more than doubles the rate of erosion (Young, 1997). Steep land is more vulnerable to water erosion than flat land because the erosive forces, splash, scour and transport all have a greater effect on steep slopes (Hudson, 1981). There is more splash downhill, higher runoff and faster flow increasing the rate of erosion as the slope increases. Build up of the amount of surface runoff, its velocity and depth occurs with increasing slope length and this lead to scour erosion which might not have occurred on a shorter slope (Mutchler *et al.*, 1994; Barthès *et al.*, 2000).

The management or treatment that a land receives affects the amount of soil erosion that occurs under a given condition. Hudson (1981) found the difference in erosion caused by different management of the same soil much greater than the difference in erosion from different soils given the same treatment. He concluded that soil erodibility is influenced more by management than by any other factor. Management can be divided into two - land and crop management. Land management involves assigning a given use to land according to its capability to ensure that it used efficiently and productively (Hudson, 1981). Crop management refers to the way in which crops are grown and there can be large variations in the amount of erosion

depending on this. Hudson (1957) quoted in Hudson (1981) found that the loss of soil from two identical adjacent experimental plots was 15 times greater from the plot with a badly managed crop of maize than from with a good maize crop.

### ***2.3.1 Effects of erosion***

Erosion damages the site on which it occurs and the larger environment with the loss of soil being the most damaging effect. In the tropical areas, plant nutrients available to arable crops are contained in the top soil and litter layer. High amount of runoff results in a substantial loss in fertility and deterioration in the physical structure of the soil. Infiltration rate decline and crop growth decreases, leaving the soil more exposed and leading to further increases in the rate of erosion. Erosion changes the physical and hydrological properties of the soil and as a result crop yields are usually lower regardless of the amount of fertiliser applied (Amir, 1996). Some of the effects of erosion on agricultural land identified by Morgan (1995), Brady and Weil, (1999) include:

i) The redistribution within and loss of soil from a field, breaking down of soil structure and the decline in soil organic matter and nutrients resulting in a reduction of cultivable soil depth and decline in soil fertility. It also reduces available soil moisture, resulting in more drought prone conditions.

ii) The loss of topsoil which exposes a less productive subsoil with reduced ability to hold and recycle nutrients, and absorb, retain, and freely circulate air and water. Erosion is a selective process, normally removing soil

organic matter, clay, and fine silt first and carrying these away leaving soils which are less favourable for seedling establishment and root proliferation which are important for early plant development (Papendick, 1992).

iii) Off-site effects which include water pollution due to sediments and nutrients moved from upland areas into rivers and lakes. Eutrophication caused by excessive nitrogen and phosphorous deposited in water bodies result in excessive growth of algae, which may upset aquatic ecosystem equilibria.

iv) Sediment that washes into streams makes water turbid thus reducing photosynthesis and survival of submerged aquatic vegetation. Since these are some of the bases of aquatic food chains, organisms higher on the food chain may be adversely affected due to inadequate food availability.

#### **2.4 Soil water and agricultural production**

Water is one of the main limiting factors to plant growth worldwide. The quantity is not just a function of recent rainfall but reflects previous cropping and soil management (Jones and Sinclair, 1989). In humid areas such as the east of England, supplementary irrigation is carried out to increase crop production (FitzPatrick, 1986). It is estimated that 1 kg of dry weight increase in plants requires about 500 kg of transpired water and therefore a grain crop yielding  $10 \text{ t ha}^{-1}$  will transpire 2000-5000 tonnes which is equivalent to 200-500 mm of rainfall hence the need for a steady supply (FitzPatrick, 1986).

Soil moisture is a very important factor in agricultural production. Allison (1973) and Sanchez (1976) considered the property of soil to retain water and return it to plants as one of the main limiting factors in tropical agriculture. In Kenya for example, erratic rainfall in several arable areas during most of the 2000 long rains season caused unfavourable long rains harvest with the year 2000 aggregate cereal production being 22% lower than that of 1999 (FAO, 2001). Temporal and spatial distribution of rain was exceptionally poor in several areas of the country, even in the normally reliable grain 'basket' districts of Western Kenya (FEWS-Kenya, 2000). Crop yields such as maize declined from a previous five-year average of 2.4 to 1.7 million tonnes (FAO, 2001).

Moisture retained in soil depends on the amount and speed of removal. Water percolates rapidly through soil if it is very porous, sandy or of a well-developed structure (Morgan, 1995). Fine textured and organic soils have relatively smaller pore spaces and the particles themselves can absorb moisture leading to high moisture retention (Fitzpatrick, 1986). The soil texture, organic matter content and structure therefore affect the movement and retention of water in soils. Clays and organic soils have the highest moisture retention capacity while silt and organic soils have the highest available moisture (Allison, 1973; Fitzpatrick, 1986).

Soil erosion and water runoff affect water/moisture and nutrient availability for crops: therefore management that alleviates these constraints have a profound effect on crop production (Amir, 1996). Erosion reduces available soil moisture resulting in more drought prone conditions. Conserving soil water means decreasing runoff, which, in sub humid –humid areas is a major agent of erosion. Soil water conservation practices should also take good land husbandry into consideration if farmers are to realise full benefits of their efforts. A healthy crop is required if it is supposed to exploit the conserved water (Gachene *et al.*, 1996). Erosion control is therefore necessary since the topsoil that is swept away contains much of the plant nutrients.

## **2.5 The role of vegetation cover**

According to Young (1997), agroforestry practices can increase water availability to land use systems by reducing loss by evapotranspiration through shading by the canopy and by litter, and reducing loss by runoff and so increasing uptake by infiltration. Rao *et al.*, (1998b) reported that baobab and *Acacia tortilis* trees reduced soil temperature under their own crowns by 6°C at 5 cm and 10 cm depth, compared with open areas in a semi arid tropical savannah of Kenya.

The major role of vegetation in reducing soil and water loss is interception of the raindrops so that kinetic energy is dissipated rather than imparted to the

soil (Elwell and Stocking, 1976). By intercepting rainfall and reducing the velocity of runoff and wind, a plant cover can protect the soil from erosion. Under certain conditions, a plant cover can exacerbate water and soil loss (Hudson, 1981; Young, 1997). Raindrops may coalesce and form bigger drops that may achieve terminal velocity while falling from leaves of very tall trees. When using plant covers for conservation purposes, it is vital that these conditions be understood and specified.

Because of differences in their density and morphology, plants differ in their effectiveness in protecting soil from erosion and enhancing soil water availability (Hudson, 1981; Omwega, 1989; Young, 1997). This also depends upon the height and continuity of the canopy, the density of the ground cover and the root density (Morgan 1995). Omwega (1989) found that maize tended to encourage coalescence of raindrops due to its widely spaced long leaves as opposed to beans that formed dense network of branches and more rounded leaves that were effective in disintegrating raindrops before falling on the ground. Plants that are short, with small leaves and branches of dense network offer good ground cover and disintegrate raindrops thus the impact is decreased while the infiltration is increased.

The cover provided by improved fallows plays a major role in the water cycle through rainfall interception. During a rainstorm, part of the water falls directly on the land either because there is no vegetation or because it passes

plant canopy as direct throughfall. Part is intercepted by plant canopy from where it is either returned to the atmosphere through evaporation or finds its way to the ground by dripping from the leaves or as stem flow (Morgan, 1995). The rainfall which reaches the ground may be stored in the small depressions or hollows on the surface or it may infiltrate the soil, contributing to soil moisture storage or by percolating deeper to ground water. When the soil is unable to take in more water, the excess will move laterally down slope within the soil as subsurface flow or interflow or it will contribute to runoff on the surface (Wild, 1993; Morgan, 1995). It is through run-off that the detached soil particles are transported.

Vegetation whether natural or planted has potential to contribute directly to the maintenance and improvement of soil productivity. The roles played include protection, conservation and increase of organic matter; as a source of nutrient and improved moisture status (Morgan, 1995; Young, 1997). The ground cover provided by improved fallows protects the soil surface from direct effects of raindrops and enhances water storage capacity.

## **2.6 Benefits of improved fallows**

Rapid population growth has forced intensification in the cultivation for food production, so that traditional mechanisms for maintaining soil fertility are no longer feasible (ICRAF, 1994). Continuous cropping coupled with the removal of crop residues either to feed animals or for fuel is contributing to soil

degradation in Kenya (Hudgens, 1996). In trying to solve this problem, alternatives to natural fallow are now being encouraged in western Kenya. Improved fallows provide protective ground cover that conserves soil moisture, reduces erosion and labour costs for weeding and contribute nitrogen to succeeding crop (Prinz, 1986; Hudgens, 1996). Improved fallows are commonly used in several regions of the tropics such as East and Central Africa, Southeast Asia and Latin America as a way for replenishing soil fertility and providing sustainability-enhancing services (Sanchez, 1999).

In the western Kenya highlands, *Tephrosia candida*, *Sesbania sesban*, and *Crotalaria grahamiana*, are some of the species currently being used (ICRAF, 1999). *Crotalaria paulina* and *Macroptilium autropurpureum* have also been introduced recently. The short fallows in western Kenya usually take between 6 and 12 months (one to two seasons) and are established by direct seeding between rows of maize in the 'long rains' (March to July). The shrubs take off after maize harvest and cover the land in the 'short rains' (September to January). The farmers then clear the fallows for regular crop in the next long rains (Rao *et al.*, 1998a).

#### ***T. candida* DC (Fabaceae)**

*T. candida* DC is a shrub 2 to 3 m tall, indigenous to Malaysia but has been introduced and naturalised in many parts of the tropics, Kenya included (Salim *et al.*, 1998). It is drought tolerant and commonly used in agroforestry systems.

It grows well on acid and impoverished soils. Its soil-improving characteristic has encouraged its use in controlling soil erosion in steep slope and as shade tree in agroforestry system (Huancheng and Jueiming, 1993). It is used as a green manure in different parts of the world. Its altitudinal range is between 0-1200 m, mean annual rainfall of 700-3000 mm and annual temperature range of 18-30°C (Salim *et al.*, 1998).

***Crotalaria grahamiana* Wight & Arn. (Fabaceae)**

*Crotalaria grahamiana* is a leguminous erect woody perennial with hollow, angular stems and many flowered racemes (Polhill, 1982). It has a wide climatic and soil tolerance. It is native to south India but has been used in Madagascar as a green manure crop (Polhill, 1982). It has a shallow rooting system and grows rapidly making it suitable for short-term rotations (Rao *et al.*, 1998a).

The preferable characteristics of the improved fallow species are that they should be easy to establish, fast growing, close the canopy quickly, suppress weeds, minimise soil erosion and require less attention/management. *Sesbania sesban* fallows have been found in eastern Zambia to provide readily available nutrients for subsequent crop and increase soil organic matter and, hence, improved soil physical condition (Kwesiga *et al.*, 1999). Rao *et al.* (1999) found in western Kenya that one season non fertiliser applied sesbania fallow reduced soil loss by 38% during the fallow period and by 75% in the

subsequent season and 5 to 27% less runoff compared to non fertiliser annual cropping during the fallow season.

According to Szott *et al.*, (1999), the rapid establishment of fallow vegetation may help conserve SOM and nutrients by moderating soil microclimate and reducing SOM mineralization thus increasing nutrient uptake and organic residue additions and, decreasing erosion, runoff and leaching losses. Competition for light, water and nutrients between improved fallows and the crop is minimised by relay inter-cropping or sequential agroforestry systems (Sanchez, 1995; Sanchez, 1999). Sequential agroforestry systems (improved fallows and relay intercropping) have been found to be more robust than simultaneous systems for example alley cropping and contour hedgerows (Sanchez, 1999).

Deep-rooted fallow species can utilise subsoil water and nutrients inaccessible to annual crops during dry seasons in bimodal rainfall regimes when the risk of crop failure is high. Fallows grown for a full year by skipping the usually unreliable short rains in bimodal rainfall regimes near the equator has proven successful (Sanchez, 1999). In central America specifically northern Honduras, the effect of increased infiltration and reduced runoff rate increase the capacity of maize planted in *Mucuna* fields to withstand dry spells during the growing season and reduce the risk of soil erosion (Buckles and Triomphe, 1999). Risks of yield losses due to drought stress are much lower in the

improved fallow system due to conservation of soil moisture by the plant. Fallowing has additional benefits such as soil erosion control and maintenance or improvement of soil physical properties. While plant nutrient reserves can be relatively managed well by inputs of fertilisers and manure, it is more difficult to manage soil physical properties (Feller *et al.*, 1996). These properties are important in enhancing the sustainability of cropping systems. Efforts should therefore be made at improving them.

In eastern Uganda, grain yield after one season of *Crotalaria ochroleuca* was 41 and 43% higher for maize and beans respectively than yields obtained after two seasons of weedy fallow. Fischler and Wortmann (1999) consider the combined effects of nutrient release, moisture conservation and weed suppression by *Crotalaria* mulch as having contributed to the increased maize yields.

The protective role of soil and water conservation structures and vegetation can be measured in terms of the quantity of water, soil or nutrients lost in comparison with a control which could be a plot without any soil conservation or with a local practice (Ong, 1996). Ong argues that the approach provides valuable insight on how the processes of soil and water losses work and on how the protective role can be improved.

## 2.7 Rainfall simulators

Rainfall simulators are research tools designed to apply water in a form similar to natural rainstorms (Meyer, 1994). They are designed to produce storms of known energy and drop size characteristics, which can be repeated on demand (Morgan, 1995). The major advantages identified by Hudson (1981) and Meyer (1994) are that the simulators are more rapid, more efficient, more controlled and more adaptable than natural rainfall research. Measurements and observations, which are difficult or impossible to make during natural rainstorms, can be made during simulated storms. The speed of research is greatly enhanced since the results are no longer dependant upon waiting for the right kind of rain to come at the right time. The efficiency is enhanced due to the ability to control one of the most important variables (rainfall). Testing and confirmation of results is possible through repeated experimentation.

Rainfall simulation has been carried in the laboratory or in the field under small areas (<10 m<sup>2</sup>) referred to as microplots (Barthès *et al.*, 2000). The major reason for using such small plots is to study in detail the basic erosion phases like surface sealing, aggregate stability, raindrop detachment and splash transport that would be difficult on larger plots (Mutchler *et al.*, 1994). Close control of the parameters of erosion process is only possible on small plots than on large plots.

The major limitation includes the relatively small area to which rain can be applied by most rainfall simulators. Measurements at the microplot scale under estimate soil loss because runoff flow cannot gain velocity and concentrate on a short slope (Barthès *et al.*, 2000). Also important on such plots are the edge effects such as movement of splash into and out of a plot, the addition of eroded soil to a plot treatment from an erodible soil ridge, a barrier effect on soil water and other boundary effects caused by the restriction of splash or runoff on a plot. These effects are magnified with small plots (Mutchler *et al.*, 1994).

### **2.5.1 The ORSTOM device**

This is a closed medium size simulator (see Plate 2.1a) designed for field experiments (Asseline and Valentin, 1978). The simulator is 3.8 metres high producing raindrops by a nozzle (see Plate 2.1b) spraying water downwards. Rainfall is produced over approximately 4 m<sup>2</sup> with runoff measured from the central 1 m<sup>2</sup> microplot. Kinetic energy of raindrops range between 10-22 j min<sup>-1</sup> m<sup>-2</sup>, which is close to that of natural rainfall. Rainfall intensity ranges from 10 to 140 mmh<sup>-1</sup> and can be changed anytime without interrupting the experiment.

A metal frame casing is inserted into the soil 10 cm deep enclosing the study parcel (see Plate 2.1c). It has oblong holes on the lower sides through which runoff is directed into the collecting tube from where it is measured. The frame is inserted such that the oblong holes on the lower side are at ground surface

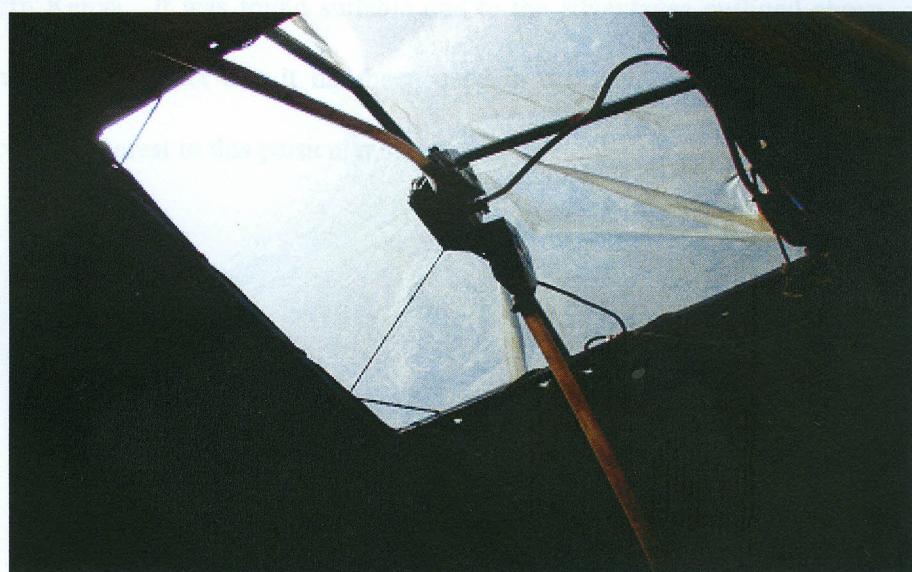
level so that runoff can flow in the collecting tube without delay. Apart from the sprinkler head, the system consists of a portable generator, a laptop computer, a water pump, a battery, a pressure gauge and intermediate containers for recuperation recycling system. An electric generator provides power for the water pump and the laptop computer (Caprian program) used to set the operating angle that determines the intensity and velocity of rainfall. The battery powers the sprinkler head while the pressure is maintained at 0.6 bars to ensure a constant flow.

