LAND DEGRADATION AND ITS CONTROL IN THE KIBWEZI AREA, KENYA

by

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DECLARATION

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

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

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Abstract

Most of our semi-arid land is threatened with increased land deterioration due to changes in land use especially in areas where soils have sealing properties which hinder infiltration of rain- water. The study was carried out in Kibwezi Division, Machakos District, a distance of 220 km. from Nairobi. It was designed to investigate major causes of land deterioration following human settlement around 1963 and low cost measures of reversing it.

The experiment was designed to investigate whether slashing bush and spreading it on the denuded ground would improve infiltration and if so, whether the effect would be due to interception of rainfall energy and reduced sealing, interception of runoff, insect activity i.e. termites or other organisms living on the deadwood and breaking the seal in the process or due to a combination of one or more factors. This was investigated using twelve (12) runoff plots on a mean slope of 0.1% with ferral chromic Luvisols and 20% brushwood cover. Different forms of treatments under natural rainfall were applied. Supplementary studies on infiltration; after insect activity on the soil seal when the soil seal is intact and after the soil seal is removed ,were conducted by surface ponding next to runoff plots for comparison. A farm survey with a questionnaire on causes and state of land deterioration, and measures used to encourage revegetation, was carried out on settled areas. Studies were conducted to determine the botanical composition of virgin land. Socio-economic data on some plants, for example, Baobabs left in cropland, was collected from the local communities.

Treatment effects compared with the control plots, were significant ($P \leq 0.05$) in reducing soil loss and runoff. Rainfall and runoff interception using 20% brushwood cover together with or without insect activity is significant in reducing soil loss and runoff.

Bare denuded plots lost an average of 53% of the rainfall as runoff and 65.5t/ha. of soil compared with 38% of rainfall as runoff and 19t/ha. of soil from plots with rainfall/runoff interception together with insect activity. Rainfall interception only and rainfall/runoff interception without insect activity lost a total of 32t/ha. and 25.7t/ha. respectively.

Efficiency values in reducing soil loss and runoff were generally high for all the treatments. Rainfall/runoff interception with insect activity treatment reduced soil loss by 71% ,without insect activity 61%, and rainfall interception only by 51%

Soil sealing in semi-arid areas as a result of raindrop impact could be due to low organic matter ($\leq$ 0.1%) and high sand content ($\geq$ 69%) and fine clay fractions which could possibly block the soil pores after the soil aggregate disintegrates under raindrop impact. Soil sealing may also be attributed to runoff. Clay fractions in the soil, act like cement in sand and it contributes to the hardness of the soils during the dry season. The effect of this is low infiltration, high runoff and water erosion when rains come. Clay content at the soil surface causes decreased porosity and thus soil sealing.

Insect activities were found to assist in creating rough and fragmented surfaces on the denuded sealed soils. This was found to enhance rainfall infiltration for a short period on ponding water, implying that enhanced revegetation of denuded lands can be achieved by creating conditions necessary for rainwater to pond.

Settlement in the area ,though relatively recent and mainly within the last 25 years, has resulted in serious erosion in some places. This indicates that much greater attention should be paid to soil and water conservation.

Most of the land deterioration from stable vegetated land with minimal soil erosion has been due to vegetation removal exposing soil to accelerated erosion and increased runoff in most cultivated farms. This has been made worse by poorly maintained and /or lack of soil and water conservation measures on cropland and lack of proper grazing management and /or restoring cover whenever it is diminished, by using measures (example, temporary bunds, basins etc.) intended to promote infiltration plus reseeding or planting grass splits on grazing land.

1. INTRODUCTION

A large part of Kenya (75%--80%) is semi-arid or arid. It is an area of low production potential and for a long period has been used by wildlife and pastoral communities or semi-pastoral communities. This is mainly due to inadequate rainfall to support rainfed agriculture. Traditionally, man and vegetation had established an exploitation level of the available resources sufficient for his subsistence needs and those of livestock.

Since Independence in 1963, there has been a change in land use. Population has increased due to the influx of predominantly farming communities to the same marginal lands which had been under grazing or wild game for a long period. The farmers have transferred their technology which is in most cases deficient in any appropriate resource conservation measures as exemplified by the area under study. Kibwezi is a typical example of a semi arid area where the ecosystem is fragile and the potential limited unless exploitation is coupled with careful management and appropriate technological inputs for intensive utilisation by livestock or for crop growing without incurring land deterioration.

In the past the original inhabitants depended on subsistence strategies more than on commercial practices and land was plentiful. The increase in population, due partly to migration of people from high potential areas and partly to natural population increase, has led to overexploitation of available resources. The natural rangelands resilience in times of drought has declined due to overgrazing and excessive trampling leading to soil erosion, land degradation and desertification.

The immigrants transfer their cultivation practices to areas where resources do not allow such resource utilization techniques without effective soil and water conservation practices. Failure to use appropriate techniques leads to abandonment of land and an increase of the badly denuded areas which are slow to revegetate because of surface sealing properties of the soil.

It has been found (Hillel and Gardner, 1969) that infiltration of sealing soils is low and this can lead to high erosion rates due to high rates of runoff and the resultant power of runoff to detach and transport sediment. This implies that measures have to be sought to promote infiltration and reduce high runoff rates in such areas.

The present trends of soil and water conservation in Kenya tend to place more emphasis on physical measures rather than cultural ones. Physical measures despite their immediate effectiveness at the time of installation are potentially dangerous, for they concentrate surface water into channels which can cause serious damage if they fail and they need maintenance and repair at regular intervals. Furthermore, due to high capital involvement and low economic returns in grazing lands and abandoned cropland, most of the structural measures have met with very limited success e.g. terraces and cutoff drains in rangelands are not only uneconomical but may be hazardous to livestock.

Reduction of surface runoff by appropriate structures or by changes in land management will help reduce erosion. Similarly, reducing erosion will usually involve preventing splash erosion or formation of soil crust and careful maintenance of structures meant to reduce runoff. All this will increase infiltration rates and thus conserve soil and water and encourage revegetation of the overgrazed and highly eroded areas where drastic reduction of surface cover has occurred (plate 14).

Ground cover prevents soil sealing through raindrop interception and splash erosion. This in turn encourages infiltration and thus reduce high runoff rates. It breaks up the falling raindrops so that they reach the soil surface as small droplets and hence their impact is reduced.

The most urgent need for restoring productivity in our denuded sealing soils is an effective, low cost and reliable system or measure of soil and water conservation which will reduce soil erosion and soil sealing, and improve infiltration under the prevailing soils and climate.

The area selected for study, Kibwezi Division,is 220km south of Nairobi,along Nairobi-Mombasa highway. It lies between 37° 55' E to 38° 05' E and 2° 2' S to 2° 35' S and an altitude of 915 metres above sea level (figure 1). It is a semi-arid area with a characteristic sealing soils and commonly overgrazed bare lands with minimum soil conservation measures.

The study had three components. The first component was an investigation into runoff and infiltration.The second was a study of the undisturbed vegetation prior to settlement and the last was farm survey of land condition and management after settlement. These were carried out at different sites.

The experiment on runoff and infiltration was conducted between November 1988 and June 1989 and concerned with the problem of degradation and low cost ways of reversing it by encouraging infiltration. It was carried out in the University of Nairobi, Kibwezi Dryland Field Station. (figure 2), an area selected for its characteristic sealing soils. Plots were laid out within the field station enclosure to minimise disturbance from the neighbouring communities.

The two subsidiary investigations were carried out during the same period .One on the composition of natural vegetation on land that has not been subjected to clearing,cultivation or overgrazing was done within the Kibwezi Field Station. The other one involved a farm survey on the problem of land degradation on farmers land.It was carried out between Kibwezi and Kambu on the Nairobi- Mombasa highway from Kibwezi towards Mtito - Andei (figure 1)

The main concern of the experiment was with the problem of degradation and low cost ways of reversing it. The data collected will supplement the existing ones on how human settlement in a fragile ecosystem can cause its deterioration and the measures which may be instituted to reverse it. The specific objectives of the study were as follows:-

A. - To develop inexpensive methods applicable on denuded land to overcome the problem of soil sealing,increase infiltration rates and promote revegetation.

- To find out the infiltration capacity of sealing soils under different treatments.

B. - To compare areas which have become degraded with areas which have been undisturbed in order to find out:-

- What are the causes of degradation and to what extent it is as a result of cultivation, livestock grazing or tracking.
- what is the composition of natural vegetation on land that has not been disturbed by clearing, cultivation

or overgrazing.

- What measures have been instituted in grazing and cropland to conserve soil and water, and how widely have they been used and how effective are they.

It is hoped that if the investigations are found to be effective in promoting rainfall infiltration in sealing soils and thus revegetation of denuded lands , the measures could be disseminated to the farmers using agricultural front line staff in the areas where the problem of sealing soils prevail.The next section of the thesis details background information of the study area.

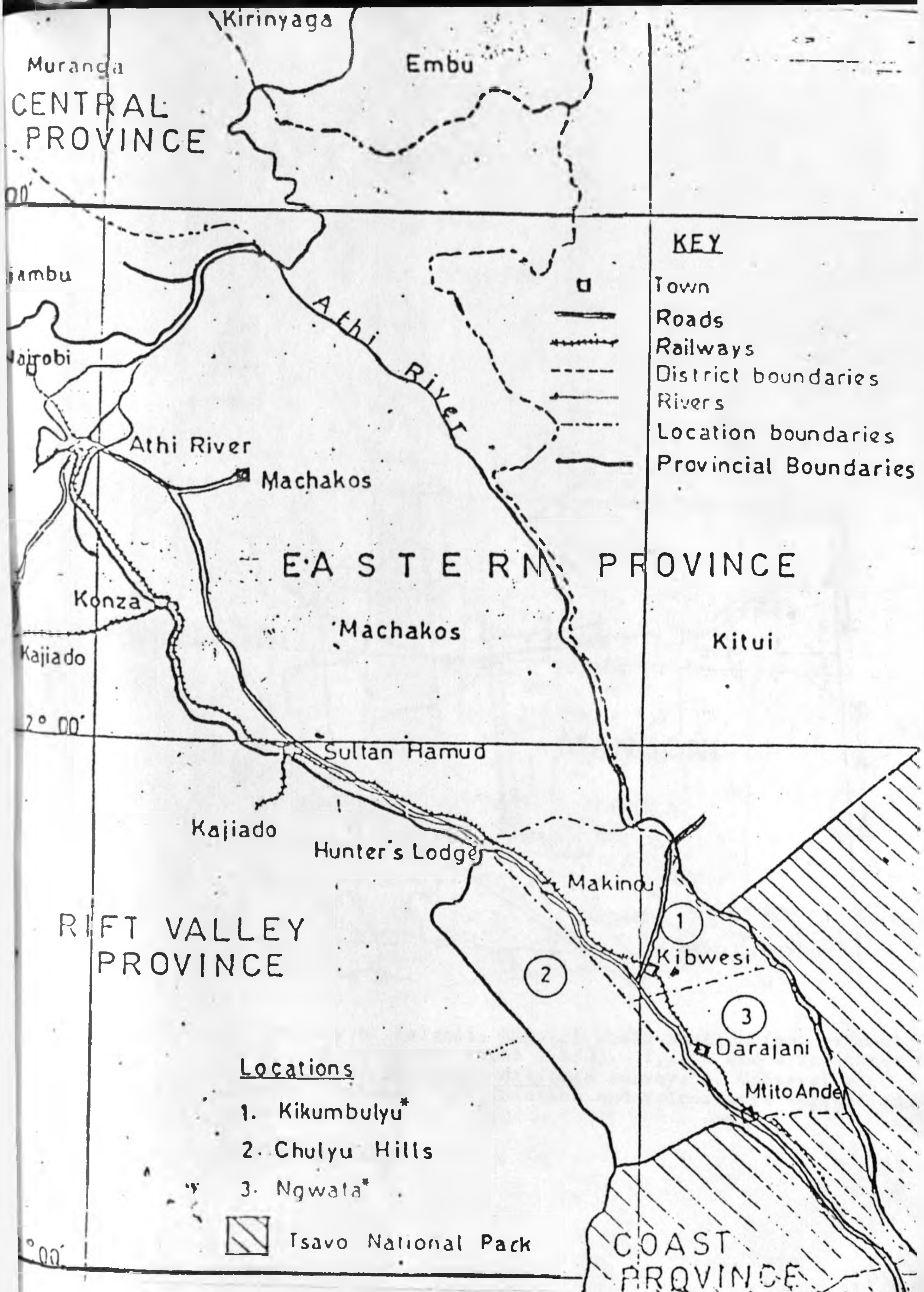

Figure 1: Location of Kibwezi Division (Locations*)

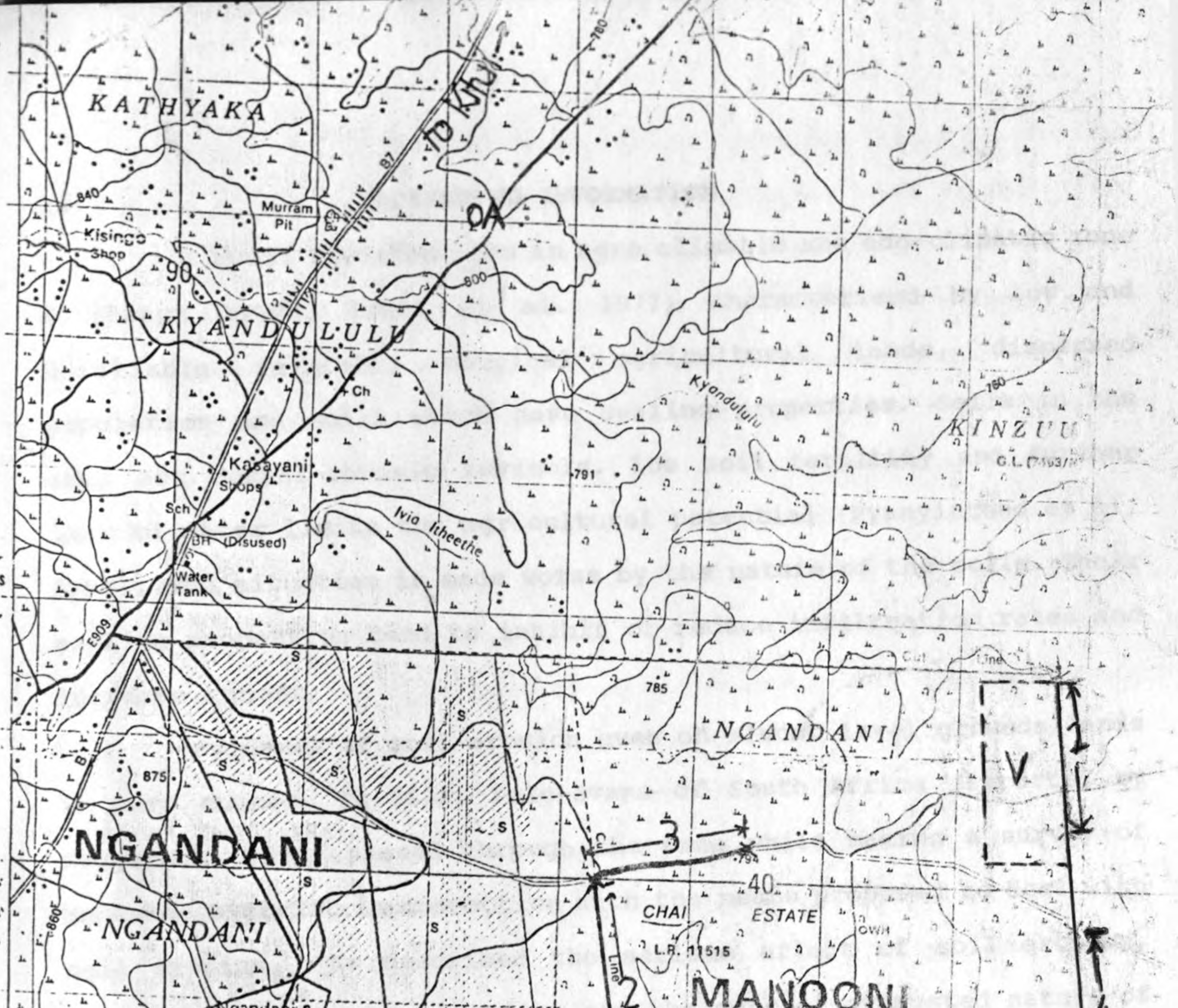

Figure 2. University of Nairobi, Kibwezi Field station (map extract from quarter degree sheet 175/3). 1,2, 3 and 4 indicates transects of Adansonia digitata survey; A, University of Nairobi, Kibwezi Field Station and V indicates vegetation survey area.

Scale: 1:50,000

2. BACKGROUND INFORMATION

Kibwezi Division lies in agro climatic and eco-climatic zone V (Braun 1977b, Pratt et al. 1977) characterised by low and unreliable rainfall, marginal agricultural lands, dispersed population and soils which have sealing properties. Soils in the area are Ferral-chromic Luvisols. Low soil fertility and further lack of water limits the agricultural potential (Nyanyintono et al, 1986). The situation is made worse by the nature of the soils. Their sealing properties tend to inhibit or reduce infiltration rates and increase runoff.

Evidence of soil erosion even on almost level grounds/lands is very common. In 1938, Pole-Evans of South Africa (reported by Saggerson, 1963) passed through the area while making a survey of Machakos District in connection with the means proposed to deal with soil erosion. He described the serious effect of soil erosion, destruction of land by termites and the general exhausted nature of the country (Machakos), which he considered due to misuse of land by the inhabitants. This was in the reference to Central Machakos but not, the Kibwezi area which was mainly unoccupied Crown Land. However, most of the accelerated erosion may be due to cultivation without any soil conservation measures to halt accelerated erosion.

Geological erosion subsequent to the mid-Tertiary period has been as a result of repeated rejuvenation with deep incision of the main river courses and the extension of their tributaries. Superficial deposits present, which include sandy soil and alluvium are products of denudation under semi-arid conditions (Saggerson, 1963).

Removal of cover by cultivation or grazing leads to surface sealing, reduced infiltration, increased runoff, soil erosion, and less favourable conditions for cover to re-establish. Continuous decline is liable if nothing is done to arrest the situation.

The surface sealing nature of the soils aggravate the problem of accelerated erosion. The seal is much less permeable than the underlying soil and rates of transmission of water can be as much as 200-2000 times less for sealed and in washed layers respectively than the soils below, (Mclntyre,1958a), though Tacket and Pearson (1965) noted much smaller differences. Hence infiltration of rainfall into the soil is restricted and this makes some areas bare/denuded.

Studies conducted show that there has been a steady migration of people from the densely populated parts of Machakos and other areas to the marginal lands of Kibwezi and Makindu (Mbithi and Barnes, 1975, Nyanyintono 1986). As a result the density of people in 1979 was 29 people per square kilometre which was still much lower than in the neighbouring medium potential areas such as Makueni which had a density of 49 persons per square kilometre. (Central Bureau of Statistics, 1981). The original inhabitants of the area were hunter-gatherers or squatters (Mbithi and Barnes, 1975) and depended very little on cultivated crops. The migrating population brought with them farming technology which involved tilling without soil and water conservation measures.

The quoted density of 29 people per km^2 is low but given the marginal nature of the area, and the low water infiltration rates of the soils due to its sealing properties, the area's population density needs to be lower than that.

FAO, (1982) recommends semi-arid areas to support 7 persons/km² at low input of technology and 21 persons/km² at intermediate technology and 98 persons/km² at high level technology which is not available in such areas. The potential population density of semi-arid areas is given as 21 persons/km² and this is when all measures are instituted to prevent the occurrence of natural catastrophes or setbacks towards utilization of available resources. The main problems in the area are lack of water, capital and labour to make land productive (Ferguson et al. 1985).

Problems due to poor land management i.e. cropping without conservation measures or rest periods or grazing without allowing time for grass to rest and recover are common. It has been shown (Grainger, 1986) that water table may start to fall, the unprotected soil may erode and the area becomes more bare and dusty. A situation which is characteristic of rangelands in general and the areas studied in particular.

2.1 **Climate**

Rainfall is bimodal with long rains from March to May and short rains from November or December to early January. Mean annual rainfall for the four nearest stations to the study area for a mean period of 46 years is 582 mm with highest rainfall of 1239 mm recorded at Makindu Meteorological Station in 1968 and lowest rainfall recorded at Kibwezi - Dwa Plantations of 0 mm (zero mm) in 1927 and 1928(table.2).

The average potential evaporation rate is given as 2094 mm per year (Braun 1977b). This figure assumes a continuous supply of water. Mean rainfall is 27% of potential evaporation.

Braun (1978) showed that there is a concentration of rainfall at the beginning of the long or short rains. 50% of the rainfall falls in the first 18 days and the stations may receive more than 40 mm rainfall during the first three (3) days of the initial (10) ten rainy days.

Rainfall intensities are usually high as portrayed by the following data from Makindu and Voi Meteorological stations in the same ecological zone.

Table 1. Rainfall intensity in mm/hr likely to be equalled or exceeded once every 2 years and every 50 years at Voi and Makindu Meteorological stations respectively.

	15 min	30 min	60 min	3 hrs	6 hrs	24 hrs
2yrs	84	62	42	20	11	3
50 yrs	120	102	82	28	-	-

The number of times per year that a rainfall intensity of 25 mm/hr is exceeded for a duration of 15, 30 and 60 minutes.

	15 min	30 min	60 min
Makindu	16	7	2

Source : Braun (1977b).

High intensity rainfall in this area causes erosion due to lack of cover to intercept raindrop impact at the onset of the rainy season.

There is a lot of variability in rainfall amounts such that there are times when there is as little as nil rainfall recorded and as high as 1295 mm of rainfall in a year. The following table 2, represents computed rainfall data per year from (4) four stations in the same ecological zone.

Table 2. Mean rainfall amounts for four stations

Station	Elevation	Mean Rainfall (mm)	Duration Years	Maximum (mm)	Minimum (mm)
Dwa Plant (Kibwezi)	915	615.2	61	1214.6 (1968)	0 1927&1928)
Makindu	1000	546.9	63	1239 (1968)	64.3 (1934)
Mtito Andei	915	659.4	30	1288 (1979)	296.5 (1983)
Kiboko R.Stn.	975	504.9	30	1028.7 (1979)	217.8 (1966)

Table 3. Rainfall reliability: Number of rainy days.

Station	Duration Years	Mean no. of Days	Max.no. of Days	Min. no. of Days
Kibwezi-Dwa Plantations	61	45	79 (1968)	0 (1927&1928)
Makindu	63	54	94 (1963/68)	14 (1926&1939)
Mtito Andei	30	48	74(1979)	26(1983)
Kiboko R.stn.	30	42	95(1973)	19(1973)

See appendix 1 on raw data. (Inclusive for Kibwezi Field Station).

Rainfall data from these areas, when analysed, suggests quite strongly that years of "good" and "poor" rainfall follow a grouped rather than a random pattern. This was also noticed by Pratt et al. (1977).

This suggests that the little available rainfall should be made use of efficiently. Measures to enhance rainfall infiltration into the sealing soils should be sought and put into practice.

2.2 Soils

Soils of Kibwezi are Ferral-Chromic Luvisols (Touber 1983). They are well drained, moderately deep, dark reddish brown soils with a well developed A horizons. A horizon have a characteristic dark-reddish brown sandy clay loam to sandy clay. B-horizon have a characteristic dark-reddish brown to dark red sandy clay loam to clay. The soils have sealing properties with sandy over wash (Touber 1983).

