A COMPARISON OF DIFFERENT GRASSES AS FILTER STRIPS FOR SOIL AND WATER CONSERVATION ON CROP LAND

By

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a degree in any university.

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DEDICATION

This thesis is dedicated to the entire Mwaniki family for their encouragement and prayers for success in all my academic endeavours.

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LIST OF ABBREVIATIONS

AIC = Agricultural Information Centre.

ASAE = American Society of Agricultural Engineers.

ANOVA = Analysis Of Variance.

C = Carbon.

Ca^{++} = Calcium ions.

CF = Crude Fibre.

Chap = Chapter.

cm = Centimetres.

CP = Crude Protein.

CRBD = Completely Randomised Block Design.

DAP = Diammonium Phosphate.

DFR = Department of Forestry Resources.

DM = Dry Matter.

F = Value to describe the significance level of two or more variables in an analysis Of variance (ANOVA) test.

FAO = Food and Agricultural Organisation.

FS = Filter Strip.

g = grammes.

hrs = Hours.

ha = Hectare ($10,000m^2$).

I = Rainfall Intensity (mm/hr)

IDS = Institute Of Development Studies.

K = Potassium.

KE = Kinetic Energy ($Jm^{-2}mm^{-1}$)

Kg = Kilogramme.

KSh = Kenya Shilling.

m = Metres.

m.e = Milliequivalents.

MOA = Ministry Of Agriculture.

mm = Millimetres.

N = Nitrogen.

Na^+ = Sodium ions.

NCPB = National Cereals and Produce Board.

NFE = Nitrogen Free Extract.

pH = Level of acidity or alkalinity.

P = Phophorous.

p.p.m = parts per million.

pvc = Polyvinyl Chloride.

SAREC = Swedish Agency for Research Cooperation with developing Countries.

Wks = Weeks.

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ABSTRACT

The experiment involved comparing three types of grasses when used as filter strips for soil and water conservation on cropland. The slope of the land was approximately 8%. The soils were the eutric nitosols developed from the Nairobi trachytes (Gachene, 1989). These soils are deep and well drained.

The three grasses tested were the napier grass (Pennisetum purpureum), Nandi setaria (Setaria anceps) and the tall signal grass (Brachiaria ruziziensis). The experimental design used was the completely randomised block design (CRBD). This comprised of three blocks that were 3 m apart. Each block comprised of four plots that were 2 m wide, 11.6 m long and 0.5 m apart. The four treatments (the control and the three types of filter strips) were randomly distributed within each block using random number tables. The grass filter strips (0.5 m wide) were established at the lower end of the plots using splits from the nearby grass bulking site. Pure stand crops of maize and beans were planted during the long and short rains respectively.

The run-off and eroded sediments collection and storage involved a collector unit at the downstream side of each plot. From the collector, the run-off and the sediments were conveyed to the main run-off storage tank (approximately 1 m^3) through a pvc pipe. The pipe was 3 m long and 6.4 cm in diameter. A small drum of approximately 0.09 m^3 was put inside the main run-off storage tank. The small drum was for storing run-off from light storms and also most of the eroded sediments were stored here for ease of removal and measurement. Apart from run-off and soil loss, other parameters measured were the crop height, crop yields, soil moisture and the fodder potential of the grasses.

The four treatments showed no significant difference in run-off and soil loss reduction during the long rains of 1990. This was well shown by the low soil loss reduction efficiencies. The efficiency during this season was 2.6, 4.0 and 13.6% for the napier, setaria and brachiaria respectively. This improved during the short rains of the same year whereby, the napier filter strip attained 17.7%. The setaria only improved to 5.9% while the brachiaria had 58.8%. During the long rains of 1991, the napier strip gave a run-off reduction efficiency of 40.5%, the setaria filter strip had 29.7%

while the brachiaria one had 68.9%.

Similarly, the treatments had no significant difference in soil loss reduction during the long rains of 1990 but improved with time as in the case of run-off reduction. The napier, setaria and brachiaria strips had a soil reduction efficiency of 3.8%, 7.9% and 19.0% respectively during the long rains of 1990. For the short rains of the same year, the napier strip had a soil reduction efficiency of 93.0%, the setaria strip had 81.9% while the brachiaria one attained 94.7%. The strips maintained high efficiency in soil loss reduction during the long rains of 1991 whereby, the napier filter strip had an efficiency of 75.6%. The setaria and brachiaria strips had 67.5% and 92.8% respectively. In overall run-off reduction efficiency, the filter strip of brachiaria was the most effective followed by the napier and lastly the setaria filter strip.

The filter strips were noted to have minimal adverse effects on the nearby crop. It was only the napier which was observed to a substantial adverse effect on the first one or two rows of the adjacent crop. Where a filter strip was planted, one row of maize or two rows of beans were foregone. In overall crop yields, the treatments had no significant difference. Though the filter strips were found to utilize the soil moisture around them, they conserved more a short distance away from the strip edge.

In the case of fodder potential, the strips of napier, setaria and brachiaria had an annual dry matter yield of 8.8, 2.5 and 2.7 Kg/m^2 respectively. This was from green fodder yields of 46.7, 12.4 and 11.7 Kg/m^2 for the napier, setaria and brachiaria respectively. Together with important nutrients content, the napier was the most superior followed by the brachiaria. The benefits of the fodder and the conservation of the soil and water were found to compensate for the crop area taken up by the grass filter strips.

1.0 INTRODUCTION

1.1 Background Information

Man's future profit can not be secure nor can his conscience be clear if he allows irreparable damage to the soil (Aldrich and Leng, 1965). Care of the soil is essential to the survival of mankind. This is because the soil provides most of the food required, fibres for clothing and wood for fuel and building materials (Omoro, 1985; Constantinesco, 1976). Soil erosion washes away the top soil which contains valuable plant nutrients such as nitrogen, phosphorus and organic matter. Erosion of the soil also results in a deteriorated soil tilth.

When the soil erodes, the farmer has to incur more costs in terms of more fertilizer purchase. This is because he has to improve the soil fertility for improved yields. The loss of soil through erosion also results in reduced soil water storage capacity and soil structure deterioration. This can reduce crop performance considerably.

Conservation of soil and water resources is of great concern in Kenya. It is also notable that African agricultural development is based on conservation of the two resources. This is because enhancement, conservation, maintenance and protection of the environment helps in improving the living standards, employment and productivity (Geoffrey, 1989). For example, for many years, Kenya shall continue to rely heavily on agriculture (MOA, 1990). This therefore requires more emphasis on proper soil and water conservation plus appropriate technology. turn to page 16.

However, with the rapidly increasing population, Kenya continues to face a soil erosion problem. This is clearly shown by the denuded and eroded fields in many parts of the country and the various research findings. For example, Barber (1983) warned that soil depth will be drastically reduced if no improvement on conservation measures is achieved. Studies by Dunne and Ogweny (1976), Dunne *et al*, (1978) and Edwards (1979) indicate high rates of sedimentation and siltation in reservoirs. This generally suggests increasing soil erosion rates in Kenya. The high population growth rate and hence increased land pressure has led to steep slopes cultivation and increased cultivation in marginal areas. This has worsened the erosion problem. For example, erosion has also become a problem in the high potential areas, especially in some parts of Central Kenya. Here, there is intensive steep slopes cultivation with annual crops and often without effective conservation measures (Gachene, 1982). This has resulted in very high erosion rates in such areas.

Selection of a desirable conservation measure is difficult (Kilewe *et al*, 1983). This is because it must satisfy several requirements such as:

(i) Provision of an economic level of crop production.

(ii) Erosion and run-off control.

(iii) Limit nutrients movement from agricultural land.

This therefore implies that the aim of soil conservation is to obtain maximum sustainable production level while permitting soil formation rate to keep pace with erosion rate (Morgan, 1986).

However, the type of soil and water conservation measures effective in a certain area depends on the soil type, climate and land slope among other factors. Morgan (1986) also noted that it is important that soil conservation strategies are based on:

(i) Soil protection against rain drop impact.

(ii) Increasing infiltration.

(iii) Increasing soil aggregate stability.

(iv) Increased surface roughness.

Gachene (1982) also noted that planning and design of such conservation measures ought to consider what are the tolerable soil erosion losses. It is also important to consider the run-off data for a given situation. Unfortunately, he notes that there is inadequate data on erodibility and run-off susceptibility of the different soils in the country. Such data if available and sufficient, could be used in the design of suitable conservation measures.

On gentle slopes and where erosion risk doesn't need mechanical measures, simple measures such as grass strips can sufficiently reduce run-off and soil loss (Hudson, 1981). Such strips are also referred to as filter or buffer strips (Wenner, 1980; Roose and Bertrand, 1971 and ASAE, 1981). Some of the advantages of using grass filter strips as a conservation measure include:

(i) Reduced run-off and soil loss.

(ii) Minimum soil disturbance.

(iii) Potential fodder source.

(iv) Can be a cheap way of establishing bench terraces.

(v) Mulch provision.

(vi) May lead to increased crop yields due to the fertile top soil and moisture conservation.

(vii) May be a suitable thatching material among other possible uses.

However, little research work has been done on grass strips as a conservation measure. Therefore, further investigations are needed, for example on which grass species are suitable as filter strips while having important alternative uses. There is also the need to quantify the risk of grass competition with the adjacent crop. Such aspects are important in determining the ease of adoption of grass filter strips by the farmers.

1.2 Importance of the Study

The research study was geared towards investigating an area which is an important aspect of soil conservation in Kenya. Biological or vegetative conservation measures are gaining popularity in this country due to their many advantages. The aspects that make this research study important are that:

(i) There is an increasing adoption of grass filter strips as a soil and water conservation measure in Kenya. The increasing trend of adoption has been noted through field surveys for example, in Narok (Tefera, 1983), Nandi (Kimutai, 1979), Embu (Viertmann, 1980) and Kiambu (Mati, 1989) districts. The Ministry of Agriculture (Kenya) annual reports also indicate such trends especially in Central Kenya and some districts in the Eastern province (Tefera, 1983).

(ii) Farmers also tend to favour less laborious and cheap conservation measures of which grass strips are a good example.

(iii) The soil and water conservation strategy (the Catchment Approach) in Kenya, currently has a lot of emphasis on biological measures.

(iv) The study has also come up with some of the advantages and the negative effects of using grass filter strips as a conservation measure e.g. fodder provision, run-off control, soil loss reduction and the effect on the crop planted.