The water used is kept in a tank from where it is pumped up to the nozzle that sprays it over the plot. Samples of the water are taken before simulation and the amount of sediment contained determined to correct for the turbidity of the runoff generated. This particular type of simulator has the advantage of water recycling. The excess water is taken back into the system therefore no wastage. It can be moved easily from one plot to another, four people being enough and can also be dismantled for easier movement over long distances. A tent covering the four sides and a plastic sheet covering the top excludes natural rainfall and wind.

A



B



C



Plate 2.1: Rainfall simulation A: ORSTOM simulator; B. Nozzle of the simulator; C: Metal frame casing surrounding the sampling parcel.

This particular simulator has been used by Barthès *et al.*, (1998) to study the effect of cultural practices on soil erodibility, aggregate stability and carbon content in Rougiers de Camarès area (Aveyron, France), Barthès *et al.*, (1999) in the Mediterranean Highland south of France to study the relationship between soil erodibility and topsoil aggregate stability or Carbon content. Boye (2000) used it to study soil erosion under different land use systems in Western Kenya. It was found suitable due to the advantages outlined above together with the fact that it has been used in different areas to study the variables of interest in this particular study.

## CHAPTER THREE

### RESEARCH DESIGN AND METHODOLOGY

#### 3.1 Experimental site

The field experiment was conducted at Ochinga, Vihiga District from September 2000 to March 2001. Ochinga (0° 06'N, 34° 34'E) is at an altitude of 1420 m above sea level (see Figure 3.1). The area is in the Tea-Coffee zone with permanent cropping possibilities, which can be divided into two cropping seasons (Arnaud, 1995). The climate is sub humid. The area receives an average annual rainfall of 1780 mm in two rainy seasons: 800 to 1200 mm from March to July (long rains) and 500 to 700 mm from September to January (short rains), (Rao *et al.*, 1999). Mean monthly temperatures range from 18 to 27°C (ICRAF, 1994).

The soils in the area are mostly developed on basic igneous rocks and on granites (Sombroek *et al.*, 1982). They are deep and well-drained, clay loam to sandy texture with low levels of available phosphorous and nitrogen (Jaetzold and Schmidt, 1982; Rao *et al.*, 1999). Laboratory tests showed that the 0-10 cm soil was moderately acidic (pH in 1:2.5 soil: water suspension =5.9), and on average contained 2.3% organic carbon and 0.2% nitrogen.

#### 3.2 Design and Methodology

During the fallow period, (July 2000 - March 2001) rainfall amounts, soil loss, runoff, soil moisture content and plant cover changes were monitored. The

Orstom rainfall simulator was used to simulate rainstorms of controlled intensities and duration (see Chapter Two).

### 3.2.1 Treatments

The study consisted of two experiments; one on soil erodibility, which used rainfall simulation and the other, was on soil moisture storage assessed using the gravimetric method.

**Table 3.1:** Experimental layout and treatments.

Rainfall simulation ( <i>surface types</i> )	Soil moisture measurements (treatments)
Improved fallow cover of <i>Tephrosia candida</i> a ( <i>IFca</i> )	<i>T. candida</i> ( <i>Tc</i> )
Continuous maize cover a ( <i>CMca</i> )	Continuous maize ( <i>CM</i> )
Improved fallow cover of <i>Tephrosia candida</i> b ( <i>IFcb</i> )	<i>T. candida</i> + <i>Macroptilium autropurpureum</i> ( <i>Tc+M</i> )
Improved fallow no cover b ( <i>IFncb</i> )	<i>C. grahamiana</i> ( <i>Cg</i> )
Improved fallow no cover tilled b ( <i>IFnctb</i> )	Natural fallow ( <i>NF</i> )
Natural fallow 2 cover b ( <i>NF2cb</i> )	<i>C. paulina</i> ( <i>Cp</i> )
Natural fallow 2 no cover tilled b ( <i>NF2nctb</i> )	Natural fallow 2 ( <i>NF2</i> )

NB: a, b and c refers to phase 1, phase 2 and cover respectively.

Rainfall simulation was carried out in phase one from 20<sup>th</sup> November 2000 to 15<sup>th</sup> December 2000. Phase 2 was carried out between 10<sup>th</sup> and 27<sup>th</sup> March 2001. This was meant to assess how changes in soil cover influences soil erodibility. Soil moisture measurements were taken in September to December 2000 and from January to March 2001.

Plot size was 15 m by 10 m with an inter plot spacing of 1 m. For the planting density, *CM* had a spacing of 75 cm by 30 cm with 2 maize seeds per hill while *Cg* and *Cp* were drilled at approximately 100 seeds/m<sup>2</sup> in rows of 75 cm

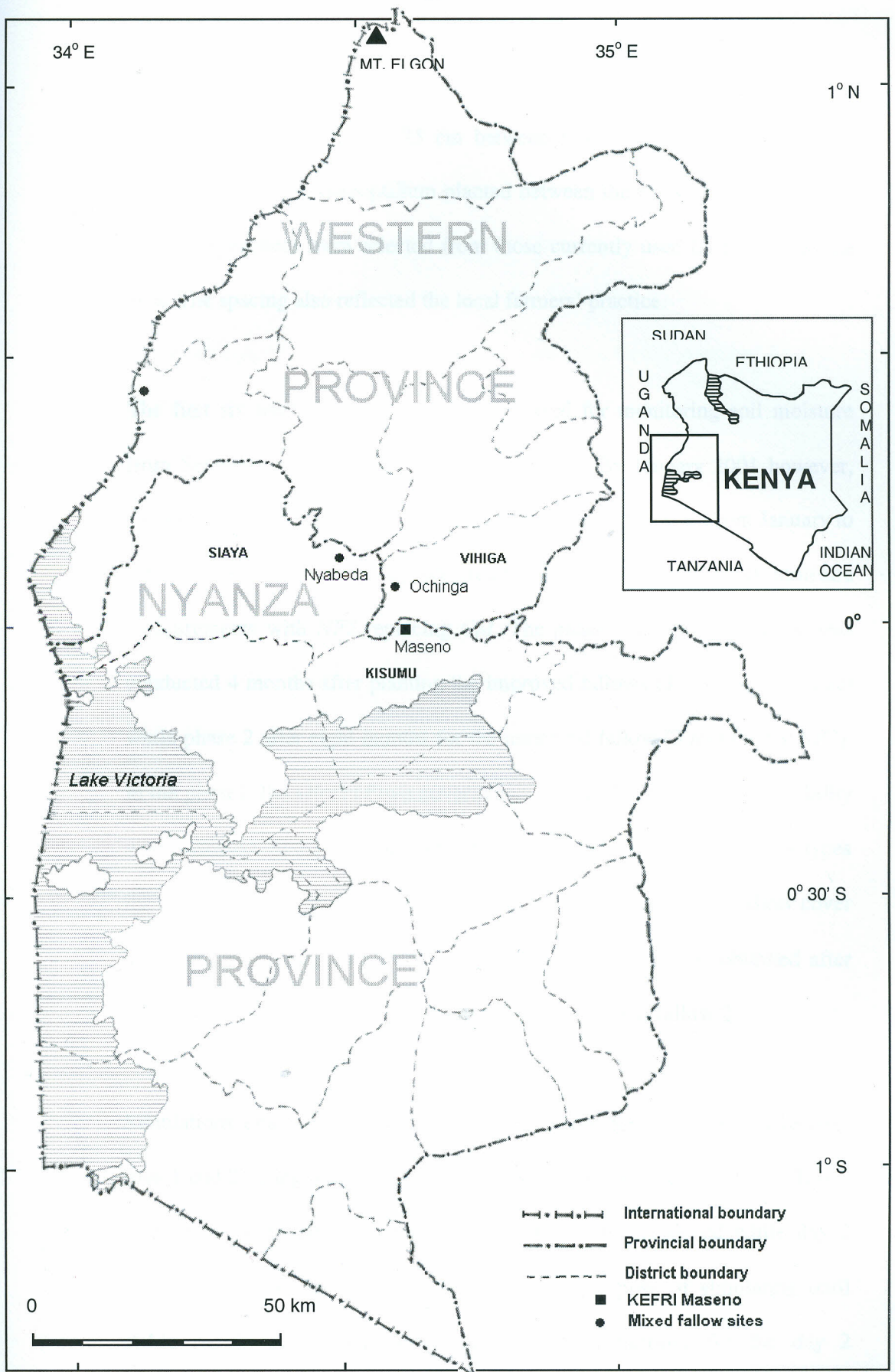


Figure 3.1: Location of the study area.  
(Source: Arnaud, 1995)

apart. *Tc* had a spacing of 75 cm between rows while *Tc+M* had similar spacing as *Tc* with *Macroptilium* planted between the rows. The species used in this experiment were selected from those currently used by farmers in the area. The spacing also reflected the local farmers' practice.

The first six treatments (Table 3.1) were used for monitoring soil moisture from September to December 2000 (Survey 1). By January 2001 however, continuous maize had dried up giving way to natural fallow 2. From January to March therefore (Survey 2), six treatments were used for soil moisture measurements with *NF2* replacing *CM*. The phase 1 rainfall simulation was conducted 4 months after planting the improved fallows (3 months for maize) while phase 2 after eight months for the improved fallow (3 months for *NF2*). In the phase 1, the effect of two cover types, *CMca* and *IFca* on soil erodibility were assessed. Phase 2 simulations were done under the last 5 surface types listed in Table 3.1. *IFncb* refers to a situation where the improved fallow cover has been cut leaving only litter on the soil surface. *IFncb* is obtained after tilling *IFncb*. *NF2ncb* is achieved after tilling the natural fallow 2.

Simulations under each replicate were carried out for two consecutive days (day 1 and 2) using a rainfall intensity of  $58 \text{ mm h}^{-1}$  (see Section 3.2.3). Day 1 simulations were carried out until stable runoff was achieved while day 2 simulations lasted for thirty minutes only. The purpose of simulating until stable runoff was to ensure similar moisture conditions for the day 2

simulations. Due to the difference in the simulation period in the day 1 simulations, comparison can only be made of turbidity ( $\text{g L}^{-1}$ ) and solid flow ( $\text{g m}^{-2} \text{min}^{-1}$ ) as far as soil loss was concerned. But for day 2, total soil loss ( $\text{g m}^{-2}$  or  $\text{t ha}^{-1}$ ) was used since the duration of simulation was similar. The simulator covers an area of  $4 \text{ m}^2$  but measurements were done from the central  $1 \text{ m}^2$  plot as shown in Plate 2.1c.

### ***3.2.2 Management of the experimental plots***

The plots were under continuous maize and beans for the long and short rains season of 1999 and long rains of 2000. Weeding was done before planting the improved fallow species in between the rows of maize and beans. This was one month to harvesting of the long rains season crop. There after no weeding was carried out except for continuous maize plot that was weeded seven weeks after planting as is practised in the area.

### ***3.2.3 Calibration of the simulator***

Calibration of the rainfall simulator was done before the beginning of the fieldwork in order to select the appropriate rainfall intensity to be used in the experiment. The rainfall intensity for this simulator is determined by the angle through which the nozzle travels during simulation. From the calibration, an angle of  $130^\circ$  gave an intensity of  $54 \text{ mm h}^{-1}$  (Table 3.2).

**Table 3.2:** Calibration angles and the respective rainfall intensities for the ORSTOM simulator.

Angle (in degrees)	80	100	120	130	140	160
Rainfall Intensity (mm h <sup>-1</sup> )	84	69	57	54	48	44

From the table above, the higher the angle the lower the intensity and vice versa. A higher angle means that the nozzle has to travel a longer distance hence spending less time over the plot as opposed to a smaller angle. This angle was used in all the simulations but a final calibration had to be done over each replicate since variation in the position of the simulator over a plot may lead to different rainfall intensity. The calibration values given apply to both day 1 and day 2 simulations. Rainfall intensity of 58 mmh<sup>-1</sup> was chosen because it is thought to be more representative for the area (Albrecht, 2001, personal communication).

### 3.3 Measurements

#### 3.3.1 Rainfall measurements

The amount of rainfall from each rainfall event was obtained from a pluviograph that tips for every 2 mm of rain collected. It was read on a daily basis where the total amount of clicks was calculated to determine the amount of rainfall (Boye, 2001, personal communication). The data on rainfall was used together with the soil moisture data from the experimental plots to determine soil moisture storage capacity under the various treatments. Rao *et al.*, (1999) used the same device for rainfall measurements to assess the effects

of agroforestry on soil, water and nutrient conservation in phosphorous deficient soils in western Kenya. 1 mm refers to 1 litre of water per square metre.

### ***3.3.2 Infiltration rates, runoff intensity and soil loss***

Infiltration rates and run-off intensities were measured by means of periodical runoff water sampling during rainfall simulation. A similar method was used by Barthès *et al.*, (1998), Barthès *et al.*, (1999) and Boye (2000). Run-off samples were flocculated and left undisturbed for two days to ensure that sediments settled to the bottom. This was followed by sucking out the clear supernatant to get the eroded sediments which was then transferred and kept in an oven for a minimum of 24 hours at 70° C. The amount of soil lost was determined after weighing the dry sediment. In Kenya, Koske (1998) and Boye (2000) have used rainfall simulation to assess soil erodibility in West Pokot and Vihiga districts respectively.

### ***3.3.3 Determination of soil moisture content***

Soil moisture content was measured weekly during the short rains period using the gravimetric method (Uriyo, 1979). According to this method, the soil moisture content is expressed as a percent of the dry soil's net weight. Sampling was done in the field using an auger driven to a depth of 60 cm with an interval of 10 cm. Six samples for each treatment were collected after bulking the samples from two points in the plot. Fresh samples were weighed

and then dried in the oven at 105°C to constant weight. The amount of soil moisture was obtained using the formula:

$$\text{Percent soil moisture} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry weight}} \times 100$$

#### **3.3.4 Laboratory analysis**

Soil samples were investigated in the laboratory to determine aggregate stability, organic carbon and nitrogen as explained below.

##### **(i) Soil aggregate stability**

Undisturbed soil samples from a 0-10 cm depth and close to the microplot of each experimental plot were collected before rainfall simulation. These were analysed for aggregate stability using the wet sieving test. This was done by taking 50 g of soil and passing through 2.00 mm sieve. This was followed by adding 300 ml of deionised water followed by hand shaking to mix the soil and the sample refrigerated overnight for thorough wetting. The samples were then shaken for one hour at 50 revolutions per minute. There after the samples were wet sieved through 2000 µm, 212 µm and 20 µm. The contents were then oven dried at 60°C and then weighed to determine the proportion of water stable aggregates.

##### **ii) Soil organic carbon and nitrogen content**

The amounts of soil organic carbon and nitrogen were determined using an Elemental Analyser. Soil samples weighing 20 mg in a tin capsule were dropped into a combustion reactor triggering a strong exothermic reaction

thereby raising the temperature to approximately 1800°C, and instantly causing the sample combustion. The gas mixture generated by combustion is conveyed across adsorption filters that retains water. Nitrogen and carbon are eluted in the chromatographic column and then conveyed to the thermal conductivity detector that generates electrical signals, which provide the nitrogen and carbon percentages (ThermoQuest Italia S.P.A. 1999).

### ***3.3.5 Canopy cover***

Canopy cover measurement was done twice (in November 2000 and March 2001) to coincide with the time of rainfall simulation using the grid and by measuring the photosynthetically active radiation (PAR) with a ceptometer. Angima (1996) used a ceptometer in assessing the relationship between cover changes and soil erosion in Embu, Kenya. The grid had a limitation in that it may give a value of 100% so long as there are hits /counts in all the squares yet not all the soil surface is covered. Light interception measurements using a ceptometer was therefore also used as a proxy to amount of soil cover in trying to overcome the problem of overestimating the amount of vegetation cover present. This was achieved by measuring the PAR above the canopy and below at midday when the sun is directly overhead. The fraction of PAR intercepted shows the extent of light interception and canopy development. These were used to correlate canopy development with runoff and soil loss during the fallow period as well as an indicator of throughfall.