2.3. Vegetation

The distribution of the vegetation in the area is controlled by a number of complex interrelated factors, climate; geological formation, soil type and the presence or absence of groundwater. Man through cutting trees, clearing, burning and grazing is the most important factor which has modified the original vegetation. According to Pratt et al. (1977) and Touber (1983), its a typical semi-arid rangeland dominated by Commiphora, Acacia and allied genera, many of shrubby habit. Baobab trees (Adansonia digitata) are common. Perennial grasses such as Cenchrus ciliaris and Chloris roxburghiana can dominate but may succumb to continuous abuse over a long period.

2.4 History of Settlement and Population.

The following history of the area is derived from Mbithi and Barnes (1975).

Between 1925 and 1936, the colonial Government declared areas settled by the Kambas around and on the Ngulia Hills (present day areas of Ngulia Lodge in Tsavo National Park) and traditionally recognised as part of Kambaland, as Crown Land. Although most of the people migrated due to the demand by the government, some people remained especially in Chyulu Hills (see figure 1). In 1962/64 people began returning to the area and in 1964, the area between the railway line and tarmac road (see map of the area on page 6) between Kibwezi and Mtito Andei (study area) was declared and designated for settlement. No other section in Ngwata (Part of study area) has been formally settled although squatters have established their own administrative system for settling new comers. This unorganised settlement has led to present land deterioration prevalent in the area.

Soil conservation techniques and fertility build up practices are extremely deficient in the area the reports adds. The use of compost, farmyard manure, crop rotation or contour furrows is almost non-existent. Drought has commonly been reported in the area partly due to increased runoff arising from overgrazing and lack of vegetation cover and possibly due to reduced precipitation.

According to the Central Bureau of Statistics 1986, Kibwezi has an area of 3,400 km^2 and a human population of 98,980 (1979 census) and a density of 29 people per km^2. It was projected that the figure would have risen by 1985 to a population of 130,414 and density of 38 people per km^2.

Mbithi and Barnes, (1975) found out that it was difficult to prohibit settlement in the area and in the neighbouring Chyulu hills.

2.5 Geology

Most of the project area has been covered by geological surveys (Baker, 1954, and Saggerson, 1963). The rocks of the survey area can broadly be subdivided into basement system rocks, volcanics and superficial deposits. (Touber, 1983).

The precambrian basement system rocks are comprised almost entirely of gneisses, except for some small areas with crystalline limestone (Saggerson, 1963). The gneisses can be subdivided into gneisses that are poor in ferromagnesian minerals and gneisses rich in ferromagnesian minerals. The former are composed mainly of quartz-feldspar and granitoid gneisses which are chemically poor. The gneisses rich in ferromagnesian minerals include mainly biotite-hornblende, biotite and hornblende-garnet gneisses together with amphibolites (Touber, 1983). These chemically richer rocks occur extensively in the project area.

Later volcanic activity has significantly enriched large areas of basement system rocks with volcanic material. These enrichments coincided with major volcanic activities in Pleistocene and Recent times (Baker, 1954). It took place either directly, through deposition, or indirectly, through redeposition of volcanic materials.

Recent volcanic rocks are represented by the string of ash and cinder cones of the Chyulu Range and its surrounding lava flows, which consists of various olivine basalts, partly covered by ash deposits of varying texture and thickness. The finer textured ashes flowed many miles along stream courses (Saggerson 1963). Volcanic ash is evident up to today. Superficial deposits are present in the form of various lacustrine, colluvial, alluvial and aeolian deposits.

3. LITERATURE REVIEW

3.1 Problems of settlement in semi-arid areas.

Problems of settlement in Kibwezi and similar areas is documented in various reports and publications.

The history of settlement in Kibwezi area can be traced from the annual report of the Ministry of Agriculture (1965) which indicates that no organised settlement was arranged except a small area where surveying was done and people given 50 acres per family. Advice of the Department of Agriculture on the need for smaller acreage and crops adapted to the environment was not supported by the people, politicians or administrators. However, any units smaller than 50 acres could actually mean overuse of meagre resources leading to more severe land degradation which is currently evident in areas where farmers have settled on smaller units.

Total population (humans and livestock) growth rate appears to have surpassed the carrying capacity of the production systems. Sindiga (1986) argues that population pressure will destabilize the resource base as overgrazing and trampling lead to more intensified erosion during the rainy season. He did not specify what level of pressure or level of management will destabilize the resources.

Increased settlement of semi-arid lands is occurring in other countries besides Kenya. For example, in 1980, I.L.C.A. (reported by Berry, 1984) showed that the Republic of Mali witnessed an 80 percent increase in rainfed crop production between 1952-1975. Similarly significant increases were reported for Niger and other countries of the Sahel.

Berry (1984) showed that expansion of rainfed agriculture to marginal land results in a direct acceleration of soil erosion through removal of vegetative cover and physical disturbance. Additional degradation occurs as trees and shrubs are cut to satisfy the construction and fuel requirements of the cultivators.

Saouma, (1989) showed that central to Africa's problems are population growth and the expansion of agriculture as the continent strives to meet the immediate needs of its hungry and undernourished people. Open and closed forests are disappearing. For example, 4 million hectares of African forest are cleared every year as agriculture advances unregulated and too fast. Farmers' settlements on the fragile soils of arid and semi-arid regions further aggravates the problem. Larger areas of wooded land are degraded by a combination of bush clearing for fuelwood and cultivation, fires and overgrazing. Some fifty five (55) million Africans are acutely short of fuelwood. The result is increasing degradation of those very natural resources that must be protected and upgraded if desertification is to be averted. He adds that agricultural development must be based on the appropriate resource conservation.

Kibwezi Division is semi-arid when described in terms of climate and vegetation. The major climatic factor is rainfall. In the Sahel, the boundaries of the semi-arid and arid zones have been defined by 500 mm and 250 mm isohyets (Njoka, 1979). He argues that, rainfed agriculture may be attempted but is hazardous unless coupled with resource conservation measures.
However, some areas have been put under agriculture though under irrigation and also accompanied with soil and water conservation measures.

Dunne (1977) showed that rate of soil erosion on even gentle gradients in Kenya rangelands is extremely high. Over the last 10-

20 years, soil loss has been at the rates of 0.1-0.5 cm per year on Athi-Kapiti plain and 0.4 - 1.2 cm per year in Northern Kenya. These values are equivalent to 1000-1800t/km^2/year (10-180t/ha/year depending on the bulk density of the soil.

Another problem arising from settlement is the consequence of settlement of Somali communities along River Dawa and River Tana (Chambers, 1969). Natural riverine forests were cut and farming was being tried where chances of any successful harvest were minimal without any soil and water conservation measures. There was overgrazing around settlement areas as the people tried to meet their customary dietary needs of milk and meat, even after adopting resource exploitation patterns i.e. cultivation. Land was left bare and denuded.

3.2. **Soil Sealing and Infiltration**

In some instances, land degradation and high erosion rates could be due to poor rainfall acceptance by the soil. Water that would normally have infiltrated is available for runoff and transport of eroded material. This is due to some sealing properties of the soil.

Wischmeier et al. (1978) showed that the universal soil loss Equation (USLE) estimates soil loss on the basis of the average annual soil loss and the soil factor in the model is considered constant. However, if soil loss is to be calculated or predicted accurately on a storm to storm basis, the dynamic nature of the soil component must be taken into account.

Cultivation breaks the soil but rainfall leads to sealing and a high percentage of rainfall can be lost. For example, Thomas et al (1978) showed that this results in a high proportion of rain being lost as runoff to the tune of 69 to 90%, in grass covered and bare- ground respectively, of rain applied with a rainfall simulator. Overall mean runoff was recorded as 63 and 64 percent respectively. Studies conducted on sealing soils (Mclntyre, 1958 Edwards and Larson 1969, Hillel and Gardner, 1969, Hillel and Gardner, 1970, Gardner 1976, Lal, 1975, Thomas et al. 1978, Kladivko et al. 1986 and Bradford et. al. 1987) show that soil sealing influences the rates of infiltration, runoff and erosion in these soils. For instance Lal, (quoted by Marimi, 1977) reports runoff losses of 11.9 cm out of 29.5 cm of rainfall from unmulched maize on a 5% slope over a period of four months (Sept.-Dec.) with structurally weak soils at 11TA Ibadan, Nigeria. This represents 40% of the total rainfall and means that a good crop cannot be a achieved even though rainfall may be adequate.

Mclntyre (1958a) characterised crusts as having a thin surface "skin" and a lower "washed in" zone of low permeability. In his study, three distinct types of crusts were observed. The first type consists entirely of a dense seal of low permeability interpreted as due to compaction by raindrop. The same view has been expressed by other researchers (Hudson, 1981; Kladivko, 1986; Lal, 1976; Bradford et al. 1987).

The second was a composite crust that consisted of a thin layer of mineral grains of fine material overlying a compacted zone. This crust apparently had first been compacted and then undergone selective removal of fine material which was then carried off in runoff.

The third crust identified by Mclntyre was composed of thin laminae of primary mineral grains and aggregates. This crust had the lowest porosity and was depositional in origin.

Hillel (1969) attributed soil crust to be due either to raindrop impact on the soils, or as a result of the spontaneous slaking and breakdown of soil aggregates during wetting.

Bogdan and Pratt, (1967) attributed capping (sealing = capping = crust) to overgrazing and trampling by livestock and wild game while browsing the available vegetation. This theory may not hold because action of livestock on the soil surface can actually break the capping. He also proposed that capping could also be due to shifting cultivation by some farming communities who leave the ground bare. The bare ground is subject to capping but he does not indicate how it caps.

Muchena (1975) has attributed soil sealing, common in semi-arid areas, to weak surface structure mainly due to low organic matter (less than 1%) and high sand content which make the aggregates disintegrate under raindrop impact resulting to soil sealing leading to high runoff.

Greenland, (1975) and Kladivko et al (1986) showed that stability of aggregates of the surface soil is particularly important since it is the aggregates which are exposed to the direct impact of the raindrops.

If they break down into their constituent particles under impact, a surface seal can readily be formed, reducing infiltration and increasing runoff and leaving an exposed layer of small readily transported particles.

Thomas et al. (1978) associated soil sealing with shortlived growth of microflora during the rainy periods notably blue-green algae (probably Gleocapsa sp) which were identified from samples.

With such biological activity soil sealing could be very effective against infiltration on bare ground and to some extent in grass covered soils if the cover is poor.

Norton, Cogo and Moldenhauer (1985) and Nortan, Schroeder and Moldenhauer (1985), in their experiment on crusting and tillage methods, found out that dense surface seals form to different extent due to the type of tillage. The crusts considerably affect the amount of runoff, infiltration and soil loss from a given soil. Tillage systems which leaves some or all of the previous year's crop residue on the surface limit soil erosion by prevention of raindrop impact and/or by reducing runoff velocity or encourage invasion of other soil borne organisms which will assist in breaking the soil seal when formed.

Wilkinson and Aina (1976) in Nigeria showed that continuous farming of former forested land reduced infiltration capacity of the soils due to crust formation and they showed that it caused serious soil erosion. The soil body beneath the crust remained hydraulically stable for a longer period but it also began to deteriorate during the second cropping year probably due to its susceptibility to tillage compaction.

Bradford et al. (1987) showed that continual beating of the raindrops upon the soil surface contributes to the sealing of the surface. The net result is gradual increase in surface resistance to splash erosion and a decrease in the water infiltration through the surface layer.

The soil crust affects, on top of soil loss, the emergence of seedlings. Falayi and Lal, (1979) showed that time to maximum emergence was affected and related it to soil crust. They found this when analyzing time required for 50 per cent emergence of cowpeas in various aggregate size soils. This implies delayed revegetation of degraded lands and considering that the rainfall amount is not well distributed, then revegetation may not be accomplished within the time available during the short rainy seasons.

Soil borne organisms, for example termites, earth worms and others have been found to be of significance in enhancing infiltration of sealing soils. Wilkinson and Aina, (1976), while working at Ife in Nigeria, showed that compaction of the well structured topsoil causes infiltration capacity to fall by about half. When worms are present, the casts they create form a very coarsely aggregated structure, with many large channels between casts, the channels acts as conduits for infiltration of water.

Darlington (1982b) found out that the various network of underground passages and numerous food- storage structures which exist around a termite mound contribute to the high infiltration rate. However, she did not attribute this to the termite ability to break the soil seal.

Termite mound building and their foraging activities have been found to greatly influence the grass production in a semi-arid rangelands (Watson 1974, Arshad 1982). They attribute this to favourable termite effects on soil conditions. However, they did not comment on the ability of the termites in breaking the soil seal. Termites are known to compete with livestock for vegetation in our rangelands.

Lee and Wood (1971) have shown that termites attack brushwood and grasses when cut and left on the ground and in such areas termites are many and their destructive potential will be aggravated by overgrazing. This will be an added obstacle to the re-establishment of grass in sealing soils if grass will not be given enough rest period to establish.

Having cited literature on soil sealing processes, infiltration and the role of insect activity in infiltration, the following sub-section deals with literature on measures used to reclaim such areas.

3.3. **Reclamation of denuded land**

Measures to prevent soil erosion and thus encourage revegetation have to be designed in line with the changing nature of the soil component. Some of the soils common in semi-arid tropical areas are particularly vulnerable to changes (Hudson, FAO No.57. 1987), either because they have poor resistance to erosion (high erodibility) or because of their chemical and physical properties .

An example is the sealing properties of Luvisols and the resultant reduced infiltration rates of the soils. This leads to high runoff rates and soil loss. The implication is that grazing land is rendered bare and badly denuded and cropland, where such soils are common, calls for effective and cheap measures of encouraging infiltration rates of the soils to make maximum use of the little available rainfall.

Many measures have been tried in an attempt to rehabilitate degraded land in our grazing lands but not as widely as measures advanced in croplands. Many of the methods used have tended to place more emphasis on physical measures than on cultural ones.

Physical measures, despite their apparent effectiveness right from installation are potentially dangerous to our livestock under rangelands conditions. It has been shown (Mututho, 1986) that due to high capital involvement in structural measures and low economic returns in grazing lands (including abandoned croplands) most of them have met with very limited success.

Studies of rehabilitation of our degraded lands dates back to as early as 1919 when the District Commissioner, Machakos (quoted by Pereira and Beckley, 1952) wanted to revegetate degraded grazing land through closure of the land for a couple of years. The method did not achieve its objectives.

Other equally expensive measures have been tried in Machakos, Kitui, Baringo, Marsabit, and Turkana (Pereira and Beckley 1952; Jordan, 1957; Pereira, 1959. Pratt, 1964; Bogdan and Pratt 1967; Lusigi, 1981; Thomas et al. 1978; Smith et al. 1983; Muhia, 1986).

The measures used in those areas to restore productivity of degraded lands ranged from tillage practices using ox-plough or hand jembe, tractor drawn cultivators and then reseeding, rotational grazing within paddocks, cutoff drains to intercept runoff, mass revegetation of the area using locally adapted grasses, installation of terraces and runoff harvesting using structures which may be hazardous to the livestock, distribution of watering points to distribute grazing and thus give degraded areas time for natural revegetation.

Relatively cheap methods of rehabilitating denuded lands have been tried in Kitui (Mututho, 1986). Semi-circular pits were tried to intercept runoff and enhance revegetation. However, this will only succeed if grazing is deferred until grass is established though the method is expensive interms of labour to apply on a large scale.The following section outlines the materials and methods used to accomplish the objectives.

4. MATERIALS AND METHODS

A trial to find out what inexpensive methods could be used to overcome problem of soil sealing and promote infiltration rates and consequently revegetation was set up. The experiment was trying to investigate whether slashing bush and spreading it on the denuded ground would improve infiltration and if so, whether the effect would be due to interception of rainfall energy and reduced sealing, interception of runoff, insect activity by termites or other organisms living on the dead wood and breaking the seal in the process or due to a combination of one or more factors. Sawn timber has been used as cover due to the difficulty of finding uniform type of brushwood which can be used to give a selected percentage of cover. Details of the experiment are in section 4.1. A supplementary experiment was set up next to the plot experiments to asses the effect of insect activity in breaking the soil seal and thus increase infiltration rates of sealing soils, details are in section 4.2.

Data on the botanical composition of the area before the settlement was determined by sampling vegetation of undisturbed land. This involved recording the number of species in virgin land and investigating why some vegetation (Baobab) have been left by the farmers on cultivated land. The methodology is detailed in section 4.3. Section 4.4 describes the soil investigations.
Observation on changes in land use and what the farmer knows about the causes and processes of degradation and his attitudes towards alternative conservation measures was documented. This was done by designing a questionnaire (appendix 7)on state of landdeterioration and rehabilitation and current land use as detailed in section 4.5.

The investigations were conducted on an area where soils are most times bare and capped. Soil erosion is a common occurrence in the area though land is not steep. Most of the rainfall runs off the land causing a lot of soil loss where land is bare. Botanical composition was conducted on an area where land has not been subjected to cultivation within Kibwezi Dryland Field Station.

4.1 Plot experiment

4.1.1 Treatments

Land preparation before treatments involved conventional tillage with a hand hoe to break the soil sealing. Land was raked and depressions evened out (see plate 2). Twelve runoff plots were then arranged in a completely randomised block design. Four treatments were replicated three times in three blocks, F.G.H.. Treatments were randomly assigned to each plot within a block. The treatments were:

A - Interception of rainfall only

B - Interception of rainfall and runoff without insect activity

C - Interception of rainfall and runoff with insect activity

D - Control - no interception of rainfall or runoff (plate 4)

On treatments, A, B, and C, 20% cover of cyprus timber was used. The figure of 20% was selected because of previous work done. Dunne (1977) and Moore et al. (1979) found out that a critical value of 15-20% basal cover is important in reducing erosion. At values less than this, erosion is intense, whereas above 15-20% little further reduction in erosion occurs.

In "A", cover materials were suspended using a piece of string at about 7 cm from the ground to intercept raindrop impact. Hooked iron rods were pegged outside the plots at an interval of 0.5 m both sides of 4 m length of the plots (See plate 2).

Plate 1 Runoff plots treatment layout. Treatments have been randomised in blocks. The surface seal had first to be broken (photo taken in February 1989).

In "B", cover is as above but the material is placed on the ground. Cover material is treated with pentachlorophenol and chopped into small pieces and then randomly thrown in the plots. This is to simulate random distribution of deadwood in the field. Treated wood could not be acted upon by any termites. With small pieces of timber, total diversion of runoff to only one side of the plot could not occur but runoff was able to find its way to lower areas of the plot and thus to the conveyance system.

In "C" cover material is not treated. It was anticipated that the material would attract all sorts of insects especially termites and other soil borne organisms which will in turn break the soil seal.

In "D" Control, there was no interception of rainfall or runoff. Round- up was used to prevent and deter spread of weeds in the plot. This kept the plot bare to simulate the condition of denuded soils. The same was used to prevent spread of weeds in treatments A & B except in treatment "C" where weeds were removed by hand, as spraying of weed killers in the plot might kill or prevent insect activity and confuse the treatment effects.

All treatments were replicated three times and randomly assigned places on land of mean slope 0.1 percent. Layout was as shown in plate 1. Note "H" block up to where a man is standing.

F	G	H
B D A C	D A C B	D B C A

where, A, B, C and D are treatments as shown above but replicated three times in three blocks.

4.1.2 **Cover**

In the three treatments A,B,C. 20 percent cover was installed using sawn cypress timber measuring 50 mm x 25 mm cross-section. This is as a result of difficulties foreseen in estimating the area of cover from brushwood.

The reason as to why cyprus timber was chosen was that it is easily acted on by termites and its area can be easily calculated to arrive at 20 percent. Termites in this case, are presumed to make tunnels in the soil which could aid in acting as channels through which water could infiltrate. In the process of burrowing activity, they may also break the soil seal. The number of pieces per plot was calculated as follows:

Area of plot = 4mx2m = $8m^2$

20% of the plot = $\frac{8x20}{100}$

= $1.6m^2$

Area of timber = 0.053x2m

= $0.016m^2$

No. of timber (each piece of 2m x0.053m) = $\frac{1.6m^2}{0.106m^2}$

=15 pcs.

One piece of timber of 2mx0.053m was added to cater for areas where they crossed each other thereby reducing the cover. The material, as stated elsewhere was cut into small pieces of 15 cm long for treatment "B" and "C" otherwise it was suspended whole in "A". (See plate 2).


Plate 2. Suspended material to intercept rainfall only. Note the hooked iron pegs used to suspend the cover material (photo taken before the long rains 1989).

4.1.3 **Plots**

The study of ways to overcome problems of sealing, increase infiltration and revegetation on denuded land was carried out as follows:

Twelve Djorovic, (1977) type, simple runoff plots were installed on a natural slope of 0.1 percent. Each plot was two meters wide and four meters long. The plots were bordered by galvanised iron sheet metal 20cm. wide, of which 10cm. were driven into the ground. A 100 cm wide space was left between plots and blocks respectively. (see plate 1). The main components of each runoff plot are collecting trough,endplate, conveyance, storage tank and hooked iron rods.

4.1.4 **Collecting trough and end plate**

Runoff from a plot is collected in the trough and channelled to the collecting tank. The end plate provides a firm seal and smooth contact between collecting trough and ground surface. Figure 3 shows a schematic diagram representing the plot set up.

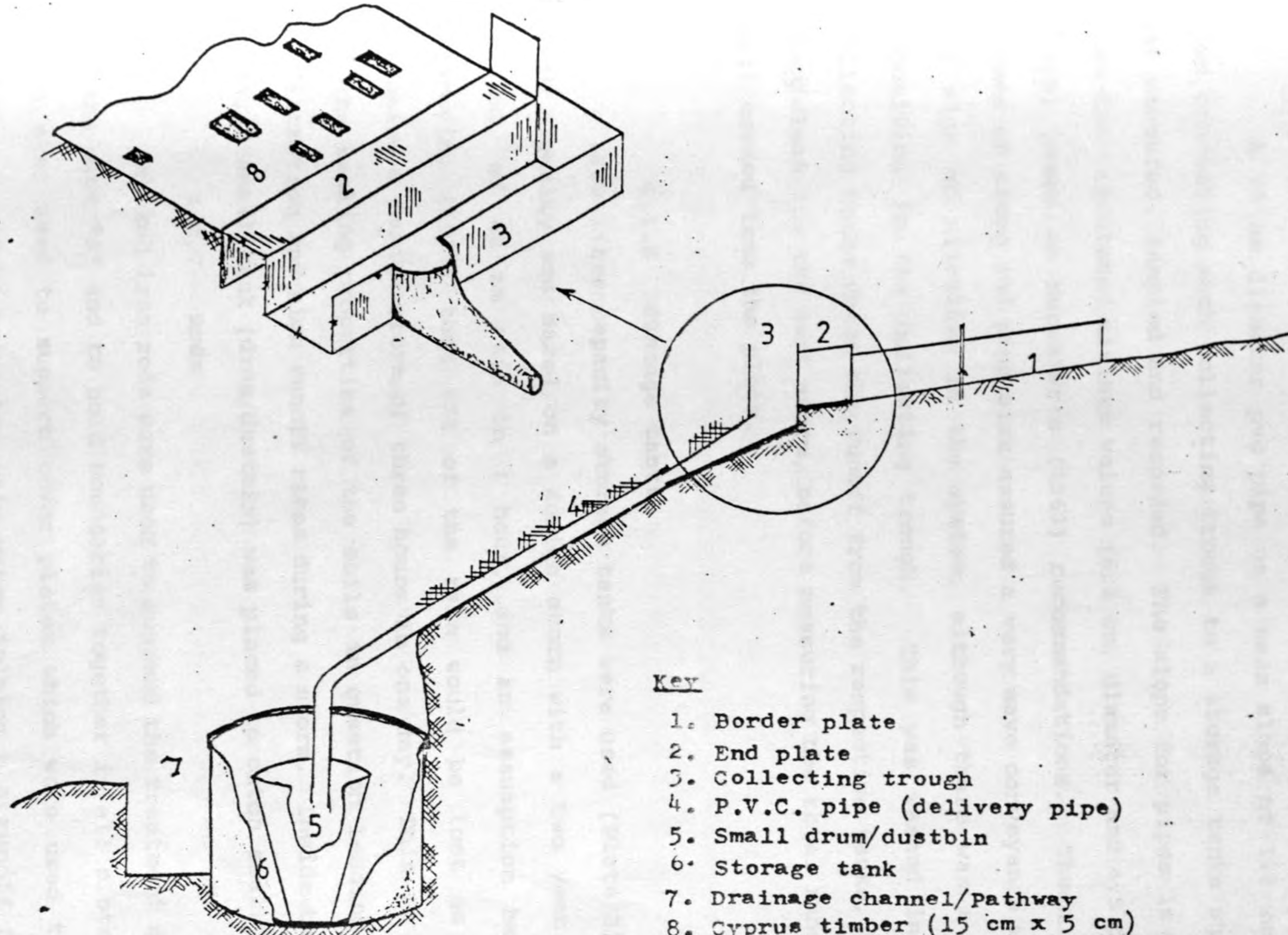

Figure 3: Isommetric View of the runoff-plot components.