1.3 Objectives of the Research Study

The objectives of the research study were geared towards applied research. The investigations were therefore expected to come up with possible recommendations to farmers on the use of grass strips as conservation measure. The objectives of the study were therefore to:

(i) Determine the effectiveness of some common grasses in controlling or reducing run-off as filter strips.

(ii) Determine the effectiveness of the filter strips in reducing soil loss.

(iii) Determine any effect of the filter strips on crop yields.

(iv) Determine the fodder potential of the grass species when used as filter strips for conservation purposes.

2.0 LITERATURE REVIEW

2.1 Soil Erosion Processes

Soil erosion processes are discussed under the following headings.

2.1.1 Factors Affecting Soil Erosion

The main factors that control the working of the soil erosion system includes soil nature, climate (especially rainfall), topography and plant cover. Other factors influencing the rate of erosion are cultivation practices and socio-economic factors.

2.1.1.1 Rainfall And Temperature

The rainfall amount, intensity and duration are critical in causing soil erosion. The intensity is the most important in erosion by overland flow and rills (Morgan, 1986). For example, the average soil loss per rain event increase with an increase in storm intensity.

Rain drop erosion (Splash) (Wenner, 1981) can take place on:

(i) Both level and sloping ground.

(ii) Soils with finely graded particles.

(iii) Soils where the size and velocity of falling rain drops is on the higher side when compared with the size and velocity of rain drops from a rainfall with an intensity of between 25 mm/hr and 100 mm/hr.

The most suitable expression of rainfall erosivity is an index based on the kinetic energy (KE) of the rain. This therefore means that erosivity of a rainstorm is a function of its intensity, duration, rain drops mass, rain drops diameter and their velocity. Therefore, the general relation between KE and rainfall intensity (I) is given by the expression $KE = 11.87 + 8.73 \text{ Log}_{10} I$ (Morgan, 1986). For tropical rainfall, the expression is $KE = 29.8 - 127.5/I$ (Morgan, 1986).

The higher the rainfall intensity, the larger the rain drop size and the higher the velocity. In normal rain, rain drop can be 1 mm in diameter and falling at 4 m/s. For a heavy rain event, the rain drop size can be 5 mm in diameter and falling at a velocity of 10 m/s. The energy of such a drop is 500 times greater than that of the 1 mm diameter drop.

Temperature affects the type of crops grown and the amount of ground cover. Cool temperatures means less evaporation and transpiration which results in increased moisture effectiveness. This therefore results in better ground cover due to better plant growth than incase of very warm temperatures. High temperatures lower the viscosity of water which therefore results in increased rates of infiltration and percolation. This therefore lessens surface run-off and hence reduced erosion.

2.1.1.2. Soil Type

The most important aspect is soil erodibility. This is the susceptibility of a soil to both detachment and transport by soil erosion agents. Soil erodibility depends on factors such as:

(i) The topographic position.

(ii) Slope steepness.

(iii) Extent of disturbance by man.

(iv) The soil inherent properties. For example, physical soil properties affects its infiltration capacity and extent to which it can be dispersed and transported (Kilewe, 1983). Such properties includes the soil structure, soil texture, organic matter content, moisture content and the bulk density. The soils chemical and biological properties are also important here. For example, divalent cations (e.g Ca^{++}) increases soil aggregation hence the soil becomes less susceptible to erosion. On the other hand, monovalent cations (e.g Na^{+}) decrease the aggregation and disperse the soil thus making the soil more susceptible to erosion (FAO, 1965). The quantity of organic matter affects the soil structure and soil water storage capacity. This is because the organic matter absorbs more water than the mineral fraction. The organic matter also forms water stable aggregates that increases soil porosity and permeability (Kilewe, 1983).

The clay particles combine with the organic matter forming soil aggregates or clods which reduces soil susceptibility to erosion. Base minerals such as iron, makes the soil more stable through chemical bonding of the agg:egates (Morgan, 1986).

2.1.1.3 Topography

Soil erosion normally increases with an increase in slope steepness and length. This is due to the respective increase in velocity and volume of the surface run-off. However, on soils that crack when dry, run-off may decrease with increase in slope length. On sloping ground, more soil is splashed down slope than up slope. On flat surface, the rain drops splash soil particles randomly in all directions.

The slope curvature (FAO, 1965) is also an important aspect. For example, convex slopes increases in steepness towards the bottom of the slope. This therefore means that the run-off velocity also increases towards the slope bottom. There is therefore more erosion towards the bottom of the slope. Concave slopes flatten out towards the bottom of the slope.

Therefore for convex slopes, no deposition occurs but only soil removal and hence these slopes becomes progressively poorer.

An increase in slope steepness also causes an increase in the intensity of wind erosion on windward slopes and on crests of Knolls. The relationship between erosion and slope (Morgan, 1986) can be expressed as:

$$Qs \propto \tan^{m}\theta \, L^{n}$$

where: Qs = Amount of erosion per unit area.

θ = the gradient angle.

L = the slope length.

m and n are exponents that vary according to other factors like the grain size of the material etc.

2.1.1.4 Plant cover

Vegetation reduces soil erosion by intercepting the rain drops. This dissipates their kinetic energy rather than being imparted to the soil (Morgan, 1986). Plant cover also dissipates energy of run-off and wind. It also imparts roughness to the flow thereby reducing its velocity and hence reduced erosivity. The effectiveness of plant cover in reducing erosion depends on:

(i) The height and continuity of the canopy.

(ii) The density of the ground cover.

(iii) The rooting density.

If water drops are falling from a canopy 7 m high, they can attain over 90% of their terminal velocity (Morgan, 1986). The rain drops intercepted by the canopy may also coalesce on the leaves forming large drops. All this results in the rain drops being more erosive. Roots of plants helps in holding soil particles against erosion. The higher the root density the more firmly the soil particles are held. The roots also increase the porosity of the soil hence increased infiltrability resulting in reduced run-off and hence less erosion.

2.2 Soil And Water Conservation Measures

Soil and water conservation measures are either agronomic or mechanical methods. Agronomic conservation measures are also referred to as biological measures. They are for soil protection and mainly utilize the role of vegetation in reducing erosion. Grass filter strips are an important example here. Soil management practices also are referred to as agronomic measures as described by Morgan (1986).

On cultivated sloping land, soil protection offered by vegetation or close-growing crops is not sufficient. This therefore requires support practices that will reduce and slow run-off (Walter *et al*, 1965). Such supporting conservation practices includes contour tillage, strip cropping on the contour, terrace systems and stabilised water ways.

Soil and water conservation measures are so interrelated that they can only be accomplished together (Troeh *et al*, 1980). Therefore, there are relatively few techniques for conserving soil that do not also conserve water. Reducing erosion keeps streams, pond and lakes from filling rapidly with sediments. This therefore results in better reservoirs capacities maintenance, flood control, power generation, sustainable and improved crop production and reduced pollution.

Planning for conservation requires knowledge on relations between factors causing soil loss and those assisting to reduce such losses on cropland. It is also important to consider specific guidelines needed in selecting conservation practices for a particular farm. This is because conservation techniques are many, varied and none has universal application (Troeh *et al.*, 1980). Some conservation techniques are restricted to certain conditions and others are widely useful. Others are expensive while some only require change of habit. The amount of erosion reduction also varies from one practice to another and one set of circumstances to another.

Land classification according to the slope and soil can be an important guideline in selection of conservation measures to adopt. For instance, according to Jaetzold and Schmidt (1982), the following are the classes according to slope for conservation purposes:

(i) Flat land, sloping less than 2%. Such land can be farmed without special conservation measures except contour farming.

(ii) Gentle slopes, 2 to 12%. Here, terracing is not a must according to the present Kenyan Agriculture Act (Chap 318). However, terracing is usually desirable on slopes exceeding 5%. In semi-arid areas and areas with erodible soils, even slopes of 2-5% usually need terracing.

(iii) Slopes exceeding 12% and less than 55%. Terraces (especially bench terraces) are necessary here if soil depth exceeds 0.75 m. For very steep slopes, modified bench terraces are recommended. This involves cutting narrow hedges into the slope.

(iv) Slopes exceeding 55%. These should be covered with grass and or forest. Such slopes however might allow cultivation of such crops like tea, sugar cane or bananas. For soils that are rocky, stony or shallow, use them for pasture, forest or construct stone terraces.

2.2.1 The Role of Crops in Soil Conservation

Control of erosion on cropland usually requires a number of conservation practices. Such practices also need to be combined with good farming techniques and management. Proper methods of fertilising, planting, rotating crops and pest control are therefore important here.

Early planting of crops results in better and healthy plants which protect the soil against erosion. Crop canopy intercepts rain drops to avoid direct impact on the soil. The crop roots also holds the soil particles against erosion. Mixed cropping is conducive to less soil erosion (Wenner, 1981). For example, beans have a better canopy cover than maize. Therefore, an intercrop of maize and beans has better erosion control than in the case of a pure stand of maize crop only.

The crop residue covering the ground also reduces rain drop erosion. This is by slowing down the water flows and increasing the infiltration of the soils. A crop that is well fertilized and managed has a better growth and hence provides good cover for the ground against erosion. Cultivation practices are therefore important in determining the role of crops in reducing erosion.

It is important to note that agricultural crops vary in their effectiveness in reducing erosion. This is because, it depends on the growth stage and the amount of ground exposed to erosion. For example, a bean crop field is less prone to erosion than a maize field at the early part of the rainy season when most erosion is expected to occur. This is because of the faster germination, higher plant density and the broader leaf cover achieved by the beans which provide very good soil protection. The crop maize has low plant density and slow ground cover development that provide very minimal soil protection against rain drop impact. Morgan (1986) noted that for adequate soil protection, at least 70% of the ground must be covered. However, as high lighted earlier, rain drops may coalesce on the crop canopy and fall with higher erosive power. This may be so with tall crops which provides greater heights of fall.

According to ASAE (1985), soil erosion can reduce crop yields by:

(i) Reducing the soil organic matter which contains important plant nutrients.

(ii) Decreasing the fine clays contents.

(iii) A reduction in water retention capacity.

(iv) Reducing the plant rooting depth.

(v) A reduction of plant nutrients most of which are in the washed top soil.

(vi) Soil structure degradation.

(vii) Non-uniform removal of the soil within a field.