### 3.4 Data analyses

The data collected was organised by calculating means, standard deviations and percentages. Simple linear correlation and regressions were done to determine existence and degree of relationships among the variables under study (Mead and Curnow, 1983). The t-test and analysis of variance (ANOVA) at  $p=0.05$  significance level unless stated otherwise, were used to test for any significant differences among the treatments. The means were separated by least significant difference (LSD).

## CHAPTER FOUR

### RESULTS

#### 4.1 Introduction

Rainfall simulation results are presented first followed by those of the soil moisture survey. The factors considered under the rainfall simulation experiment include soil cover, runoff, turbidity, solid flow, soil loss and aggregate stability. Under the soil moisture survey, changes in soil water stocks under the various treatments in relation to natural rainfall were determined at various depths.

#### 4.2 Soil cover and slope characteristics

Soil cover was similar under CM and IF during the first phase of simulation. In the second phase, IF which was 8 months old had a higher amount of cover than the 3 months old NF2 (Table 4.1).

**Table 4.1:** Soil cover, plant height and slope characteristics.

Variable	Phase 1			Phase 2		
	<i>CM</i>	<i>IF</i>	Stat	<i>NF2</i>	<i>IF</i>	Stat
Soil Cover (%)	56	49	(0.311) NS	37	76	(0.047) NS
PAR (%)	63	48	(0.384) NS	-	82	-
Plant height (cm)	115	108	(0.249) NS	9	198	(0.002) S
Slope (%)	6.0	5.3	(0.611) NS	9.3	9.1	(0.922) NS

S= significantly different; NS= Not significantly different at  $p \leq 0.05$  (t-test)

PAR was not measured under *NF2* due to the low height that was below 10 cm, while *IFncb*, *IFnctb* and *NF2nctb* had no vegetation cover.

The *IF* cover increased from the phase 1 to phase 2 by an average of 27% using the grid and 35% using the ceptometer although it was not significant. The cover provided by improved fallow increased from the beginning of the study to the end as opposed to that of continuous maize/natural fallow 2 which reduced when maize started drying leading to a period when there was minimal soil cover (<20%) under this treatment. *IFncb* and *IFnctb* had a similar slope as *IFcb* (9.1%) while slopes for *NF2nctb* and *NF2cb* were also similar (9.3%) (Table 4.1).

### 4.3 Runoff initiation, solid flow and soil loss

#### a) Phase 1 day 1

Runoff initiation was faster and higher under continuous maize compared to improved fallow during the day 1 simulations. It was less than 5 minutes in all the three replicates under continuous maize compared to improved fallow where it took more than one hour before runoff initiation (see Figure 4.1). The runoff also took longer to stabilise under improved fallow (1 hour after runoff initiation) compared to under 35 minutes for continuous maize. Turbidity was 6 times higher under continuous maize compared to improved fallow (see Table 4.2).

Solid flow was 16 times higher and more variable under *CMca* than under *IFca*. The amount of rainfall under *IFca* was five times that under the *CMca*. *IFca* was characterised by low antecedent moisture as shown in Table 4.2.

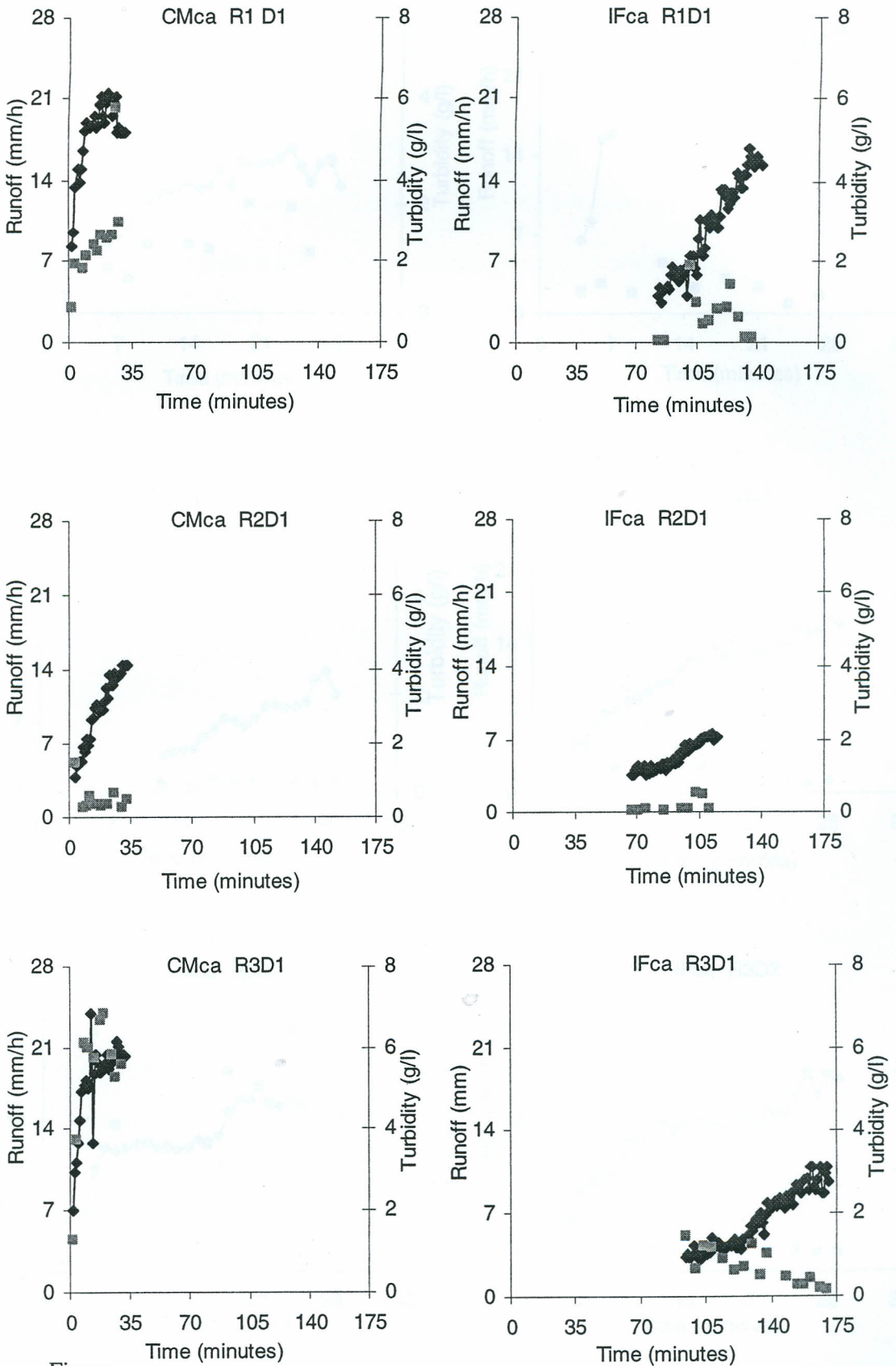
***b) Phase 1 day 2***

All the day 2 simulations lasted for 30 minutes only to allow for comparison among the treatments. There was a higher rise in runoff under *IFca* than *CMca* (see Figure 4.2). The second replicate under *CMca* was characterised by a delay in the initiation of runoff and this could be attributed to the nature of the surface which was rougher compared to the others. A significant positive relationship existed between turbidity and runoff under *CMca* ( $R^2=0.86$ ) but not under *IFca* ( $R^2=0.13$ ). Both the solid flow and soil loss values (see Table 4.2) were three times higher under *CMca* ( $0.31 \text{ g min}^{-1}\text{m}^{-2}$ ;  $0.09 \text{ t ha}^{-1}$ ) compared to *IFca* ( $0.11 \text{ g min}^{-1}\text{m}^{-2}$ ;  $0.03 \text{ t ha}^{-1}$ ). Even though soil cover was similar under *CMca* (56%) and *IFca* (49%) in the first simulation phase (see Table 4.1), the soil loss for *CMca* was three times that of *IFca* (see Table 4.2).

**Table 4.2:** Antecedent moisture, rainfall, solid flow, soil loss and turbidity values covering both phase 1 and 2 of the rainfall simulation experiment.

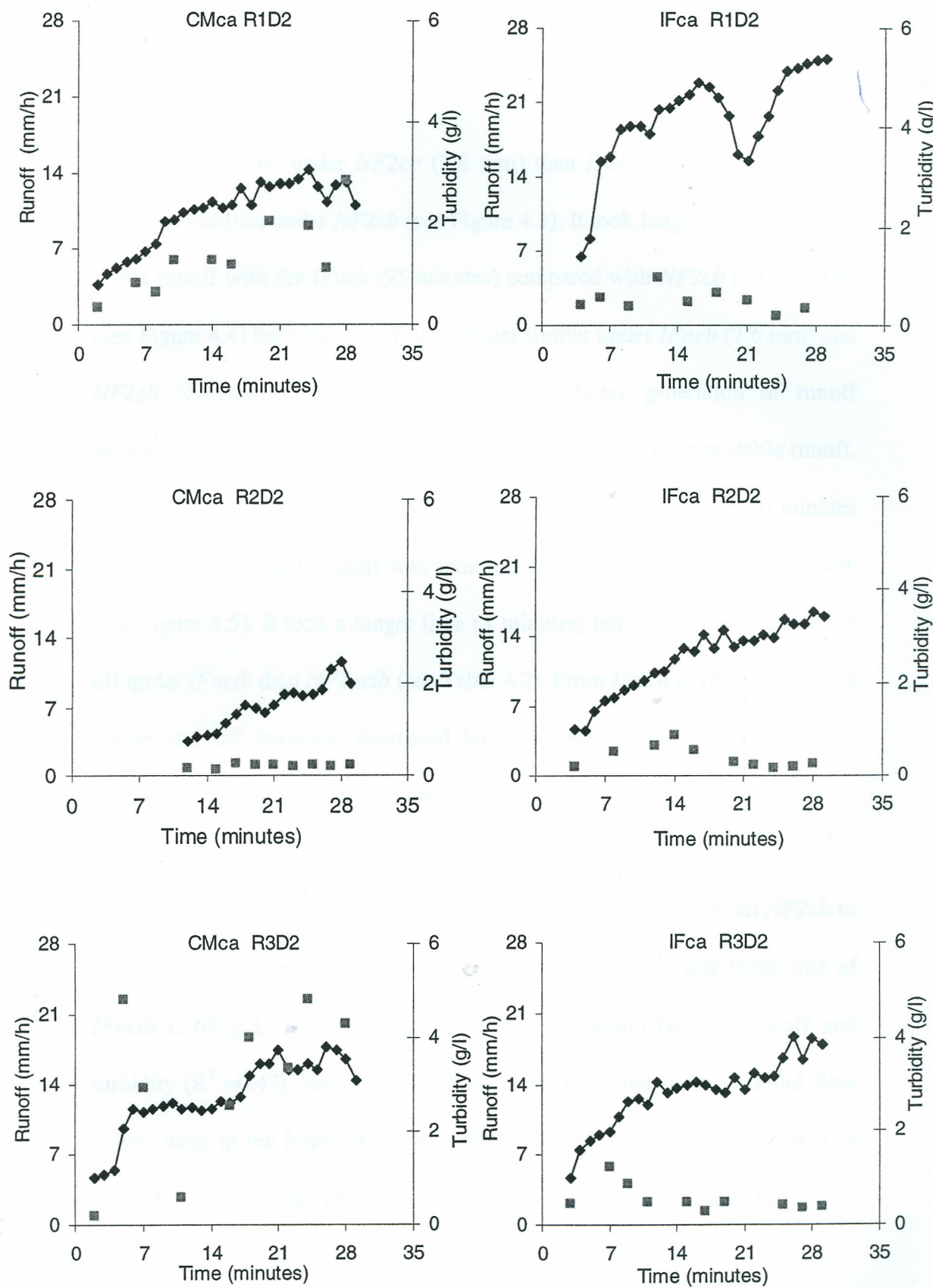
Treatment	Antecedent moisture (%)		Rainfall intensity (mmh <sup>-1</sup> )	Rainfall (mm)		Solid flow (gmin <sup>-1</sup> m <sup>-2</sup> )		Soil loss (tha <sup>-1</sup> )	Turbidity (gL <sup>-1</sup> )		Simulation Period (min)
	D1	D2	For D1 & D2	D1	D2	D1	D2	D2	D1	D2	D1
<i>CMca</i>	35.5	34.6	55.8	30	28	0.83	0.31	0.09	2.8	1.5	33**
<i>IFca</i>	19.6	31.7	58.5	140	29	0.05	0.11	0.03	0.5	0.5	143**
<i>IFcb</i>	26.5	32.6	58.8	67	29	0.07	0.04	0.03	0.2	0.3	68
<i>IFncb</i>	33.2	35.1	58.8	93	29	0.13	0.15	0.04	0.4	1.1	95
<i>IFnctb</i>	34.3	35.1	58.8	66	29	2.02	4.53	1.31	3.7	4.9	68
<i>NF2cb</i>	29.8	32.8	58.4	73	29	0.13	0.44	0.12	0.6	0.4	75
<i>NF2nctb</i>	34.4	35.5	58.4	51	29	4.57	10.45	3.02	6.8	11	52

Comparison is done between rows but within a phase (a or b). \*\* Significant difference at  $p \leq 0.05$  (t-test). D1=day 1, D2=day 2.



Figure

**Figure 4.1:** Runoff initiation and turbidity under continuous maize and improved fallow cover -phase 1 day 1 (◆- runoff intensity in mm/h; ■-turbidity in g/l).

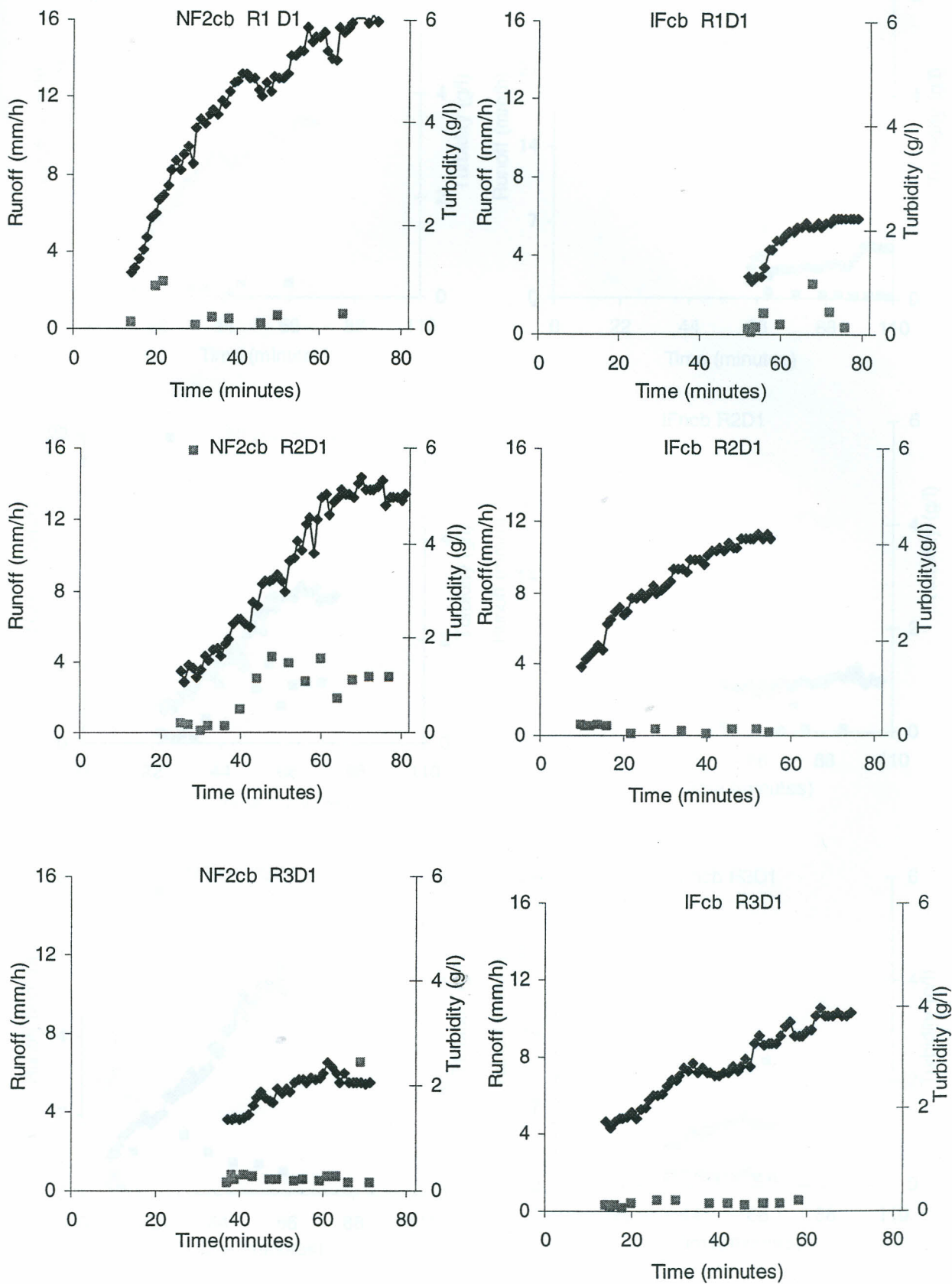


**Figure 4.2:** Runoff initiation and turbidity under continuous maize and improved fallow cover- phase 1 day 2. (◆- Runoff intensity in mm/h; ■-turbidity in g/l).