4.1.5 Conveyance

A 75 mm diameter pvc pipe on a mean slope of 14% was laid down connecting each collecting trough to a storage tanks where it was measured, sampled and recorded. The slope for pipes is higher than the calculated minimum values (6.2 cm. diameter and 4.5 percent slope) based on Mutchler's (1963) recommendations. These higher values of slope and pipe size assured a very save conveyance without any sign of siltation in the system, although there was a slight deposition in the collecting trough. This was washed into the collecting tanks using the runoff from the respective tanks, to make them clean for the next storm, before measuring the total runoff and soil eroded from the plots.

4.1.6 Storage tanks

670 litre capacity storage tanks were used (Plate 3). The tank capacity was based on a design storm with a two year return period, of 42 mm rain in 1 hour, and an assumption based on Djorovic, (1977) that 67% of the rain would be lost as runoff assuming a design storm of three hours in one day. This is because of the sealing properties of the soils in question leading to low infiltration and high runoff rates during a storm. Inside the large tank, a small tank (drum/dustbin) was placed to catch small storms.

4.1.7 Rods

Hooked iron rods were used to suspend the treatment material in the plot "A" and to hold boundaries together in all plots. They were also used to support cover plates which were used to cover endplates. This prevented rain water joining the runoff from the plots.

4.1.8 **Rain gauges**

A standard 5" inch diameter manual rain gauge was used to record rainfall during the short rains on site. The same continued until April when a recording rain gauge was calibrated and installed on site. This meant that some rainfall intensity data was not collected and the nearest rainfall station is 20 kilometres and does not use a recording rain gauge. The University Field Station being a new one did not have a meteorological station which could be used.

4.1.9 **Determination of runoff and soil loss**

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

(a) After a small runoff event.

If the runoff in the small tank inside the large tank had not overflowed, it was mixed thoroughly and a bucket used to measure volume and a sample taken from each bucket. Total volume could be got by additions of the volume measured. If samples looked alike and had little sediment they were combined in one plastic container.

If samples did not look alike or had substantial amounts of sediment they were not mixed/combined afterwards. This procedure was followed when the bucket had a small amount of sediment. When there was lot of sediment its weight was measured and a sample taken. After sampling the tank was drained and washed for the next storm. Runoff measurement was carried out once a day.

(b) After a large runoff event

Depth of runoff collected in the bigger storage tank overflowing the smaller dustbin (drum) was measured using a steel tape (after the drum has been removed and runoff settles to a new level in the storage tank) to measure to the nearest millimetre at four points at the middle of every side and the average taken. Later, the depth was converted into volume using the dimensions of the storage tank. Runoff in the small drum, which had been removed when measuring volume in the storage tank was measured using 20 litre calibrated buckets and samples taken in open mouthed bottles of 1300 mls after it had been thoroughly mixed. In the large tank, the water was agitated to ensure complete mixing of all fine sediments and 1300 mls of sample was taken using open mouthed plastic bottles. Total volume of the runoff from each plot was obtained by adding the figures from the small tank and the calculated volume of runoff in the large storage tanks.

The evaporation method (Dendy et al, 1979) was followed to determine the water content and sediment concentration of samples. Samples of known volume were put into bowls of known weight and a drop of flocculating agent (Alum) was added so that the soil settles quickly and firmly at the bottom. Samples were left to settle overnight after the flocculant, Alum solution (Aluminium potassium sulphate, $Al\ K(SO_4)_2 . 12H_2O$) was used. The resultant clear supernatant water was poured off and the bowl containing the thick sludge of soil was put in the oven at 105°C for 24 hours. After cooling, the oven dried sample was weighed to determine weight of soil in the sample.

The volume of soil in the sample was determined by taking particle density of soil to be 2.65 grams per cubic centimetre. It is a generally accepted value and is sufficiently exact for the majority of mechanical analyses (Baver et al, 1972).

Volume of soil in the sample was necessary since measurements of runoff was in volumes. However, making this adjustment made only a minor difference to the volume of runoff and did not alter the overall picture presented.

Plate 3. Storage tank and the drum inside with small storm awaiting sampling (Photo taken on 8/4/89).

Plate 4. Control after the rains. Note the surface seal and activity of termites after the rains (Photo taken in April 1989).

4.2 Determination of infiltration rates

This is a supplementary experiment which was set up to supplement data on the effect of insect activity (mainly termites) in breaking the soil seal after a rainfall event and thus enhancing infiltration rates of the soil following the subsequent rainfall events. Land next to the runoff plots was subjected to the following treatments.

(a) - Conventional tillage using a hand hoe and removal of the uprooted weeds. Sealing was allowed to take place for a period of one month, See plate 5. This was followed by total covering of the area with cyprus timber and other weeds for 3 weeks (See plate 6). This encouraged termites and associated insects to invade the covered land.

Termites were expected to act on the dead material and in the process break the soil seal (see plate 7). Infiltration tests were carried out after removal of the cover and leaving the land bare for two weeks.

(b) - Conventional tillage and weeds removed as above. Soil seal was allowed to form for two months but no cover was applied - Infiltration tests were carried out with the surface seal unbroken.

(c) - Conventional tillage and weeds removed as above. Soil seal allowed to form on the soil surface for two months. This was later peeled off evenly with a pen knife before the infiltration test was carried out.

Two weeks before infiltration tests were done on treatment "a", cover material was removed to bring down the high soil moisture status created by the mulch material. Tunnels dug by the termites were left open once the material was removed.(see plate 6).

Moisture status in the soil was determined before infiltration tests were done by taking soil samples at depths 0-30 cm, 31-50cm, 50-80 cm and 80-110 cm and then getting mean soil moisture of the whole profile. Soil samples were taken to the laboratory, weighed before putting in the oven and after oven drying for 24 hours at 105°C. The percentage moisture was calculated and expressed as percentage of wet weight as follows;

i.e. Let Weight of wet sample be = x gms

Weight of oven dry sample = y gms

Weight of water lost = (x-y) gms

percent soil moisture $= \frac{(x-y) * 100}{x}$

$= z\%$

Double ring infiltration tests was done using constant head procedure(Michael et al.1972) with inner and outer rings of 30 and 60 cm respectively.

Ring infiltrometer tests were carried out in duplicates in the three treatments on the same plots. See plate 8 for the apparatus.The double ring infiltrometer method was chosen to avoid uncontrolled lateral movement of water from the rings. Earlier studies conducted using single rings gave data of high degree of variability (Michael et al. 1972).

In order to assess the effect of activity of termites on soil sealing, graphical presentation of infiltration versus elapsed time have been plotted in one graph to show the differences in treatments. (see fig. 6).

Plate 5. Land prepared for infiltration tests. Seal is broken and land levelled (Photo taken in April 1989).

Plate 6. After seal is formed, total cover of treatment material (timber and brushwood) is put to attract termites to break the surface seal (Photo taken in May 1989).

Plate 7. Tunnels created by termites after the cover material is removed (Photo taken in May 1989).

Plate 8. Experimental set-up for determining infiltration characteristics of sealed soils under different treatments (Photo taken in June 1989).

4.3 Vegetation survey

The survey/inventory was conducted within the University of Nairobi -Kibwezi field station, on an area which had not been subjected to formal clearing or cultivation. See fig. 2 (extract from a map quarter degree sheet 175/3, survey of Kenya (1974).

Transects are of considerable importance in the description of vegetative change along an environmental gradient, or in relation to some marked feature of topography (Kershaw, 1973). It is important and usually sufficient to record transects - after 2-3 years or even up to 10 years if there is no reason to suppose that no rapid change took place, (Pratt et al. 1977). Temporary transects were cleared for the inventory (see plate 9). Time was insufficient to conduct a comprehensive survey. Data was collected to document the perennial vegetation of undisturbed woodland for comparison with land which has been subjected to clearing or heavy grazing.

Efforts were made to document socio-economic reasons as to why some species of vegetation are preserved on the cropped lands. In this case, occurrence of Adansonia digitata (Baobab) was surveyed both on cultivated land and in the same wooded vegetation but using a different approach. Socio- economic reasons for retention of the tree were gathered from the inhabitants of the area (see plate 11 and 12).

The most characteristic features of vegetation, trees and shrubs were surveyed by quadrat method. Most plant characters chosen to assist in identification of specific trees and shrubs, were restricted to those which could readily be seen by eye or with al. (1961) Latin - Kikamba-translation of range plants was used to assist in identification. However, care was taken where one local name referred to a variety of species.

Adansonia digitata (Baobab) was sampled using a different approach. This was as a result of its infrequent occurrence both in cropland and land not subjected to cultivation (See Plate 11). The method of Strikler et al. (1963) for determining density of randomly distributed populations was followed; i.e. The closest individual method and the nearest neighbour method;

(a) Closest Individual Method. The sample is the distance between a sampling point (a point identified by the writer on the transect) and the nearest plant. Mean area per individual is obtained by squaring the doubled value of the mean distance i.e Mean area per plant = $(2d)^2$ where "d" is the mean distance.

(b) The Nearest Neighbour Method. The distance between an individual baobab and its nearest neighbour was taken as the sample. The observed distances are multiplied by a correction factor of 1.67 before squaring to obtain mean area per plant.

The correction factors; 1.67 and 2.0 when used to multiply mean distances have been found by Cottam et al. (quoted by Strikler and Stearns, 1963) to adjust mean distances to mean area per plant closer to actual counts on pure stands or mixed stands of randomly distributed species.

In both methods, transects were selected as the roads/cutline indicated on the attached fig. 2 (pp. 7) extracted from the quarter degree sheet 175/3, Survey of Kenya (1974).The method involved riding on a motor bike and stopping randomly to measure the distance between the writer and the closest Baobab and measure the distance between the writer and the closest Baobab and then simultaneously measuring the distance between the same Baobab tree and its neighbour.

This ensured collecting data for both methods at the same time. Four transects were selected and the data tested to determine whether the methods are significantly different in determining density of the Baobabs.

The first inventory was carried out to find botanical composition of the understorey in the woodland to be used later to supplement composition of the whole vegetation. A transect was set out in the area indicated on the topo-map (see fig. 2) using the cutline grid reference 968405 to 967416 in quarter degree sheet 175/3 of 1973 (see map extract 2, Survey of Kenya, 1974). This was taken as the base transect from which subtransects were set out at a right angle and at regular intervals of 100 meters. This was in an effort to remove bias in sampling. A line of 50 meters running across the zone to be sampled was set facing eastward using range rods and a compass to make sure that samples are taken at regular intervals. See plate 9.

Sampling sites of 2x2 meters quadrat were determined by assigning letters "A, "B", "C" and "D" to 20m, 30m,40m and 50m respectively and then picking two at random. "A" and "D" were picked and a 2mx2m quadrat was set out by pegging down the sampling area. Sampling was done by identifying each species in the quadrat and recording its frequency on a designed form. Other observations made were on the presence of termites (see plate 10), percent litter cover and bare ground in the undisturbed woodland and soil sealing.

Percent species cover was then computed from the total frequency of all species.

The first inventory of understorey vegetation was done in the middle of dry weather and the second of perennial trees and shrubs, just before the rains i.e. March and April respectively.

The second inventory was done using quadrat of 10mx10m. The quadrat were used in recording the occurrence of large perennial vegetation i.e. trees and shrubs, and common grasses. They were randomly distributed in an area of 8.5 hectares. Each quadrat was subdivided into a small area which could be sampled easily and accurately. Occurrence of each species was recorded in a designed form and the data was analyzed for frequency, percent cover of each species (cover of each species relative to the total frequency of all species combined) and botanical composition of the area. Data on grasses and sedges, and on trees and shrubs were separated out. A large quadrat was chosen in order to record large species of plants.

VEGETATION SURVEY FORM

(After Brown, 1954)

Line transect recording sheet

Sheet No_____

U.O.N. Kibwezi Field Station

Writer: Gachimbi, L.N.

Location: Katalamuni

Date: ________________

Slope ~ direction

Soil texture (x) ________

Quadrat Size

Species	Frequency	Total occurrence	Comments

Plate 9 Transect cut into the woodland (Photo taken in March 1989).

Plate 10. Presence of termite mound in the undisturbed Woodland. Note the tunnels in the mound (Photo taken in March 1989).

Plate 11. Baobab tree on cultivated land. Note good crop under the tree and the grassed fanya juu terrace (Photo taken in May 1989).

Plate 12. Baobab tree on land with no soil conservation measures (Photo taken in May 1989).

4.4 Soil Properties

4.4.1 Physical and Chemical Properties

To evaluate the influence of soil properties on surface sealing, infiltration and runoff, physical and chemical characteristics of soil samples were determined.

(a) Soil texture

Particle size was determined by the pipette method (Day,1965 as detailed by Hinga et al. (1980) in order to determine silt, sand and clay. Disturbed soil samples were collected at depths 0-5cm, 6-15cm, 15-30cm and at 31-55cm, using soil auger and taken to the laboratory for analysis. The samples were then analysed in duplicates so that an average of the two samples could be taken.

(b) Percent carbon

Organic carbon was determined by using Walkley - Black method as detailed by Hinga et al. (1980). Samples were collected in the field as for particle size analysis and analysis done in duplicates.

4.4.2 Change in soil resistance due to raindrop impact.

In order to assess the effect of the treatments on the soil sealing, soil resistance was determined before and after the main treatments as follows.

(a) Under the suspended material. This was directly under the timber to assess the implications of raindrop interception by the cover material.

(b) Exposed bare surface in control plots.

(c) Under the untreated timber subjected to termite activity where there were no tunnels made by termites.

(d) Under the timber in areas where termites had made some tunnels (in treatment "c" on the termite tunnels).

Measurements were taken using a pocket penetrometer which measures resistance of soil at the depth of 0.5 cm and measures resistance in Kg/cm^2. Measurements were taken when the crust was broken before the rains and after the rains when the soil seal was formed. Measures were taken to prevent external interference in the plots from compacting the soil. Results are presented in chapter 5.

4.5 Questionnaire on state of land deterioration, rehabilitation and current land use.

The main objective of the survey was to make observations on changes in land use and find out what the farmer knows about the causes and processes of degradation and his attitudes towards alternative conservation strategies. Plate 13 to 17 shows the current state of land degradation and the existing rehabilitation measures.

Road traverse method was used and farms were selected for survey at an interval of five hundred meters (500m) to eliminate bias. 35 farmers were interviewed along Mombasa-Nairobi road from Kibwezi to Kambu area (fig. 1, Kibwezi to Mtito- Andei) of Machakos District. The farmers selected relied on natural rainfall for their livelihood. The survey excluded farmers who rely wholly on irrigation. A questionnaire was designed by the writer for the type of information to be collected. A copy of the questionnaire has been included in appendix 7 and the answers obtained analysed under Results.

Plate 13. Exposed roots on farmers' land as an evidence of erosion process in action (Photo taken in May 1989).

Plate 14. An erosion mound protected by vegetation while the surrounding grazing land surface is reduced by erosion.(photo taken in October 1988).

Plate 15. Land dissected by erosion , no measures to control erosion or prevent surface sealing (Photo taken in March 1989).

Plate 16. Soil conservation measures on grazing land: At the foreground marked B. overgrazed land, no soil conservation measures used except rest period to allow cover to establish in A , "C" Bench terracing on grazing land. Note also the sisal planted to prevent further gully development (Photo taken in September 1988).

Plate 17. Comparison of land under conservation measures "A" and with no conservation measures "B". Note the presence of <u>Adansonia digitata</u> in the background which has been preserved (Photo taken in September 1988).

5. RESULTS

5.1 Results of runoff plot studies

Total rainfall for the long rains, 1989, was 386mm. A small percentage of the total rains 29% (113mm), fell in January/February. The rest 71% (273mm) fell from March to May. During the season only 10 days (table 4) produced substantial runoff and the analysis and therefore results are presented on the seasonal totals.

5.1.1 Soil loss

Table 5, shows the total soil loss (t/ha) and annual runoff (thousand M^3 / ha.) for the rainy periods of the year. Analysis of variance (Appendix 2a) of the total mean soil loss data show that treatment effects were significant. Mean separation using least significant difference showed that there was no significant difference between them in reducing soil loss. Seasonal soil loss was 65.7t/ha. for control plots, 19t/ha. for rainfall and runoff interception with insect activity, 25.7t/ha. for rainfall and runoff interception without insect activity and 32t/ha. for rainfall interception only. The treatments were on land of mean slope of 0.1%.

The efficiency of treatments in reducing soil loss relative to the control plot was calculated as follows:

$$\text{Efficiency} = \frac{Pc - Pt}{Pc} \times 100$$

where

Pc = Soil loss from control plot and

Pt = Soil loss from treatment plot.

Efficiency values are generally high for all the treatments. Computed values show 51% for rainfall interception only, 61% for

Table 4. Soil loss (t/ha.), runoff (m^3/ha.) and percent runoff from the twelve (12) runoff plots. The letters i.e A(11) are the identification numbers of the treatment (A,BC,D) replicated three times A(11), A(12) & A(13) in three blocks (F, G and H)

(a) Soil loss t/ha from the twelve runoff plots.

		F				G				H			
Date	Rain (mm)	B(20)	D(01)	A(11)	C(30)	D(02)	A(12)	C(31)	B(21)	C(32)	B(22)	D(03)	A(13)
2/4/1989	61.2	1.6	5.8	1.5	1.1	9.9	1.7	0.7	1.6	1.1	1.1	9.3	1.2
6/4/1989	7.1	0.4	0.4	0.2	0.2	0.3	1.0	0.8	0.9	0.2	0.2	1.7	0.7
7/4/1989	82.3	4.0	5.6	5.2	2.7	2.6	8.0	2.1	5.6	2.5	1.5	10.1	2.3
8/4/1989	15.0	0.7	0.8	0.6	0.5	1.1	0.7	0.5	1.2	1.4	0.1	2.3	0.9
12/4/1989	5.8	0.2	0.5	1.1	0.1	0.4	0	0.2	0.3	0.1	0	0.6	0.1
20/4/1989	7.5	1.6	0.8	0.2	0.3	0.7	0.3	0.2	0.3	0.1	0.1	1.3	0.4
29/4/1989	25.0	1.1	0.1	0.2	0.3	0.8	0.5	0.1	0.1	0.5	0.8	0.8	0.2
30/4/1989	3.9	0	1.3	0	0.2	0.2	0.1	0	0	0	0	0.5	0.1
10/5/1989	29.2	0.6	1.5	0.4	0.4	1.5	0.1	0.7	1.0	0.7	0.2	1.0	1.7
18/5/1989	8.4	0.2	0.9	0.1	0.2	1.3	0.2	0.4	0.2	0.7	0.1	1.4	2.3
total		10.4	17.7	9.5	6.0	18.8	12.6	5.7	11.2	7.3	4.1	29.0	9.9

(b) Runoff (m3/ha.) from the twelve runoff plots.

		F				G				H			
Date	Rain (mm)	B(20)	D(01)	A(10)	C(30)	D(02)	A(12)	C(31)	B(21)	D(03)	B(22)	C(32)	A(12)
2/4/1989	61.2	251.4	347.5	316.3	251.0	362.5	314.5	237.4	252.0	264.1	254.1	211.8	349.6
6/4/1989	7.1	40.0	47.5	37.5	39.3	48.8	43.6	42.5	40.3	40.0	35.0	31.3	37.6
7/4/1989	82.3	479.0	596.0	508.0	517.5	614.8	552.9	467.1	497.1	582.4	527.3	354.8	592.4
8/4/1989	15.0	72.5	95.8	50.0	84.1	103.8	83.0	76.3	84.8	100.0	85.0	78.9	83.1
12/4/1989	5.8	18.1	21.3	12.6	21.3	21.5	23.8	22.3	16.3	17.5	17.5	21.6	25.0
20/4/1989	7.5	35.0	41.3	21.3	27.5	34.8	22.8	21.3	31.3	40.6	30.5	21.6	21.6
29/4/1989	25.0	100.0	135.0	100.0	83.8	125.0	125.0	125.0	100.0	111.3	109.4	75.0	100.0
30/4/1989	3.9	3.1	9.5	3.4	2.9	9.5	2.8	3.0	3.3	9.3	3.1	2.9	2.6
10/5/1989	29.2	145.0	172.5	125.0	112.5	168.8	143.0	95.0	140.0	162.5	145.0	91.3	144.8
18/5/1989	8.4	32.6	42.8	25.0	25.6	35.3	25.3	23.1	27.5	40.4	28.8	24.8	40.0
total		1176.7	1508.2	1199.1	1165.5	1524.8	1336.7	1113.0	1192.6	1368.1	1225.7	914.0	1396.7

(c) Percent runoff from the twelve runoff plots.

		F				G				H			
Date	Rain (mm)	B(20)	D(01)	A(11)	C(30)	D(02)	A(12)	C(31)	B(21)	C(32)	B(22)	D(03)	A(13)
2/4/1989	61.2	41.0	48.9	51.6	40.9	59.2	51.4	38.8	41.2	34.6	41.5	59.5	60.8
6/4/1989	7.1	56.3	66.9	52.8	55.3	68.7	61.4	59.8	56.7	44.0	49.3	56.3	53.0
7/4/1989	82.3	58.2	72.5	61.7	62.8	74.7	67.2	56.7	60.4	55.2	64.0	70.7	72.0
8/4/1989	15.0	48.3	63.3	33.3	56.1	69.2	55.3	50.8	66.5	52.5	56.6	66.7	55.4
12/4/1989	5.8	31.2	36.6	21.7	36.6	37.1	40.9	38.3	28.0	37.3	30.1	30.0	43.1
20/4/1989	7.5	46.6	55.0	28.3	36.5	46.3	30.5	28.3	41.7	28.3	40.6	54.1	28.3
29/4/1989	25.0	40.0	54.0	40.0	33.5	50.0	50.0	50.0	40.0	30.0	43.8	44.5	40.0
30/4/1989	3.9	8.0	24.4	8.6	7.3	24.4	7.1	7.6	8.3	7.3	8.0	23.7	6.7
10/5/1989	29.2	49.7	59.0	42.8	38.5	57.7	48.9	32.5	47.9	31.2	49.6	55.6	49.6
18/5/1989	8.4	38.8	50.9	29.7	30.5	42.0	30.0	27.5	32.7	29.5	34.2	48.0	47.6
% mean runoff		41.8	53.2	37.1	39.8	52.9	44.3	39.0	42.3	35.0	41.8	50.9	45.7

rainfall, runoff interception without insect activity and 71% for rainfall, runoff interception with insect activity.