Maize (zea mays) and beans (Phaseolus vulgaris) are the two most common food crops in most areas of this country. These two crops are therefore an important aspect when considering conservation on crop land in Kenya. Maize belongs to the family gramineae (Berger, 1962). It has a fibrous root system and individual roots may penetrate up to 2.5 m. For a rain fed maize crop, moisture deficiency is the greatest limiting factor to higher yields (Aldrich and Leng, 1965). In areas where maize is grown, yields of not less than 6000 kg/ha are considered satisfactory (AIC, 1981). The bean crop belongs to the family leguminosae and has a well developed tap root. The root can grow up to 90 cm into the soil (Kay, 1979). In East Africa yields vary from 225 to 670 Kg/ha (Kay, 1979). However, with better crop management coupled with efficient crop protection a yield of 1120 Kg/ha is attainable (Kay, 1979). All beans require a rich soil that has been well cultivated (Stanton, 1966). Erosion will therefore reduce their yields due to washing away of nutrients.

2.2.2. Grasses in Soil Erosion Control

On gentle slopes and where soils are not very erodible as mentioned earlier, simple measures can sufficiently reduce run-off and soil loss (Hudson, 1981). Grass filter strips are an important aspect of such simple conservation measures. Grass strips like other conservation measures reduce sediments entering streams. This contributes to reduced pollution and improved quality of water resources. The grass filter strips slow run-off, increase infiltration and provide habitat for microorganisms (ASAE, 1981). The grass strip is able to remove sediments efficiently by filtration, infiltration, adsorption, absorption, decomposition and volatilization.

The grass strips as highlighted earlier are also known as filter or buffer strips (Wenner, 1980; Roose and Bertrand, 1971) due to their way of functioning in run-off control and soil erosion reduction. Grass strips are also a kind of a wash stop (Wenner, 1981) because they distribute water flows into small non-erodible flows. This also increases infiltration. Other vegetative wash stops include trash lines, sisal hedges and bush hedges. Filter strips and sediments basins are primarily the two economical and widely used methods of removing sediments from water (ASAE, 1981).

Countries in Africa where use of narrow grass strips is common includes Kenya (Wenner, 1980), Tanzania (Rapp *et al*., 1973) and Swaziland (Hudson, 1987). Since the ground slope affects the flow velocity of run-off, the land slope of the area where to establish grass strips has to be considered seriously. The strips must also be laid out properly for erosion control. For example, Hudson (1981) recommended slopes of less than 4% for grass strips as a conservation measure. Roose and Bertrand (1971) suggested use of grass strips on steeper slopes. Hayes *et al* (1979) and Barfield *et al* (1979) worked on simulated vegetation on steeper ground slopes. They observed high sediment out flow concentration thereby reducing the grass strips trap efficiency.

Grass filter strips should also be of a minimum width that can effectively control most of the sediment load. However, the area of cropland taken up by the grass strips must be acceptable. This is important especially to small scale farmers where land is limiting. Wilson (1967) said that grass strip width depends on run-off rate, ground slope and the grass characteristics. Wenner (1977) gave 0.5 m to 1.5 m strip widths as the most common in Kenya. However, it was found that increasing the strip width beyond 0.60 m gave no significant differences in sediment trapping. This is because the upper edge of the strip is the most important (Tefera, 1983) in trapping sediments. Therefore, the type of grass used for filter strips establishment determines its effectiveness and suitability in run-off control. Some grasses, mainly the tufted ones, allow considerable amounts of run-off to pass without obstruction. A good example is Nandi setaria (Setaria anceps). Some stoloniferous and rhizomatous grasses grow low and provide less resistance to flow. Such grasses also spread into the adjacent crop area hence demand some maintenance labour.

Wenner (1977) recommended napier grass (Pennisetum purpureum) for grass strips establishment. However, this grass may compete with the adjacent crop for moisture and nutrients and also tend to leave gaps. Wilson (1967) gave the following as some of the requirements in the selection of grass types for conservation purposes:

(i) A deep root system to resist scouring in case of swift currents.

(ii) A dense and well developed top growth.

(iii) Resistance to flooding and drought.

(iv) Ability to recover growth.

(v) Yielding an economic return.

For more than 5 years now, the World Bank (Smyle and Magrath, 1990) has been promoting use of Vetiveria zizanioides (Linn) Nash or vetiver grass as vegetative barriers in conservation. According to the World Bank (1990), the following are some of the characteristics making a grass suitable for conservation purposes as a vegetative barrier:

(i) Forms a permanent denser hedge that slows run-off and spreads it out so as to infiltrate into the soil.

(ii) Has a strong fibrous root system penetrating and binding the soil to sufficient depth.

(iii) Requires little or no maintenance.

(iv) Has no germinating seeds and no stolons or rhizomes hence can not become a pest on cropland.

(v) Does not attract or harbour pests.

(vi) Its leaves and roots are disease and pest resistant.

(vii) Does not complete with adjacent crop for moisture and nutrients.

(viii) Ability to grow under xeric and aquic conditions.

(ix) Cheap and easy to establish.

(x) Performing well on a variety of soil conditions and having good fodder potential.

(xi) Use in paper production.

Grass characteristics are therefore important in determining its suitability for erosion control and ease of adoption by farmers. A farmer classifies a grass as useful or useless according to its agricultural value (Moore, 1966). This therefore means that the value of a grass depends on its productivity (yield), feeding value (chemical composition), palatability, persistency and earliness among other factors. The yield depends on its tillering ability, ease of recovery after grazing or harvesting and the growth duration for each season. Grasses are usually palatable at early growth stages. They also recover easily if some growth (approximately 2.5 cm to 5 cm) is left after grazing or harvesting. This also assists in controlling erosion in the early stages because the grass stumps can trap sediments and also slow run-off.

Some of the grasses commonly used in Kenya and other tropical countries as fodder grasses includes napier grass (Pennisetum purpureum), Nandi setaria (Setaria anceps) and the tall signal grass (Brachiaria ruziziensis). These grasses are also being used for erosion control in these countries. The grasses are also suitable for stabilising embankments of terraces. Napier grass is also referred to as elephant grass (Skerman and Riveros, 1989). It is a perennial with a vigorous root system and can grow up to 4.5 m high (McIloy, 1972; Skerman and Riveros, 1989). Napier grass is of high nutritive value and can yield over 180 tons of green fodder per year per ha (Skerman and Riveros, 1989; McIloy, 1972). It also gives very effective erosion control in its own ecological conditions.

Setaria anceps is a tufted perennial growing up to 1.5 m high and distributed through out tropical Africa (McIloy, 1972). Yields of up to 4.3 tons of DM per acre (i.e approximately 10.6 tons of DM per ha) were recorded in Tanzania (Soneji and Vrajlal, 1970).

Setaria anceps has 3.7% of oxalate content which can poison animals especially milking cows (Skerman and Riveros, 1989; and Whiteman *et al.*, 1980).

The tall signal grass (Brachiaria ruziziensis) is also commonly called Congo signal grass in Africa and prostrate signal grass in Kenya (Skerman and Riveros, 1989). The grass is easy to establish and able to maintain reasonably high crude protein content. It is non-toxic and yields of more than 21 tons of dry matter per hectare have been recorded in Tanzania (Skerman and Riveros, 1989). The grass is also useful for erosion control when it grows well.

The above three grasses are being used for erosion control as filter strips at the University's farm, Kabete, Nairobi. Other grasses performing well in erosion control and terrace embankments stabilization at the farm include:

(i) Makarikari grass (Panicum Coloratum var Makarikariensis).

(ii) Guatemala grass (Tripsacum laxum).

(iii) Bana grass (Pennisetum purpureum x Pennisetum americanum) i.e Bana grass is a result of a cross between napier grass and bullrush millet.

(iv) Donkey grass (Panicum trichocladum).

As mentioned earlier, vetiver grass is another grass type being promoted for conservation purposes by the World Bank (1990). This is being done mainly in Africa and Asia. Multiplication of this grass is being done at the University's farm, Kabete, Nairobi. This is for future trials as filter strips, vegetative barriers and terrace embankment stabilization vegetation. The grass is said to possess lot of advantages. For example, Greenfield (1989) noted that it is not attacked by pests (e.g. termites, rodents, etc.) and tolerates poor soils and long floods. The World Bank (1990) also cites the following as some of the other advantages making vetiver grass suitable for conservation purposes:

(i) Regenerates well at rains onset.

(ii) Has fire resistant stalks.

(iii) Does not encroach on crops.

(iv) Needs no maintenance.

(v) Its roots grow vertically into the soil hence does not interfere with the growing space of adjacent crop.

(vi) Forms good mulch for fruit and other trees.

Smyle and Magrath (1990) also noted that vetiver grass has ease of propagation and establishment. It can also be used for thatching, brooms, basket making, animals bedding, ornamental purposes and fodder. However, the grass is unpalatable to livestock. This means that they can only eat it in extreme drought conditions (World Bank, 1990). For example, farmers in Haiti are reluctant to adopt vetiver grass but voluntarily plant napier grass and Guatemala grass (DFR, 1990). They say this is because these last two species provide forage during the 4 months dry season. However, the unpalatable nature of vetiver grass means that it can be very suitable for erosion control in arid ares where free grazing is common. That is, it may not require much protection from livestock damage.

It is therefore noticeable that fodder provision and other benefits are important where grasses are to be used for erosion control. This is especially so in the high potential humid areas where land is scarce. For example, Young (1989) noted that where grass barriers are effective and acceptable for erosion control, trees can be planted on them for added benefits of fodder or fruits production. However, the benefits of grass strips in soil and water conservation may be short lived. This is because some farmers are tempted to dig up the strips once they become fertile through deposition (Staples, 1934).

The mechanism of how grass filter strips reduce run-off and soil loss involves several aspects. The strips spread the flow thereby reducing the velocity and causing sediment deposition (Wilson, 1967). The deposition is mainly due to the flow obstruction by the strips. There is also the adsorption of the negatively charged particles to the positively charged dead plant parts (Wilson, 1967). The main force retarding the run-off flow is the drag resistance. A large portion of this drag force is dissipated on the grass (Kao and Barfield 1978; Barfield *et al.*, 1979). Tollner *et al.* (1976) and Hayes *et al.* (1979) noted the following as some of the factors that determines the sediment deposition:

(i) Flow rate.

(ii) Particle size of the eroded material.

(iii) The filter strips spacing and width.

(iv) Grass elements density.

Foster (1982) also included infiltration rate as another factor affecting the flow's sediment transport capacity.