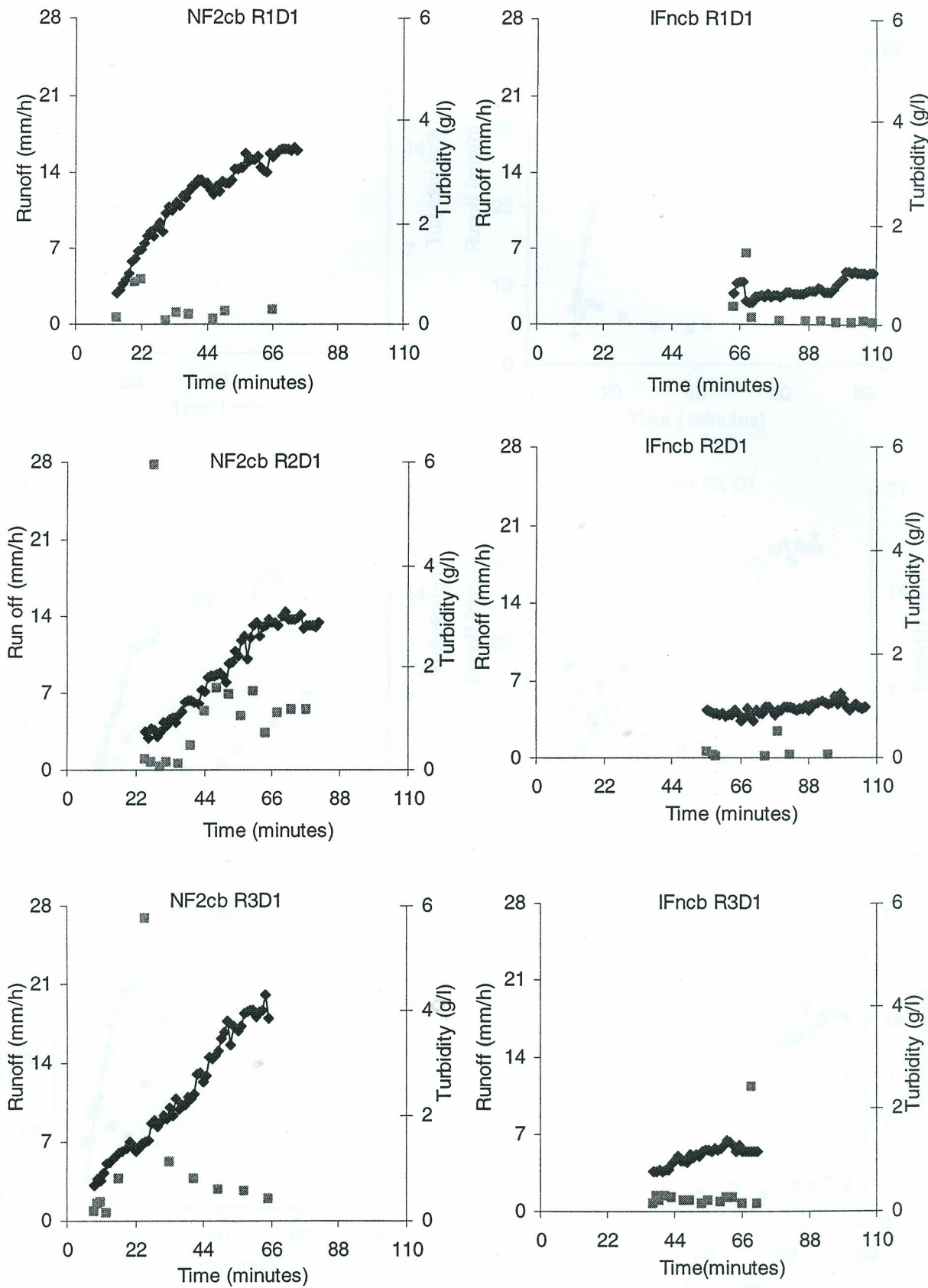
*c) Phase 2 day 1*

Runoff was higher under *NF2cb* (7.8 mm) than *IFcb* (5.7 mm) and it took longer to stabilise under *NF2cb* (see Figure 4.3). It took longer time to achieve stable runoff with the *IFncb* (95 minutes) compared with *NF2cb* (75 minutes) (see Figure 4.4) but total runoff was almost similar under *IFncb* (7.6 mm) and *NF2cb* (7.8 mm). With tillage, there was faster generation of runoff accompanied by rapid increase in the runoff and time to achieve stable runoff, from cover to no cover tilled surfaces also reduced by more than 20 minutes (see Table 4.2). Stable runoff was achieved faster under *NF2nctb* than *IFnctb* (see Figure 4.5). It took a longer time (4 minutes) before the initiation of runoff under *IFnctb* than *NF2nctb* (see Table 4.2). From *IFncb* to *IFnctb*, the time before runoff initiation decreased by 27 minutes while from *NF2cb* to *NF2nctb*, it decreased by 23 minutes.

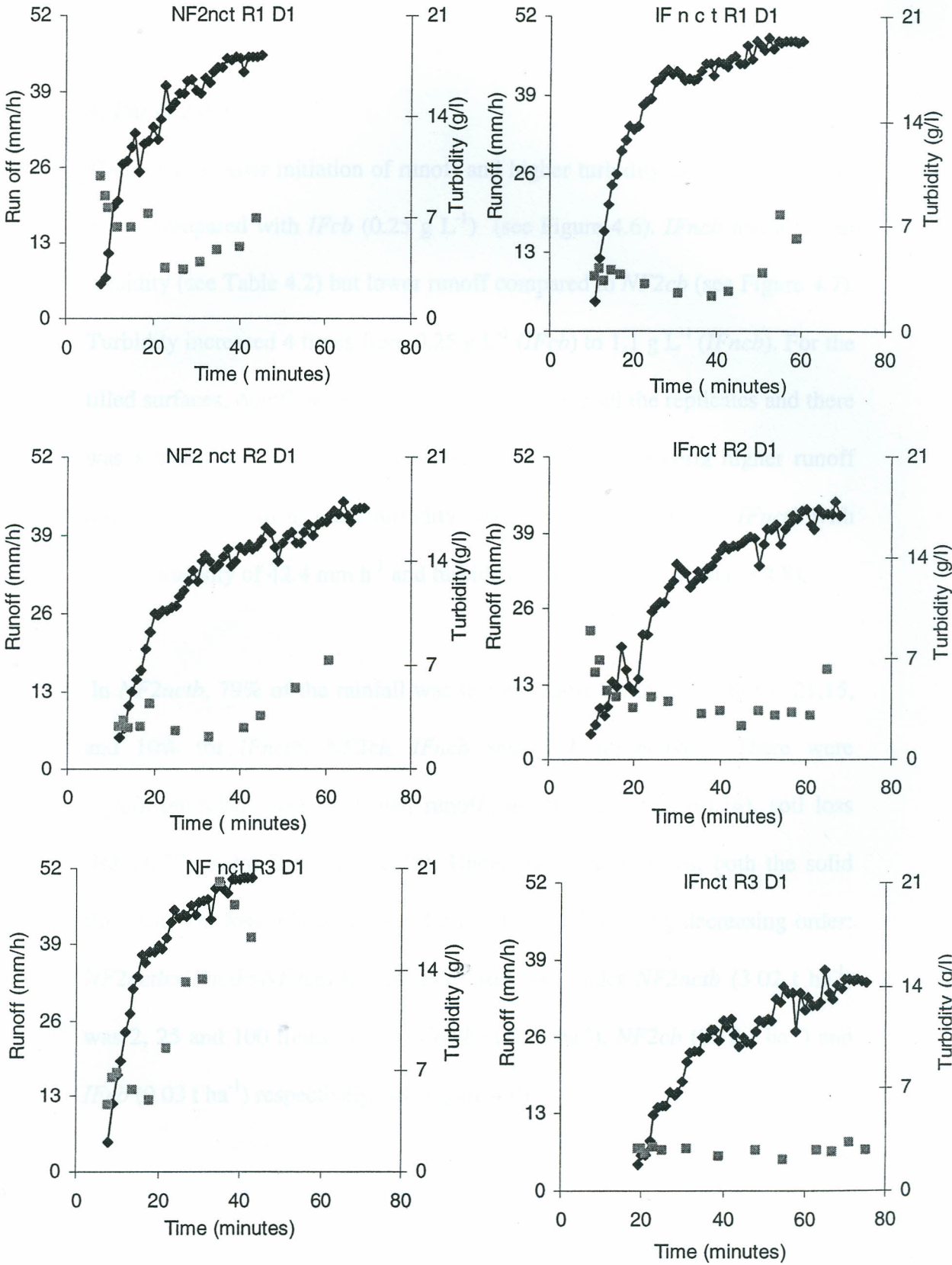
Turbidity increased 19 times from *IFcb* to *IFnctb* and 11 times from *NF2cb* to *NF2nctb* (see Table 4.2). That under *NF2nctb* ( $6.81 \text{ g L}^{-1}$ ) was twice that of *IFnctb* ( $3.68 \text{ g L}^{-1}$ ). There was a positive relationship between runoff and turbidity ( $R^2 = 0.47$ ), soil loss ( $R^2 = 0.34$ ) under the tilled surfaces. Solid flow values were in the following order *NFnctb* > *IFnctb* > *IFncb* > *NF2cb* > *IFcb*. The solid flow values under *IFncb* and *NF2cb* were similar (see Table 4.2).



**Figure 4.3:** Runoff initiation and turbidity under natural fallow 2 cover and improved fallow cover -phase 2 day 1 (◆- runoff intensity in mm/h; ■-turbidity in g/l).



**Figure 4.4:** Runoff initiation and turbidity under natural fallow 2 cover and improved fallow no cover -phase 2 day 1 (◆- runoff intensity in mm/h; ■-turbidity in g/l).

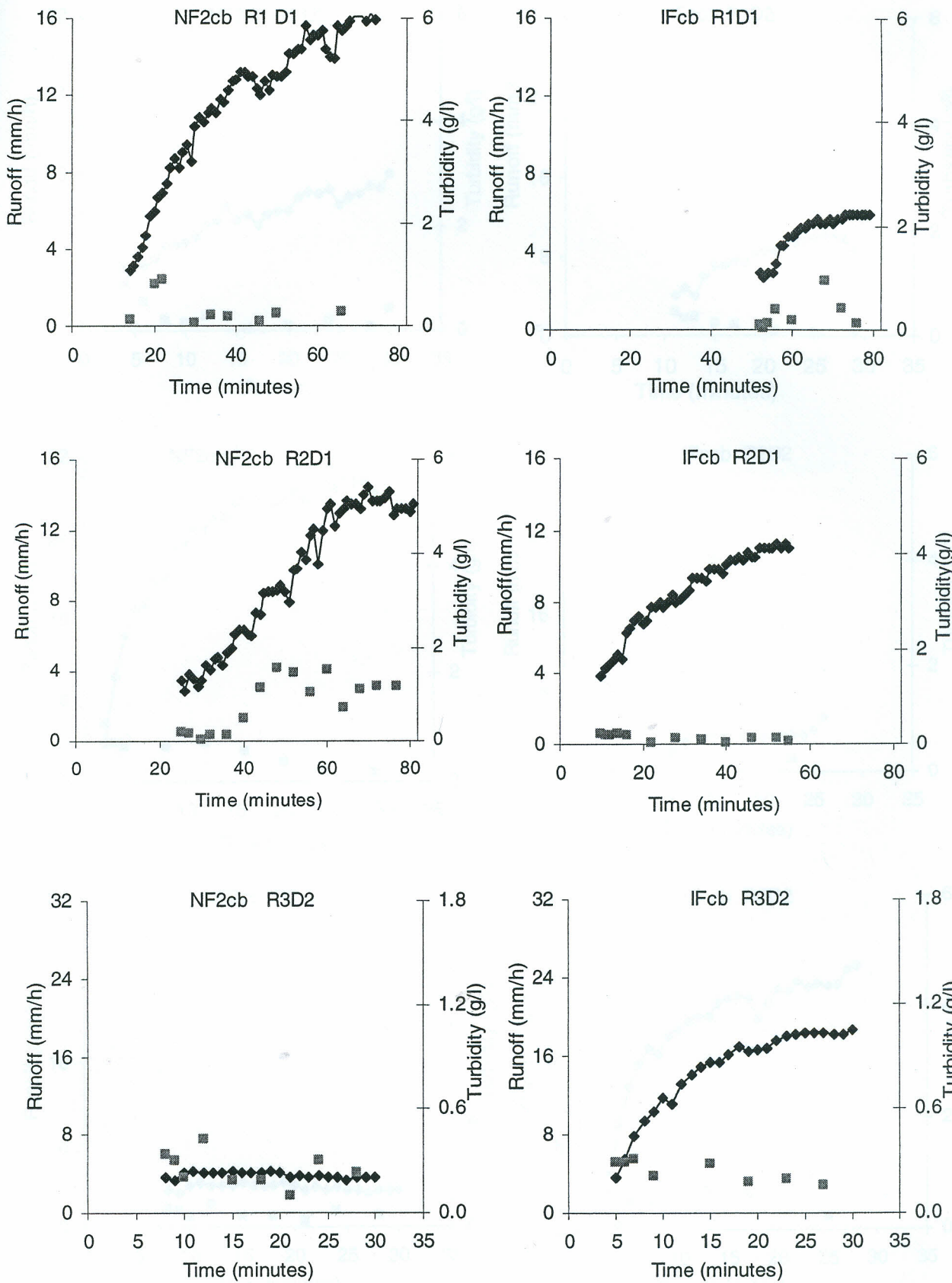


**Figure 4.5:** Runoff initiation and turbidity under natural fallow 2 no cover tilled and improved fallow no cover tilled -phase 2 day 1 (◆- runoff intensity in mm/h; ■- turbidity in g/l).

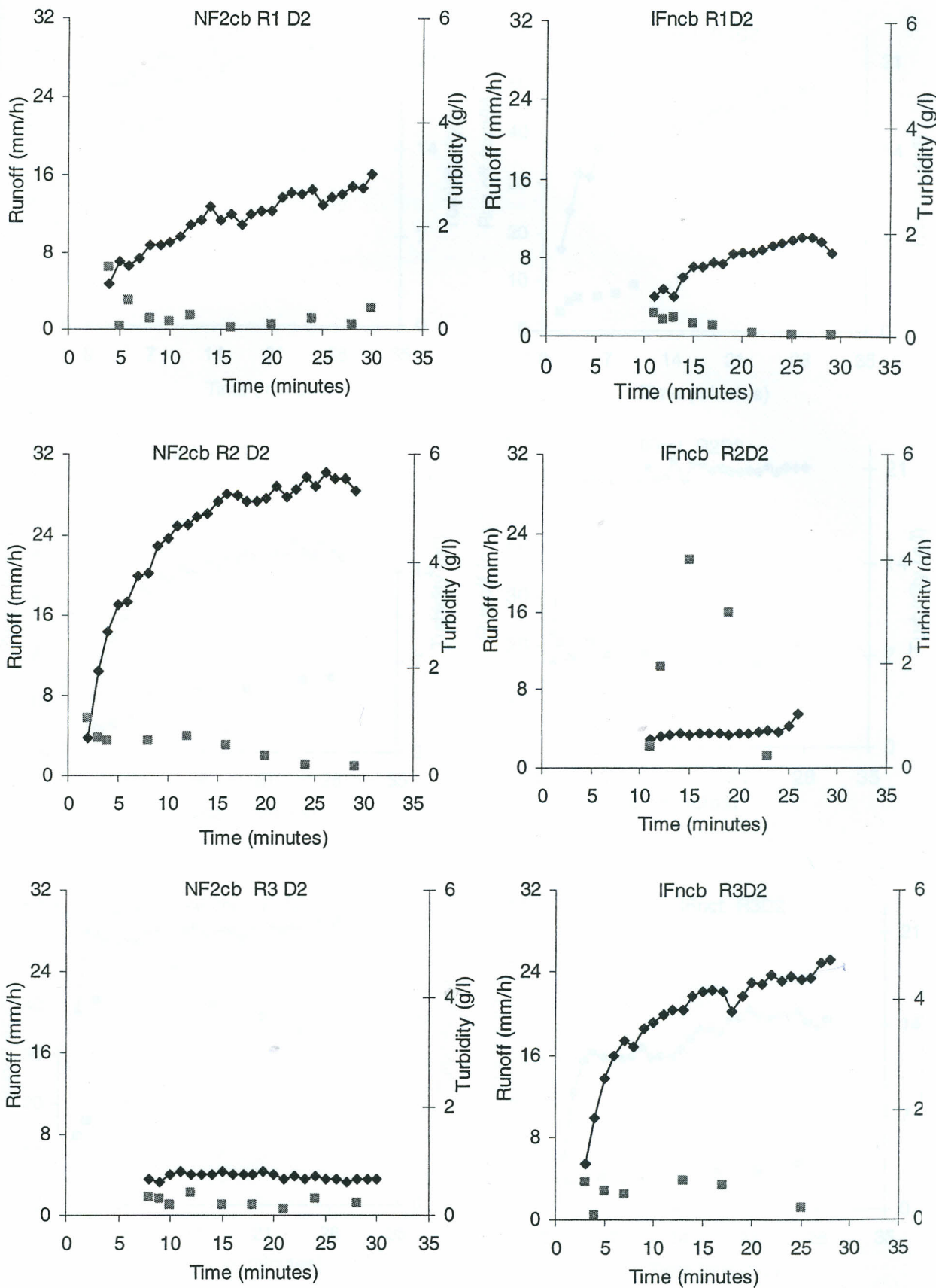
*d) Phase 2 day 2*

There was a faster initiation of runoff and higher turbidity under *NF2cb* ( $0.37 \text{ g L}^{-1}$ ) compared with *IFcb* ( $0.25 \text{ g L}^{-1}$ ) (see Figure 4.6). *IFncb* had a higher turbidity (see Table 4.2) but lower runoff compared to *NF2cb* (see Figure 4.7). Turbidity increased 4 times from  $0.25 \text{ g L}^{-1}$  (*IFcb*) to  $1.1 \text{ g L}^{-1}$  (*IFncb*). For the tilled surfaces, runoff began in the second minute in all the replicates and there was a sharp rise in the runoff intensity with *NF2nctb* having higher runoff intensity ( $47.6 \text{ mm h}^{-1}$ ) and turbidity ( $10.87 \text{ g L}^{-1}$ ) compared to *IFnctb* with runoff intensity of  $42.4 \text{ mm h}^{-1}$  and turbidity of  $4.92 \text{ g L}^{-1}$  (see Figure 4.8).