Table 5 : Total soil loss (t/ha.)and runoff (thousand m^3 / ha.)from the four treatments and three blocks (F, G and H) during the long rains (March to May) 1989

(a) Total soil loss (t/ha.) during the long rains (March to May) 1989

		Treatments			
		A	B	C	D
Blocks	F	9.5	10.4	6.0	17.7
	G	12.6	11.2	5.7	18.8
	H	9.9	4.1	7.3	29.0
total		32.0	25.7	19.0	65.5

(b) Total runoff (thousand m^3/ha)during the long rains (March to May) 1989.

		Treatments			
		A	B	C	D
Blocks	F	1.20	1.18	1.17	1.51
	G	1.34	1.19	1.11	1.51
	H	1.40	1.23	0.91	1.37
total		3.94	3.60	3.19	4.4

NB: in all cases in the text A, B, C and D represents:

A, Interception of rainfall only

B, Interception of rainfall and runoff without insect activity

C, Interception of rainfall and runoff with insect activity

D, Control - no interception of rainfall and runoff.

5.1.2 **Runoff**

Total runoff (m^3 /ha.) data (table 4 and 5) shows that the treatment effects were significant (appendix 2b) in promoting rain water infiltration into sealed soils. Mean separation using least significant difference showed that there was no significant difference between the three treatment effects i.e.rainfall interception only ; rainfall / runoff with insect activity and rainfall, runoff interception without insect activity in reducing runoff. Seasonal runoff was 4,400m^3 /ha for control plots , 3,940m^3/ha from rainfall interception only , 3,600m^3 /ha. from runoff and rainfall interception without insect activity and 3,190m^3 /ha from runoff,rainfall interception together with insect activity.

The highest mean percentage runoff recorded was 72.7% (table 6) from the control plots from a storm of 82.3mm of rainfall. The lowest runoff was 7.5% from rainfall and runoff interception with insect activity from a storm of 3.9mm. Overall means show that control plots lost 53% of the total rainfall, rainfall interception only lost 43%, rainfall and runoff interception with no insect activity 42% while rainfall and runoff interception with insect activity lost 38%.

Efficiency of the treatments in reducing runoff in plots of mean slope 0.1% are 10.5% for rainfall interception only, 18.2% for rainfall, runoff interception without insect activity and 27.5% for rainfall, runoff interception with insect activity.

Table 6 : Mean percentage runoff from the four treatments for the specified storms and their intensities.

Date	Rain. (mm)	intensity (mm/hr)	A (%)	B (%)	C (%)	D (%)
2/4/89	61.2		53.4	41.4	38.1	57.4
6/4/89	7.1		55.7	54.0	42.9	63.9
7/4/89	82.3		66.9	61.0	58.3	72.7
8/4/89	15.0		53.0	53.6	53.2	66.3
12/4/89	5.8		35.0	29.8	37.4	36.8
20/4/89	7.5		29.1	43.0	31.1	51.8
29/4/89	25.0	5.4	43.3	41.3	37.8	49.5
30/4/89	3.9	3.9	7.5	8.1	7.5	24.1
10/5/89	29.2	5.3	47.0	49.1	34.0	58.0
18/5/89	8.4	5.6	36.0	36.0	29.2	47.0
total	245.5		426.9	417.3	379.5	527.5
mean			42.7	41.8	38.0	52.8
Std deviation			15.8	14.3	13.9	13.7

5.1.3 **Water loss:**

If the values for runoff are adjusted to take account of the volume occupied by sediment, the figures for runoff lost are reduced by about 1% but the overall results remain the same.

5.2 **Results of infiltration tests**

As already mentioned in the methodology, the tests were carried out on soil with seal intact, soil with seal removed and on a sealed soil after insect activity. Each test was done in two replicates per treatment.

Infiltration tests were limited to a maximum of three hours, the reason being that maximum rainfall duration is about two hours.

Raindrop impact on the soil surface to cause sealing will cease to be effective after a lot of runoff is generated. Data obtained is as shown in appendix 3a to 3f. The effects of insect activities, removing soil sealing and the combined effect of both treatments on infiltration rates of sealing soils has been plotted together with rates when the soil seal is not removed (figures 4, 5 and 6).

The mean soil moisture content by weight before the treatment were applied was 8.73%. Only one representative pit was dug to determine moisture content in the treatment plots. Treatment plots were then covered with a polythene bag to prevent further evaporation from the soil surface. Soil moisture content by weight according to depth is shown in table 7.

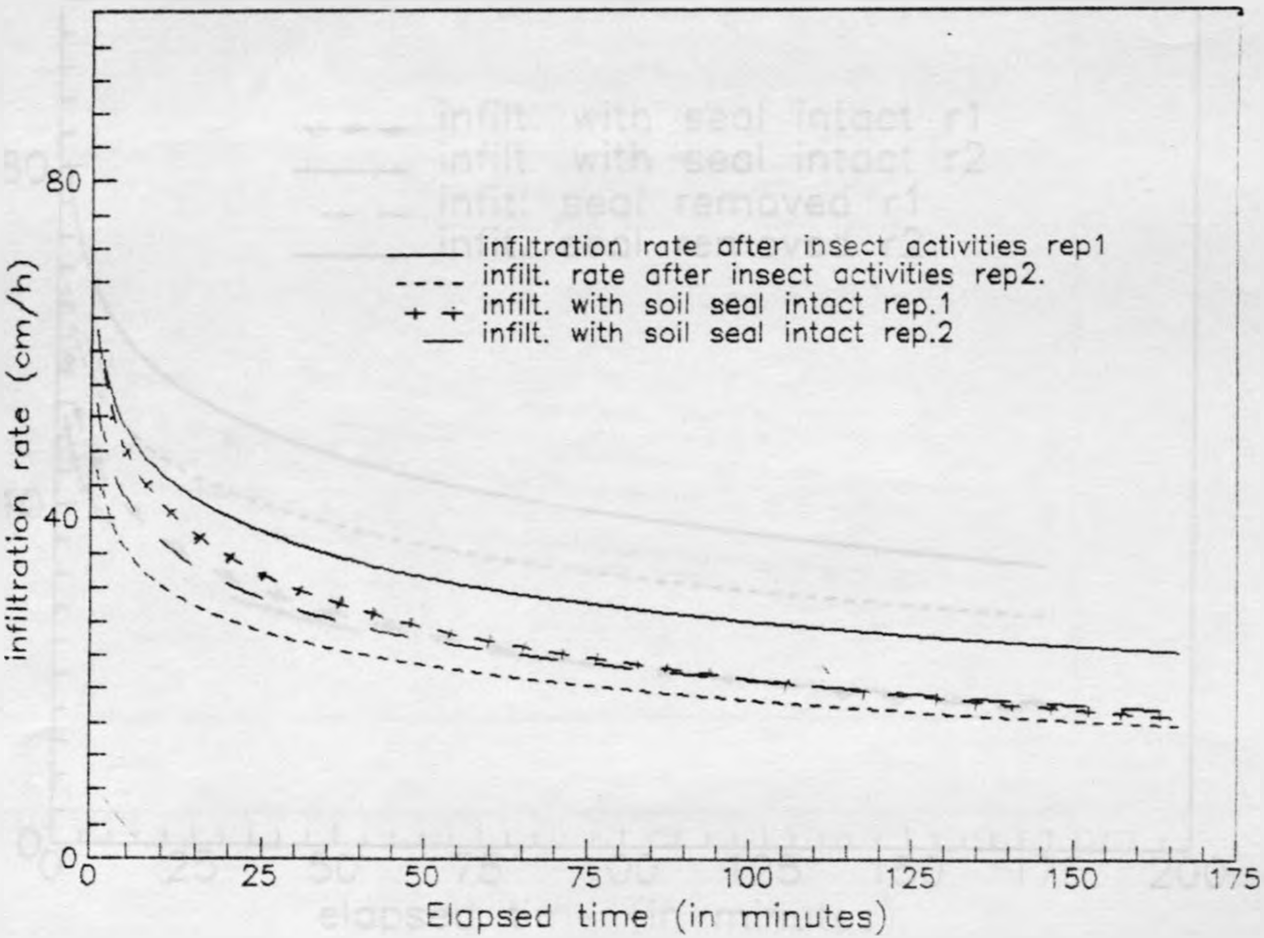

Fig. 4 . Effect of insect activities on infiltration rates of sealing soils.

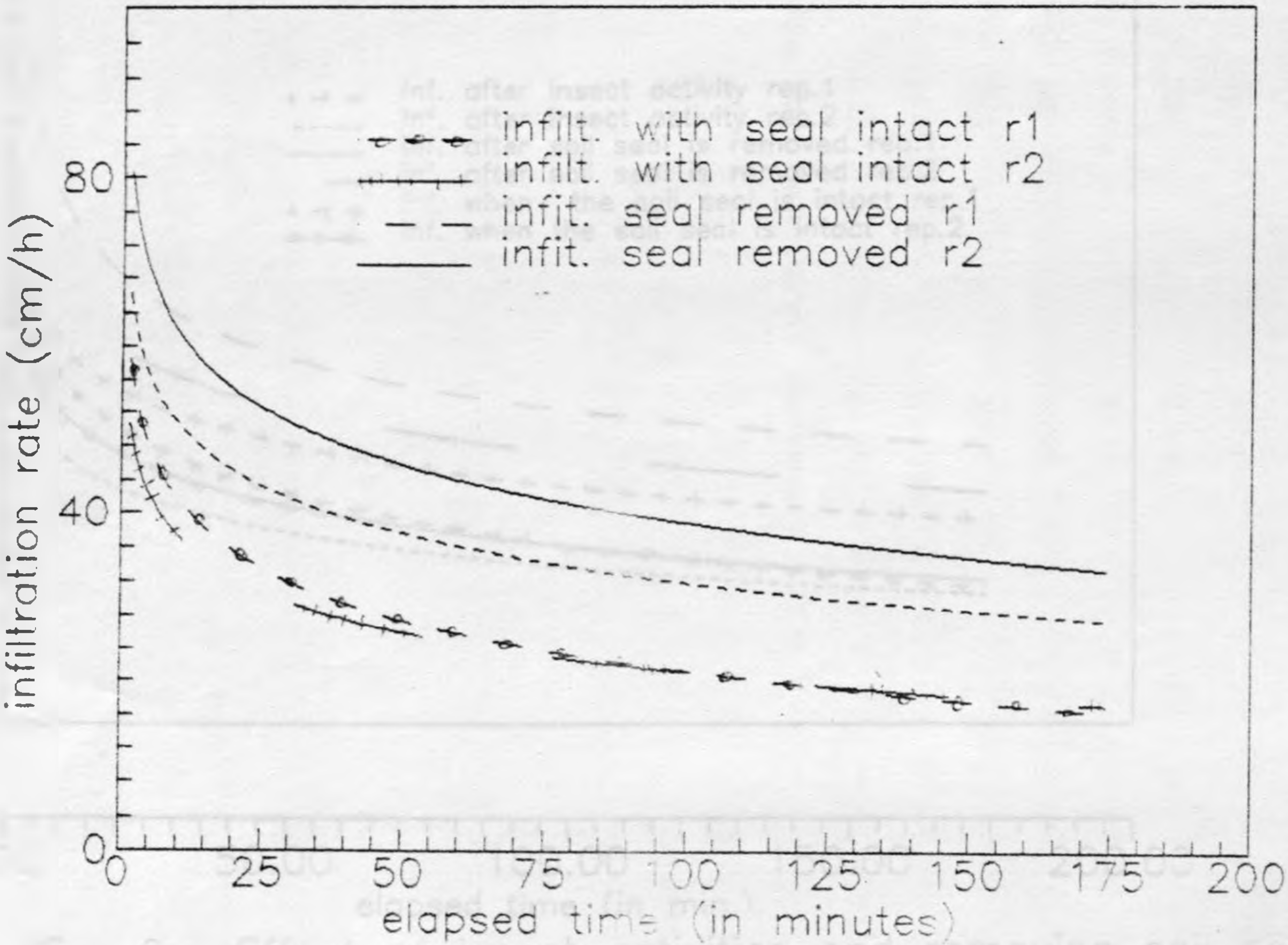

Fig. 5 . Effect of removing soil seal on infiltration rates of sealing soils.

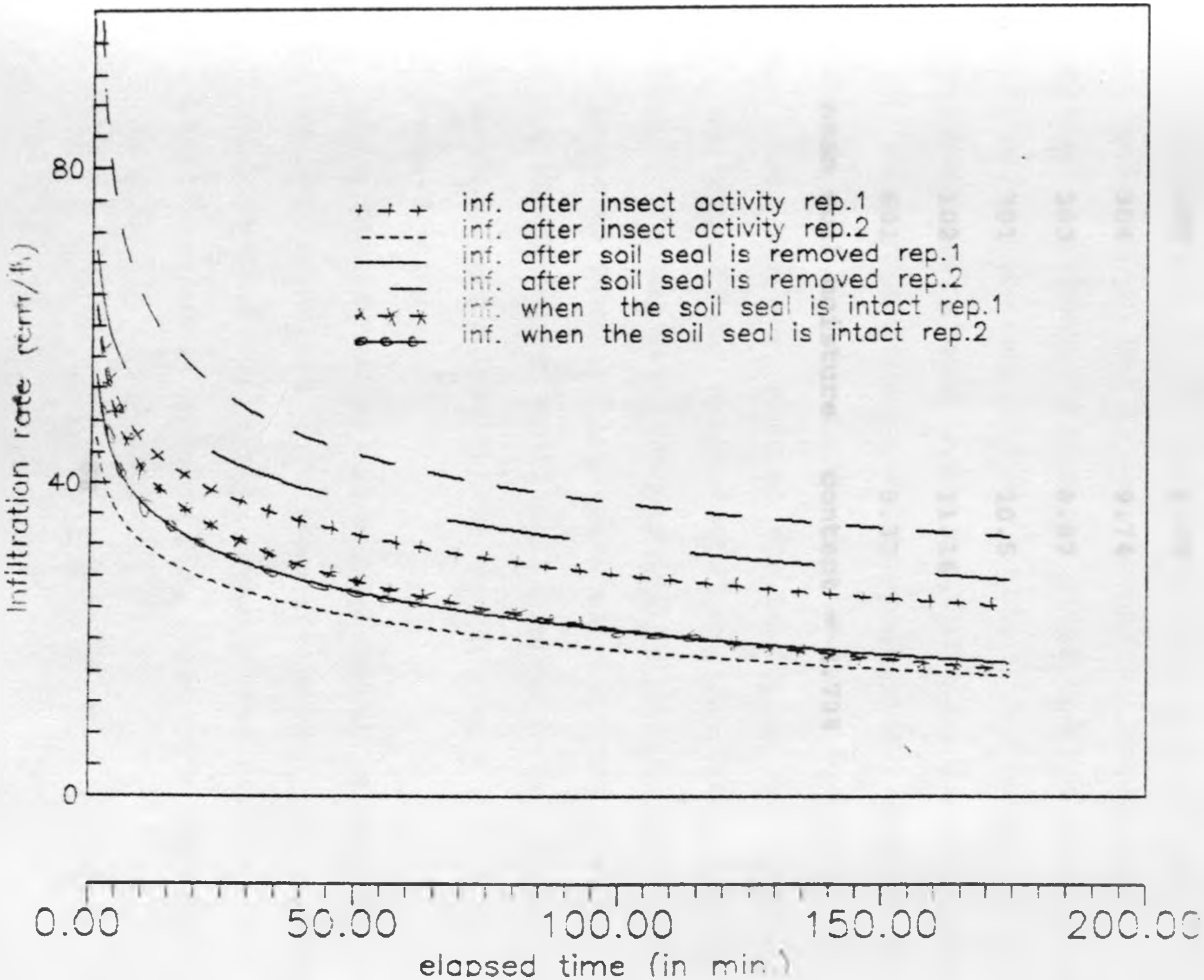

Fig. 6 . Effect of insect activities and removing soil seal on inf. rates of sealing soils.

Table 7 : Soil moisture as on 8/6/89

Depth (cm)	Sample No.	% Soil moisture content by weight
0-30	01	5.98
	02	6.23
	03	6.80
31-50	04	8.52
	104	9.09
	603	9.70
50-80	103	8.85
	304	9.74
	303	8.87
80-110	301	10.5
	102	11.16
	601	9.37

mean soil moisture content = 8.73%

5.3 Vegetation survey

5.3.1 Botanical composition of the vegetation in study area

The number of trees and shrub species found in the study area is as tabulated in table 8, 9 and 10. The total is the result of 16 quadrat of 10m by 10m randomly placed. The species are arranged in order of relative abundance and percent cover. Frequency of each species and its family is also indicated in the same tables.

Efforts were made to document the composition of the understorey vegetation in the same area using smaller quadrats of 2m by 2m. Table 11, 12 and 13 show botanical composition of the tree seedlings and shrubs, forbs and grass species found in the understorey vegetation respectively. This is the result of twenty four quadrats randomly placed in the area. The species are arranged in order of relative abundance, and percent cover. The family of each species is also indicated. The most abundant species is at the top of the table and the least at the bottom of the table.

One hundred (100) species have been identified in the study area (appendix 6). This excludes <u>Adansonia</u> <u>digitata</u> sampled using different methods. Since a large part of the study area was not examined, one should expect additional species to be listed if the inventory is done over a larger area over a longer period of time and in different seasons.

The number of species encountered include, eighty four (84) dicotyledons and seventeen (17) monocotyledons. The dominant species distributed as follows:- Leguminoceae, sixteen (16) (9 species in Papilionaceae); Acanthaceae, eight (8); Labiatae, six

(6); Capparidaceae, five (5); Tiliaceae, five (5); Malvaceae, four (4); Verbenaceae, four (4); Euphorbiaceae, four (4); Amaranthaceae, three (3); Anacardiaceae, three (3); Convolvulaceae, three (3), Combretaceae, three (3); Solanaceae, three (3); Vitaceae, three (3); Burseraceae, two (2); Sterculiaceae, two (2). The rest had only one species i.e. Boraginaceae, Celastraceae, Compositeae, Rubiaceae, Liliaceae, Rhamnaceae, Polygonaceae and Ochnaceae. The dominant family in Monocotyledons is Gramineae with fifteen species (15). The other monocotyledons are Commelinaceae and Agavaceae with one (1) and two (2) species respectively.

During the course of the vegetation survey, observation was made on the presence of termite, percent litter cover, percent bareground, percent cover, and evidence of soil sealing by trying to peel off the soil seal if any from exposed grounds. Table 14 shows distribution of these aspects in the sixteen (16) quadrat of 10m by 10m. Percent cover in all cases refer to cover of each species relative to the total frequency of all species combined. Vegetation has been separated so that dominant trees and shrubs, forbs and grasses can be identified inorder to fully describe vegetation condition of land before human encroachment.

Unlike the other vegetation cover, distribution of Baobab trees (Adansonia digitata) was determined using both the nearest neighbour method and the closest individual method as detailed by Strickler et al. (1963). The results are as in table 15 and 16. Table 15 shows the result of the two methods used while table 16 shows mean plants per hectare of Baobab trees from the two methods used.

Table 8. Botanical composition of vegetation, trees and shrubs.

Trees and shrubs	Family	Total	% Species cover
1. Ochna insculpta	Ochnaceae	216	19.0
2. Acacia brevispica	Leguminoceae	154	13.6
3. Tephrosia villosa	Leguminoceae	83	7.4
4. Grewia similis	Tiliaceae	69	6.0
5. Premna holstii	Verbenaceae	58	5.0
6. Ocimum basillicum	Labiatae	41	3.6
7. Combretum exalatum	Combretaceae	32	2.8
8. Entada abyssinica	Leguminoceae	31	2.7
9. Albizia antihelmintica	Leguminoceae	29	2.7
10. Boscia coriaceae	Capparaceae	25	2.4
11. Croton dichogamus	Euphorbiaceae	25	2.4
12. Acalypha fruticosa	Euphorbiaceae	24	2.1
13. Ruttya fruticosa	Acanthaceae	20	1.8
14. Rhyncosia minima	Leguminoceae	20	1.8
15. Combretum molle	Combretaceae	19	1.7
16. Duosperma kilimandscharicum	Acanthaceae	19	1.7
17. Grewia bicolor	Tiliaceae	17	1.5
18. Hermannia alhensis	Sterculiaceae	17	1.5
19. Lippia javanica	Verbenaceae	15	1.3
20. Erythrococca bonghensis	Euphorbiaceae	14	1.2

21. Hibiscus aponeurus	Malvaceae	14	1.2
22. Ipomea kituensis	Convolvulaceae	14	1.2
23. Satureia biflora	Labiatae	14	1.2
24. Commiphora riperia	Buseraceae	13	1.1
25. Hoslundia opposita	Labiatae	13	1.1
26. Lannea schimperi	Anacardiaceae	13	1.1
27. Boscia angustifolia	Capparidaceae	12	1.0
28. Cissus rotundifolia	Vitaceae	9	0.8
29. Lantana trifolia	Verbanaceae	9	0.8
30. Ocimum kilimandscharicum	Labiatae	9	0.8
31. Grewia villosa	Tiliaceae	8	0.7
32. Glycine wightii	Leguminoceae	7	0.6
33. Solanum incanum	Solanaceae	6	0.5
34. Acacia tortilis	Leguminoceae	5	0.4
35. Abutilon mauritianum	Malvaceae	5	0.4
36. Tennatia sennii	Rubiaceae	5	0.4
37. Acacia mellifera	Leguminoceae	4	0.4
38. Maytenus putterlickoides	Celastaceae	4	0.4
39. Rhoicissus revoilli	Vitaceae	4	0.4
40. Grewia hexamita	Tiliaceae	3	0.3
41. Grewia trichocarpa	Tiliaceae	3	0.3
42. Asparagus racemosus	Liliaceae	2	0.2
43. Commiphora paoli	Buseraceae	2	0.2
44. Cassia singueana	Leguminoceae	2	0.2
45. Maerua trichophylla	Capparaceae	2	0.2
46. Platycelphium voense	Leguminoceae	2	0.2

47. Solanum sessilistellatum	Solanaceae	2	0.2
48. Solanum renschii	Solanaceae	2	0.2
49. Thylachium africanum	Capparaceae	2	0.2
50. Acacia nilotica	Leguminoceae	1	0.1
51. Combretum macrostigmatum	Combretaceae	1	0.1
52. Clerodendrum myriocoides	Verbenaceae	1	0.1
53. Maerua sphaerocarpa	Capparaceae	1	0.1
54. Pavonia patens	Malvaceae	1	0.1
55. Rhamnus staddo	Ramnaceae	1	0.1
total		1129	100%

Table 9. Botanical composition of vegetation - Forbs

Species	Family	Total freq.	% Species cover.
Lepidagathis scariosa	Acanthaceae	8	42.1
Sansevieria conspicua	Agavaceae	7	36.8
Sansevieria raffilii	Agavaceae	3	15.8
Euphorbia heterochroma	Euphorbiaceae	1	5.23
total		19	100

Table 10 : Botanical composition of the vegetation - Grasses, Family Gramneae (from quadrat of 10 by 10m)

Grasses	Total frequency	Percent species cover
Panicum brevifolium	40	29.2
Enteropogon macrostachyus	25	18.2
Panicum deustum	21	15.3
Chloris roxburghiana	17	12.4
Eragrostis racemosa	10	7.3
Perotis hilderbrandtii	8	5.8
Panicum maximum	6	4.4
Aristida keniensis	5	3.6
Digitaria macroblephara	3	2.2
Eragrostis superba	2	1.6
Total	137	100

The total number of plants is a total of 16 Quadrat of 10m by 10m randomly placed in the study area.