2.3. Field Observation And Research On Grass Strips

Little research has been done on grass filter strips in erosion control. There is also the need for further investigations on which grasses are most suitable for erosion control. Such grasses should for example, have other alternative uses as described earlier. There is also a need to quantify grass competition with the adjacent crop as emphasized earlier.

Planting of hedge rows is an old practice. However, few species have been found to have a mix of desirable characteristics. Such characteristics are expected to ensure permanency, effectiveness and ease of establishment and maintenance.

Tefera (1983) studied the suitability of Nandi setaria as grass strips for erosion control at Kabete, Nairobi. He was working on a eutric nitosol and on a natural slope of approximately 10%. The grass filter strips under comparison were of 0.5 m, 1.0 m and 1.5 m wide. It was observed that such filter strips can play an essential role in controlling erosion and water conservation. For example, the filter strips of 0.5 m, 1.0 m and 1.5 m wide gave soil losses of 35.4 t/ha, 35.6 t/ha and 17.8 t/ha respectively. The control plot gave 97.7 t/ha. The run-off from the 0.5 m, 1.0 m and the 1.5 m wide strip was 56%, 44% and 24% of the run-off from the control plot. The strips were less effective during heavy and intensive storms. However, the effectiveness improved with time as deposition extended up slope. Most sediment deposition occurred at or just along the upper edge of the filter strips.

Mati (1989) conducted a survey on cultural and structural conservation measures in Kiambu District, Kenya. She found that 29% of the farms visited had grass strips for erosion control purposes. Overall, 68% of the farms visited had grass strips for erosion control and fodder provision. She also found that the strips established easily due to the relatively wet conditions. After about 6 months it was found that the strips can be harvested for fodder. Then after 2 years, she found that they are well spread to control run-off. It was noted that on slopes of 4 to 20%, the strips were quite efficient and developed into bench terraces within 3 years. In Haiti (DFR,1990), napier grass and guatemala grass have been observed to perform well on slopes of up to 30%. This is in areas of 1700 mm of annual rainfall, with clayey soils.

Some research work on narrow grass strips has been done in Tanzania as reported by Christiansson (1989). This was done on cropping land with slopes of 3.5° (approximately 6%). The grass strips planted across cultivated plots reduced soil loss by 53% compared to plots with no conservation measures.

Othieno (1978) reported use of narrow strips of oats (a grass plant) between rows of newly planted tea plants in Kericho, Kenya. The tea plants were planted 1.22 m apart. Soil losses of 34.9 t/ha for the first year and 4.3 t/ha for the second year were obtained. The soil loss from the plots without oats strips were 161.4 t/ha and 48.3 t/ha for the first and second year respectively.

Neibling and Albert (1979) used a rainfall simulator at an intensity of 63.5 mm/hr for 2 to 8 hours in testing sod strips. The 1.83 x 6.1 m bare soil plots with sod strips of 0.6 m, 1.22 m, 2.44 m and 4.88 m widths established across the base of the plots gave the following conclusions:

(i) All the four sod strips reduced total sediment discharge rates by a factor of more than 10.

(ii) Increasing strip width beyond 0.63 m provides very little additional benefit if the purpose of strip is to reduce total sediment discharge regardless of the particle size.

(iii) As strip width increased, velocity of overland flow through the strips decreased slightly.

(iv) Changes in particle size distribution for sediment entering and leaving the strips were similar for all widths. However, for each case, the percentage of particles in size > 0.02 mm decreased while for those < 0.02 mm increased.

(v) Although the percentage of particles in 0.02 mm to < 0.002 mm range in the run-off leaving the strip was greater than the percentage of these particles entering the strip, sediment discharge rate of the particles decreased.

(vi) Due to the effects noted in (iv) and (v) above, almost all particles > 0.02 mm were deposited in or above the sod strips. An increasing large number of particles < 0.002 mm was deposited in the sod strip as strip width increased.

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The experiment was carried out at the University's farm, field 14, Kabete, Nairobi. The site was being used for research on soil and water conservation. The findings of a detailed soil survey (and other basic data) of the site by Gachene (1989) is as described below.

3.1.1 Altitude And Location

The altitude is approximately 1940 m above sea level and accessibility to the site is good (Gachene, 1989). The location of the site is 1°15 S and 36°44' E. It is approximately 12 km West-North-West of the Nairobi City Centre.

3.1.2 Climate

The site is in the semi-humid, agro-ecological zone III as described by Sombroek *et al.* (1982) using the Kenya soil survey agro-climatic zonation methodology. The area has a rainfall record of 18 years. The rainfall is of bimodal distribution (Long rains from March to May and Short rains from October to December). The mean annual rainfall is approximately 1006 mm. The average seasonal rainfall for the long rains and short rains is 506 mm (50.2%) and 285 mm (28.3%) respectively. The dry months contribute 215 mm (21.5%). The mean annual temperature using the equation T°C = 30.2 - 0.0065x where x is altitude in metres is 17.6°C. Potential evaporation is approximately 1727 mm and the evapotranspiration is estimated at 1152 mm.

3.1.3 Soils

Using the FAO-UNESCO system, Sombroek *et al.* (1982) and Gachene (1989) described the Soils of the site as follows:

(i) Are a eutric nitosol.

(ii) Developed on tertiary trachytic lava

(Nairobi trachytes) with a red clay A-horizon.

(iii) The A-horizon overlying a red B-horizon with a strong sub-angular blocky structure.

The soils of the site were also found to have an erodibility factor (K) of 0.04 according to Barber *et al* (1979). Gachene (1989) also found out that the soils are well drained red. The soil chemical fertility status in terms of available nutrients at 0-30 cm as found by Gachene (1989) was as follows on average basis:

(i) pH of 5.7.

(ii) C % 1.99.

(iii) N % 0.23.

(iv) P p.p.m. 14.60.

(v) Na m.e % 0.43.

(vi) Ca m.e. % 9.76.

(vii) K me % 1.69.

(viii) Organic matter % 3.44.

The soils were also found to contain 18% sand, 24% silt and 58% clay for the top 0 cm to 20 cm.

3.1.4 Experimental Plots

The experiment was carried out on 12 run-off plots arranged in 3 blocks as installed in 1981. However, several renovations and improvements were done on the plots set up for better and more accurate data collection. The soils and previous land use history of the experimental plots is as described below. The experimental site comprises an area of approximately 4 ha. Variations are expected even within such an area and therefore it is necessary to look at the conditions of the experimental plots.

3.1.4.1 Past Land Use History

According to Tefera (1983) and Nurzefa (1989), the past land use of the experimental plots is as tabulated below:

Table 1. Previous land use of the experimental plots.

Year / Period	Land Use /Activity
(i) 1975 to 1976	Pasture.
(ii) 1977 to 1980	Maize, beans and potatoes.
(iii) 1981	Potatoes only.
(iv) 1982 to 1983	Plots bare with grass strips at the lower end of the plots.
(v) 1984 to 1987	Grass strips still at the lower end of the plots, Maize crop in the long rains and a bean crop in the short rains.
(vi) 1988 Long rains	Maize crop on 6 of the 12 plots and beans on the other 6 plots.
(vii) 1988 short rains	Only a stone cover experiment conducted by Nurzefa (1989) up to early 1990

3.1.4.2 Soils of The Experimental Plots

The soils were found to be deep and well drained (Gachene, 1989; Tefera, 1983). Soil Samples taken by Tefera (1983) from the top 30 cm gave 22% Sand, 24% Silt and 54 % Clay. Soils of the first 0 to 3 cm were then found to contain 32% Sand, 60% Silt and 8% Clay. Sampling for the top 0-30 cm was finally done on

30/7/90 for both texture and chemical fertility. Texture wise, the soils were found to contain 18% Sand, 18% Silt and 64% Clay. The chemical fertility test gave the following results:

(i) pH 5.5.

(ii) Na m.e % 0.52.

(iii) K m.e.% 0.97.

(iv) Ca m.e % 6.0.

(v) P.p.p.m 7.5.

(vi) N % 0.29.

(vii) C % 1.64.

(viii) Organic matter 2.84 %.

3.2 Experimental Design

The experiment was set up on 12 existing run-off plots. The plots were arranged in 3 blocks each comprising of 4 plots. The plots were installed in 1981 and therefore were renovated and improvement also done on the various components to ensure accurate data collection. The slope of the ground where the experimental plots were installed was approximately 8%. The plots were 11.6 m long and 2.0 m wide. The length of the plots therefore represented a typical width of a forward sloping terrace or the distance between contour strips on sloping land.

The blocks were 3 m apart while the plots were 50 cm apart. The run-off plots were bounded by galvanized sheet metal. The sheet metal was stabilized by iron rods at intervals of approximately 1 m along the plot length. The galvanized sheet metal making plot boundaries was 20 cm wide of which approximately 10 cm was driven into the ground.

At the lower end of the plot was a collector connected to the main run-off storage tank by a pvc pipe (Conveyor). The pvc pipe (Conveyor was approximately 3 m long and 6.4 cm in diameter. The pvc pipe was placed at a slope to avoid deposition of some sediments as the run-off passes through it. The collector comprised of an end plate and a collecting trough as shown in Fig. 2. The end plate was for connecting the lower end of the plot to the run-off collecting trough. This avoided any run-off from passing under the trough as seepage. The run-off collecting trough was designed and fabricated with a slope of approximately 10% (Tefera, 1983) towards the centre from both ends. This was to avoid or minimise deposition of some eroded sediments within the collector. The design and set up of the experiment is as illustrated in Figures 1 and 2 below:

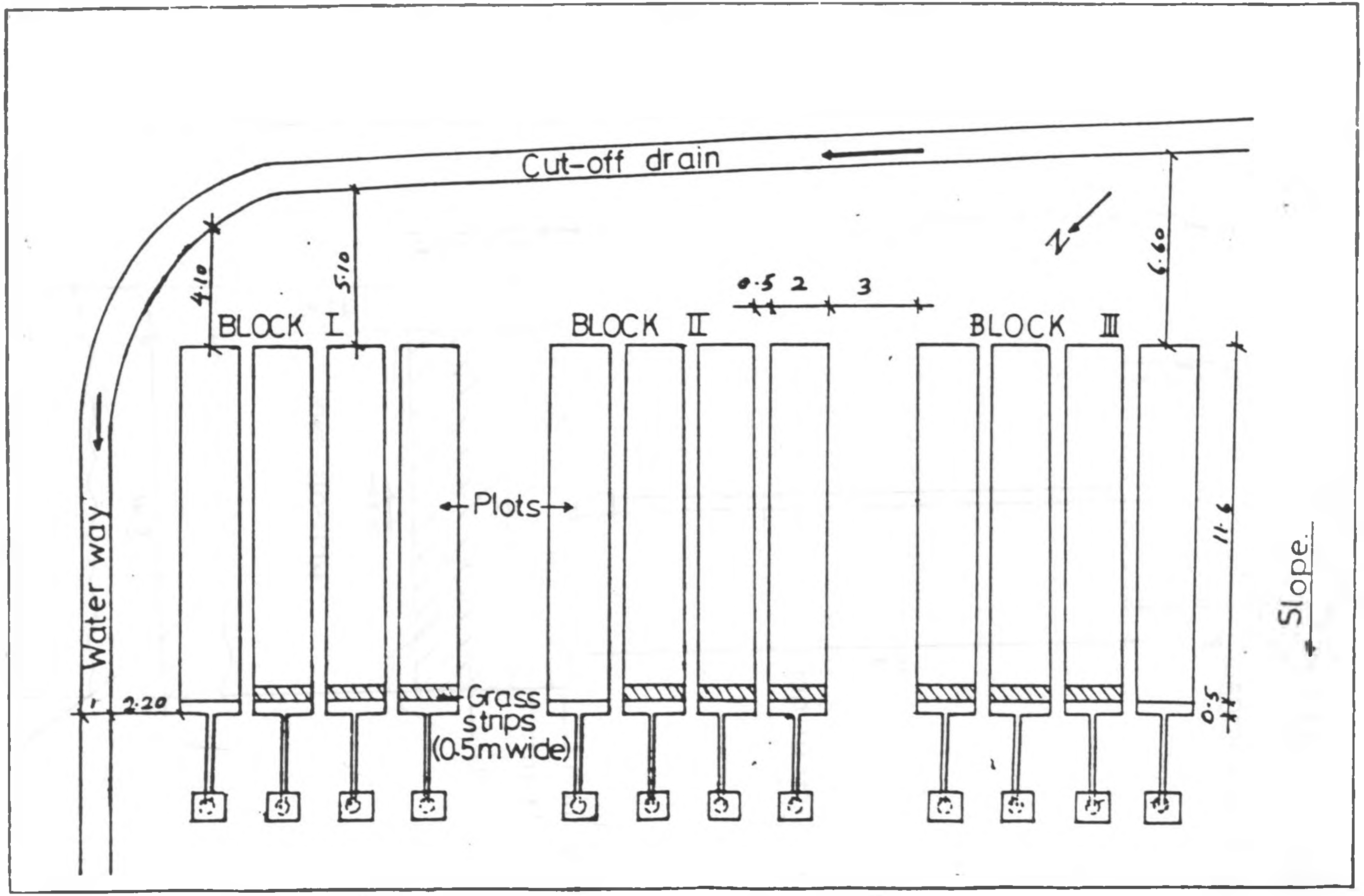

Fig. 1. Experimental layout. scale 1:200 dimensions in metres.

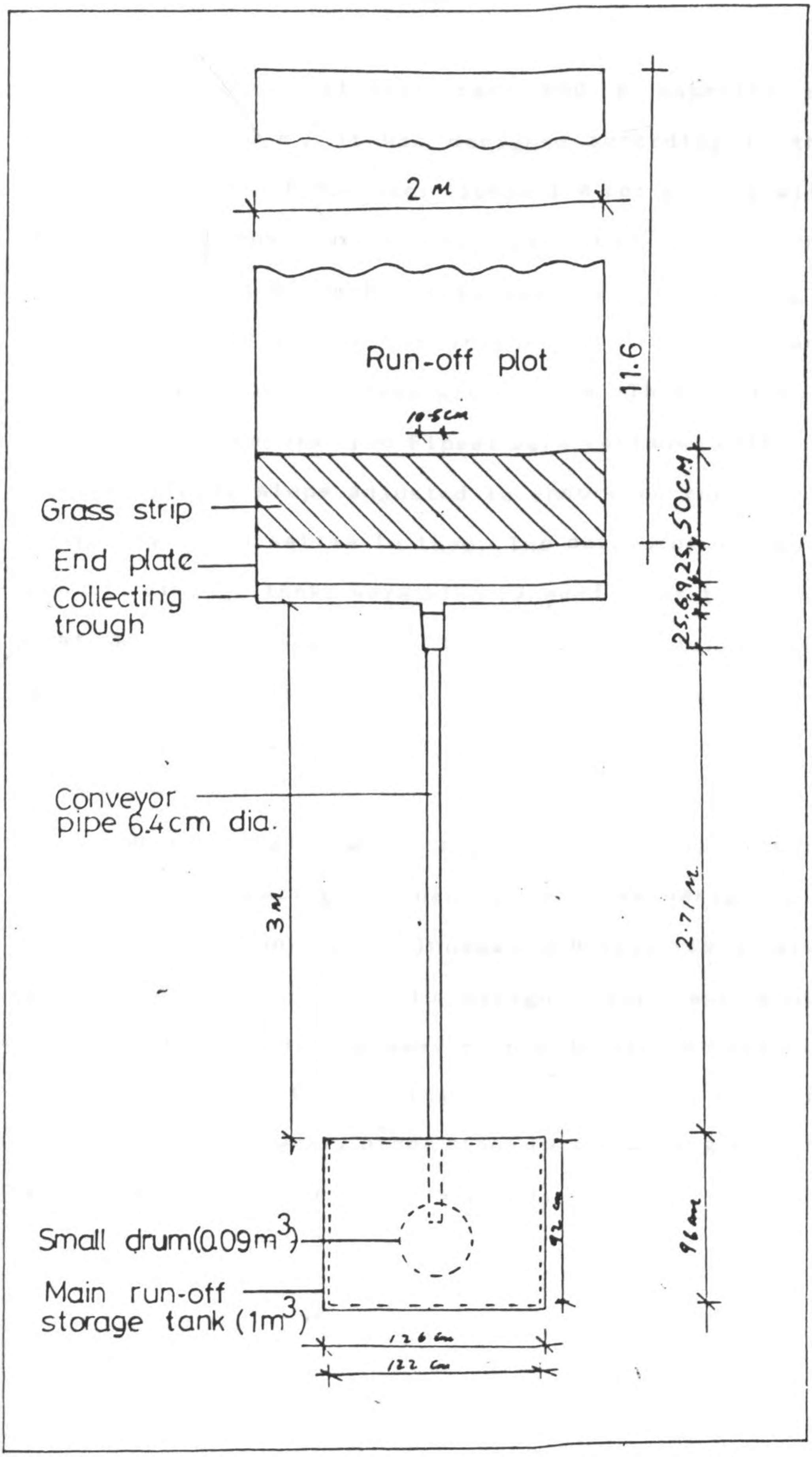

Fig. 2. Run-off source, collection, conveyance and storage system. scale 1:33 1/3

The main run-off storage tank had a capacity of approximately 1 m^3. It was designed according to the recommendations of Mutchler (1963) i.e for a storm with a duration of one hour, a return period of 20 years and an intensity of 60 mm/hr. This was also by assuming a run-off coefficient of 50% (Barber *et al.*, 1979) and that the depth of soil loss was 0.24 mm (Thomas *et al.*, 1981). The conveyors (pvc Pipes) were replaced with new ones and their slope adjusted to ensure no run-off or sediments could settle in them. The covers of the main run-off storage tanks were also renewed so as to ensure that no rain drops could fall into the tanks. The details of the set up and dimensions of the various components were as shown in Figures 1 and 2 above.

It is notable that the spacing of grass strips can be based on the spacing of channel terraces design on a steep area (Hudson, 1971). Thomas and Barber (1979) also gave a proposal on how to design steep back slope terraces in semi-arid areas. Such a design can also be used to determine the spacing of filter strips for soil conservation. However, other other farm planning aspects should also be taken in to account.

The experimental design used for the experiment was therefore a completely randomised block design (CRBD). Such a randomised complete block design is done when an experimenter is interested in one set of treatments and wants to control an extraneous source of variability (Dowdy and Weaden, 1983).

3.3 Experimental Method

3.3.1 Treatments

Four treatments were involved and were randomly applied in each of the 3 blocks (replications) as follows:

(i) Control plot with no grass filter strip.

(ii) Plot with a 0.5 m wide filter strip (FS) of napier grass (Pennisetum Purpureum).

(iii) Plot with a 0.5 m wide filter strip of Nandi setaria (Setaria anceps).

(iv) Plot with a 0.5 m wide FS of tall Signal grass (Brachiaria ruziziensis).

The filter strips were planted on 20/3/90 at the onset of the long rains. The three grasses are common with farmers in Kenya and the tropics in general. The grasses are also doing well at the research site as noted earlier. The tall signal grass is becoming common in coffee growing areas of Kenya where it is planted on embankments of bench terraces. Napier grass is drought resistant and the tall signal grass also endures dry spells though it requires reasonably high rainfall. No toxicity has been experienced with napier grass though it contains small amounts of oxalates (Skerman and Riveros, 1989). Its optimum growth temperatures are 25°C to 40°C and prefers fertile, well drained soils in high rainfall areas (over 1500 mm annually). However, due to its deep root system, it can survive in dry times hence a mean annual rainfall of 1482 mm ± 620 mm is adequate.

Nandi setaria will not do well in low rainfall areas compared to the other two grasses. According to Skerman and Riveros (1989) and Soneji and vrajlal (1970), this grass is more common at altitudes of 660 m to 2660 m above sea level. It requires optimum mean growth temperatures of 18 to 22°C and a mean annual rainfall of 900 mm to 1825 mm.

According to Moore (1966), Soneji and Vrajlal (1970) and Skerman and Riveros (1989), the tall signal grass prefers well drained soils and rainfall of 1000 mm to 1500 mm. However, they say it endures hot dry spells as stated earlier. The grass also requires high phosphorous at early growth, establishes easily and maintains high crude protein even at late growth.

The filter strips in the experiment were established from splits and planted in two rows and in a staggering manner. The rows were 50 cm wide and the planted splits were approximately 10 cm apart. The rows were planted across the slope and no fertilizer or manure was used. The staggered planting was done to ensure a good vegetative barrier i.e run-off interception, especially before the grass strips were well established. The filter strips were located at the lower end of the plots as shown earlier in Figures 1 and 2.