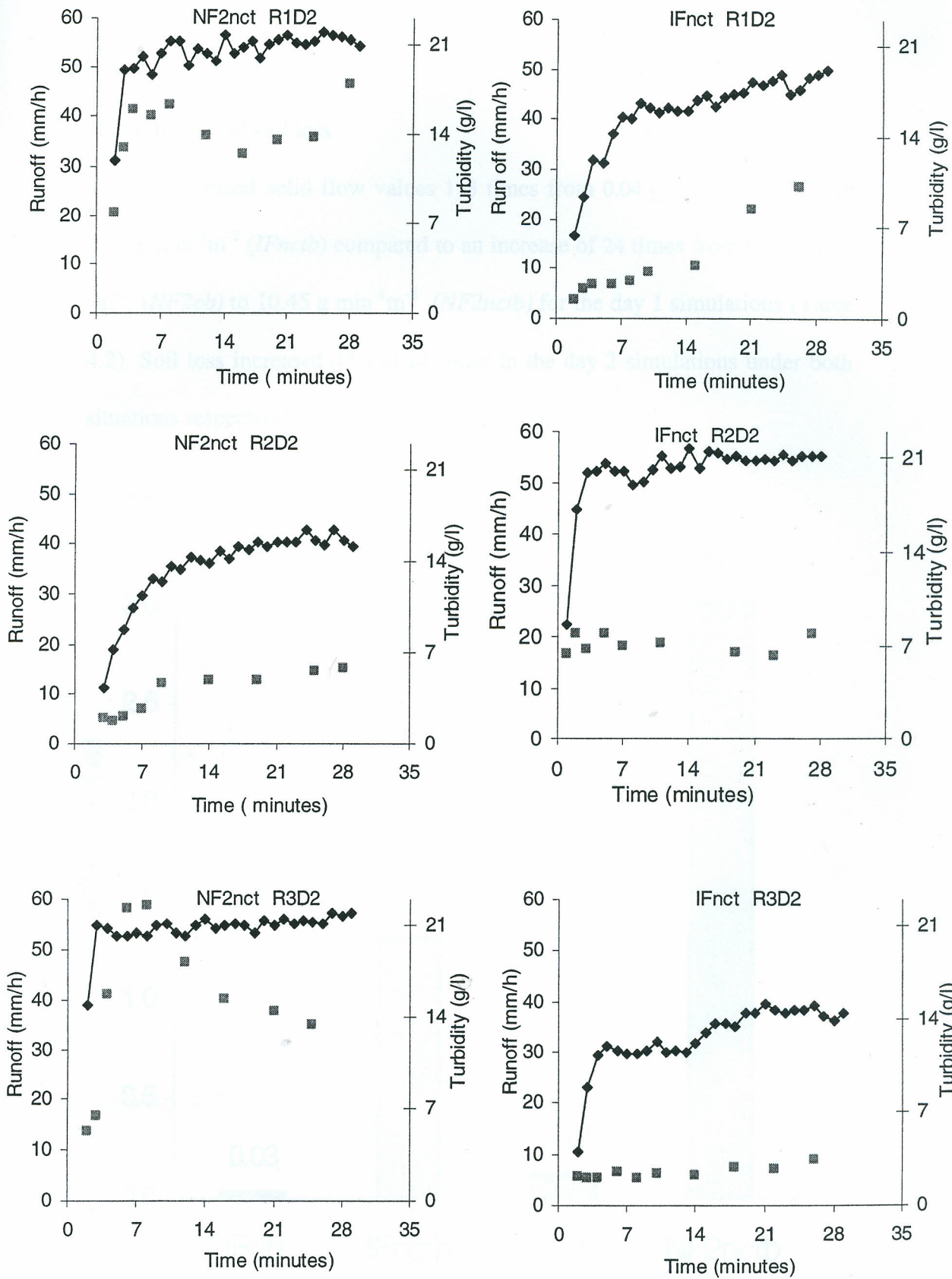
In *NF2nctb*, 79% of the rainfall was lost as runoff compared with 67, 21, 15, and 10% for *IFnctb*, *NF2cb*, *IFncb* and *IFcb* respectively. There were significant relationships between runoff, and turbidity ( $R^2 = 0.74$ ), soil loss ( $R^2 = 0.77$ ), solid flow ( $R^2 = 0.78$ ). Under the tilled surfaces, both the solid flow and soil loss followed a similar trend in the following decreasing order: *NF2nctb* > *IFnctb* > *NF2cb* > *IFncb* > *IFcb*. Soil loss under *NF2nctb* ( $3.02 \text{ t ha}^{-1}$ ) was 2, 25 and 100 times that of *IFnctb* ( $1.31 \text{ t ha}^{-1}$ ), *NF2cb* ( $0.12 \text{ t ha}^{-1}$ ) and *IFcb* ( $0.03 \text{ t ha}^{-1}$ ) respectively (see Figure 4.9).



**Figure 4.6:** Runoff initiation and turbidity under natural fallow 2 cover and improved fallow cover- phase 2 day 2 (◆- runoff intensity in mm/h; ■-turbidity in g/l).



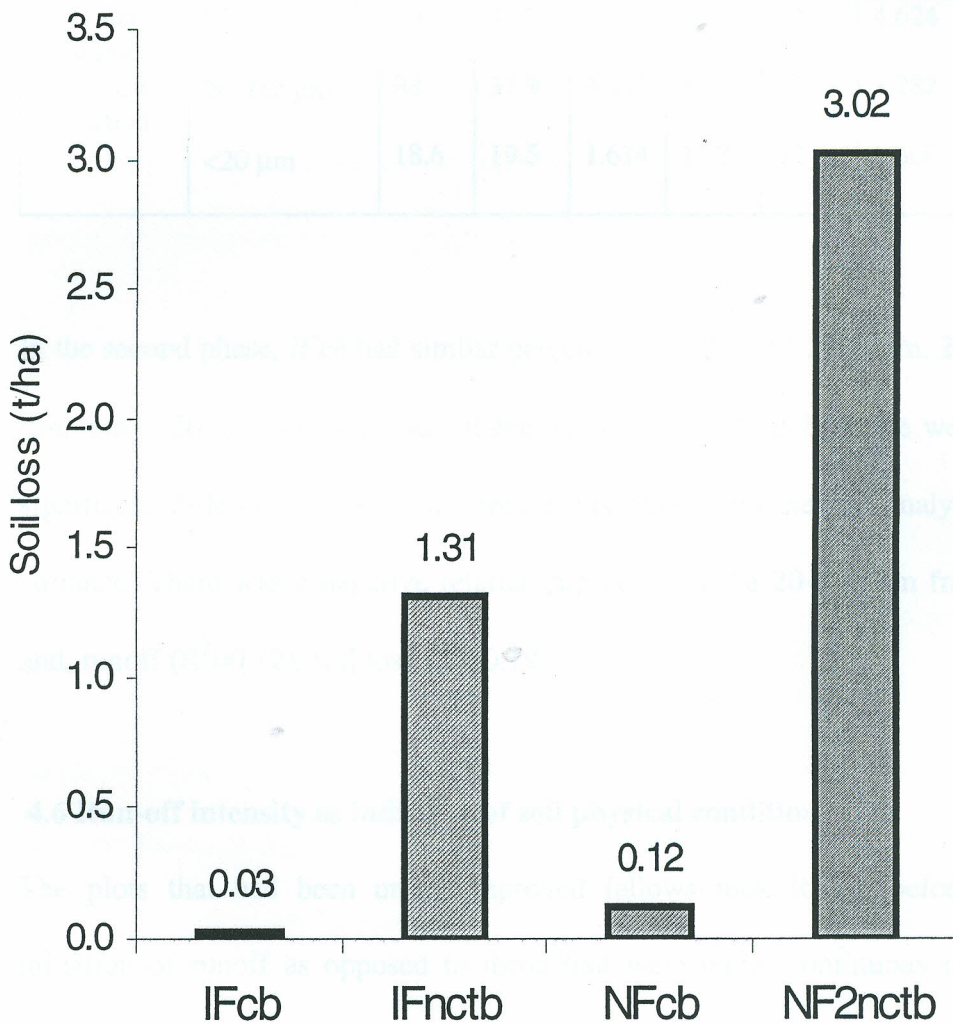
**Figure 4.7:** Runoff initiation and turbidity under Natural fallow 2 cover and improved fallow no cover - phase 2 day 2 (◆- runoff intensity in mm/h; ■-turbidity in g/l).



**Figure 4.8:** Runoff initiation and turbidity under improved fallow no cover tilled and Natural fallow 2 no cover tilled surfaces phase 2 day 2 (◆- runoff intensity in mm/h; ■-turbidity in g/l).

#### 4.4 Tillage and soil loss

Tillage increased solid flow values 113 times from  $0.04 \text{ g min}^{-1}\text{m}^{-2}$  (*IFcb*) to  $4.53 \text{ g min}^{-1}\text{m}^{-2}$  (*IFnctb*) compared to an increase of 24 times from  $0.44 \text{ g min}^{-1}\text{m}^{-2}$  (*NF2cb*) to  $10.45 \text{ g min}^{-1}\text{m}^{-2}$  (*NF2nctb*) for the day 1 simulations (Table 4.2). Soil loss increased 47 and 24 times in the day 2 simulations under both situations respectively as shown in Figure 4.9 below.



**Figure 4.9:** Effect of tillage on soil loss for a 30 minute simulated rainfall.

( $\text{LSD}_{0.05}=2.02$ )

#### 4.5 Water stable aggregates

The results (Table 4.3) show that *IFca* had a similar proportion of the 212-2000  $\mu\text{m}$ , 20-212  $\mu\text{m}$  and  $<20$   $\mu\text{m}$  of the water stable aggregates in the first phase as *CMca*.

**Table 4.3:** Water stable aggregates (%) under the various treatments.

Treatment		Phase 1			Phase 2		
		<i>CMc</i>	<i>IFc</i>	LSD	<i>IFc</i>	<i>NFc</i>	LSD
Water stable aggregate fraction	212-2000 $\mu\text{m}$	43.5	42.7	2.953	43.7	42	4.624
	20-212 $\mu\text{m}$	38	37.9	3.057	38.6	41	3.282
	$<20$ $\mu\text{m}$	18.6	19.5	1.614	17.7	17	1.600

In the second phase, *IFcb* had similar percentages of the 212-2000  $\mu\text{m}$ , 20-212  $\mu\text{m}$ , and  $<20$   $\mu\text{m}$  fraction water stable aggregates as *NF2cb*. There were no significant differences among the treatments when subjected to analysis of variance. There was a negative relationship between the 20-212  $\mu\text{m}$  fraction and, runoff ( $R^2=0.12$ ), soil loss ( $R^2=0.19$ ).

#### 4.6 Run-off intensity as indicator of soil physical condition

The plots that had been under improved fallows took longer before the initiation of runoff as opposed to those that were under continuous maize/natural fallow 2.

**Table 4.4:** Final and initial runoff intensities in the day 1 simulations.

Treatment	Duration of simulation (min)	Antecedent moisture (%)	Waiting period (min)	Runoff duration (min)	Initial runoff intensity (mmh <sup>-1</sup> )	Final runoff intensity (mmh <sup>-1</sup> )
<i>CMca</i>	33	35.6	3	30	6.4	17.6
<i>IFca</i>	143	19.6	81	61	3.6	10.7
<i>NF2c b</i>	75	29.8	25	50	3.3	11.6
<i>NF2nct b</i>	52	34.4	9	43	5.4	46.4
<i>IFcb</i>	68	26.5	25	43	3.8	9.1
<i>IFncb</i>	95	33.2	43	52	3.4	10.3
<i>IFnct b</i>	68	34.3	13	54	4.6	41.9

When the final runoff intensities were compared, it was found that plots that had been under continuous maize/natural fallow 2 tended to have higher runoff intensities compared to those that had been under improved fallows (Table 4.4).

#### 4.7 Soil moisture dynamics

Soil moisture measurements were carried out in two phases: the first from September to December 2000 (Survey 1) while the second from January to March 2001 (Survey 2). Total monthly rainfalls were 149.2, 198, 113.3, 117.2, 163.9, 85.6, and 177 mm for September, October, November, December, January, February and March respectively. Soil moisture changes was analysed in two different ways: by looking at the deviations from C. maize (Survey 1) and N. fallow 2 (Survey 2) at various depths, and the second approach was by assessing the cumulative soil water stocks. The choice was made in order to determine whether the treatments being tested were better than the local farmer's practices in terms of soil water storage.

#### 4.7.1 Dynamics of soil moisture in the survey 1

C. maize had the lowest amount (28.7 mm) of stored soil moisture in most of the sampling dates in the 0-10 cm depth but *C. grahamiana* had the highest (31 mm) followed by *T. candida* + *Macroptilium* (30.8 mm), N. fallow (30.6 mm), *C. paulina* (30.2 mm), *T. candida* (29.8 mm) and lastly C. maize throughout the survey. In the 10-20 cm depth, *T. candida* + *Macroptilium*, N.fallow, *C. paulina* and *C. grahamiana* had values higher than C. maize, but *T. candida* had values lower than C. maize (see Table 4.5). In the 20-30 cm, only *T. candida* + *Macroptilium* had higher stored soil water (32.7 mm) than C. maize (32.6 mm) (see Table 4.5).

In the 30-40 cm, *C. grahamiana* had the highest stored soil water (34.8 mm) followed by C.maize, *T. candida* + *Macroptilium* and *C. paulina* which had similar stocks (34.1 mm) followed by *T. candida* and N.fallow. In the 40-50 cm, the stocks were in the following decreasing order: *C. grahamiana*, *C. paulina*, C.maize, *T. candida* + *Macroptilium*, N.fallow and *T. candida*, and then. In the 50-60 cm, *C. grahamiana* had the highest stocks (36.2 mm) followed by *C. paulina*, *T. candida* + *Macroptilium*, C.maize, then N. fallow and *T. candida* which were equal (34.7 mm) (see Table 4.5).