Table 11 : Botanical composition of tree seedlings and shrubs in the understorey vegetation from 2m by 2m quadrat

Tree seedlings & shrubs	Family	Total frequency	% Species cover
1. Acalypha fruticosa	Euphorbiaceae	103	12.7
2. Hibiscus aponeurus	Malvaceae	102	12.5
3. Ochna insculpta	Ochnaceae	89	10.9
4. Tephrosia villosa	Leguminoceae	79	9.7

5.	Acacia brevispica	Leguminoceae	50	6.2
6.	Grewia similis	Tiliaceae	42	5.2
7.	Hoslundia oppositia	Labiaceae	37	4.6
8.	Albizia antihelmintica	Leguminoceae	28	3.4
9.	Combretum exalatum	Combretaceae	25	3
10.	Ipomea kituensis	Convolvulaceae	24	2.9
11.	Melhania velutina	Sterculiaceae	21	2.6
12.	Paulopsis imbrica	Accanthaceae	21	2.6
13.	Indigofera spicata	Leguminoceae	19	2.3
14.	Sida cuneifolria	Malvaceae	18	2
15.	Glycine wightii	Leguminoceae	16	2
16.	Ocimum basillicum	Labiatae	14	1.7
17.	Commiphora riperia	Buseraceae	12	1.5
18.	Achyranthes aspera	Amaranthaceae	11	1.4
19.	Vigna vexillata	Leguminoceae	10	1.2
20.	Croton dichogamus	Euphorbiaceae	9	1.1
21.	Lippia javanica	Verbenaceae	9	1.1
22.	Grewia hexamita	Tiliaceae	8	1.1
23.	Premna holstii	Verbenaceae	8	1
24.	Tennatia sennii	Rubiaceae	8	1
25.	Lepidagathis scariosa	Acanthaceae	7	0.9
26.	Erythrococae bongensis	Auphorbiaceae	6	0.7
27.	Solanum renschii	Solanaceae	6	0.7
28.	Cassia singueana	Leguminoceae	5	0.6
29.	Entada abyssinica	Leguminoceae	5	0.6
30.	Evolvulus alsanoides	Convolvuaceae	5	0.6
31.	Grewia villosa	Tilcaceae	4	0.5
32.	Boscia angustifolia	Capparaceae	2	0.3

33. Thylachium africanum	Capparaceae	2	0.3
34. Stylosanthes fruticosa	Leguminoceae	2	0.3
35. Combretum molle	Combretaceae	1	0.1
36. Crotolaria verdcourtii	Leguminoceae	1	0.1
37. Lannea fulva	Anacardiaceae	1	0.1
38. Pavonia patens	Malvaceae	1	0.1
39. Trichodesma zeylanicum	Boraginaceae	1	0.1
40. Plectranthus teitensis	Labiatae	1	0.1
total		813	100

Table 12 : Botanical composition of forbs in the understorey vegetation from 2m by 2m quadrat

Species	Family	Total freq.	%species cover
Leucas grabrata	Labiatae	692	6.4
Barleria submollis	Acanthaceae	287	9.2
Barleria sp.k	Acanthaceae	152	10.2
Barleria vetricosa	Acanthaceae	114	7.6
Blepharis integrifolia	Acanthaceae	90	6.0
Commelina benghalensis	Commehanceae	86	5.8
Nothosaeva brachita	Amaranthaceae	23	1.5
Oxygonum sinuatum	Polygonaceae	17	1.1
Cyphoslemma orondo	Vitaceae	16	1.1
Eriosema jurionianum	Leguminoceae	9	0.6

Astripomea hyoscyamoides	Acanthaceae	5	0.3
Bothriocline somalensis	Compositeae	1	0.1
Euphorbia heterochroma	Euphorbiaceae	1	0.1
	total	1493	100

Table 13 : Botanical composition of the understorey vegetation from 2m by 2m quadrat: Grasses, Family Gramineae

Grasses	Total frequency	% Species Cover
1. Enteropogon macrostachyus	312	40.8
2. Eragrostis superba	123	16.1
3. Panicum reptans	94	12.3
4. Digitaria velutina	63	8.3
5. Chloris roxburghiana	54	7.1
6. Echinocloa haploclada	39	5.1
7. Eragrostis cilianensis	31	4.0
8. Aristida keniensis	23	3.0
9. Heteropogon contortus	18	2.3
10.Eragrostis racemosa	5	0.7
11.Perotis hilderbrandtii	2	0.3
total	764	100

An observation of the above tables and plates 9, 12, 18 and 19 taken from different places in the study area can be derived that the vegetation of the area was a dense woodland and wooded bushland of Enteropogon macrostachyus and Chloris roxburghiana (> 30% of all grasses) with Acacia brevispica, Combretum exalatum, Commiphora, Premna holstii, Ocimum basillicum and Grewia species and other woody species. Adansonia digitata (Baobab) is a common vegetation component in the area. Makin and Pratt (1984) showed that the vegetation is a characteristic of the drier sectors of eco- climatic zone V. Grazing was poor in the undisturbed land but browse was in general of rather good quality and quantity due to Grewia, Premna, Ocimum and Acacia species.

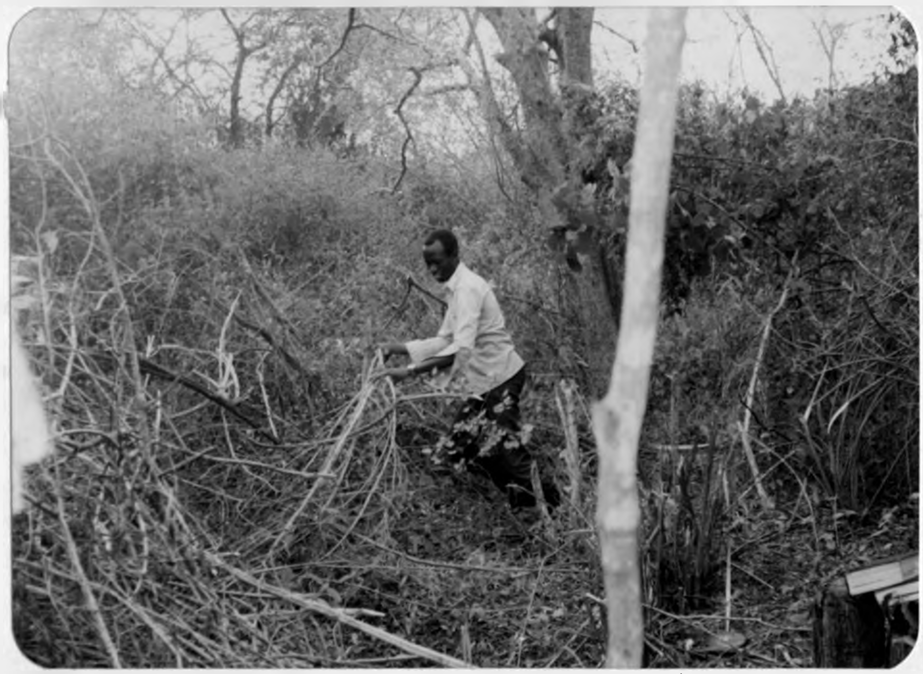

Plate 18: Wooded bushland. Note Premna holstii and associated shrubs in the foreground and Commiphora species trees in the background (Photo taken in March 1989).

Plate 19: Baobab (Adansonia digitata) retained on farmers land for its social-economic uses (Photo taken in April 1989).

Table 14 : % Bare ground, litter cover and general comments in 16 quadrats of 10m by 10m from well vegetated virgin land.

	Quadrat	Appro.% bare ground	% Litter cover	Other comments
	1	65	40	
	2	0	1	
	3	0	70	
	4	2	40	
	5	1	80	
	6	0	70	
	7	1	10	
	8	7	75	near termite mound
	9	40	65	
	10	40	75	
	11	15	10	
	12	40	40	
	13	3	75	slight sheet erosion
	14	1	80	near a pond.
	15	0	1	
	16	0	80	
total	16	207	812.8	
mean		13%	51%	

Presence of termite mounds, and absence of erosion, except slight sheet erosion in areas where the ground was bare and acted as a path for wildlife, was a general observation deduced from the above table. Results of Adansonia digitata are presented below.

5.3.2 **Adansonia digitata**, Family: BOMBACACEAE

Unlike the other vegetation cover, the distribution of baobab was determined using Nearest Neighbour Method and Closest Individual Methods as detailed by Strickler et al. (1963). The results of the methods are in table 15.

Table 15: Results of two methods of baobab survey

Method 1. Nearest individual method

Date 20/5/89 Location : Kibwezi

transects	1	2	3	4
points	dist.in m	dist.in m	dist.in m	dist.in m.
1	27	5.5	30.7	52.6
2	20	23.4	84.7	300
3	170	25	110.7	42
4	3.3	19.1	220.1	120.1
5	4.1	50	20.9	134.3
6	144	35	89.0	63.7
7	15	100	20.7	180.9
8	79.8	70	90.1	81.3
9	38	120	36.4	15.7
10	10	32	117.9	21.1
11	170	82	102	
12	48	170.7	63.4	
13	42.6	69	134.4	
14	220.8	21.4	67.2	
15	43.8	105	95	

16	22.3	73.2	47.9	
17	96.8	65	67.8	
18	47	192.7		
19	23	97		
20	46.6	102		
21	78	10		
22	21	60.4		
23	157.3			
24	180.7			
25	240.8			
Mean area/ plant (m^2/plant)	16,236.9	10,972	18,675	28,545.4
Plants/ha	0.6	0.9	0.50	0.36

Method 2.   Closest Individual Method

Date   21/5/89   Location : Kibwezi

transects	1	2	3	4
points	dist. in m	dist. in m	dist. in m	dist.in m
1	22.8	127.2	28	54
2	10.8	58	38	120
3	20	117	45	15
4	12	27.4	47.5	117
5	56.7	47.6	25	47.5
6	39.2	45.7	10.0	31
7	120	41.3	47.7	10.1
8	3	110.0	110.0	101.7
9	4	52.3	15.0	99.8
10	33.4	130	30.8	
11	1.5	122	5.7	
12	4.5	220	138.8	
13	12.3	85.0	80.9	
14	1.2	52	6.9	
15	3.4	62	84.8	
16	90.2	24	95.8	
17	24.1	0	15.3	
18	17		71.8	
19	9.4		122.4	
20	23.6		21.2	
21	124		56.9	

22	4.7		102.8	
23	26.2		60.8	
24			10.1	
25			21.6	
mean area (m^2/plant)	3,333	20,963	15,585	14,835
Plants/ha	2.9	0.5	0.6	0.7

The following is a summary of mean plants per hectare from the four transects chosen at random and sampled by two different methods.

Table 16: Mean number of Baobab per hectare

Transects	1	2	3	4
Length of transect (Km)	2.08	1.68	1.64	1.69
Method 1	0.6	0.9	0.5	0.35
Method 2	3	0.5	0.6	0.7

See appendix 2c.on the anova table comparing the treatments statistically.

Comment.

The two methods are not statistically different at 5 %. Therefore the mean plants of Baobab per hectare is one (1) in disturbed cropland and in least disturbed lands.

5.3.3 Checklist of plant species sampled in the study area.

The list is arranged in an alphabetical order by plant families, and under each family the species are also arranged alphabetically. However, all plants have been broken down into major families of the Angiosperms under which the Dicotyledons are listed first followed by Monocotyledons (Appendix 5).

5.3.4 Socio-economics of Adansonia digitata L.

Family: BOMBACACEAE.

Survey was conducted to investigate farmers views on the use of Adansonia digitata. The following information was gathered.

The baobab is a tree that could be extensively exploited for its multiple use benefits. It can be used for fodder (leaves), food, drink, medicines and dye. On occasions, the hollow trunks acts as water storage facility during the dry season, serve as houses, prisons, storage barns and even places of refuge from maraunding animals.

The first attribute is ornamental; it is a symbol of beauty and acts as an indicator of the onset of rainy season. It sheds its leaves just before the rains and stays throughout the wet season without leaves. Leaves will come out just before the dry season and stay on during the season. This ensures that shade effect on cropland during crop growth is not felt as could be expected with other trees on cropland.

A high density of Baobabs per unit area will result in poor crop growth due to competition for water. However, it was observed that a few baobabs on the shamba will not be detrimental to the crops. It could not be ascertained how many Baobabs are adequate per hectare. All farmers interviewed seemed to have found the tree where they stand at present and have not influenced the distribution in any way. Young Baobabs are beautiful especially because of the large leaves and white, shinny flowers.

The roots are at subsurface and it was observed that they restrict soil removal by runoff (see plate 13). The plates show exposed roots and trapped soil. Roots intercept runoff and sediment and this encourages infiltration of rainfall which could have otherwise been lost. Roots will act as an indicator of land deterioration if they are exposed through water erosion (plate 20).

The bark is boiled and drunk as a cure for pains in the body by some people. It is also used in making baskets.Other uses includes food value of the fruits which have been found to be very nutritious.

From the survey carried out, (tables 15), each farm has been found to have from one to three Baobabs which the farmer relies on during dry seasons. The tree is drought resistant and its fruits edible. Farmers seemed to have found Baobab trees in their shambas. None of the farmers interviewed could approximate the age of the trees. The tree was related to the time of "Noah" when viable seeds were distributed. However, scientific studies through carbon dating have shown (Gilbert, 1989) that some of the trees may be 3000 years old.

Plate 20: Baobab roots can act as an indicator of land deterioration. Note the poor state of crops next to the tree and a good crop few meters from it, also indicated in plate 12, possibly due to competition for nutrients or shade effects (Photo taken in May 1989).

5.4 Soil investigations

5.4.1 Soil chemical and physical properties

Many theories have been advanced about soil sealing (see literature review). The main aim of determining some soil physical properties is to investigate whether sealing is due to low organic matter (organic carbon) or texture. Soil sealing could be due to low organic matter and high sand content which makes soil disintegrate under raindrop impact leading to soil sealing as shown in the literature review.

Samples were taken from all the twelve (12) plots at depths detailed in the methodology section and the samples mixed thoroughly to get a sample from each depth respectively.

Soil texture was also determined to confirm that sealing is due to clay illuviation to lower layers thereby causing sealing of soil pores which act as conduits for water during a rainfall event. This will in turn encourage surface ponding increasing the chances of increased surface runoff and the associated soil loss and land deterioration. A lot of clay in the upper soil surface will reveal that the soils have high clay content which could block soil pores. The results got for soil physical and chemical properties are in table 17.

Table : 17 Soil physical and chemical properties

Soil type Ferral-chromic Luvisols (Touber, 1983)

Depth (cm)	0-5	6-15	16-30	31-55
texture;				
% sand (0.05-2mm)	66	66.5	68	36
% silt (0.05-0.002mm)	11	11	8	4
% clay <0.002mm	24	20.5	23	60.5
textural Class	SCL	SCL	SCL	C
% carbon	0.66	0.72	0.69	0.22

A close observation on the soil profile confirmed a lot of clay illuviation to lower layers. The evidence was derived from the visible clay skins and a hard layer evident from depth of 15cm.

Soil sealing was seen to crack during the dry weather after a rainfall event. Many surface cracks were seen in all plots especially in the control plot which was directly exposed and bare. "A" and "O" horizons were absent and the soil surface had a sandy over wash. (see plate 21).

Plate 21: Sandy over wash evident in the control plots. Also noted in plate 4 (Photo taken in April 1989).

5.4.2. **Soil resistance due to raindrop impact.**

The objective of runoff plot studies was to investigate the effectiveness of brushwood on runoff and raindrop interception. Effective rainfall interception will possibly prevent soil sealing due to raindrop impact and thus all incoming rainfall may infiltrate into the soil. It has been demonstrated (Hudson 1981, Elwell et al. 1976) that for tropical conditions protection from raindrop impact, as provided by vegetal cover, maintains the soil infiltration rate.

Protection from direct rainfall impact prevents soil sealing due to raindrop impact which lead to high runoff and soil loss. Soil compaction or resistance created by the raindrop impact was determined after the rainy seasons. Table 18 represents the means of raw penetrograph readings in the appendix 4.

Table 18 : Means of soil resistance in kg/cm^2 upto a depth of 0.5cm

Treatments.	Mean resistance(kg/cm^2)	Number of measurements	Sum of all readings
Control-no rainfall, runoff interception.	1.99	96	191.2
Under the suspended timber.	2.7	70	185.2
With rainfall, runoff interception with insect activity (timber removed).	2.0	88	178.6

On the termite tunnels (timber removed) , all the measurements got were more than 4.5 kg/cm^2 and could not be measured using a pocket penetrograph. (This was done to determine the stability of the tunnels).

Soil resistance before the rains (at a depth of 0.5cm) was 0kg/cm^2. The soil seal was broken using ordinary fork jembe and the depressions created levelled using a rake. Soil surface seal impedes seedling germination. The seedlings have to break the soil seal and this may restrict or slow down seedling emergence. See plate 22.

Plate 22 Impeded seedling emergence through the soil surface seal. Note thin cracked soil upper layer (Photo taken in April

1989).

5.5 Farmer survey on state of land deterioration, rehabilitation and current land use.

The following information was gathered in order to find out what farmers know about the problem of land degradation in the area.

The 1988 short rains were exceptionally high compared to other years. Kibwezi/Dwa plantations recorded rainfall amount of 967mm. The last time the area recorded ample rainfall was 1982, when it recorded 1024mm during the year. This turned Kibwezi to a maize producing area temporarily compared to other years when its marked by crop failures due to poorly distributed and low rainfall amount. The information gathered represents the situation in April 1989 and not any other period of the year unless stated.

5.5.1 General

The farmers were asked for how long they had been settled in the area and the results are shown in table 19. It can be observed that most farmers settled here 20-30 years ago and only 8.5% of the farmers have been there for more than 31 years.

Table 19 : Duration of farmers settlement in Kibwezi Division

Years	No.of farmers	Percent
0.1-5	3	8.6
6-10	5	14.3
11-15	5	14.3
16-20	3	8.6
21-25	14	40.0
31-35	3	8.6
no response	2	5.7
total	35	100

The reasons as to why they settled in the area ranged from being squatters before 1966 (17.1%), purchased land from the local inhabitants (34.3%), settled by the government 20%, inherited land from their parents (8.6%) to no response (17.1%). Table 20 shows distribution of number of farmers and reasons given.

Table 20: Reasons why farmers settled in Kibwezi Division

Reasons	Number of farmers	Percent
Was a squatter before 1966	6	17.1
Purchased land	12	34.3
Inherited land from my parents	3	8.6
Settled by the Government	7	20.0
No response	6	17.1
Others	1	2.9
total	35	100

Table 21 shows the lengths the community has cultivated the same piece of land. It can be seen that 45% of the farmers have utilized land for 21-30 years and only 1% have used land for more than 31 years.

Table 21. Duration of cultivation on the same piece of land

Years	No.of farmers	Percent
1-10	6	17.1
11-20	6	17.1
21-30	16	45.7
>31	2	5.7
no response	5	14.3
total	35	100

Table 22 shows farm holdings in hectares. It can be noted that the bulk of the farmers (77.1%) have total land area which does not exceed 10 hectares and which caters for livestock grazing and crop growing. Farms often lack set boundaries.

Table 22. Farm holdings in hectares

Farm holding (ha)	No.of farmers	Percent
1-5	15	42.8
6-10	12	34.3
11-15	7	20
16-20	1	2.9
>21	-	-
total	35	100

Subsistence agriculture is the main occupation but surplus crops are sold for cash together with horticultural crops, if any. The most important crops in the area were maize, beans, cowpeas and pigeon peas. Bulrush millet is grown to a lesser extent and only small areas of land were allocated to sorghum, cassava and horticultural crops. Given the dry climatic conditions with unreliable rainfall family plots need to be fairly large and accompanied by soil and water conservation measures. Table 23 shows total hectarage under cultivation. Farmers were observed to practice mixed farming to distribute risks of crop failure.

Table 23 : Total hectarage under cultivation

Areas (Ha)	No.of farmers	Percent
0.1-5	27	77.1
6-10	4	11.4
11-15	2	5.7
2216-20	1	2.9
>21	1	2.9
total	35	100

The survey also included questions as to whether farmers had noted any change in crop yields during their farming period. This is represented in Table 24.

Table 24 : Number of farmers who have noted changes in yield (productivity) per unit area.

Nature of change	No.of farms	Percent
No change	14	40
Slight decline	9	25.7
Slight improvement	4	11.4
Major decline	1	2.9
Major improvement	4	11.4
No response	3	8.6
total	35	100%

5.5.2 **Abandoned land, bare land and measures applied to restore grass cover.**

Abandoned land after use through cultivation is a common phenomenon in our semi-arid or arid areas which have been subjected to subsistence or cash cropping. Reasons for abandonment and the subsequent use of abandoned land were investigated. Table 25 shows distribution of cleared land which was later abandoned due to responses given in Table 26. Table 27 shows measures employed to restore grass cover in such areas which are otherwise useless unless appropriate measures are employed.

Farmers were giving more than one response or reason for abandoned land . All the responses were recorded and tabulated to find out which one is the major cause of bare lands in these semi-arid areas. Tables 26, 28, and 29 shows the responses but not the number of farmers.

Table 25 : Area of land cleared, cultivated and now out of production.

Area (ha)	No.of farmers	Percent
0.1-2	5	14.3
2.1-4	6	17.1
4.1-6	1	2.9
N/A + Zero	23	65.7
total	35	100

Table 26 : Reasons why land is bare or out of production (former cropland and grazing land).

Reason	Responses	Percent
Overgrazing	9	20.0
Bush clearing, Charcoal burning	2	4.4
Termites	8	17.8
Water erosion and sudden rainstorms	14	31.1
Stony land	3	6.7
N/A	9	20.0
total	45	100

Table 27 : Measures used to restore cover on bare or denuded lands

Measures	No.of farmers	Percent
No measures	8	50.0
Planting grass	3	18.7
Abandoning to allow natural revegetation	4	25.0
Terraces	1	6.3
total	16	100

From the above, overgrazing, water erosion and termites are major factors leading to bare lands or land deterioration. This is rated by the farmers, 20.0%, 31.1% and 17.8% respectively. The reasons are not exhaustive and the list can be long if the survey could have been extended to cover more farmers.

From table 27, it can be deduced that most farmers (75%) are not doing anything about bare lands and only a small percentage of them (25%) are putting efforts to revegetate the areas.

Farmers were asked the major causes of soil erosion from their standpoint. The following observations were made. 58.6% of farmers attributed soil erosion to sudden storms which come when land is bare, 21.7% attributed it to lack of cover throughout the year, and 4.3% attributed soil erosion due to soil sealing and low infiltration rates. Table 28 depicts the distribution of the responses gathered from the farmers.

Table 28 : Major causes of soil erosion on farmers land.

Causes	Responses	Percent
1. Sudden storms when land is bare.	27	58.6
2. Land too steep	6	13
3. Crops grown do not cover the ground throughout the year.	10	21.7
4. Soil sealing and low infiltration of soils.	2	24.3
total	46	100

Table 29 shows farmers view on the problem of soil erosion during heavy rains. The magnitude of soil erosion during heavy rains have been found to be very great (47.3%) and great (31.6%).

Table 29 : Magnitude of soil erosion on cropland during heavy rains

Nature	Responses	Percent
Very great	18	47.3
Great	12	31.6
Moderate to slight	0	0
Very slight	2	5.3
None	1	2.6
No response	5	13.2
total	38	100.0

5.5.3 **Grazing land:**

Much grazing land is normally bare and degradation is taking place quite rapidly, and little is being done in many places. This was observed as shown in plate 14 taken in October 1989 and from information given in tables 26 and 27. Even after the rains revegetation was noted to be slow in some areas. This is evident from plate 23.

Conservation measures installed in grazing land to rehabilitate overgrazed, bare lands were investigated. Table 30 shows the overall soil and water conservation measures and other measures used to encourage revegetation of the grazing lands. Most of the structures were installed less than ten years ago. Table 31 shows how long the measures in table 30 have beene installed. Plate 16 shows some of the measures implemented on grazing lands.