3.3.2 Crop Planting

At the onset of the long rains 1990, a pure stand of maize (Variety H625) was planted. The spacing was 75 cm x 30 cm using one seed per hole and approximately 5 g of DAP per hole. Using the 75 cm inter row distance, the control plot had 16 rows while the plot with a filter strip accommodated 15 rows. This is because part of the crop area was taken up by the grass filter strip. The same maize crop was grown again in the long rains 1991 using the same procedures described above.

For the short rains 1990, a pure stand of bean crop (variety Rose coco, GLP2) was planted. The spacing was 50 cm x 15 cm using one seed per hole and no fertilizer. A pure stand of beans or an early maturing maize variety is favoured in this zone during the short rains. This is because the short rains are usually unreliable and minimal. The control plot had 24 rows (all rows of the crops planted across the slope as in maize). The plot with a grass filter strip had 22 rows because of the area taken up by the filter strip.

Manual weeding was carried out for both the maize and the bean crop. Two weedings were adequate since weed emergence was minimal. There was no serious experience of diseases or pests except an attack of the black bean aphid (Aphis fabae) on the bean crop. The short rains of 1990 were inadequate. The bean crop therefore did not get sufficient moisture especially during the late flowering and pod formation.

3.3.3 Crop Height And Yield Measurement

Except for the maize crop of the long rains of 1990, both crops had their heights monitored for the first 6 rows from the filter strip edge. This was carried out at 2 Wks interval starting from 2 Wks after germination. The height measurement was discontinued when the crop was seen to be mature enough such that no significant increase in height was expected. Any competition for moisture and nutrients between the grasses and the adjacent crop was likely to result in a stunted crop. The yields were also expected to be lower.

Incase of the crop not reaching maturity for grain harvesting, the height of crop was used to give an indication of the expected effect on crop yield. The total biomass can also be used in such circumstances. However, the farmer is mainly interested in the actual grain yields. An economic consideration on the effects of loosing part of the crop to filter strips also requires the actual grain yields and the fodder yields. The crops were harvested row wise and grain yields measured after the grains were dry enough for storage purposes.

3.3.4 Run-off And Soil Loss Measurement

A small drum of approximately 0.09 m^3 was placed inside each of the main run-off storage tanks as shown in Fig. 2 Plate 9. This was for small storms with little sediments. It was therefore easy to remove and measure the run-off from the drums than in the case of heavy storms which had run-off over spilling into the main run-off storage tank. Measurement and sampling for run-off and soil loss was done for every storm that produced run-off.

For normal run-off events, the run-of sampling procedure first involved thorough mixing of the drum contents until all sediments were evenly suspended. This was done only after washing the collector with some of the run-off so as to include the eroded sediments that had been deposited within the collector. A 20 litre capacity graduated bucket was used to determine the volume of the run-off. A representative sample was taken in 1 litre capacity sampling jar after thorough stirring of the bucket contents. Samples from the various buckets were then thoroughly mixed and representative samples taken in the 1 litre sampling jars. These final samples were taken to the laboratory for analysis of soil and water loss.

For heavy soil loss and run-off events, quick stirring will not suspend all sediment deposits (Dendy *et al.*, 1979). Therefore for such events, samples for both the run-off and the sediments were taken as described below. Here, the run-off was not disturbed while in the tank. The 20 litre capacity bucket was used to remove the run-off while noting the volume. The contents of each bucket were thoroughly mixed and samples taken in the 1 litre sampling jars. The samples were then thoroughly mixed and representative samples taken as described earlier. The sediments were finally removed using buckets and weighed using a spring balance. The sediments were then thoroughly mixed to attain uniformity. Samples were then taken in the 1 litre sampling jars for laboratory determination of water content and oven dry sediment weight.

In the laboratory, the run-off and sediment samples were analyzed using the evaporation method as described by

Dendy *et al.* (1979). The run-off and sediments were removed from the sampling jars and their volume and weight determined. For the wet sediments, only the weight was taken. This was done using an electronic balance with a precision of 0.1 g. The samples were then put in evaporation bowls and two drops of an aluminium hydrate ($AlK(SO_4)2.12H_2O$) was added to each of the run-off samples. This was to act as flocculant so as to have most of the suspended sediments settled. After approximately 12 hrs of settling, the clear water was decanted from the samples. The samples were oven dried at 105°C for approximately 24 hrs. They were then weighed after which further drying and weighing was done until constant weight was achieved. The results were used for computation of water and soil loss.

3.3.5 Grasses Fodder Potential Determination

The grasses were harvested at the recommended stages of growth. This is important in ensuring high nutritive value and palatability of the grass. McIloy (1972) noted that the nutritive value of a herbage depends on the following factors:

(i) Leaf/stem ratio. The higher the ratio, the more the nutritive value.

(ii) Stage of growth at harvesting or grazing.

(iii) Soil fertility.

(iv) Manure application.

(v) Climatic conditions.

The first harvesting was purposely delayed to ensure good establishment of the newly planted grass filter strips. The tall signal grass and the Nandi setaria were harvested at their flowering stages. This was when the grasses had approximately 50% to 60% of their stalks flowered. The tall signal grass however, showed less flowering during dry spells. Napier grass was harvested when it had reached a height of approximately 1.5 m. The harvesting was carried out using a sharp matchet. Stumps of approximately 7.6 cm were left to ensure quick recovery and some good sediment trapping efficiency during erosion.

The freshly harvested green fodder for each plot was weighed using a spring balance. Then it was chopped into small pieces and samples taken for dry matter (DM) and major nutrients content determination. In the laboratory, the fresh samples were weighed using an electronic balance correct to 0.1 of a gramme. The samples were then oven dried at 105°C for approximately 30 hours to remove all the free water. The samples were weighed again so as to determine the water content and dry matter.

The oven dry samples (DM) were then analyzed for the most important nutrient contents. This was carried out using the procedures of proximate analysis. The proximate analysis is regarded as the traditional method by which feeds and food are analyzed (Heath *et al.*, 1973). This method is a combination of analytical procedures developed in Germany over a century ago (Church and Pond, 1974). The nutrients determined were the crude protein (CP), nitrogen free extract (NFE) and the crude fibre (CF). These nutrients are expressed as a percentage of the dry matter. The proximate analysis was carried out as described by Berhane and Nganga (1984).

A survey was also carried out on the local prices of fodder grasses. Farmers around Kabete, Nairobi, were found to sell the local fodder grasses at approximately KSh 15 per a bag of approximately 27 kg. This price was used to value the green fodder harvested from the filter strips.

3.3.6 Soil Moisture Profile Measurement

Level grass strips are known to create level areas above the filter strips i.e benching effect due to deposition of the eroded sediments. The run-off from areas between the filter strips collects on the silty or sandy bench where it infiltrates into the ground (Wenner, 1981). This increases the soil moisture thereby creating a moisture zone on the upstream of the filter strips. However, this zone of moisture is not expected to extend more than a few metres from the filter strip edge.

The moisture content profile for the moisture zone was monitored at 40 cm, 80 cm and 120 cm depth. This was done along the plot length starting at 10 cm from the edge of the filter strips. The sampling along the plot length was carried out at intervals of approximately 0.5 m. The sampling was carried out after the bean harvesting and then again just before maize planting in the long rains of 1991. This was to detect any moisture conservation or depletion from the four treatments.

The sampling was carried out using the gravimetric method as described by England *et al.* (1979). This could not be done during crop growth to avoid trampling and disturbance of the soil which could affect crop performance plus the water and soil loss results. The gravimetric method is regarded as the most accurate and the standard method to which all other methods are compared (Edwards, 1979). The 40 cm depth was selected because most of the moisture in the upper soil layers is lost during the dry spell. The soil samples were taken (using a soil auger) for a distance of 2.5 m from the upper edge of the filter strip. The samples were then immediately placed in airtight polythene bags for soil moisture analysis. In the laboratory, the samples were weighed using an electronic balance correct to 0.1 of a gramme. They were then oven dried at 105°C for approximately 24 hrs until all the water was expelled i.e to constant weight. The samples were then weighed to determine the weight of the oven dry soil and the water lost. The soil moisture content was then expressed as a percentage of the oven dry soil i.e on dry weight basis. The soil moisture content just before planting is important because it boosts the amount of water available for the crop to be planted soon. This is important especially if the rains are insufficient for a rain fed crop.

3.3.7 Run-Off Control And Soil Loss Reduction Efficiency

The efficiency of the filter strips in controlling run-off was calculated by comparing the run-off from the filter strip plot with the run-off from the control plot. This was therefore expressed as:

$$E = \frac{Q_{CP} - Q_{FS}}{Q_{CP}} \times 100$$

Where: E = Efficiency (%).

QCP = Run- off from control plot (mm).

QFS = Run-off from the filter strip plot (mm).

Similarly, efficiency of the filter strips in reducing soil loss was expressed as:

$$E = \frac{SL_{CP} - SL_{FS}}{SL_{CP}} \times 100$$

Where: E = Efficiency (%).

SLCP = Soil from the control plot.

SLFS = Soil loss from the filter strip plot.

4.0 RESULTS AND DISCUSSION

4.1 Rainfall

The long rains (March-May) of 1990 had a total of 741 mm. The short rains (Oct.-Dec.) of the same year totalled 276 mm. Including the dry months, the annual rainfall for the year 1990 was 1169 mm as shown in Appendix I. Out of the 741 mm received during the long rains of 1990, 287 mm generated run-off in six storms. The short rains of the same year had 45 mm generating run-off in only two storms. However, two storms that occurred before the six storms during the long rains of 1990 were not included because the experimental set up was not complete by then. The short rains of 1990 were not much and even the bean crop did not get sufficient moisture during flowering and pod formation.

During the long rains (March-May) of 1991, a total 515 mm of rainfall was realised. However, the total rainfall from January to May 1991 was 562 mm as indicated in Appendix I. Out of the 515 mm received during the long rains, 242 mm generated run-off in nine storms. The amount of rainfall received every month from 1990 to May

1991 was as shown in Appendix I. A summary table of the run-off generating storms during the three seasons discussed above is shown below:

Table 2. Characteristics of the run-off generating storms.