Cumulative soil water stocks (mm or  $\text{kgm}^{-2}$ ) up to a depth of 60 cm at the beginning of the survey in the first part covering September to December 2000, was 160, 189, 181, 176, 182, and 186 under *T. candida*, C.maize, *T.*

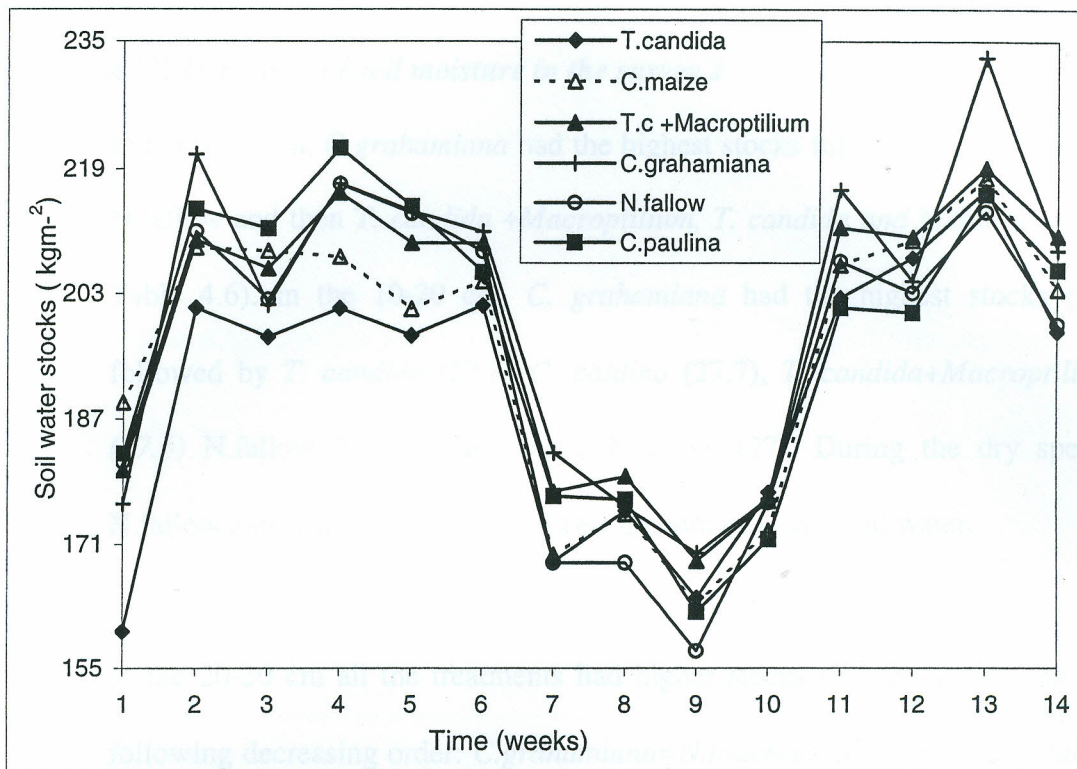
*candida* + *Macroptilium*, *C. grahamiana*, N.fallow and *C. paulina* respectively compared to 198, 204, 210, 209, 199, and 206 at the end of the survey.

**Table 4.5:** Average soil water stocks (mm or  $\text{Kgm}^{-2}$ ) at various depths in the survey 1.

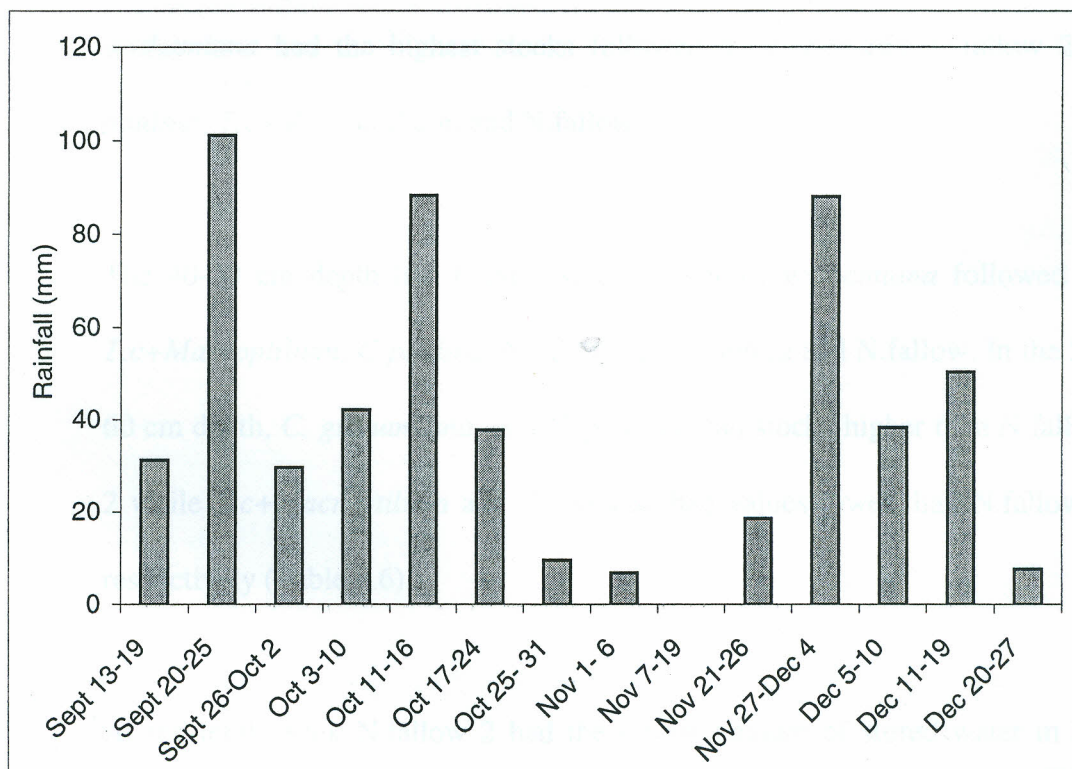
Treatment	Soil sampling depth (cm)					
	0-10	10-20	20-30	30-40	40-50	50-60
<i>CM</i>	28.7	30.1	32.6	34.4	35.1	34.8
<i>Nf</i>	30.6	30.3	31.2	33.4	34.4	34.7
<i>Tc</i>	29.0	28.8	30.6	33.7	33.9	34.7
<i>Tc+M</i>	30.8	31.3	32.7	34.1	34.9	35.1
<i>Cg</i>	31.0	30.5	32.1	34.8	35.8	36.2
<i>Cp</i>	30.2	30.4	32.0	34.1	35.3	35.2

On average, only *Tc* ( $190.7 \text{ kgm}^{-2}$ ) and *NF* ( $194.8 \text{ kgm}^{-2}$ ) had lower cumulative stocks than *CM* ( $195.6 \text{ kgm}^{-2}$ ) but *Cg* ( $200.5 \text{ kgm}^{-2}$ ), *Tc+M* ( $198.9 \text{ kgm}^{-2}$ ) and *Cp* ( $197.2 \text{ kgm}^{-2}$ ) had higher cumulative stocks than *CM*. In all the treatments, there was an increase in water stocks at beginning compared to the end with *C. grahamiana* having the highest amount of stored soil water followed by *T. candida* + *Macroptilium*, *C. paulina*, N.fallow, C.maize, and *T. candida* (see Figures 4.10a and 4.10b)

The driest period fell between the 7<sup>th</sup> and 9<sup>th</sup> week. In terms of the cumulative stocks during this period, the decreasing order was as follows:  $Cg > T.c+M > Cp > Tc = CM > Nf$  with the following mean values 176, 175, 172, 169, 169, 165  $\text{kgm}^{-2}$  for the three week period (see Figure 4.10a). Ninth week was the driest.



4.10a : Dynamics of soil water stocks at 0-60cm depth, survey 1.



4.10b: Weekly rainfall totals in the survey 1

#### 4.7.2 Dynamics of soil moisture in the survey 2

In the 0–10 cm, *C. grahamiana* had the highest stocks followed by *C. paulina*, N.fallow and then *T. candida* +*Macroptilium*, *T. candida* and N.fallow 2 (see Table 4.6). In the 10-20 cm, *C. grahamiana* had the highest stocks (28) followed by *T. candida* (27.8) *C. paulina* (27.7), *T. candida*+*Macroptilium* (27.6) N.fallow 2 (27.2) and lastly N.fallow (27). During the dry spells, N.fallow and N.fallow 2 had the lowest amount of stored soil water.

In the 20-30 cm all the treatments had higher stocks than N.fallow 2 in the following decreasing order: *C.grahamiana*=*N.fallow*>*T.candida*> *T.candida*+*Macroptilium*>*C. paulina*>*N.fallow 2* (Table 4.6). In the 30-40 cm, *C. grahamiana* had the highest stocks followed by *T. candida*, N.fallow 2, *C. paulina*, *T.c*+*Macroptilium*, and N.fallow.

The 40-50 cm depth had highest stocks under *C. grahamiana* followed by *T.c*+*Macroptilium*, *C paulina*, N.fallow 2, *T. candida* and N.fallow. In the 50-60 cm depth, *C. grahamiana*, and *C. paulina*, had stocks higher than N.fallow 2 while *T.c*+*Macroptilium* and *T. candida* had values lower than N.fallow 2 respectively (Table 4.6).

At the tenth week N.fallow 2 had the lowest amount of stored water in the upper 0-10 cm layer. In the 10-20 cm, it was higher than N.fallow and *C. paulina* during the driest point. In the subsequent depth, N.fallow 2 had the

lowest stored soil water. N.fallow 2 was less than N.fallow and *C. grahamiana* at 40-50 cm depth while in the 50-60 cm it was only lower than *C. grahamiana* (see Figure 4.11).

**Table 4.6:** Average soil water stocks (mm or Kgm<sup>-2</sup>) at various depths in the Survey 2.

Treatment	Soil sampling depth (cm)					
	0-10	10-20	20-30	30-40	40-50	50-60
<i>NF2</i>	25.4	27.2	29.1	31.8	32.8	33.0
<i>Nf</i>	26.2	27.0	31.0	31.0	32.4	32.5
<i>Tc</i>	25.8	27.8	30.2	32.0	32.5	32.2
<i>Tc+M</i>	26.1	27.6	30.0	31.4	33.3	32.5
<i>Cg</i>	26.8	28.0	31.0	33.1	34.1	34.2
<i>Cp</i>	26.7	27.7	29.9	31.7	33.0	33.9

Cumulative stocks (mm or kgm<sup>-2</sup>) up to 60 cm depth were as follows at the beginning of the survey: *C. grahamiana* (186), *T. candida+Macroptilium* (180), N. fallow 2 (170), *C. paulina* (164), *T. candida* (162) and N.fallow (150) compared to the end of the survey where *C. grahamiana* had (228), *C. paulina* (222), N.fallow (217), *T. candida* (213), *T. candida+Macroptilium* (211) and N.fallow 2 (204).

In the whole of survey 2, *C. grahamiana* had the highest (187.2) followed by *C. paulina* (182.7), *T.c+Macroptilium* (180.9), *T. candida* (180.4) and N. fallow 2 (179.2) and N.fallow (177.9) as shown in Figures 4.11a and 4.11b.

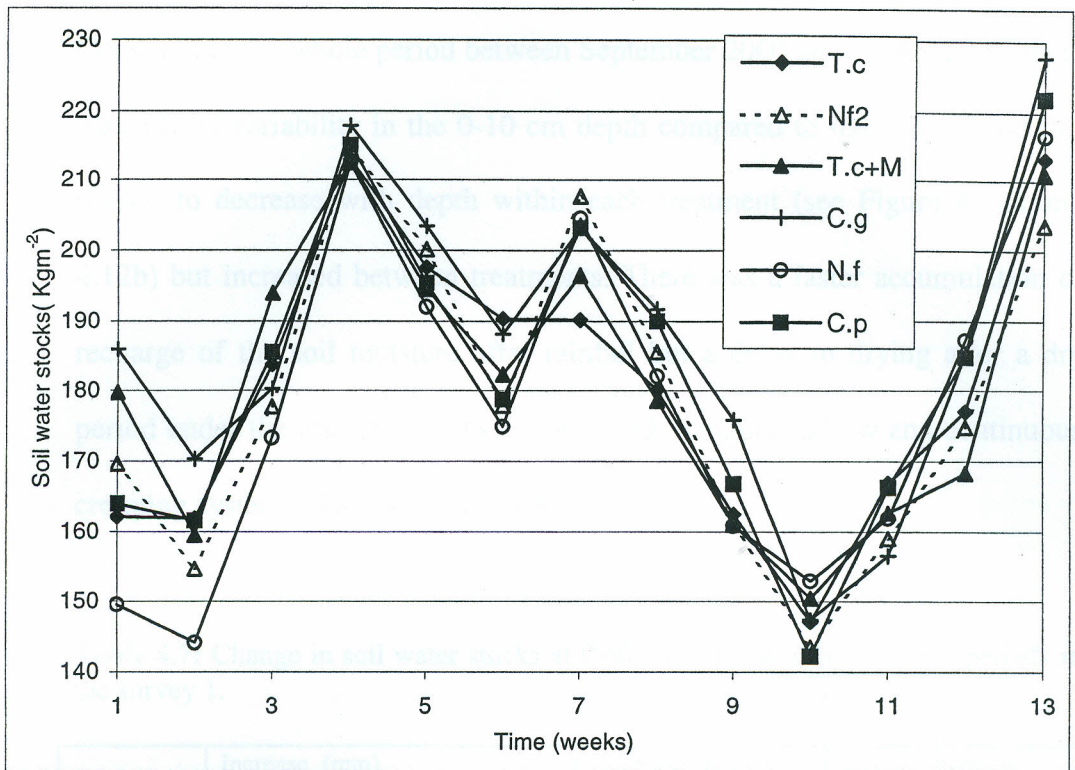
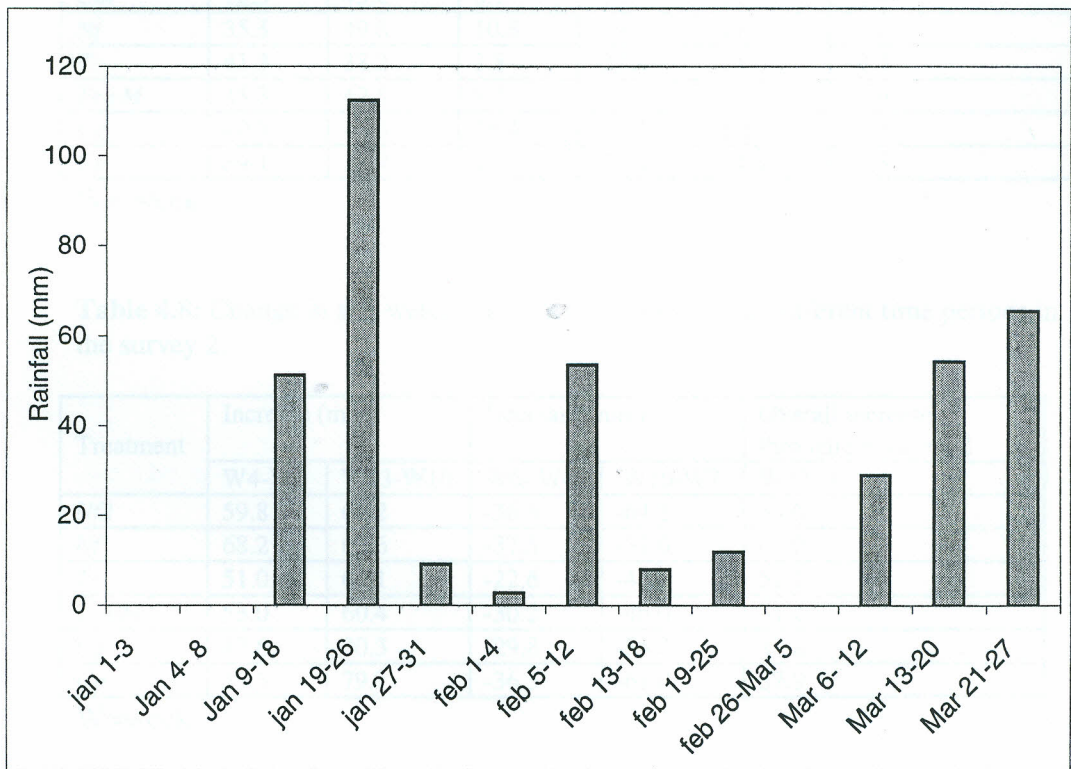


Figure 4.11a: Changes in soil water stocks under various treatments at 0-60cm depth, survey 2



4.11b: Weekly rainfall totals in the survey 2

Considering the whole period between September 2000 and March 2001, there was a high variability in the 0-10 cm depth compared to the subsoil and this tended to decrease with depth within each treatment (see Figure 4.12a and 4.12b) but increased between treatments. There was a faster accumulation or recharge of the soil moisture after rainfall but a delay in drying after a dry period under the improved fallows compared to natural fallow and continuous cropping systems (Tables 4.7 and 4.8).