Plate 23: Some patches of bare denuded lands evident in grazing lands even after the rains, note rill erosion (Photo taken in May 1989).

Table 30 : Main measures used to control erosion or revegetate grazing lands.

Measures	No.of farmers	Percent
Fanya juu terrace	5	14.3
Cut off drains.	3	8.6
Paddocking to control Grazing	0	0
Semi-circular bunds/pits to catch runoff.	0	0
No measures, i.e land abandoned to encourage natural revegetation.	25	71.4
Planted grass.	2	5.7
total	35	100

Table 31 : Time since application of the conservation measures on grazing land.

(Years) Duration	No.of farmers	Percentage
1-5	4	11.4
6-10	2	5.7
>10	3	8.6
No response.	5	14.3
Not applicable.	21	60.0
total.	35	100

5.5.4 Ground Cover.

Overall ground cover in grazing lands in terms of annuals, perennial and weeds was graded according to very great, great, moderate, slight and very slight. The writers observation was that most grazing lands were bushy. The good rainfall amount in 1988 short rains made the land better than ever before in terms of vegetal cover. Cutoff drains and terraces where applicable, looked bushy and silted up while plant remains protected the soil from rain splash but exposed roots were common due to initial high erosion rates due to bare lands which existed before. Presence of annuals and perennial are represented in Table 31 as per the abundance. Plate 14 shows reduced cover through overgrazing and soil erosion.

Table 32: Annual grasses/weeds and perennials on grazing lands.

Annuals			Perennials	
score.	No. of farmers	percent.	No. of farmers	Percent
Very slight	13	37.1	9	25.7
Slight	5	14.3	6	17.1
Moderate	3	8.6	4	11.4
Great	10	28.6	10	28.6
Very great	4	11.4	6	17.1
total	35	100	35	100

5.5.5 **Cropland.**

Evidence on reduced crop land production potential was also investigated. Previous visit to the area revealed bare dissected land on fairly steep slopes and even on gentle grounds. See plate 13 and 15, an indication of land deterioration.

In general, deposited sediment, sheet erosion and rill erosion appeared to be the major evidence of land deterioration. The observations were evident in each farm which was visited.

Overall ground cover on cropland was assessed by awarding marks one (1) for very slight and five (5) for very great and three (3) for moderate cover. Table 33 and 34 shows observations in farms on measures intended to prevent soil erosion and general cover in cropland.

Table 33 : Observations on farmers land on measures intended to prevent soil erosion in cropland.

Measures	Observations (No. of responses)	Percent
Put a trash line to intercept runoff.	11	23.9
Plant grass strips.	1	2.2
Construct a stone terrace.	8	17.4
Construct fanya juu terraces.	23	50.0
Prevent human trampling.	1	2.2
No effort.	2	4.3
total	46	100

Table 34 : Distribution of the general cover on cropland.

Score.	Observations. (No. of farms)	Percent.
Very slight	5	14.3
Slight	8	22.9
Moderate	11	31.4
Great	4	11.4
Very great	1	2.9
N/A/stony	6	17.1
total	35	100

Plates 24 and 25 compares overall ground cover before the rains and the consequences of leaving some cover. Plate 24 does not show any evidence of soil erosion possibly due to cover left on the ground, but note also the presence of termites and their burrowing activity, Plate 25 in contrast shows prominent rill erosion due to poor ground cover before the rains. If the situation is not halted the rills may develop into gullies. The land of plate 25 is less steep than that of plate 24 but the reason for the difference in erosion is related to cover rather than steepness.

Plate 24. Moderate ground cover can prevent soil erosion. (Photo taken in April 1989).

Plate 25. Rill erosion on a gentle slope. Lack of ground cover paved the way to rill erosion (Photo taken in April 1989).

An investigation was carried out on grassed terrace banks and whether any grass was planted or had grown naturally. It was observed that most cover on the terraces was self sown grasses and weeds. Makarikari grass was only common in a few croplands where it could be used as fodder for livestock when need arises, see plate 26. It shows a well established fanya juu terrace with grassed bank. The terraces have developed into bench terraces which retains most of the little available rainfall for crop use. Note the good crop stand in plate 26 compared with crop stand in plate 25 in the same area, a case where farmers have not installed any measures to conserve soil and water.

Plate 27 shows a grass strip. It was observed in one farm where the intention was to create a bench terrace in the long run. All that is needed is a wash stop, a small ridge planted with grass across the slope along the contour. Rainwater will be checked by such a barrier of grass. Water will then be distributed and will sink into loose soil of the earth barrier. The soil carried by the water flows will also be checked by the barrier, and the resultant soil deposit will help to form level ground along the barrier. This level ground will become higher and higher, eventually forming a bench terrace. The method needs a few man days to set up unlike digging a fanya juu terrace although the strip has to be initially accompanied by structural measures to prevent its destruction in case of a heavy storm.

However, as noted above, not all terraces had grassed banks. Plate 28 shows a bench terrace which has resulted from a fanya juu terrace. Its bank is covered by leguminous crop while other terraces in other shambas were covered by self sown weeds or grasses and were silted up as in plate 28.

Plate 26. A well established fanya juu terrace. Note grassed bank and the resultant bench terraces (Photo taken in May 1989).

Plate 27: A grass strip planted in a row along the contour (Photo taken in April 1989).

Plate 28: Bench terrace and a silted up fanya juu terrace. Note bank covered by a leguminous crop (Photo taken in April 1989).

6. DISCUSSION

6.1 Runoff and soil loss

This trial was investigating if slashing bush and spreading it on the denuded land would improve infiltration and if so, whether the effect would be due to interception of rainfall energy and reduced sealing, interception of runoff, insect activity for example termites or other organisms living on the deadwood and breaking the seal in the process, or due to a combination of one or more factors.

The effectiveness of each of these in reducing percentage of rain which is lost as runoff or detached soil was related to the rainfall amount, the initial soil moisture content and the treatment. With high rainfall amount (83mm) and saturated soils, high rates of runoff, in the region of 64-73% of the rainfall can be expected particularly if the ground is bare. This can be compared with 53-59% from plots having rainfall, runoff interception and insect activity.

The lowest figure of 7.5% from 4mm of rainfall (intensity 2.4mm/hr) occurred from the same treatment. This had followed a rainy day. The low figure could be due to brushwood runoff interception or termites tunnelling activity. The losses from heavy rain are high considering that the plots were on a mean slope of 0.1%. In spite of low rainfall amount(table 6) and intensity (5.4mm/hr and daily amount of 25mm) and some cracks in the soil surface as a result of eight (8) days of dry weather, runoff from bare plots was still relatively high (49.5% of the rainfall) indicating the seriousness of the sealing problem.

The average rainfall losses as runoff ranged from 53% from bare denuded plots to as low as 38% in plots with rainfall and runoff interception together with insect activity.

Total soil loss during the long rainy season was 65.5t/ha. from bare plots and 19t/ha. from rainfall and runoff interception together with insect activity. Treatment effects were significant in reducing soil loss and runoff in sealed denuded grazing lands. The heaviest rainfall of 83mm resulted in soil loss of 6.1t/ha., 5.2t/ha, 3.7t/ha and 2.4t/ha. from treatment plots; bare denuded plots, rainfall energy interception only, rainfall and runoff interception without insect activity and from rainfall and runoff interception together with insect activity respectively. The figures are high considering that the losses are only from one day and from an almost level ground. Soil loss values are bound to be higher with high rainfall amount and research extended to cover two seasons and on much steeper slopes.

When total soil loss values (table 5) are compared with Riquier's (1978) standard land degradation values, it shows that in one season losses were moderate (10-50t/ha/year) from the treatments;rainfall interception only , rainfall and runoff interception without insect activity and with insect activity. The losses are high (51-200t/ha)for the control plots. Efficiency of the treatments in reducing soil loss indicate high value (71%) for rainfall and runoff interception with insect activity.

Treatment effects were significant in promoting rain water infiltration into denuded sealed soils. This is more so if the denuded land is covered with brushwood to intercept rainfall and runoff and at the same time allow insect activity which will possibly create some tunnels .

The result (table 5) suggest that brushwood cover (20%) played a role in reducing runoff by creating significant storage impeding overland flow thereby allowing a longer time for infiltration to occur. On bare ground, no such retarding mechanism was present and thus there was a high percentage runoff, even as high as 24% from 4mm of rainfall (table 6).

This means that on denuded lands which have no cover to intercept overland flow, farmers need to encourage insect activity which, possibly through their burrowing will make the soil surface rough, create depression storage on the soil surface and promote infiltration.

Analysis of variance (appendix 2d) of the resistance data from the various treatments after the rains (table 18 and appendix 4) showed that cover is significant in reducing or preventing raindrop impact and thus reduce incidence of soil sealing.

The above suggest that failure to maintain a certain percent cover on the bare grazing land leads to a fairly rapid erosion of upper layers until the parent rock is reached. At this stage it will be difficult to bring back land to production even after exclusion of livestock. Revegetation of denuded land may also require temporary exclusion of animals after abandoning the cropland to give it time to revegetate. However, this may also be slow due to restricted seedling emergence as a result of soil sealing (see plate 22). The seedlings may totally fail to emerge or die soon after due to lack of moisture thus restricting revegetation. This calls for breaking the seal or preventing it from forming through maintenance of cover by proper grazing management and/ or restoring it whenever it is diminished, by means of temporary bunds, basin pits etc plus reseeding or planting grass splits.

6.2 Effect of insect activity on infiltration rates of sealing soils

Though the implications of insect activity on soil sealing cannot be said with certainty as the activity was also found in other treatment plots where there was no brushwood, it was observed that in plots where termites were active, the soil surface configuration was generally uneven, loose and sometimes fragmented (plate 24 and 29) as a result of cast deposition and burrowing activity. This was also observed by Kladviko et al (1986) when dealing with earthworms. The soil was loose and thus could easily be eroded.

Plate 29. Loose soil surface as a result of termite activity in rainfall interception treatment plots (Photo taken in April 1989).

As mentioned earlier, a supplementary experiment on infiltration was carried out on soils when seal is removed, seal formed but after insect activity and when seal is intact. Removal of the seal made a big difference to the rate of infiltration but the effect of termites was only noticeable in the intial stages.

Soil acceptance of water is highest when soil sealing is removed. From (Figures 5 and 6) activity of termites, which in this case means applying total cover on sealing - soils after seal has formed to encourage insect activity on the soil seal, was effective during the first few minutes of ponding and then slowed down immediately. This can be seen from high initial infiltration rates on ponding after termite activity (appendices 3a and 3b). After two minutes, infiltration rate was 87cm/hour and then slowed down to 54 cm/hour after the next two minutes interval. In the second replicates, infiltration rates was 66cm/hr after two (2) minutes and then decreased to 27 cm/hr after the second interval of two (2) minutes.

From the plot experiments, mean runoff rate of 49.5% from rain with an intensity of 5.4mm per hour from the bare plots was recorded (table 6). This indicates that ponding water on the surface e.g. by the matengo pits used by Mututho (1986) creates better conditions necessary for revegetation. On the other undisturbed soil seal treatment, initial infiltration rate was relatively low compared with that after termite activity and it decreased gradually.

One could have expected the rates to be higher after termite activity than the other treatments though the soil surface was covered (plate 7). A possible explanation to slowed down infiltration rates could be the cemented hardened sides (walls) of tunnels (force of 4.5 kg /cm^2 required to penetrate with a pocket penetrometer). Arshad (1977) in his study of role of Microtermes michaelseni, a species identified in the study area, together with Odontotermes, showed that the tunnels are made up of the same soil material with the mound. They have high clay content compared to adjacent soils which makes the infiltration rates low.

Termites make holes in the process of foraging (I.C.I.P.E. annual report,1976). The area foraged by a single termite mound the report further states, and thus the tunnels made in the process, varies from 132m^2 in April to 55m^2 in May and the number of holes (tunnels) follow proportionately the decrease of standing crop and litter. This implies that their numbers decrease from a tall grass to short grass cover.

The best fit curve of the measured infiltration rates indicates that infiltration rates of sealing soils in spite of termite activity is low. This was also showed by Arshad (1982) when determining infiltration rates of the termite mound.

Darlington (1982b) explained high initial infiltration rates by underground passages and numerous food storages for termites which exist around the mound. It has been argued (I.C.I.P.E. annual report, 1974) that all termite holes lead indirectly to an underground mound. The external openings through the mound measure up to 64cm deep and can have closed openings and open chimneys (openings). The tunnels in this case had open chimneys.

Infiltration rates of the sealing soils when the soil seal is removed is higher than the other treatments when the soil seal is intact. This means that removal of the seal improves water acceptance capacity of the soils and this promotes rainfall infiltration leading to enhanced revegetation of denuded sealing soils. This was also observed by Chepkwony (1980) when investigating restoration of vegetation cover in degraded grazing lands in a low rainfall area. That soil sealing impedes flow of water was also reported by Hillel and Gardner, (1969).

With few replications of the infiltration experiment ,it cannot be stated with certainty whether insect activity or peeling the soil seal with a knife has higher infiltration rate but certainly sealing impedes infiltration rates of the sealing soils and infiltration can be improved by removal or disturbance of the seal with either of the two methods.

However, there is reason to believe that soil cover with brushwood will have higher infiltration rates than bare soils, partly because the material used will decompose to improve the soil structure and improve water holding capacity of the soil and thus hasten revegetation at the same time as intercepting rainfall energy. It can also be assumed that brushwood will provide a more favourable environment for seedlings to become established by encouraging deposition of sediment and protecting the emerging seedlings from sun, wind and grazing animals. Termite tunnels will act as conduits for water though not for a long period. The bare ground on the other hand does not experience these activities. It is only exposed to the raindrops destructive impact on soil structure. One fortunate thing about the soil sealing is that the seal formed was not uniform over the soil surface but was broken by cracks, also noted by Thomas et al. (1978).

All the above suggest that a farmer faced with soil sealing problems must always do something to the soils. He either encourages a lot of termite activity by providing total cover of the land by brushwood or ensures that the soil seal is removed once it has formed and surface storage for rainwater e.g. ridges or pits are created to ensure rainfall infiltration and hence revegetation of denuded lands.

6.3 Soil physical and chemical properties.

In an effort to determine the cause of soil sealing and resulting high runoff rates, soil texture, percent organic carbon and soil resistance were determined as detailed in the methodology section.

The results (Table 17) show higher clay content in the lower layers relative to the surface. The surface (0-5cm) has on the other hand more sand content and silt. The profile had relatively low organic carbon (0.7%). High clay content at 31-55cm depth will cause decreased porosity. This decrease, coupled with a decrease in surface porosity due to sealing (Onofiok and Singer, 1984) causes a reduction in both infiltration and soil detachment rates (Mclntyre, 1958, Moldenhauer, 1970). Clay fractions in the soils by acting like cement in sand contributes to the hardness of the soils during the dry season. The resultant effect of this is low infiltration and high runoff and water erosion when rains come.

Low organic carbon (0.7%) and high (66%) sand and low silt (11%), contents can possibly cause sealing when soil disintegrates under raindrop impact. Fine silt may block the soil pores thus causing soil sealing ; a situation also observed by Muchena ,(1975).

This clearly shows the need to intercept rainfall energy using some cover to prevent soil sealing. This has been noted due to increase in soil resistance from initial zero (0) kg/cm^2 at a depth of 0.5cm to as high as more than $4.5 kg/cm^2$ on termite tunnels and 2.7 kg/cm^2 directly under suspended cover material.

High soil resistance in the termite tunnels contributes to low infiltration rates until it collapses when infiltration rates increases.

High soil resistance directly under suspended cover could have been due to water on the cover forming large drops (coalesce) and then falling with more energy to cause more compaction.

From the above it implies that farmers have to intercept rainfall to prevent soil with high sand content and low organic matter content disintegrating and sealing which in turn contributes to low infiltration rates.

6.4 Farmer survey on state of land deterioration, rehabilitation and current land use.

Farmers have cultivated in the area for the last 21-30 years (45.7%). They are mainly small scale farmers relying wholly on farming as a source of food and income. Crop failure is a common phenomenon due to lack of rainfall. Crops grown do not cover the ground most of the year. The implication is that water erosion is high especially on exposed ground where rainfall energy causes soil sealing.

Farmers (42.9%) have 1-5 hectares of land out of which 0.1 - 2ha (14.3%) is out of production. The small land area is used as cropland and grazing land with homestead included. The area, being semi-arid, faces the problem of intensive management of small holdings under very variable and unreliable rainfall. The immigrants need to devise ways of harnessing the little available rainfall to reap maximum benefit in terms of increasing crop production and livestock. The prevailing pattern of land use is one of cropland surrounded by patches of bush land. These latter are preserved for grazing and browsing after land is abandoned especially at times when cultivated land is not under crop.

Livestock carrying capacity according to Pratt et al. (1977) is 4 (four) hectares per livestock unit (a zebu cow and its calf) which does not exist in the area. This has contributed to the present problem of land deterioration as is seen in plate 14, 15 and 16.

There are many instances where denuded croplands have been abandoned to allow natural revegetation and then grazed even before revegetation has taken place. Grazing land is left to revegetate naturally, this has resulted in serious land degradation/soil erosion. Many reasons were given by farmers why land is abandoned. They ranged from water erosion (31%), overgrazing (20%) to termites (17.7%). Other reasons included the steep slopes but some farmers did not understand the questions.

The situation calls for a reduction of livestock numbers to a level where overgrazing will not be evident thereby reducing amounts of runoff and encouraging infiltration of the sealing soils to hasten revegetation. Some measures have been instituted to reverse the situation on grazing land, though emphasis has been more on cropland.

6.4.1 **Grazing land**

An observation made before the onset of the rains (see plate 16) revealed that much grazing land had serious erosion problems, particularly steep lands. Such land was rendered bare (see plate 15) during the rains and degradation is taking place quite rapidly and very little seem to be done about it. This is evident from table 30.

The 1988 short season rainfall was above average. This had led to soil conservation measures on grazing land, where present by the time of survey, becoming silted up. Exposed roots were common due to initial high erosion rates because of bare land before the rains. In spite of heavy rains, revegetation has been slow (see plate 23) in some grazing lands. The measures installed in grazing lands, such as terraces and cutoff drains (Table 30) have silted up due to lack of cover before the onset of the rains or are in the process of silting up. This was also observed by Mbithi et al. (1977) but as noted elsewhere in the thesis the structures have been found to be uneconomical and dangerous to livestock.

It was observed that revegetation of the denuded grazing lands by the farmers was inadequate. Only 5.7% of the farmers had attempted artificial revegetation otherwise, most farmers relied on natural revegetation.

The problem of termites appears acute (Table 28 and plate 10 and 24). They were noticed in cropland, grazing land and even in land with minimal disturbance (virgin land). They have been associated with land degradation (Pole-Evans, 1938). They will eat most of the dead material leaving the ground bare. They were found to eat brushwood of castor oil plant chopped and dropped on the ground next to the runoff plot experiments in under one week. They do not even wait for the brushwood to dry out. Their foraging activities mean that dry grass which acts as fodder for livestock during the dry season is eaten up and during the rains capped soils provide a hostile environment for seedling emergence (see plate 22).

From the above, maintenance of vegetal cover is important before and after the rains. This will intercept raindrop impact and prevent soil sealing which restricts seedling emergence and rainfall infiltration into the soils. This can be done if livestock numbers are reduced to match with reduced grazing land due to increase in cropland.

Farmers should try to revegetate denuded lands using locally adapted grasses and give grass ample time to establish. As has been observed in section 6.2, termites make soil surface uneven and create tunnels which are resistant to water erosion. Uneven soil surface will act as depression storage for water and hence increased infiltration to hasten revegetation. The following section deals with conservation measures in cropland.

6.4.2 Cropland

Soil and water conservation measures are diverse (Table 33). The bulk of the measures were fanya juu terraces and in a few cases trash lines for intercepting runoff and soil loss.

However, some farmers had not installed (plate 15) any measures and the installed ones were silted up and require maintenance.

Evidence of land deterioration was clear from gullies, sheet erosion and deposited sediments (plate 13 and 20). Deposited sediment, sheet erosion and rill erosion constituted the major evidence of land degradation in almost all farms (77%). This is an indication of lack of cover on land and the subsequent soil erosion with the onset of the rainy season especially where ground was totally bare. Most land preparation except weeding is done using oxen drawn plough. This creates ridge like depression (plate 28) storage for runoff and soil and an overall reduction of high erosion rates except on steep lands.

Overall ground cover was ranked from very great to very slight. During the survey, farms had moderate ground cover (31.4%). This included maize stovers, annual and perennial weeds. Plate 24, shows how moderate ground cover can prevent soil erosion by runoff interception and depression storage for soil. In such a case, erosion will be reduced and rainfall infiltration improved for crop growth.

Terrace bank stabilization (plate 26 and 28) was provided by Panicum coloratum var. Makarikariensis and self sown grasses, weeds or leguminous plants. This was also observed by Mbithi et al. (1977) during an evaluation study of the Machakos manual terracing programme. However, some farmers had not installed (plate 15) any measures and the installed ones, terraces were silted up and called for adequate maintenance as erosion was taking place on the banks and in the [illegible] land between.

6.5 Botanical composition of land with minimal disturbance.

The section details the kind of vegetation originally found in Kibwezi Division before settlement and what has happened since then. It also enumerates the condition of soils before cultivation and the species of vegetation left by farmers in crop and grazing land after bush clearing and why it has been left. As observed earlier, the vegetation survey covered a short period and thus the inventory is not exhaustive of the species available and vegetation might change if sampled in a different season.

One hundred and one (101) species were collected as part of Kibwezi Division original vegetation . Wooded bushland of Commiphora riperia, Premna holstii, Acacia brevispica, Grewia species, Combretum exalatum and other woody species (> 87%) dominate the vegetation with Enteropogon macrostachyus, Chloris roxburghiana, Eragrostis superba among the perennials and other annual grasses (< 2%). Adansonia digitata is a common vegetation component in the area. The understorey vegetation is composed of Leucas, Barleria species, Blepharis among other forbs (< 11%). The same vegetation was identified by Makin and Pratt (1984) and Touber (1983). Grazing was very poor due to low grass cover while browse was in general rather good due to Acacia, Grewia, Ocimum and Premna species.

However, not all the vegetation recorded were present in grazing and cropland. With human settlement, woody plant species have been cut for fuelwood, building posts, boma fencing to protect livestock at night, creating land for cultivation and for other purposes while some species have been left e.g. Baobab (plate 11) due to its socio-economic significance to the farmers.

6.5.1 Socio - economics of Adansonia digitata

Baobabs in cropland serve as an "alternative food crop" in times of drought. This is due to its edible fruits always there despite low rainfall and subsequent crop failure in the area. Its roots are at subsurface thereby stabilizing the soil against erosion and occasionally acting as deposition storage for sediment (plate 13). The plant has no shade effects in cropland (plate 11).

Fruit pods and seeds are also fed to stock; cattle and goats browse on fallen dry leaves and flowers. It has been shown (Gilbert, 1989) that Baobab can be damaged by elephants and may be essentially eliminated over large areas as happened in Tsavo East National Park in the late 1970's. The Elephants can fell and practically completely devour Baobabs in a short time, eating even the roots and fruits .

Vegetation removal has exposed soil to accelerated erosion and increased runoff in most farms (plate 13, 15, 16 and 20). Vegetation cover removal has been shown (Dregne, 1985) to be one stage of desertification process in arid lands. This has led to the existing land deterioration since settlement less than thirty (30) years ago. During the vegetation survey of land which has not been subjected to cultivation or formal grazing, no evidence of erosion was found. Land degradation has mainly been due to settlement and lack of proper soil and water conservation measures accompanying the existing land use.