Season	Date	Storm Amount (mm)	Average storm intensity (mm/hr)
Long rains 1990			
	6/4/90	33	70
	17/4/90	54	21
	23/4/90	44	9
	13/5/90	79	19
	15/5/90	14	10
	23/5/90	63	28
Short rains 1990			
	30/10/90	15	6
	8/11/90	30	5
Long rains 1991			
	23/4/91	15	18
	29/4/91	48	6
	12/5/91	22	6
	13/5/91	37	16
	14/5/91	51	12
	17/5/91	7	16
	18/5/91	19	5
	19/5/91	22	5
	20/5/91	21	3

4.2 Run-Off Control

The amount of run-off from the four treatments during the long rains of 1990 is as shown under Fig.3 below:

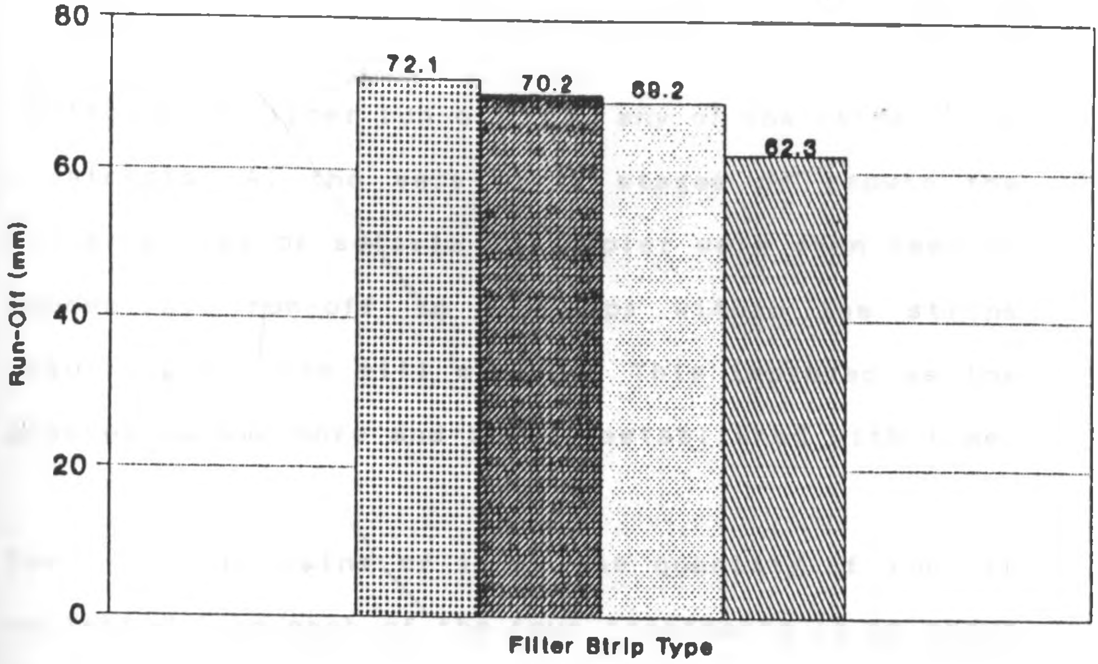

Fig.3. Run-off versus the filter strip type, long rains 1990.

The efficiency of the grass filter strips in reducing run-off during the long rains of 1990 was 2.6, 4.0, and 13.6% for the Napier, Setaria and the brachiaria respectively. This shows that the effectiveness of the filter strips in reducing run-off was considerably low. However, the brachiaria showed better performance when compared with the other two grasses. When statistically tested, F-test at 5% level, there was no significant difference between the four treatments in terms of run-off reduction efficiency. That is, there was no significant difference in terms of run-off reduction between the control and the grass filter strips and even between the filter strips themselves. However, the control gave higher run-off than any of the other three treatments. At the very early stages of growth the filter strips of setaria and napier were even seen to concentrate run-off to the gaps within the strips resulting in some rill erosion. This improved as the grasses became more and better established with time.

For the short rains of 1990, the quantity of run-off collected from each of the four treatments is as shown in Fig.4 below:

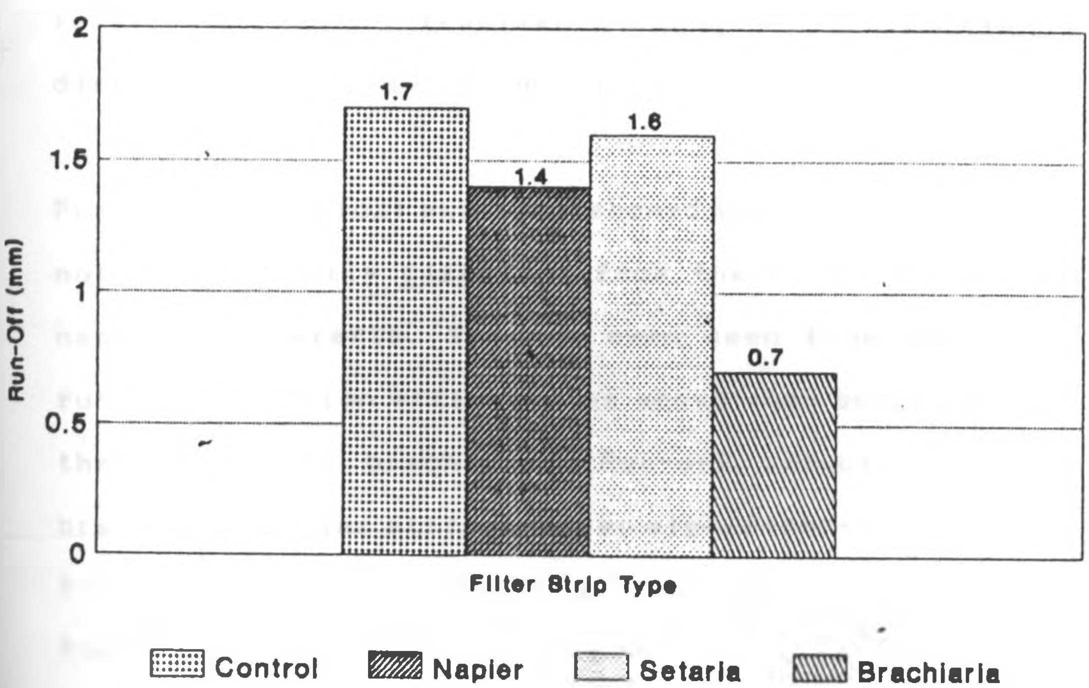

Fig.4. Run-off versus the filter strip type, short rains 1990.

The efficiency of the napier, setaria and brachiaria filter strips in reducing run-off during this season was 17.6%, 5.9% and 58.8% respectively. This shows considerable improvement when compared with the performance of the filter strips during the long rains of 1990. However, the setaria showed low improvement and was even overtaken by the napier as the results of the two successive seasons indicate. The brachiaria continued to have the highest run-off reduction efficiency while the control maintained the highest run-off amount. When statistically tested, F-test at 5% level, the four treatments showed a significant difference in terms of run-off reduction.

Further statistical analysis showed that the control was not significantly different from the filter strips of napier and setaria. This is even seen from their low run-off reduction efficiencies above when compared with the one of the brachiaria. Run-off reduction by the brachiaria filter strip was also significantly different from that of the setaria and napier filter strips. Therefore, the filter strip of brachiaria was also superior to those of the other two grasses. The strips of napier and setaria showed no significant difference in run-off reduction.

The low run-off reduction efficiency during the long rains of 1990 was due to the fact that the grass filter strips were not yet well established. The newly planted filter strips therefore did not differ significantly from the control in the ability to control run-off. Another important observation was that most of the run-off during the long rains of 1990 occurred at the early stages of the filter strips establishment. The strips were therefore not well established to impede the run-off more efficiently. This was especially so for the setaria and the napier grass which showed slow establishment. By the onset of the short rains, the filter had considerably improved in establishment. This therefore resulted in the treatments showing some quite distinct differences in run-off reduction.

During the long rains of 1991 the amount of run-off from each of the four treatments is as shown in Fig.5:

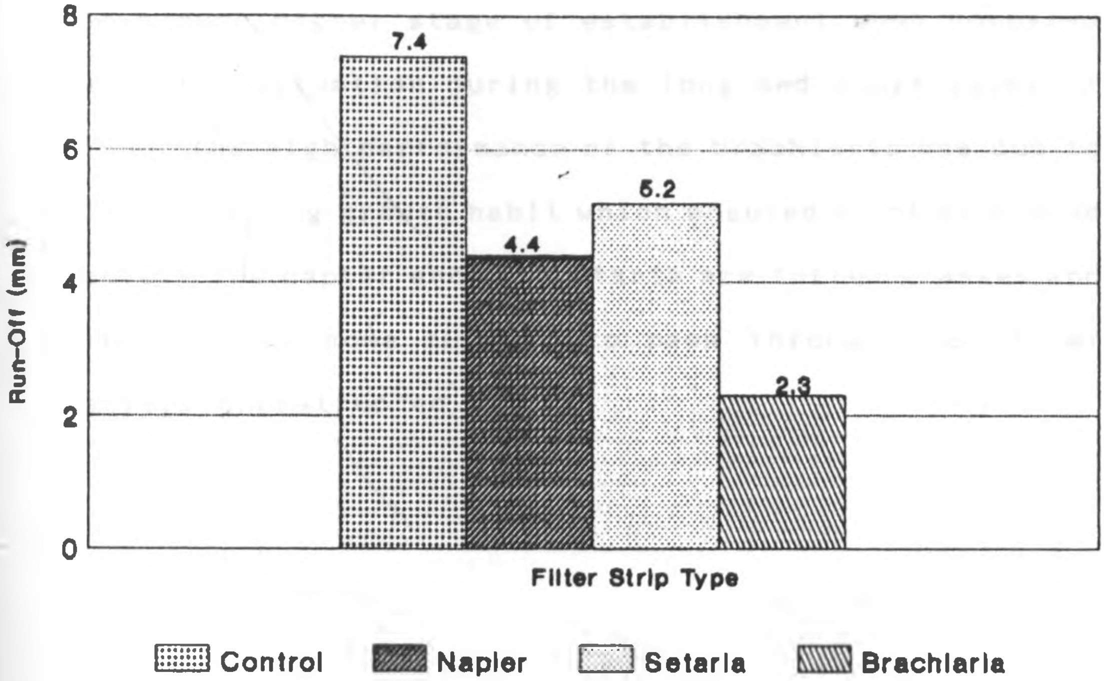

Fig.5. Run-off versus the filter strip type, long rains 1991.