**Table 4.7:** Change in soil water stocks at 0-60 cm depth at different time periods in the survey 1.

Treatment	Increase (mm)			Decrease (mm)		Overall increase throughout survey 1
	W4-W1	W11-W9	W13-12	W7-W6	W9-W8	
<i>Cm</i>	18.5	43.2	8.1	-34.9	-11.5	14.4
<i>Nf</i>	35.5	49.8	10.3	-39.7	-11.4	17.6
<i>Tc</i>	41.3	38.2	8.8	-32.8	-11.0	38.5
<i>Tc+M</i>	35.3	42.5	9.0	-31.7	-10.8	29.9
<i>Cg</i>	40.9	46.4	28.4	-28.2	-5.8	32.3
<i>Cp</i>	39.1	38.9	15.1	-28.6	-14.4	23.5

W= week

**Table 4.8:** Change in soil water stocks at 0-60 cm depth at different time periods in the survey 2.

Treatment	Increase (mm)		Decrease (mm)		Overall increase throughout survey 2
	W4-W2	W13-W10	W6- W4	W10-W7	
<i>Nf2</i>	59.8	60.2	-36.6	-64.2	34.0
<i>Nf</i>	68.2	63.6	-37.5	-51.6	67.0
<i>Tc</i>	51.0	66.1	-22.6	-43.0	51.1
<i>Tc+M</i>	53.0	60.4	-30.2	-46.0	31.1
<i>Cg</i>	47.6	80.3	-29.8	-55.8	41.8
<i>Cp</i>	53.5	79.7	-36.3	-61.0	57.9

W=week

The difference among the treatments in terms of cumulative stocks increased with the depth. In all the treatments, the lowest soil moisture storage of water ( $\text{kgm}^{-2}$ ) was in the 0-10 cm depth and this increased with increasing depths as shown by the following mean values 30.1, 30.2, 31.9, 34.1 34.9 35.1 (Survey 1) and 26.2, 27.5, 29.8, 31.8, 33.0, 33.1 (Survey 2) from the 0-10 cm to 50-60 cm soil depth respectively. The highest increase in water stocks in the Survey 1 was under 20-30 cm depth and the least in the 0-10 cm depth as opposed to Survey 2 where the highest was in the 0-10 cm depth and the least 50-60 cm depth respectively.

Rainfall events lower than 10 mm had less effect on soil water stocks under *T. candida* and *T. candida+Macroptilium* compared to other treatments especially in the second part of the survey when the cover was well developed (>70%). Improved fallows were better than N.fallow in soil water storage but *C. grahamiana*, *C. paulina* and *T.c+Macroptilium* were better than C.maize as well. *C. grahamiana* was the best overall followed by *C. paulina* and *T.c+Macroptilium*, continuous maize, *T. candida* and lastly N.fallow which had the lowest stored soil water than any other treatment throughout the survey.

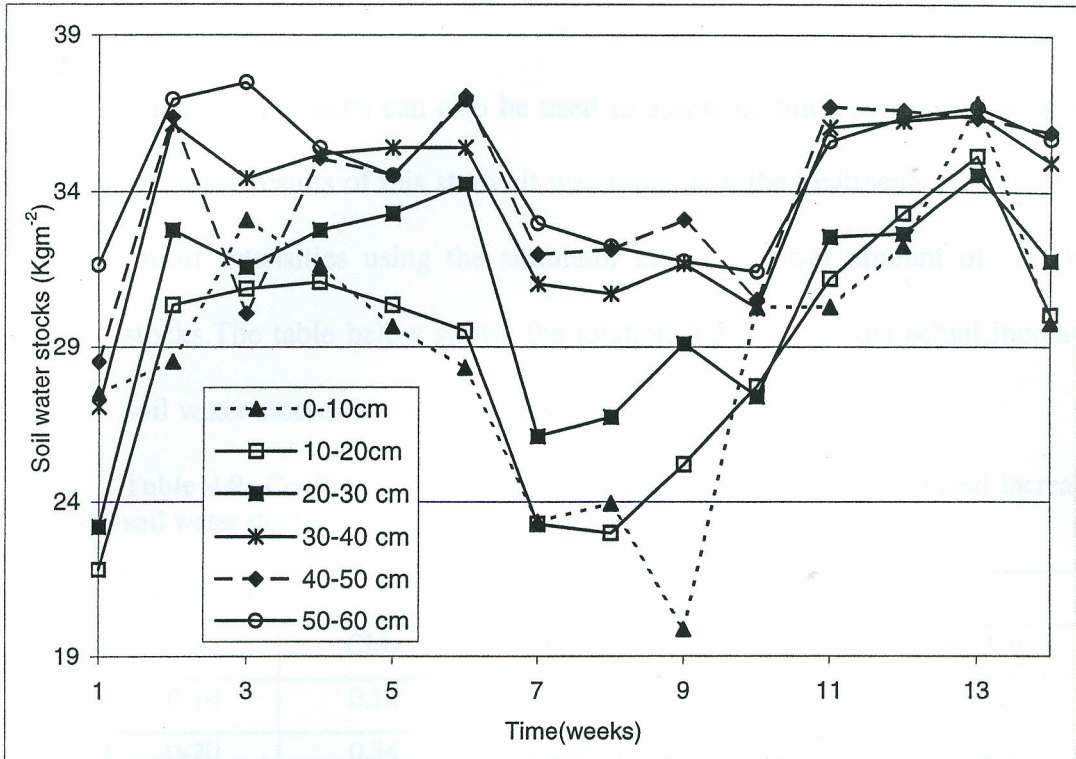


Figure 4.12a: Soil moisture changes at various depths under *T.candida* in the survey 1

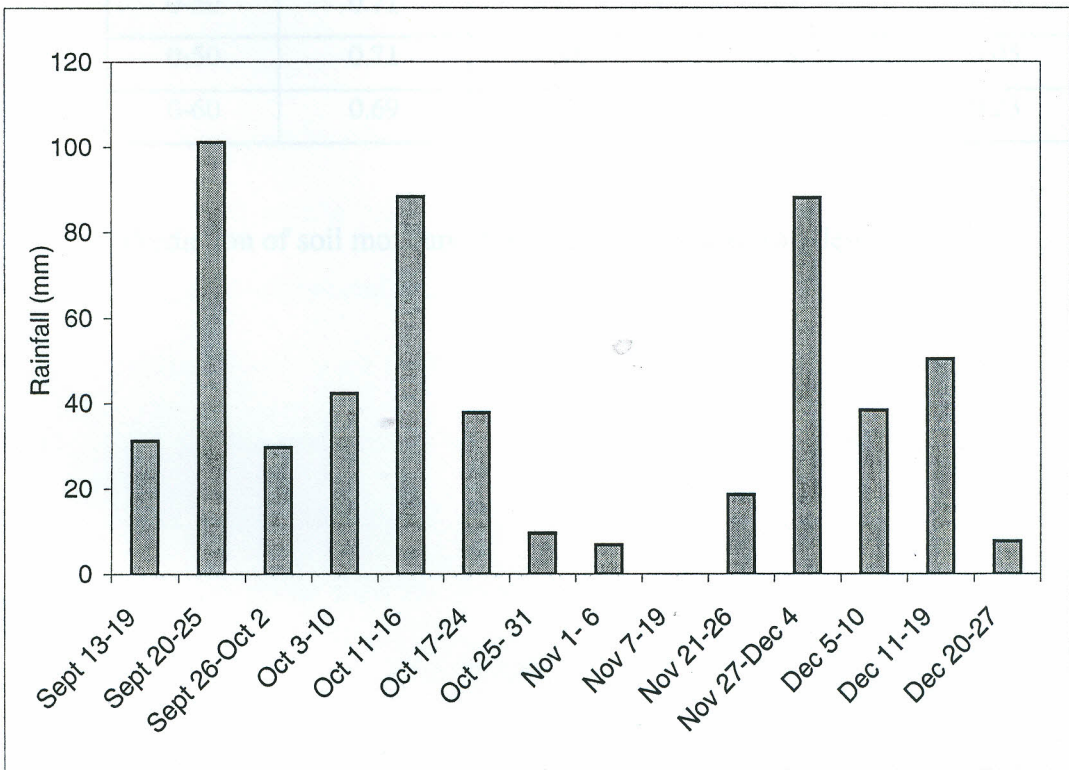


Figure 4.12b: Weekly rainfall totals in the survey 1

Rainfall simulators can also be used to assess or study soil moisture storage.

From the results of this study, it was found that the treatments that had higher runoff intensities using the simulator also had lower amount of soil water stocks. The table below shows the relationship between the actual increase in soil water stocks that occurred and the predicted increase.

**Table 4.9:** Coefficient of correlation between the actual and predicted increase in soil water stocks.

Soil depth (cm)	Treatment			
	CMa	TCa	NF2b	TCb
0-10	0.10	0.15	0.35	0.12
0-20	0.34	0.09	0.01	0.12
0-30	0.63	0.01	0.18	0.10
0-40	0.71	0.13	0.29	0.00
0-50	0.71	0.40	0.58	0.05
0-60	0.69	0.55	0.83	0.23

Prediction of soil moisture storage improves with soil depth.

## CHAPTER FIVE

### DISCUSSION

#### 5.1 Introduction

This study sought to monitor soil cover changes under maize crop, natural and improved fallow conditions, and to determine the influence of improved fallows on soil physical conditions and soil moisture storage. Rainfall velocity and intensity were kept constant to allow for an in-depth analysis of soil erodibility and the role of cover and management in the erosion process. The factors assessed and reported in the previous chapter include soil cover changes, aggregate stability, runoff and soil loss, and soil moisture changes under the various cover treatments.

#### 5.2 The nature, changes and effects of vegetation cover on soil erodibility

From the results presented in chapter four the way in which the plots were managed influenced the rate at which the cover established. Under continuous maize, weeds were controlled through weeding thus reducing competition for the growth resources as opposed to the improved fallows. This might explain why maize had a slightly higher (but not significant) amount of soil cover in the first phase than the improved fallows. The height of the various cover types also varied, with natural fallow having the lowest height and the improved fallow the highest. Previous reports (Hudson, 1981; Omwega, 1989; Lal, 1994) show that shorter plants are more effective in controlling soil detachment than high ones from whose leaves intercepted raindrops may

coalesce to form bigger drops that may achieve terminal velocity higher than that of the rainfall. The density of the plants also matters. Maize is maintained at 2 plants per hill while the improved fallows are maintained at a relatively higher number per hill (>5) and therefore can cover much of the soil surface. Natural fallow, on the other hand, randomly occupies almost the whole soil surface as opposed to continuous maize and improved fallows that are planted in rows. In terms of density therefore, natural fallow have the highest, followed by the improved fallows and then continuous maize. Improved fallows and continuous maize are planted in rows leaving some areas open.

All the treatments differed in terms of the leaf sizes and shapes. Though no measurements were taken, it was noted that maize had very broad but few leaves compared to improved and natural fallows. Broad leaves tend to coalesce the falling raindrops that may have a higher amount of energy as opposed to the smaller leaves under the improved fallows and natural fallows. The broad and long leaves under maize concentrate the intercepted raindrops and might cause much localised erosion at the points in which they are rechannelled onto the soil surface as also observed by Omwega (1989).

Smaller and numerous leaves are more effective in intercepting raindrops and breaking them into tiny droplets with limited amount of energy to cause detachment and transport. This difference in terms of leaf sizes and shape could partly explain why continuous maize had a higher amount of runoff and

soil loss than the improved fallow despite having similar amount of soil cover in the phase 1. The difference in terms of cover in the phase 1 was only seven percent (see Table 4.1) while the difference in soil loss was more than double. In the second phase, the differences were twice for cover and four times for soil loss. Some covers are more effective than others in protecting the soil. Cover was almost equal for *CMca* and *IFca* treatments but soil loss differed among treatments (see Table 4.1 and 4.2).

The provision of cover during the short rain season varied among the treatments. While cover under the improved fallows increased from the beginning of the study period to the end, that under continuous cropping system increased up to the time when maize was just about to be harvested and started drying and falling. This left a period in between where the cover was minimal (<20%) and should a high intensity rainfall occur during this period, then chances of losing much soil would be higher compared to the improved fallow system.

Soil cover is a predominant factor in controlling detachment and transport of soil. Increase in the amount of soil cover leads to a reduction in the amount of soil loss and runoff. This is due to the fact that cover protects the soil surface from the direct impacts of raindrops and that erosion only takes place from the exposed surfaces where soil is detached by raindrops. The reduction in the area of the soil surface exposed to detachment by the impact of raindrops

means that less soil material is available for transport as well. Several authors (Bradford and Huang, 1996; Sharma, 1996; Brady and Weil, 1999) have recognised that it is the impact of raindrops rather than the flow of running water that initiate most erosion. It was found that rainfall events less than 10 mm had very limited effect on the amount of water stored under those treatments with over 70% soil cover. With this amount of cover, rainfall intensity of  $20 \text{ mmh}^{-1}$  for half an hour will therefore have very little effect on the soil surface as far as detachment is concerned.

### **5.3 Surface roughness and slope**

Cover alone could not explain the soil loss since the nature of the surface and slope of the various plots were not uniform. Surface roughness was an important factor as far as the generation of runoff was concerned. The rough surfaces led to a delay in the generation of runoff. The surface depressions had to be filled first before runoff could begin as opposed to those with relatively smoother surfaces. On plots with rough surfaces, the presence of water pools on the soil surface meant that the falling raindrops did not hit the soil surface directly and therefore may not have caused soil detachment. With rougher surfaces, deposition of detached particles may occur within the plot as opposed to a smoother surface.

The lower runoff and soil loss under those plots with high amount of cover could have been due to the increased surface roughness. Slope length was

uniform for all the plots and measurement was taken of the slope angles (%) to explain differences that might occur among replicates and treatments but was not expected to have influenced the results since simulation was done on microplots measuring 1m<sup>2</sup>. In addition, all the plots were located in one place.

#### 5.4 Aggregate stability, infiltration and runoff intensities

Aggregate stability is one of the parameters used as an indicator of the soil structure. The higher the percentage of stable aggregates, the lower might be the soil erodibility (Feller *et al.*, 1996). The 212-2000 µm aggregates are mainly affected by management and /or cultivation of soils because their development is related to the growth of roots and hyphae while the 20-212 µm are not affected by cultivation and are stable because of their small size and because they contain several types of binding agents whose effects are additive (Tisdall and Oades 1982). *T. candida* had a lower percentage of both the 212-2000 µm and 20-212 µm in the phase 1 but there was an improvement in the 212-2000 µm fractions, which could be attributed to the effects of its roots and organic matter added. The relatively higher amounts of the 212-2000 µm aggregates (see Table 4.3) observed could have resulted in macropores leading to increased water percolation into the soil in *T. candida* compared to the C.maize/N.fallow 2 treatment. With comparatively more water percolating into the soil, the potential runoff is reduced together with its ability to scour and transport soil.

Soils in good physical condition have a higher proportion of stable aggregates that can withstand the disintegrating force of raindrop. The higher the percentage of stable aggregates, the lesser the amount of soil detached by the raindrop impact. Higher proportions of stable aggregates will lead to bigger pores formed between the aggregates and hence higher amounts of infiltration rates leading to less runoff. In this study, there were no significant differences between Improved fallow, continuous maize and natural fallow in the percentage of water stable aggregates (see Table 4.3) but there seemed to be reduced soil detachability leading to low amount of soil loss (see Table 4.2).

Some improvement might have occurred under the improved fallow as opposed to the continuous maize and natural fallow where higher amount of soil loss and runoff was experienced. A weak negative relationship existed between the 20-212  $\mu\text{m}$  fraction and, runoff and soil loss. Other researchers (Barthès *et al.*, 1999 and Barthès *et al.*, 2000) have reported negative relationships between water stable macroaggregates and runoff and soil loss.

Infiltration and runoff intensities are other indicators of soil physical conditions used in this study. Good soil structure is associated with higher infiltration rates and lower runoff. Rainfall simulators and double ring infiltrometers have been used to estimate the infiltration rates of various soils. When using a field rainfall simulator, it is a bit difficult to accurately determine a soils' infiltration since there is the element of surface storage also

accounting for the difference between the rainfall applied and the amount that runoff. Though measurements were taken of infiltration rate and surface storage combined, it is the runoff intensity that is used here since a clear distinction could not be made between the surface storage and infiltration rate.

Continuous maize had a faster initiation of runoff and higher rise in the intensity than improved fallows (see Figure 4.1), probably due to faster disaggregation when the soil was subjected to rainfall. Lower amount of runoff under the improved fallows may also be attributed to the fact that a higher proportion of the rainfall is intercepted compared to the maize crop.

As reported in Chapter Two and Four, some of the intercepted rainfall is lost through direct evaporation without necessarily reaching the soil surface. The tiny drops reaching the soil surface at a reduced speed also have low energy to cause soil detachment and therefore less clogging. In addition to this, it is the detached and loosened soil particles that lead to surface sealing and crusting. It therefore follows that the lower the amount of soil detached the lesser the amount of surface sealing and impediments to soil infiltration. Less runoff and high infiltration will therefore be experienced in soils with high proportion of stable aggregates.

The major role of the running water is transport of detached soil particles. High runoff intensity therefore means the transport capacity of the rainwater is

enhanced increasing soil loss from a given place. High runoff volume also means that the ability of the running water to cause detachment is increased and therefore higher rate of soil erosion (see Table 4.4 and Figure 4.8). Reduction of both the speed and size of the raindrops by the soil cover will reduce the ability to detach and transport soil particles.