7. CONCLUSION

Treatment effects compared with the control, were significant (p 0.05) in reducing total soil loss and runoff and thus enhancing rainfall infiltration in denuded lands. 20% brushwood ground cover of denuded sealed soils for rainfall / runoff interception together with or without insect activity reduces soil loss. Bare denuded plots lost an average of 53% of the rainfall as runoff and 65.5t/ha of soil compared with 38% rainfall as runoff and 19t/ha.of soil from plots with interception of rainfall and runoff together with insect activity. Rainfall interception only and rainfall / runoff interception without insect activity lost a total of 32t/ha. and 25.7t/ha. respectively.

Efficiency values in reducing soil loss and runoff were high for all the treatments. Rainfall, runoff interception together with insect activity reduced soil loss by 71% , without insect activity by 61% and rainfall interception only by 51%. Treatments reduced runoff by 10.5% in rainfall interception only , 18.2% in rainfall, runoff interception without insect activity and 27.5% in rainfall, runoff interception with insect activity.

Denudation is common on soils which are sandy clay to clay loams and derived from basement complex schists and gneiss. Sealing of such soils is mainly due to raindrop impact which can be prevented by rainfall energy interception by brushwood. Further soil sealing, after raindrop impact can be attributed to runoff. Brushwood on the ground causes deposition storage of sediment and promotes rainfall infiltration. It also provides a more favourable environment for seedlings to become established by protecting the emerging seedlings from the sun, wind and grazing animals.

Clay fractions in the soils, by blocking soil pores after soil aggregates disintegrate due to raindrop impact, contribute to hardness of the soils during the dry season. The clay content at the soil surface causes decreased porosity and hence soil sealing. The resultant effect of this is low infiltration and high runoff and water erosion when rains come.

Insect activities alone do not have a significant impact in promoting infiltration by breaking the soil seal or by their tunnelling activities. Their effects in promoting rainfall infiltration in sealing soils was investigated by ponding water using ring infiltrometers when soil seal is intact, when it was removed and after insect activity. Their impact, though initially high with ponded water, is short lived. This calls for an alternative method of promoting infiltration for example by creating pits for rainwater to pond.

The mean number of baobab trees per hectare is (1) one to (3) three both in cropland and in least disturbed land. Its soil and water conservation effects should be accompanied with structural measures in cropland or good grazing management in grazing lands.

Most land deterioration from stable vegetated land with minimal soil erosion has been due to vegetation removal exposing soil to accelerated erosion and increased runoff.

This has been made worse by lack of proper grazing management and established methods of restoring grass cover whenever it is diminished, by temporary basins, pits, bunds etc to promote infiltration plus reseeding or planting grass splits on grazing land; and by poorly maintained soil and water conservation measures on cropland.

Appropriate soil and water conservation measures in grazing and croplands have to be installed and where installed should be adequately maintained to halt the current land degradation associated with the current land use.

Settlement in the area, though relatively recent, mainly within the last (25) twenty five years has resulted in serious erosion in some places. This indicates that much greater attention should be paid to soil and water conservation.

8. RECOMMENDATIONS

1. In grazing areas where there are no conservation measures and land is denuded, use of brushwood should be considered to encourage deposition of sediment and promote infiltration of rainfall and hence revegetation.

2. Investigations are needed to identify suitable animal drawn implements to facilitate creation of depression storage. This is to promote infiltration of scarce rainfall into bare denuded lands to enhance revegetation.

3. Study is needed on specific ecological requirements, management techniques and commercial uses of *Adansonia digitata*. A starting point could possibly be understanding its domestic significance to the local communities.

4. Vegetation should be allowed to establish in abandoned cropland before effecting controlled grazing to prevent erosion taking place during the onset of the rains.

5. There is need for more information on the effect of insect activity and brushwood interactions on soil sealing over a long period and on different slopes.

6. Change in land use, from wild game in a fragile ecosystem to human utilization should always be accompanied by soil and water conservation measures. Natural perennial

vegetation should be preserved in an optimum condition to maintain productivity, promote maximum rainfall infiltration, reduce erosion and avoid expensive and often inadequate remedial treatments. For better land utilization, the fullest cooperation is required between the Government and the farmers. Conservative stocking is strongly advocated on grazing lands to prevent further land deterioration due to overstocking.

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APPENDICES

Appendix 1: Rainfall amount for DWA plantations, Makindu.

Muito-Andei and Kiboko Meteorological stations (from 1926-1988).

	DWA Plantation		Makindu		Mtito Andei		Kiboko	
Year	Amount (mm)	Days	Amount (mm)	Days	Amount (mm)	Days	Amount (mm)	Days
1926	132.2	9	362.5	14				
1927	0	0	746.9	21				
1928	0	0	299.3	16				
1929	515.9	22	375.4	21				
1930	1008.7	47	1006.6	34				
1931	567.6	23	405.7	20				
1932	704.4	31	624.3	33				
1933	707.1	28	509.5	20				
1934	234.6	12	67.3	4				
1935	553.7	38	377.0	18				
1936	703.5	25	351.9	24				
1937	721.8	31	680.7	34				
1938	592.8	28	656.5	20				
1939	390.6	14	343.6	14				
1940	684.4	33	668.2	28				
1941	889.6	66	654.0	61				
1942	436.5	45	489.0	71				
1943	546.0	39	523.7	52				
1944	704.0	47	553.9	67				
1945	386.5	29	406.9	57				
1946	398.4	40	390.5	58				

1946	398.4	40	390.5	58				
1947	1028.8	61	733.4	82				
1948	621.1	42	748.9	72				
1949	384.4	38	333.6	62				
1950	377.8	35	314.9	54				
1951	869.3	67	798.5	99				
1952	376.0	41	509.6	78				
1953	604.0	31	562.4	70				
1954	547.2	44	352.2	52				
1955	360.6	42	382.7	67				
1956	704.2	52	641.9	83				
1957	-	-	480.2	58				
1958	-		401.4	49				
1959	553.1	33	611.9	51	766.8	40	322.9	20
1960	373.9	40	411.0	40	568.8	40	276.5	35
1961	975.4	59	978.5	82	908.2	56	884.7	43
1962	625.0	45	590.0	80	645.3	55	413.0	43
1963	860.0	59	1030.8	94	703.2	66	801.7	62
1964	955.7	49	685.7	70	819.3	47	641.7	41
1965	375.4	37	384.3	64	375.4	37	366.0	21
1966	508.9	51	485.7	77	502.3	55	217.8	15
1967	825.3	53	817.7	69	1032.5	54	897.9	63
1968	1214.6	79	1246.2	94	1239.1	89	1028.7	95
1969	566.0	58	569.8	64	386.8	49	581.5	49
1970	501.6	62	379.8	51	403.0	40	391.0	38
1971	666.0	48	590.5	50	566.5	43	671.0	46
1972	547.6	57	435.5	57	296.6	42	335.8	53
1973	590.7	25	410.2	46	391.5	31	246.2	19

1974	576.1	42	404.2	57	421.1	56	396.2	39
1975	119.9	25	343.1	41	305.1	27	220.9	9
1976	491.2	83	364.4	43	506.7	54	234.5	26
1977	1303.4	98	723.4	85	655.7	67	645.9	67
1978	985.5	44	700.9	67	709.3	50	638.2	62
1979	1193.8	70	696.2	88	1288.8	74	800.6	86
1980	535.2	44	346.0	83	654.9	41	266.9	55
1981	722.0	70	661.3	67	838.2	50	439.1	50
1982	1024.0	82	937.5	76	1064.3	56	564.3	39
1983	431.0	46	259.4	42	296.5	26	313.5	21
1984	632.0	53	689.1	49	486.3	26	368.2	29
1985	618.0	76	507.1	75	538.0	39	618.0	52
1986	697.0	77	619.3	77	979.3	67	486.6	43
1987	342.0	32	212.8	31	616.4	35	441.0	29
1988	966.8	55	711.5	54	813.7	43	569.7	36

Kibwezi Field Station

rainfall amount.

Month	Amount	No.of rainy days
October	-	-
November	347.9	8
December	116.3	8
total	464.2	16
January 1989	91.8	4
February 1989	11.2	1
March 1989	22.1	1
April 1989	219.8	7
May 1989	40.0	2
total	386.3	15

Appendix 2

Anova (a); Total soil loss (t/ha) from four treatments during the long (March-May) rains.

Source of variation	df	ss	mss	Fcal.	Ft= 0.5
treatments	3	424.43	141.2	7.7^{**}	4.76
blocks	2	6.06	3.03	$0.17^{n.s}$	
error	6	108.97	18.16		
total	11	539.49			

* * significant at 5% .

Mean separation using least significant difference.

Aa Ba Ca Db

nb. " a" denotes no significant difference between the treatments, A,B,C.(see pp. 61 for the treatments) compared with the control,D.

anova (b); Total runoff(thousand m^3 /ha.)during the long rains (March-May) 1989.

Source of variation.	df.	ss	ms	fc.	ft .05
treatments.	3	0.264	0.088	8.06^{**}	4.76
blocks	2	0.008	0.004	0.365^{ns}	
error	6	0.064	0.011		
total	11	0.336			

** significant at 5%.

Mean separation using least significant difference.

Aa Ba Ca Db

Nb. as in above.

Anova (c) Differences in the number of survey methods. Testing whether there is a difference in the two methods used in surveying Adansonia digitata.

Source of variation	df.	ss	ms	Fcal.	Ft.=0.05
treatment	1	0.7	0.7	0.94^{ns}	5.99
error	6	4.5	0.75		
total	7	5.22			

Anova (d) Soil resistance due to raindrop impact.

Source of variation	df	ss	ms	Fcal.	Ft.=0.05
treatments	2	37.97	18.98	57.38*	
error	251	83.07	0.33		
Total	253	121.05			

*Significant at 5%.

Appendix 3. Data of cylinder infiltration on soil seal intact, seal removed and after insect activity

Appendix 3a. After insect activity rep.1.
Date 7/6/1989.

elapsed time (min.)	average rate (cm/hour)	distance after filling (cm)	distance after filling (cm)	depth (cm)	cumul infilt (cm)
		11.0			
	87.0	11.0	13.9	2.9	2.9
2.0	54.0	11.0	12.8	1.8	4.7
4.0	51.0	11.0	12.7	1.7	6.4
6.0	48.0	11.0	12.6	1.6	8.0
8.0	45.0	11.0	12.5	1.5	9.5
10.0	42.0	11.0	12.4	1.4	10.9
12.0	39.0	11.0	12.3	1.3	12.2
14.0	36.0	11.0	12.2	1.2	13.4
16.0	36.0	11.0	12.2	1.2	14.6
18.0	33.0	11.0	12.1	1.1	15.7
20.0	42.0	11.0	12.4	1.4	17.1
22.0	36.0	11.0	12.2	1.2	18.3
24.0	30.0	11.0	12.0	1.0	19.3
26.0	27.0	11.0	11.9	0.9	20.2
28.0	26.0	11.0	11.8	0.8	21.0
30.0	27.0	11.0	11.9	0.9	21.9
32.0	26.0	11.0	11.8	0.8	22.7
34.0	26.0	11.0	11.8	0.8	23.5
36.0	36.0	11.0	12.2	1.2	24.7
38.0	30.0	11.0	12.0	1.0	25.7
40.0	30.0	11.0	12.0	1.0	26.7
42.0	36.0	11.0	14.0	3.0	30.8
47.0	32.4	11.0	13.7	2.7	33.5
51.0	31.2	11.0	13.6	2.6	36.1
56.0	30.0	11.0	13.5	2.5	38.6
61.0	33.6	11.0	13.8	2.8	40.4
66.0	32.4	11.0	13.8	2.8	43.2
71.0	32.4	11.0	13.7	2.7	45.9
76.0	34.8	11.0	13.9	2.9	48.8
81.0	32.4	11.0	13.7	2.7	51.5
86.0	33.6	11.0	13.8	2.8	53.5
91.0	33.6	11.0	13.8	2.8	56.3
96.0	32.4	11.0	12.7	2.7	59.1
101.0	32.4	11.0	12.7	2.7	61.8
105.0	31.2	11.0	12.6	2.6	64.4
111.0	30.0	11.0	12.5	2.5	66.9
116.0	28.8	11.0	13.4	2.4	69.3
121.0	28.8	11.0	13.4	2.4	71.7
126.0	28.8	11.0	13.4	2.4	74.4
131.0	28.8	11.0	13.4	2.4	76.5
136.0	28.8	11.0	13.4	2.4	78.9
141.0	28.8	11.0	13.4	2.4	81.3
146.0	28.8	11.0	13.4	2.4	83.7
151.0	28.8	11.0	13.4	2.4	86.1

Appendix 3b After insect activity rep.2

Elapsed time (min)	average rate (cm/hr)	distance before filling (cm)	distance before filling (cm)	depth (cm)	cumula. infilt.
			11.5		
2	66	13.7	11.5	2.2	2.2
4	27	12.4	11.5	0.9	3.1
6	24	12.3	11.5	0.8	3.9
11	26.4	13.7	11.5	2.2	6.1
30	21.6	13.3	11.5	1.8	11.9
35	22.8	13.4	11.5	1.9	13.9
40	21.6	13.3	11.5	1.8	17.3
45	24	13.5	11.5	2	20.5
53	25	14.9	11.5	3.4	23.7
61	24	14.7	11.5	3.2	26.9
70	24	14.7	11.5	3.2	28.9
78	24	14.7	11.5	3.2	30.6
83	24	13.5	11.5	2	32.3
88	20	13.2	11.5	1.7	33.8
93	20	13.2	11.5	1.7	35.3
98	18	13	11.5	1.5	36.8
103	18	13	11.5	1.5	38.3
108	18	13	11.5	1.5	39.8
118	18	13	11.5	1.5	41.3
123	18	13	11.5	1.5	42.8
128	18	13	11.5	1.5	44.3
133	18	13	11.5	1.5	45.8
138	18	13	11.5	1.5	47.3

Appendix 3c. After soil seal is removed rep. 1

elapsed time (min)	average rate (cm/hr)	distance before filling (cm)	distance after filling (cm)	depth (cm)	cumulat. infiltra. (cm)
			10.0		
1.5	64.0	11.6	10.0	1.6	1.6
3.0	60.0	11.5	10.0	1.5	3.1
4.5	56.0	11.4	10.0	1.4	4.5
6.0	56.0	11.4	10.0	1.4	5.9
7.5	52.0	11.3	10.0	1.3	7.2
9.0	50.0	11.2	10.0	1.2	8.4
10.5	50.0	11.2	10.0	1.2	9.6
13.5	48.0	12.4	10.0	2.4	12.0
16.5	46.0	12.3	10.0	2.3	14.3
19.5	44.0	12.2	10.0	2.2	16.5
22.5	46.0	12.3	10.0	2.3	18.8
25.5	44.0	12.2	10.0	2.2	21.0
28.5	42.0	12.1	10.0	2.1	23.1
31.5	38.0	11.9	10.0	1.9	25.0
34.4	36.0	11.8	10.0	1.8	26.8
37.5	38.0	11.9	10.0	1.9	28.7
40.5	44.0	12.2	10.0	2.2	30.9
43.5	42.0	12.1	10.0	2.1	33.0
47.5	40.0	12.0	10.0	2.0	35.0
50.5	42.0	12.1	10.0	2.1	37.1
56.5	39.0	13.9	10.0	3.9	41.0
52.5	40.0	14.0	10.0	4.0	45.0
68.5	39.0	13.9	10.0	3.9	48.9
74.5	38.0	13.8	10.0	3.8	53.1
80.5	37.0	13.7	10.0	3.7	60.6
86.5	36.0	13.6	10.0	3.6	64.2
92.5	35.0	13.5	10.0	3.5	67.7
98.5	34.0	13.4	10.0	3.4	71.1
104.5	33.0	13.3	10.0	3.3	74.4
110.5	32.0	13.2	10.0	3.2	77.6
116.5	31.0	13.1	10.0	3.1	80.7
122.5	30.0	13.0	10.0	3.0	83.7
128.5	29.0	12.9	10.0	2.9	86.6
134.5	28.0	12.8	10.0	2.8	89.4
140.5	27.0	12.7	10.0	2.7	92.1
146.5	26.0	12.6	10.0	2.6	94.7
152.5	25.0	12.5	10.0	2.5	97.2
158.5	24.0	12.4	10.0	2.4	99.6
164.5	23.0	12.3	10.0	2.3	101.9
170.5	23.0	12.3	10.0	2.3	104.2

Appeendix 3d. After soil sealing is removed rep.1

elapsed time (min)	average rate (cm/hr)	distance before filling (cm)	distance after filling (cm)	depth (cm)	cumulat infilt (cm)
			9.0		
3.0	70.0	12.5	9.0	3.5	3.5
6.0	68.0	12.4	9.0	3.4	6.9
9.0	58.0	11.9	9.0	2.9	9.8
12.0	56.0	11.8	9.0	2.8	12.6
15.0	54.0	11.7	9.0	2.7	15.3
19.0	54.0	12.7	9.0	3.6	18.9
23.0	52.5	12.5	9.0	3.5	22.4
27.0	51.0	12.4	9.0	3.4	25.8
31.0	52.5	12.5	9.0	3.5	29.3
35.0	50.0	12.3	9.0	3.3	32.6
44.0	49.0	16.4	9.0	7.4	40.0
53.0	50.0	16.5	9.0	7.5	47.5
62.0	49.0	16.4	9.0	7.4	54.9
71.0	53.5	17.0	9.0	8.0	62.9
80.0	47.0	16.0	9.0	7.0	69.9
89.0	49.3	16.4	9.0	7.4	77.3
98.0	46.0	15.9	9.0	6.9	84.2
107.0	45.0	15.7	9.0	6.7	90.9
116.0	43.3	15.5	9.0	6.5	97.4
125.0	43.0	15.3	9.0	6.3	103.7
134.0	40.0	15.0	9.0	6.0	109.7
143.0	38.0	14.8	9.0	5.8	115.5
152.0	37.0	14.6	9.0	5.6	121.1
161.0	35.0	14.3	9.0	5.3	126.4
163.0	30.0	10.0	9.0	1.0	125.8
165.0	27.0	9.9	9.0	0.9	127.4
167.0	24.0	9.8	9.0	0.8	128.3
169.0	24.0	9.8	9.0	0.8	129.1
171.0	24.0	9.8	9.0	0.8	129.9
173.0	24.0	9.8	9.0	0.8	130.7
175.0	24.0	9.8	9.0	0.8	131.5

Appendix 3e. Undisturbed soil (soil sealing intact)rep.1

Date:6/6/1989

elapsed time (min)	infilt. rate (cm/hr)	distance before filling (cm)	distance after filling (cm)	depth (cm)	cumulat. infiltra (cm)
		12.5			
2.0	60.0	12.5	14.5	2.0	2.0
4.0	58.0	12.5	14.4	1.9	3.9
6.0	51.0	12.5	14.2	1.7	5.6
8.0	45.0	12.5	14.0	1.5	7.1
10.0	42.0	12.5	13.9	1.4	8.5
12.0	39.0	12.5	13.8	1.3	9.8
14.0	37.0	12.5	13.7	1.2	11.0
16.0	39.0	12.5	13.8	1.3	12.3
18.0	36.0	12.5	13.7	1.2	13.5
20.0	39.0	12.5	13.8	1.3	14.8
22.0	36.0	12.5	13.7	1.2	16.0
24.0	36.0	12.5	13.7	1.2	17.2
26.0	34.0	12.5	13.6	1.1	18.3
28.0	33.0	12.5	13.6	1.1	19.4
30.0	30.0	12.5	13.5	1.0	20.4
32.0	27.0	12.5	13.4	0.9	21.3
34.0	24.0	12.5	13.3	0.8	22.1
36.0	24.0	12.5	13.3	0.8	22.9
38.0	27.0	12.5	13.4	0.9	23.8
40.0	24.0	12.5	13.3	0.8	24.6
42.0	21.0	12.5	13.2	0.7	25.3
44.0	24.0	12.5	13.3	0.8	26.1
46.0	23.0	12.5	13.2	0.8	26.9
48.0	24.0	12.5	13.2	0.8	27.7
50.0	27.0	12.5	13.4	0.9	28.6
52.0	24.0	12.5	13.3	0.8	29.4
54.0	21.0	12.5	13.2	0.7	30.1
56.0	27.0	12.5	13.4	0.9	31.0
58.0	26.0	12.5	13.4	0.9	31.9
60.0	24.0	12.5	13.3	0.8	32.7
62.0	24.0	12.5	13.3	0.8	33.5
64.0	24.0	12.5	13.3	0.8	34.3
66.0	27.0	12.5	13.4	0.9	35.2
68.0	21.0	12.5	13.2	0.7	35.9
70.0	24.0	12.5	13.3	0.8	36.7
72.0	21.0	12.5	13.2	0.7	37.4
74.0	24.0	12.5	13.3	0.8	38.2

76.0	21.0	12.5	13.2	0.7	38.9
78.0	21.0	12.5	13.2	0.7	39.6
80.0	24.0	12.5	13.3	0.8	40.4
82.0	30.0	12.5	13.5	1.0	41.4
84.0	27.0	12.5	13.4	0.9	42.3
86.0	24.0	12.5	13.3	0.8	43.1
88.0	21.0	12.5	13.2	0.7	43.8
90.0	21.0	12.5	13.2	0.7	44.5
92.0	24.0	12.5	13.3	0.8	45.3
94.0	21.0	12.5	13.2	0.7	46.0
104.0	21.0	12.5	16.0	3.5	49.5
119.0	22.8	12.5	18.2	5.7	55.2
124.0	21.6	12.5	14.3	1.8	57.0
129.0	21.6	12.5	14.3	1.8	58.8
134.0	21.6	12.5	14.3	1.8	60.6
139.0	21.6	12.5	14.3	1.8	62.4
144.0	21.6	12.5	14.3	1.8	64.2
149.0	21.6	12.5	14.3	1.8	66.0
154.0	21.6	12.5	14.3	1.8	67.8
159.0	21.6	12.5	14.3	1.8	69.6
164.0	21.6	12.5	14.3	1.8	71.4

Appendix 3r.Undisturbed soil(soil sealing intact)rep.