### **5.5 Effects of land management on soil erodibility**

The way in which land is managed influences soils physical condition. Tillage and weeding had a profound effect on the infiltration rates, runoff intensity and soil loss. Runoff intensity in phase 2 simulations increased more than 4 times (see Table 4.4) when plots formerly under improved fallows and natural fallow were tilled indicating that there was a decrease in the infiltration rates together with surface storage. This could have resulted from the clogging of pores and surface sealing.

Tillage destroys soil aggregates resulting in increased runoff (see Figure 4.5). Tilled surfaces had more soil loss since they had no cover on the surface and therefore, the raindrops were directly hitting the soil that had already been loosened. Moreover, the detached finer particles could clog the pores decreasing infiltration and thus increasing surface runoff. The day 2 simulations under tilled surfaces had even higher run off intensities implying a reduction in the infiltration rates (see Figure 4.8).

The increase in the runoff intensity meant an increase in the transport capacity together with increased ability to detach soil particles. Significant relationships between runoff, and turbidity, solid flow, soil loss existed (see section 4.3, phase 2 day 2) under no cover-tilled surfaces. This means that the higher the runoff the higher the soil loss. The runoff intensities of phase 2 day 2 no cover tilled surfaces showed that the soils have poor structure (see Figure 4.8).

The percentage of rainfall lost as runoff in the phase 2 day 2 simulations were as follows *IFcb* (10%), *NFcb* (21%), *IFncb* (15%), *IFnctb* (67%), *NF2nctb* (79%). Loss of soil and nutrients results in poor crop growing conditions. When the tilled surfaces without cover (*IFnctb* and *NF2nctb*) were compared, plots previously under improved fallows lost less than a half of those that were under continuous maize and natural fallow 2 (see Figure 4.9). These differences in runoff intensities and soil loss could partly be explained by their past land use history and how they were managed during the experimental period. The continuous maize/natural fallow 2 plots had more tillage operations than improved fallows. The influence of cover was eliminated by its removal in both treatments in addition to tilling both surfaces to have similar surface conditions.

## 5.6 The role of vegetation cover in rainfall interception

The amount of soil water stored in an area is a function of many factors including the prevailing weather conditions, the type and amount of cover

present, soil type and the way in which it is managed. The major sources of water to a farming system are rainfall and irrigation. The water received is lost either through evaporation, transpiration, runoff and deep percolation.

In this study, soil moisture changes under different cover types were assessed. Generally, so long as there is cover, not all the rainfall will reach the soil surface. Some of the rainfall will be intercepted and evaporates before reaching the ground surface. Part of it may reach the soil surface as stem flow. It was observed in this study that the higher the ground cover, the higher the amount of rainfall that was intercepted with less water reaching the soil surface. It therefore means that the soil water recharge is low with a high cover after a rainfall event. And with rains less than 10mm. There was little change in stored soil water where the cover had reached 70 percent as in *T.c+M* and *T.c* treatments (see Figure 4.11a). Rainfall events of lower amounts are intercepted and evaporated with only very little reaching the soil surface.

High amount of soil cover is important in controlling kinetic energy of raindrops. Since much of the raindrops will be intercepted and their energy dissipated, fewer and in some cases smaller drops reaching the soil surface will have little energy to detach soil particles. Chances of runoff generation are also reduced together with the possibility of transporting the particles as shown in Table 4.4. *IFcb* had relatively higher percentage cover but less runoff and soil loss compared to *NF2cb*. This is important in that the soil porosity will not

change drastically and therefore will be able to transmit water vertically into the profile. Tiny raindrops falling from leaves have near zero velocity and therefore chances of losing much of the rain as runoff is reduced. Two types of drops were observed under the *T. candida* cover, which was over one meter high. There were drops falling directly on the soil surface and there were those intercepted and coalesced to form bigger drops that fell from a short distance to the ground, probably with little energy though.

#### ***5.6.1 Effect of cover on soil water stocks***

Under relatively high percentage of cover, the decrease in the amount of soil water stored was gradual (see Tables 4.7 and 4.8). This is partly due to the effect of shade provided which ameliorates the effect of high temperatures, which could have otherwise meant that a lot of water is lost from the soil through direct evaporation. The improved fallows were found to be effective in controlling fluctuations in soil water stocks. The recharge was faster upon rainfall but the decrease gradual (Tables 4.7 and 4.8). The gradual decrease in soil water stock may lead to higher stocks being made available for the next crop at the time of planting. When various improved fallow species were considered, *Tephrosia candida* had lower amount of soil water stocks. This could be attributed to the high amount of cover/biomass present under this treatment. Jones and Sinclair, (1989); Gachene *et al.*, (1996) also reported a higher rate of soil water depletion under plots with vigorous crop growth.

Greater fluctuations in soil water stocks are observed in the upper horizons and decreases with depth into the profile (see Figure 4.12a). Highest storage was found to be at the 50-60 cm depth. Shallow rooted plants are therefore more susceptible to water stress due to the rapid change in the upper soil layers. The deep-rooted crops can explore a wider area and extract the stocks in the lower horizons and this can be more beneficial during dry periods.

### 5.7 Comparison with a previous study

Comparison with a previous study conducted by Boye (2000) in the same area (Table 5.1) shows a similar trend in terms of soil cover, turbidity, solid flow and soil loss. Soil cover, rainfall intensity and soil loss were similar for *CM* in both studies. Turbidity was higher in the present study but solid flow was less compared to the previous study.

**Table 5.1:** Comparison of rainfall intensity, soil cover, turbidity, solid flow and soil loss with a previous study

Treatment	Rainfall intensity (mm h <sup>-1</sup> )		Soil cover (%)		Turbidity (g L <sup>-1</sup> )		Solid flow (g min <sup>-1</sup> m <sup>-2</sup> )		Soil loss (t ha <sup>-1</sup> )	
	57	56	56	57	1.5	0.5	0.3	0.4	0.1	0.1
<i>T. candida</i>	59	64	76	84	0.3	0.3	0.04	0.3	0.03	0.1
No cover (IF)	59	64	0	0	1.1	0.2	0.2	0.5	0.04	0.1
No cover tilled (IF)	59	64	0	0	4.9	2.4	4.5	2.4	1.3	0.7

Source (Boye, 2000).

Under each variable, values in the first column are for the present study.

This study also had natural fallow as an additional treatment compared to Boye (2000). The results of this study (see Figure 4.9 and Table 4.2) are consistent

with those of previous ones carried out in the area (Rao *et al.*, 1999; Boye, 2000). In both studies, continuous maize had a higher amount of runoff and soil loss than improved fallows. Improved fallow had lower runoff and soil loss compared to natural fallow as well. The results further confirm that the soils are of poor structure. Lal (1992) also reported that planted fallows of either legume or grass covers are generally more effective in restoring soil fertility and improving soil physical properties than natural fallows.

## CHAPTER SIX

### SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

#### 6.1 Summary

Results presented in Chapter Four indicate that different cover types offer different degree of protection against erosion. *CMca* had a higher soil loss than *IFca* despite having the same percentage of soil cover (see Table 4.2). Continuous cropping provides cover only in between the cropping seasons leaving the soil surface bare after crop harvesting. Improved fallows offer better cover throughout the year since they are only removed when preparing the land for planting. Short term improved fallows were also better than natural fallow in cover provision and addition of organic matter.

Improved fallows improve soil physical conditions as shown by the low detachability and runoff intensities compared to natural fallow and continuous cropping (see Figures 4.8 and 4.9). Soil loss and runoff intensities were lower under the improved fallows. Tillage may have reduced soil porosity and resistance to erosion. The soils were characterised by fast breakdown of soil aggregates, showing that they are physically degraded. Any tillage operation impacts on them negatively.

The amount of soil water stocks depends on prevailing weather conditions, physical soil conditions and the nature of vegetation cover present. The higher

the cover, the higher the amount of rainfall intercepted but shade provision guard against rapid decrease in the soil water stocks. Improved fallows together with minimum tillage practices improve infiltration that may lead to increased soil water availability. Improved fallows therefore provide opportunities for conserving soil moisture in the study area thus improving crop yields.

## 6.2 Conclusion

This study was set up to assess the effect of short-term improved fallows on soil erosion and soil water conservation compared to continuous cropping and natural fallow systems. The results shows that short-term improved fallows are better than continuous cropping or natural fallow in controlling soil erosion and conserving soil moisture.

## 6.3 Recommendations

Based on the findings of this study, the following recommendations have been made:

i) Farmers may use short-term improved fallows as opposed to natural fallow to improve the soil physical conditions since this system was found to conserve soil and water better than the conventional system.

ii) Continued rotation of the short-term improved fallows with annual crops over time might lead to significant improvements in terms of soil

resistance to erosion and increased infiltration. It should not be a one-time activity. We need to build over the little gains that may be achieved.

iii) The aim of tillage is to aerate the soil and increase water infiltration providing a suitable environment for germination and crop growth. The number of tillage operations should be kept to a minimum in order to increase infiltration and decrease destruction of soil aggregates. Other methods for example slashing of weeds may be used whenever appropriate.

iv) Because of the different nature, in which the various cover types are planted or establish themselves, different methods should be used in estimating the amount of cover present. In the case of natural fallow which consists of grasses and other small plants, at the initial stages of the fallow measurements taken using the grid may overestimate the amount of cover present since there is likely to be a count in each square yet not all the soil surface is covered. The use of a ceptometer in estimating cover provides an opportunity to accurately determine the amount of cover present. The ceptometer on the other hand may not be suitable for very short plants hence the need for both.

#### **6.4 Areas for further study**

There is little information on the effect of improved fallows on soil physical properties in the area of study. There is need for further research on non-nutrient benefits of improved fallows in order to enhance their adoption by farmers.

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## APPENDICES

### Appendix 1a. Rainfall simulation Results-Phase 1

Treatment	Day	Slope (%)	Soil cover (%)	PAR (%)	Antecedent Moisture (%)	Plant height (cm)	Rainfall intensity (mmh <sup>-1</sup> )	Soil loss (tha <sup>-1</sup> )	Total runoff (ml)	Turbidity (gL <sup>-1</sup> )	Solid flow (gmin <sup>-1</sup> m <sup>-2</sup> )	Simulation period (min)	Runoff duration (min)
<b>CMca</b>	<b>1</b>	<b>6.0</b>	<b>56.2</b>	<b>63.1</b>	<b>35.6</b>	<b>115.4</b>	<b>55.8</b>	<b>0.26</b>	<b>7580</b>	<b>2.78</b>	<b>0.834</b>	<b>32.7</b>	<b>30.0</b>
Stdev		0.5	5.7	19.2	0.3	5.8	3.6	0.2	2371.7	2.4	0.8	1.2	1.0
<b>IFca</b>	<b>1</b>	<b>5.3</b>	<b>49.0</b>	<b>48.2</b>	<b>19.6</b>	<b>107.7</b>	<b>58.5</b>	<b>0.04</b>	<b>8024</b>	<b>0.50</b>	<b>0.052</b>	<b>142.7</b>	<b>61.3</b>
Stdev		2.1	8.5	18.1	0.2	8.0	2.1	0.0	2700.4	0.3	0.0	28.0	14.6
<b>CMca</b>	<b>2</b>	<b>6.0</b>	<b>56.2</b>	<b>63.1</b>	<b>34.6</b>	<b>115.4</b>	<b>55.8</b>	<b>0.09</b>	<b>4265</b>	<b>1.54</b>	<b>0.312</b>	<b>30.0</b>	<b>24.7</b>
Stdev		0.5	5.7	19.2	0.3	5.8	3.6	0.1	1777.8	1.4	0.3	0.0	5.9
<b>IFca</b>	<b>2</b>	<b>5.3</b>	<b>49.0</b>	<b>48.2</b>	<b>31.7</b>	<b>107.7</b>	<b>58.5</b>	<b>0.03</b>	<b>6496</b>	<b>0.48</b>	<b>0.111</b>	<b>30.0</b>	<b>27.0</b>
Stdev		2.1	8.5	18.1	2.9	8.0	2.1	0.0	1470.2	0.1	0.0	0.0	0.0

Appendix 1b. Rainfall simulation summary-phase2

Treatment	Day	Slope (%)	Soil cover (%)	PAR (%)	Antecedent Moisture (%)	Plant height (cm)	Rainfall intensity (mmh <sup>-1</sup> )	Soil loss (tha <sup>-1</sup> )	Total runoff (ml)	Turbidity (gL <sup>-1</sup> )	Solid flow (gmin <sup>-1</sup> m <sup>-2</sup> )	Simulation period (min)	Runoff duration (min)
<b>IFcb</b>	<b>1</b>	<b>9.12</b>	<b>76.00</b>	<b>82.7</b>	<b>26.53</b>	<b>198.3</b>	<b>58.81</b>	<b>0.03</b>	<b>5673</b>	<b>0.19</b>	<b>0.0700</b>	<b>68.0</b>	<b>42.67</b>
Stdev		2.6	21.6	2.1	1.7	12.6	1.0	0.0	2581.9	0.1	0.0	12.1	14.6
<b>IFncb</b>	<b>1</b>	<b>9.12</b>	<b>0.00</b>	<b>0.00</b>	<b>33.17</b>	<b>0.0</b>	<b>58.81</b>	<b>0.07</b>	<b>7644</b>	<b>0.44</b>	<b>0.1271</b>	<b>94.67</b>	<b>52.00</b>
Stdev		2.6			1.7		1.0	0.1	4772.9	0.5	0.1	22.3	7.5
<b>IFnctb</b>	<b>1</b>	<b>9.12</b>	<b>0.00</b>	<b>0.00</b>	<b>34.33</b>	<b>0.0</b>	<b>58.81</b>	<b>1.12</b>	<b>28990</b>	<b>3.68</b>	<b>2.02</b>	<b>67.67</b>	<b>54.33</b>
Stdev		2.6			1.1		1.0	0.3	4431.8	0.9	0.7	7.5	4.7
<b>NF2cb</b>	<b>1</b>	<b>9.28</b>	<b>37.00</b>	<b>-</b>	<b>29.77</b>	<b>8.7</b>	<b>58.37</b>	<b>0.07</b>	<b>7848</b>	<b>0.60</b>	<b>0.125</b>	<b>75.33</b>	<b>50.00</b>
Stdev		0.5	15.0		2.8	2.1	0.3	0.0	4148.9	0.5	0.0	5.1	14.0
<b>NF2ncbt</b>	<b>1</b>	<b>9.28</b>	<b>37.00</b>	<b>-</b>	<b>34.43</b>		<b>58.37</b>	<b>1.90</b>	<b>24739</b>	<b>6.81</b>	<b>4.570</b>	<b>52.33</b>	<b>43.00</b>
Stdev		0.5	15.0		1.8		0.3	0.9	5312.3	3.6	2.9	14.5	12.2
<b>IFcb</b>	<b>2</b>	<b>9.12</b>	<b>76.00</b>	<b>82.7</b>	<b>32.60</b>	<b>198.3</b>	<b>58.81</b>	<b>0.03</b>	<b>2986</b>	<b>0.25</b>	<b>0.04</b>	<b>30.00</b>	<b>17.33</b>
Stdev		2.6	21.6	2.1	0.7	12.6	1.0	0.0	2878.6	0.1	0.0	0.0	7.1
<b>IFncb</b>	<b>2</b>	<b>9.12</b>	<b>0.00</b>	<b>0.00</b>	<b>35.07</b>	<b>0.0</b>	<b>58.81</b>	<b>0.04</b>	<b>4341</b>	<b>1.10</b>	<b>0.15</b>	<b>30.00</b>	<b>21.33</b>
Stdev		2.6			0.7		1.0	0.0	4182.1	1.3	0.0	0.0	4.9
<b>IFnctb</b>	<b>2</b>	<b>9.12</b>	<b>0.00</b>	<b>0.00</b>	<b>35.13</b>	<b>0.0</b>	<b>58.81</b>	<b>1.31</b>	<b>19698</b>	<b>4.92</b>	<b>4.53</b>	<b>30.00</b>	<b>29.00</b>
Stdev		2.6			2.1		1.0	0.8	4501.9	2.9	2.8	0.0	0.0
<b>NF2cb</b>	<b>2</b>	<b>9.28</b>	<b>37.00</b>		<b>32.77</b>	<b>8.7</b>	<b>58.37</b>	<b>0.12</b>	<b>6336</b>	<b>0.37</b>	<b>0.44</b>	<b>30.00</b>	<b>25.67</b>
Stdev		0.5	15.0		1.4	2.1	0.3	0.1	5566.3	0.2	0.3	0.0	3.5
<b>NF2ncbt</b>	<b>2</b>	<b>9.28</b>	<b>0.00</b>	<b>0.00</b>	<b>35.00</b>	<b>0.0</b>	<b>58.37</b>	<b>3.02</b>	<b>22925</b>	<b>10.87</b>	<b>10.45</b>	<b>30.00</b>	<b>28.67</b>
Stdev		0.5	0.0		1.6		0.3	1.8	6302.3	6.1	5.8	0.0	0.6