Date:6/6/1989

elapsed time (cm)	distance before filling (cm)	distance after filling (cm)	depth (cm)	average rate (cm)	cumul infi (cm)
		13.0			
3.0	15.9	13.0	2.9	58.0	2.9
6.0	15.6	13.0	2.6	52.0	5.5
9.0	14.9	13.0	1.9	38.0	7.4
12.0	14.7	13.0	1.7	34.0	9.1
15.0	14.5	13.0	1.5	30.0	10.6
18.0	14.4	13.0	1.4	28.0	12.0
21.0	14.3	13.0	1.3	26.0	13.3
24.0	14.2	13.0	1.2	24.0	14.5
27.0	14.3	13.0	1.3	26.0	15.8
30.0	14.2	13.0	1.2	24.0	17.0
33.0	14.3	13.0	1.3	26.0	18.3
37.0	14.2	13.0	1.2	24.0	19.5
38.0	13.4	13.0	1.2	24.0	20.7
44.0	14.1	13.0	1.1	22.0	22.3
47.0	14.5	13.0	1.5	30.0	23.8
50.0	14.3	13.0	1.3	26.0	25.1
53.0	14.7	13.0	1.7	20.4	26.8
58.0	14.7	13.0	1.7	20.4	28.5
63.0	15.1	13.0	2.1	25.2	30.6
68.0	15.0	13.0	2.0	24.0	32.6
73.0	15.0	13.0	2.0	24.0	34.6
78.0	15.0	13.0	2.0	24.0	36.6
83.0	15.0	13.0	2.0	24.0	38.6
88.0	15.0	13.0	2.0	24.0	40.6
91.0	15.0	13.0	2.0	24.0	42.6
96.0	16.9	13.0	3.9	23.4	45.9
96.0	16.9	13.0	3.9	23.4	49.8
106.0	16.9	13.0	3.9	23.4	53.7
116.0	16.9	13.0	3.9	23.4	57.6
126.0	16.9	13.0	3.9	23.4	61.5
136.0	16.9	13.0	3.9	23.4	65.4
146.0	16.9	13.0	3.9	23.4	69.3

Appendix 4. Soil resistance due to raindrop impact measurements in Kg/cm^2.

in the control plots		under the suspended material		under the timber i.e. after termite activity	
2.1	2.5	2.0	2.7	1.9	2.0
2.8	2.7	1.8	3.2	3.2	2.6
2.5	1.8	2.7	3.2	2.3	2.2
2.3	2.8	3.6	3.2	1.3	2.0
2.7	1.5	2.5	3.0	2.5	2.7
2.2	1.3	2.3	2.5	3.2	2.5
2.3	2.0	3.0	2.8	2.0	2.8
1.6	2.2	3.8	2.8	1.8	2.7
0.7	1.5	3.0	2.7	2.1	2.5
2.5	2.5	3.5	3.5	2.8	2.2
2.0	1.7	3.2	2.5	2.2	2.8
2.0	2.5	1.7	3.0	2.2	1.5
2.5	2.0	2.3	2.3	1.8	2.0
2.0	2.2	2.3	3.0	2.0	1.8
1.8	2.7	2.0	3.3	1.5	2.2
2.8	1.8	1.5	2.1	2.8	2.2
1.5	1.8	2.3	2.3	2.2	2.8
1.1	1.8	2.0	3.3	2.5	2.8
2.0	1.5	2.0	3.5	2.7	2.1
2.8	2.5	1.8	3.0	2.0	1.8
2.2	2.2	1.8	2.7	2.8	1.8
2.3	2.2	2.8	3.0	2.5	2.0
2.0	2.2	2.3	2.8	2.6	2.3
1.8	1.8	2.0	3.0	2.7	2.0
1.5	2.5	2.8		2.0	2.0
2.8	2.2	1.8		2.6	2.6
1.0	2.0	2.0		2.3	2.0
1.0	2.0	2.8		2.4	1.0
1.5	2.3	3.2		2.6	1.9
1.8	2.3	3.2		1.3	3.2
2.2	2.0	2.5		1.0	2.3
1.5	1.8	2.0		1.8	1.8
2.2	1.0	1.8		1.6	1.3
1.5	0.8	2.3		1.8	2.5
1.3	1.3	3.2		1.8	3.2
1.5	1.5	2.7		1.3	2.6
1.3	2.5	3.2		1.5	2.6
1.8	3.0	3.2		1.5	0.8
1.8	1.8	2.7		0.8	0.8
1.5	2.0	3.2		0.3	1.3
2.0	2.0	3.8		0.3	1.6
3.0	2.3	3.2		2.0	2.0
2.0	2.7	2.3		1.3	
2.3	2.8	2.5		1.5	
1.5	2.3	2.5		1.3	
2.3	2.7	2.0		1.3	
2.3	2.0	2.8			
2.8	1.8				

Appendix 5. Checklist of plant species

Part. A. DICOTYLEDONS

ACANTHACEAE

Barleria Sp.k

Barleria submollis **Lindau**

Barleria vetricosa **Nees**

Blepharis integrifolia **(L.f) Schinz**

Duosperma kilimandscharicum **(Lindau) Dayton.**

Lepidagathis scariosa. **Nees.**

Phaulopsis imbrica **(Forsk) Sweet**

Ruttya fruticosa **Lindau**

AMARANTHACEAE

Achyranthes aspera **L.**

Nothosaeva brachita **(L) Weight.**

Pupalia lappaceae (L) **A.Juss.**

ANACARDIACEAE

Lannea fulva **(Engl.) Engl.**

Lannea schimperi **(Hochst ex. A. Rich) Eng.**

Lannea triphylla **(A.Rich) Engl.**

BURSERACCEAE

Commiphora paoli **chiov.**

Commiphora riperia **Eng.**

BORAGINACEAE

Trichodesma zeylanicum **(L) R.Br.**

CAPPARIDACEAE

Boscia angustifolia **A. Rich.**

Boscia corriaceae **Pax.**

Thyrachium africanum **Lour**

Maerua sphaerocarpa **Gilg.**

Maerua trichophylla **Gilg.**

Thylachium africanum **Lour.**

CELASTACEAE.

Maytenus putterlickoides **(Loes) Exelland Mendenca.**

COMBRETACEAE

Combretum exalatum **Eng.**

Combretum macrostigmateum **Eng.**

Combretum molle **R. Br. Ex. G Don.**

COMPOSITEAE

Bothriochline somalensis **Agnew.**

CONVOLVULACEAE.

Astrimpomea hyoscyamoides **(vartke) Varde.**

Evolvulus alsanoides **(L) L**

Ipomea kituensis **Vatke.**

EUPHORBIACEAE

Acalypha fruticosa **Forssk.**

Croton dichogamus **Pax.**

Erythrococa bongensis **Pax.**

Euphorbia heterochroma **Pax.**

LABIATAE

Plectranthus teitensis **(Bak.) Agnew.**

Hoslundia opposita **vah.**

Leucas glabrata **R. Br.**

Ocimum basilicum **L. (O.Americanum. L).**

Ocimum kilimandscharicum **Guerke.**

Satureia biflora **(D. Don) Berth.**

LEGUMINOCEAE SUBFAM. CAESALPINIOIDEAE

Cassia singueana **Del.**

LEGUMINOCEAE SUBFAM. MIMOSODAE

Acacia brevispica **Harms.**

Acacia mellifera **(Vahl) Berth.**

Acacia nilotica **L. Del.**

Acacia tortillis **(Forssk) Hayne.**

Entada abyssinica **strud ex.A.Rich.**

Albizia antihelmintica **Brongn.**

LEGUMINOCEAE SUBFAM. PAPILIONACEAE

Eriosema jurionianum **Staner and Decraene**

Crotolaria verdcourtii **Polhill.**

Glycine wightii **(Wight and Arm) Verdc)**

Indigofera spicata **Forssk.**

Platycelphium voense **Engl. Willd.**

Rhyncosia minima **(L) Pers.**

Stylosanthesis fruticosa **Retz.**

Tephrosia villosa **(L) Pers.**

Vigna vexillata **Benth.**

LILIACEAE

Asparagus racemosus **Willd.**

MALVACEAE

Abutilon mauritianium **(Jacq) Medio.**

Habiscus apaneurus **Sprague and Hutch.**

Pavonia patens **(Andr.) Chiov.**

Sida cuneifolia **ROXB.**

OCHNACEAE

Ochna insculpta **Sleumer.**

POLYGONACEAE

Oxygonum sinuatum **(meins.) Dammer**

RAMNACEAE

Rhamnus staddo **A. Rich**

RUBIACEAE

Tennatia sennii **Tenant**

SOLANACEAE

Solanum incanum **L.**

Solanum renschii **Vatke.**

Solanum sessistellatum **Bitter.**

STERCULIACEAE

Hermannia uhligii **Eng.**

Melhania velutina **Forsk**

TILIAECEAE

Grewia bicolor **Juss.**

Grewia heximita **Burret.**

Grewia similis **(K. Schum).**

Grewia trichocarpa **(Hochst).**

Grewia villosa **Willd.**

VERBENACEAE

Clerodendrum myriocoides **(Hochst) R. Br.ex. Vatke.**

Lantana trifolia **L.**

Lippia javanica **(Burmf.) Spring**

Premna holstii **Gurke.**

VITACEAE

Cissus rotundifolia **(Forssk) Vahl**

Cyphostemma orondo **(Gilg and Brandt) Desc.**

Rhoicisus revoillii **Planch.**

PART B: MONOCOTYLEDONS:

AGAVACEAE

Sansevieria conspicua **N.E.BR.**

Sansevieria raffilii **N.E. Br.**

COMMELINACEAE

Commelina benghalensis **L.**

GRAMINEAE

Aristida keniensis **Hernr.**

Panicum reptans **Napper.**

Chloris roxburghiana **Schult.**

Digitaria macroblephara **(Hack.) Stapf.**

Echinochloa heploclada.**(Stapf) Stapf.**

Enteropogon macrostachyus **(A.Rich) Benth.**

Eragrostis cilianensis **(All.) Lutati.**

Eragrostis racemosa **(Tumb) Steud.**

Eragrostis superba. **Peyr.**

Heteropogon contortus (L) **Roem and Schult.**

Panicum deustum. **Thumb.**

Panicum maximum **Jacq**

Panicum brevifolium **L.**

Perotis hilderbrandtii **Mez.**

Appendix 6. Botanical composition of the vegetation per quadrat.

Botanical composition pre quadrat of 10m by 10m.	Quadrats																total
Trees and shrubs	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1. Acacia nilotica									1	1							1
2. Acacia brevispica							9	33	4	98	1		8		1		154
3. Acacia mellifera	3															1	4
4. Asparagus recemosus					2												2
8. Abutilon mauritianum											5						5
9. Boscia angustifolia		2							3		6					1	12
10. Boscia coriaceae	6	3		5				1		2		1				1	28
11. Commiphora paoli		1		1													2
12. Commiphora riperia	5	2			1				1		2		2				13
13. Combretum molle										16						3	19
14. Combretum macrostigmatum	1	1															1
15. Combretum exalatum	2		3	8								8					32
16. Croton dichogamus							26			1							27
17. Cissus rotundifolia									1	8							9
18. Clerodendrum myricoides									1								1
19. Cassia singueana				1													2
20. Duosperma kilimandscharicum	2	10	5	2													19
21. Entada abyssinica		6		1		5	2	3		7	1	4			1		31
22. Euphorbia heterochroma																	
23. Erythrococa bongensis		1	2	1		1	5	4									14
24. Grewia bicolor		3	5	5		1	2	1									17
25. Grewia similis		13	4	5		3	9	7	6	2	14			1	1	4	69
26. Grewia villosa		4	1	1											2		8
27. Grewia trichocarpa									3								3
28. Glycine wightii										1	6						7
29. Hoslundia opposita	1	2	2	2		5	3	1									13
30. Hibiscus aponeurus	4														9	1	14
31. Grewia hexamita	3																3
32. Hermannia alhensis													17				17
33. Ipomoea kituensis											4		10				14
34. Lannea schimperi	1		1	2					2				2	1	4		13
35. Lantana trifolia									2		7						9
36. Lepidagathis scariosa									7							1	9
37. Lippia javanica	2					11				1							15
38. Maerua trichophylla		1		1													2
39. Maerua sphaerocarpa	1																1
40. Maytenus putterlickoides							1	3		1							5
41. Ocimum basillicum								3	26		5				4	3	41
42. Ocimum kilimandscharicum													8			1	9
43. Ochna insculpta		1	3	5	5	18	31	72	17	2	47	7	4		2	2	216
44. Pavonia patens						1											1
45. Premna holstii		2	10	2	2	2	3	6	13		14	4					58
46. Platycelphium voense									1	1							2
47. Ruttya fruticosa							20										20
48. Rhamnus staddo												1					1
49. Rhyncosia minima											20						20
50. Rhoicissus revoilii									1		1				2		4
51. Satureia biflora									2		12						14
52. Solanum sessilistellatum											1				1		2
53. Solanum incanum													6				6
54. Sansevierеia raffillii															3		3
55. Solanum renschii	1	1															2
56. Tephrosia villosa							15					47		20			83
57. Thylachium africanum								2									2
58. Sansevieria consoicua															7		7
59. Tennatia sennii			1	1	1						2						5

Grasses	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	total
Panicum reptans																	
Chloris roxburghiana																17	17
[illegible] Digitaria macroblephara													3				3
Digitaria velutina																	
Enteropogon macrostachyus												5		7	13		25
Eragrostis racemosa													10				10
Eragrostis superba													2				2
Panicum deustum		8										13					21
Panicum maximum													4			2	6
Panicum brevifolium	40																40
Perotis hilderbrandtii													7			1	8
Aristida Keniensis													5				5
total																	132

Botanical composition of understory vegetation per quadrat of 2m by 2m

Species	1 A	1 D	2 A	2 D	3 A	3 D	4 A	4 D	5 A	5 D	6 A	6 D	7 A	7 D	8 A	8 D	9 A	9 D	10 A	10 D	11 A	11 D	12 A	12 D	total
Achyranthes aspera					10													1							11
Astripomoea hyoscyamoides																	4						1		5
Acacia brevispica						9		7	6	2	1	-	18	-	2	-	-	-	-	5					50
Acalypha fruticosa	-	16	-	-	-	25	1	10	20	4	4	1	19	2	15	3	-	1	-	-	2				103
Albizia antihelmintica												1	2	-	-	13	10	-	-	1	-	1			28
Bothriocline somalensis				1																					1
Barleria sp.K.	3	8	2	-	54	17	83	15	51	32	15	5	-	-	-	-	-	-	-	-	-	-	-	-	287
Blepharis integrifolia							5	1							3	-	10	1	-	-	66	-	8		99
Boscia angustifolia												2													2
Barleria vetricosa	12	60			20	-	2	8	-	7			-	1	-	4									114
Barleria submollis							30	[illegible]	24	-	3	15	17	-	72	50	-	-	21	1	-	6	1	-	275
Cassia singueana					4	1																			5
Crotolaria verdcoutii									-	1															1
Plectranthus teitensis															1										1
Combretum exalatum									1	-	-	3	-	-	2	5	2	-	6	2	2	-	2	-	25
Commiphora riperia													4	1				1	1	-	3	2	1	-	12
Cyphostemma orondo																			2	-	-	2	-	3	7
Combretum Molle																			.1						1
Croton dichogamus					7	1	-	[illegible]	1	-															9
Commelina benghalensis	1	1	24	5	2	-	2	1	9	-	8	9	24	-	-	9	-	-							86
Euphorbia heterochroma																									
Entada abyssinica	4	-																				1			5
Eriosema jurionianum			-	9																					9
Evolvulus alsanoides																	4						1		5
Erythrococca bongensis					2	-															1	2	-	1	6
Grewia villosa							-	4																	4
Grewia hexamita										7				1											8
Hoslundia opposita					1	2	3	2	-	1	2	-	3	10	-	-	3	1	-	-	5	-	-	4	37
Ipomea kituenis							5	-	-	7	1	1	1	4	1	-			1	-	-	1	1	1	24
Indigofera spicata	-	-	3	1	-	1	-	1	6	2	2	1					1						1		19
Lepidagathis scariosa																					-	7			7
Lippia javanica	1	3	-	-	4				1																9
Leucas glabrata	8	25	-	-	-	149	-	-	63	-	116	30	48	19	29	7	-	24	-	5	10	15	114	-	692

Lannea fulva						1																			1
Melhania velutina	-	-	17	4																					21
Nothosaeva brachita																			23						23
Oxygonum sinuatum	-	5	2														10								17
Ocimum basilicum	-	-	1	-			-	11															2	-	14
Ochna insculpta	-	-	-	-	5	4	4	27	6	3	1	4	7	4	3	4	1	3	-	-	4	-	-	4	89
Pavlopsis imbrica							-	2	-	-	1	-	1	1	-	-	-	-	-	2	5	2	-	7	21
Pavonia patens	[illegible]																								[illegible]
Premna holstii	-	-	-	-	2	-									3	-					2	1			8
Pupalia lappaceae	-	-	-	-	-	2	2	-	4	-	1	-	6	2	6	-	6	31	-	-	1	1	-	1	64
Solanum renschii	-	-	-	1											1	-	1	-	1	-	-	-	1	1	6
Stylosanthes fruticosa	-	-	2	-																					2
Sida cuneifolia	-	-	-	18																					18
Sansevieria raffillii																			3	-					3
Tennatia sennii							6	-	-	1													-	1	8
Tephrosia villosa	-	-	21	56																			2	-	79
Trichodesma zeylanicum																			1						1
Thylachium africanum							2	-																	2
Vigna vexillata																	10								10
total																									2306
Grasses																									
Aristida kenensis	-	-	7	5													-	1					10	-	23
Chloris roxburghiana	-	4	7	-	2	-													-	-	1	-	40	-	54
Panicum reptans	-	-	3	14	-	1							-	2	1	62	1	10							94
Digitaria velutina	-	6	-	-	1	-	-	1	-	-	-	4	-	-	-	-	-	44				1	2	4	63
Euchinochloa haploclada	-	-	3																-	36					39
Enteropogon macrostachyus	-	-	-	2	-	1	-	55	-	2	-	9	-	1	2	-	-	134	-	1	27	3	30	45	312
Eragrotis ciliamensis	-	-	-	-	-	-	12	-	-	-	9	-	-	-	3	-	4	-	-	-	-	-	3	-	31
Eragrostis racemosa	-	-	-	5																					5
Eragrostis superba	-	-	-	123																					123
Heteropogon contortus	-	-	-	18																					18
Perotis hilderbrandtii																	2								2
total																									794

Appendix 7 <u>U N I V E R S I T Y O F N A I R O B I</u>

Department of Agricultural Engineering

Questionnaire On The Subject of Land Degradation and Its Control In Kibwezi, Kenya

District - Machakos

Division - Kibwezi

Sublocation/

Location -

Writer - Louis Gachimbi

Farmer's Name -

Date -

Part 1 <u>Questions to Farmer</u>

1. Has land been demarcated or registered.

    1. Yes
    2. No
    3. N/a

2. Farm holding ....(unit...........)

3. Land under cultivation (cropped)...................acres (unit.......Ha.)

4. Which is the most important crop grown?

    1. Beans
    2. Cowpeas
    3. Pigeon peas
    4. Maize
    5. Sorghum
    6. Millet
    7. Others (specify)

....-

5. Which is the most important pulse?

1. Beans
2. Cowpeas
3. Pigeon peas
4. Other (specify)........................
5. N/A

6. Which is the most important foodstuff?

1. Maize
2. Cassava
3. Millet
4. Sorghum

7. How long have you cultivated the same land?...........years.

8. Have you noted any change in yield?

1. No change
2. Slight decline
3. Major decline
4. Slight improvement
5. Major improvement

9. How long have you been settled here?....................years

10. Why did you settle in this area?

1. Was a squatter here before 1966
2. I purchased the land from an individual
3. I inherited the land from my parents or grandparents
4. Was settled by the government in 1966
5. Other (specify).................................

11. What area of the land you cleared and cultivated is now out of production?.....................acreas ....(units............ha.)

12. What was the main reason why the land has been out of production?

1. Erosion
2. Declining yields
3. Wildlife menace
4. Others (specify)....................................

13. For how long has the land been left?................................years

14. Did you do anything to restore the grass cover on the abandoned cropland?

1. Yes
2. No
3. N/A

15. If yes, what were the main measures used.

1. Cultivated and planted grass
2. Planted grass without cultivation
3. Cultivated and left it bare
4. Kept livestock out to allow natural recovery
5. Other (specify)..
....

16. Which of the following do you think is the main reason for the land to become bare or denuded?

1. Overgrazing
2. Drought
3. Termites
4 Other (specify)..

17. If grass has been planted which species seems most effective?

1. Eragrostis sp.
2. Cenchrus sp.
3. Cynodon sp.
4. Panicum sp.
5. Other (specify)...............................

18. Which of the following listed factors do you think is the major cause of soil erosion on your farm?
    1. Sudden rainstorms which comes when the land is bare
    2. Crops grown do not cover the ground most of the year
    3. Land too steep
    4. Overgrazing and consequently lack of cover
    5. Other(specify)..........................
19. What is the magnitude of soil erosion during heavy rains?
    1. Very great
    2. Great
    3. Moderate
    4. Very slight
20. What is the major evidence of soil erosion on cropland?
    1. Gullies
    2. Sheet erosion and rill erosion
    3. Deposited sediment
    4. Exposed subsoil, rocks + roots
21. What main measures do you undertake to prevent soil erosion?
    1. Put a trash line to intercept runoff
    2. Plant grass strips
    3. Construct fanya juu terrace
    4. Construct a stone terrace

5. Other (specify).....................................

22. When were the main soil conservation works i.e. in Q21 introduced?.........year

23. Was this done on a advice from Ministry of Agriculture or own initiative?

1. Own initiative

2. MoA

3. N/A

24. Since then, has there been any improvement in yields of crops grown?

1. Yes

2. No

3. Not sure

25. If no increase in yields has been observed, do you think the following factors contributed to the decline?

1. Poor design leading to measures being washed away

2. No rain since installation

3. Land is not fertile

4. Other (specify)...-
....

26. What is the area of grazing land? ....acres (unit ....ha.)

27. What area of your grazing land has never been cultivated?...acres (unit.....ha)

28. What area of the grazing land is abandoned cropland?
.........................acres (unit...........ha.)

29. How many acreas of the natural bush land is bare (i.e. area

used for grazing) land?...........acres (unit ....ha.)

30. Which of the following reasons contributed to bare land?

1. Overgrazing
2. Bush clearing for fuel/wood + charcoal
3. Termites
4. Other (specify ========

31. How many livestock units do you maintain on your farm (take one livestock unit to be equivalent to be one cow and its calf or equivalent to 5 goats or 5 sheep.....(goats/cattle ... ...l.u)

32. Is the population of either of the following livestock increasing or decreasing as compared to their respective population more than twenty three years ago or compared to when you settled?

1. Cattle decreasing
2. Cattle increasing
3. Goats increasing
4. Goats decreasing
5. N/A

33. If answer to Q32 is decreasing, which of the following fits as to why the number is decreasing?

1. Died due to lack of forage
2. Had to sell them to meet domestic demand
3. Changed the species from local breed to exotic breed and this needed few of them to meet my domestic demands.
4. Other (specify)...................................
....

34. Which is the main methods of livestock rearing?

1. Free range grazing

2. Tethering the animals on the grazing land

3. Zero grazing

4. Other (specify)....................

35.If you answer to Q34 is "3" What is the main fodder used?

1. Crop residue

2. Nappier/bana grass

3. Other(specify) ....

36. Are the soils in the denuded area sealed?

1. Yes

2. No

37. What are the main measures used to control erosion on grazing land?

1. Fanya juu terraces

2. Cut off drains

3. Paddocking to control grazing

4. Semicircular bunds/pits to catch runoff

5. No measures

6. Other (specify)....................................

38. When were the above conservation measures installed on your grazing land........years

39. Have you planted any trees?

1. Yes

2. No

3. N/A

40. What was the main purpose of the trees?

1. Fruits

2. Fuel wood

3. Fodder

4. Building posts

5. Other (specify)..................................

41. What are the most common trees (species) planted?

1. Citrus

2. Cassia sp.

3. Mangoes

4. Neem

5. Other(specify)

....

Part II Questions answered from observation by enumerator

1. Severity of erosion on cropland. (scores 1-5, one for slight, severe = 5)

1. Gullies/gully ....

2. Exposed subsoil/crop roots/rooks ....
....

3. Sheet/rill erosion.............................

4. Surface sealing.................................

2. Soil conservation measures on cropland.

2.1. Terrace types

1. Bench <u>Number of them</u>

2. Transhline

3. Fanya juu

4. Grass strip

5. Cutoff drain

2.2 Residue cover (score 1-5 as above)

2.3 Vegetation cover on terrace banks (score 1-5)

Plenty = 5, nil = 1

2.4 Name of grass (veg) cover used

3. Soil conservation on grazing land. (score for the following measures i.e. 1-5, one for nil, and abundant = 5)

Paddocking

Terracing

4. Overall ground cover score, very poor = 1 V. good = 5).

Perennials (sparse = 1 Abundant = 5)

Annuals (sparse = 1, abundant = 5)