The efficiency of the napier, setaria and brachiaria strips in reducing run-off was 40.5, 29.7, and 68.9% respectively. This shows great improvement especially in the case of the napier and setaria filter strips when compared with their low performance during the long and the short rains of 1990. When statistically tested, F-test at 5% significance level, all the filter strips were now significantly different from the control. Among the three filter strips, it was only the strips of napier and setaria that still showed no significant difference in run-off reduction between themselves. The above results also indicate that the filter strips were at a much higher stage of establishment when compared with the situation during the long and short rains of 1990. The high performance of the brachiaria was due to its spreading growth habit which ensured a lot of ground cover. The napier and the setaria are tufted grasses and this allows some run-off to pass through the filter strips unobstructed.

4.3 Soil Loss

The total amount of soil loss from each of the four treatments during the long rains of 1990 is as shown in Fig. 6 below:

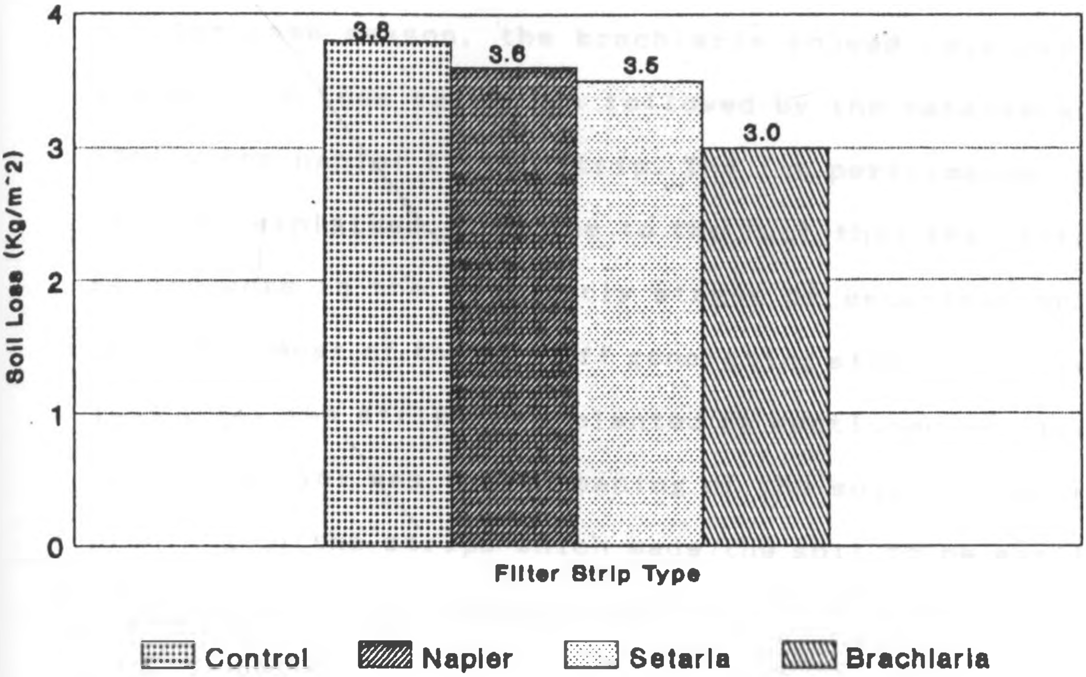

Fig.6. Soil loss versus the filter strip type, long rains 1990.

The efficiency of the napier, setaria and brachiaria filter strips in reducing soil loss was 3.8%, 7.9% and 18.9% respectively. When statistically tested, F-test at 5% level, there was no significance difference between the four treatments in terms of soil loss reduction during the long rains of 1990. This can be seen from the results of the ANOVA (F-test, 5%) in Appendix III. As in the case of the run-off during the same season, there was no distinct difference between the treatments in terms soil loss reduction. The efficiency of soil loss reduction is also low as the above figures indicate. As in the case of the run-off for the same season, the brachiaria showed relatively higher soil loss reduction followed by the setaria and lastly the napier filter strip. The low performance can again be explained to be due to the fact that the filter strips were in the very early stages of establishment. Secondly, most of the run-off generating storms occurred just after the strips were planted as mentioned earlier. Another factor was the loosening of the soil during the planting of the strips which made the soil to be easily transported by the eroding water.

For the short rains of 1990, the amounts of soil loss from the control and the plot with napier were 1.5 t/ha (0.149 Kg/m^2) and 0.1 t/ha (0.010 Kg/m^2) respectively. The plots with setaria and brachiaria gave 0.3 t/ha (0.027 Kg/m^2) and 0.1 t/ha (0.008 Kg/m^2) respectively. This is shown in Fig.7 below:

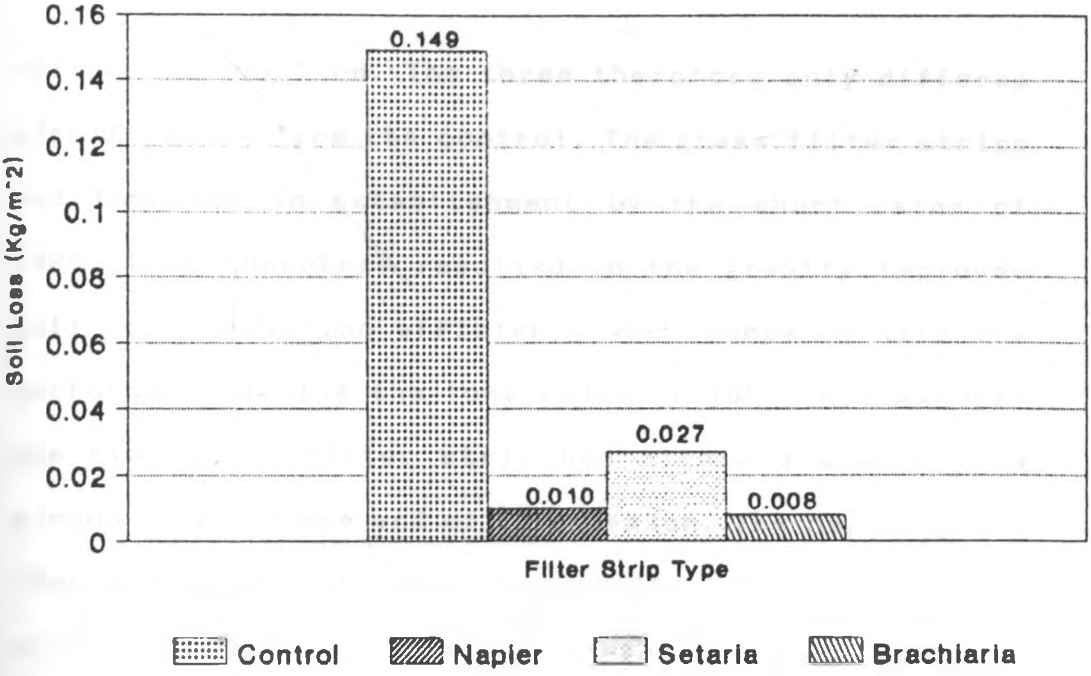

Fig.7. Soil loss versus the filter strip type, short rains 1990.

The soil loss from the four treatments during this season were therefore more distinct as the bar graphs indicate. The figures shown are to three decimal places so as to show the slight difference between some of the treatments though it was not significant. The soil loss reduction efficiency for the napier, setaria and brachiaria filter strips was 92.9%, 81.9% and 94.7% respectively. This shows considerable improvement when compared with the low efficiencies during the previous season. When statistically tested, F-test at 5% level, there was a significant difference between the treatments. However, there was no significant difference between the three types of filter strips in terms of soil loss reduction. The three therefore only differed significantly from the control. The grass filter strips had improved in establishment by the short rains of 1990. This therefore resulted in the greatly improved soil loss reduction efficiency when compared with the performance during the long rains of 1990. For example the brachiaria filter strip had attained almost 100% ground cover by the end of this season. The napier grass improved in ground cover through its tillering ability while the setaria tended to remain as large distinct stools.

The soil loss from the control and napier during the long rains of 1991 were 2.1 t/ha (0.21 Kg/m^2) and 0.5 t/ha (0.05 Kg/m^2) respectively. The plots with setaria and brachiaria gave 0.7 t/ha (0.07 Kg/m^2) and 0.2 t/ha (0.02 Kg/m^2) respectively. This is shown in Fig. 8 below:

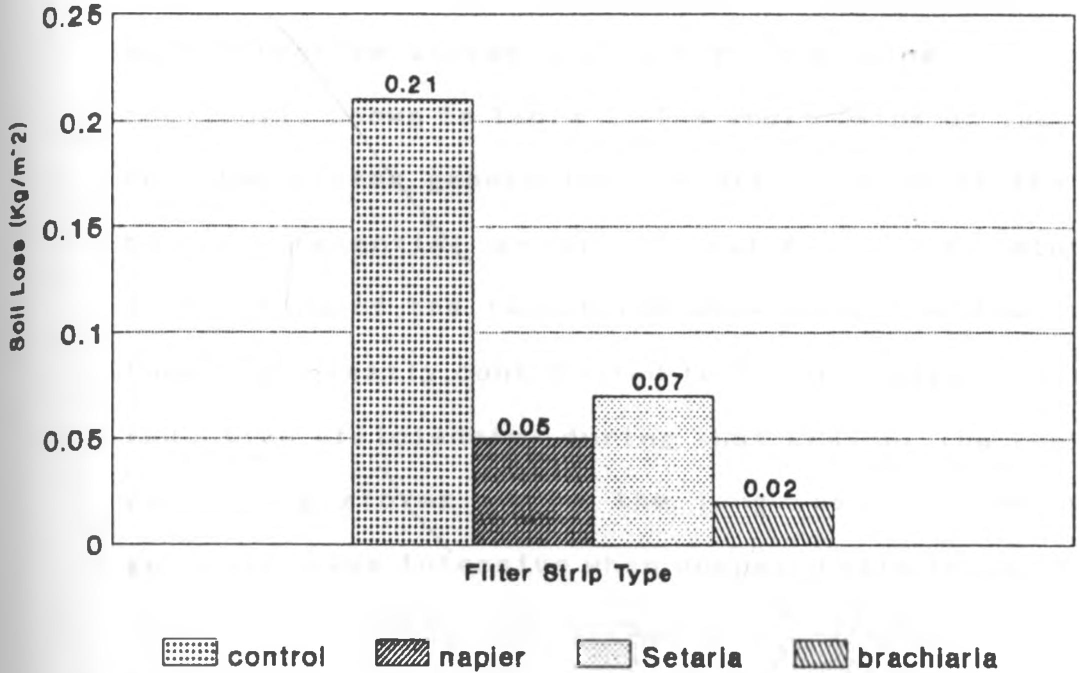

Fig.8. Soil loss versus the filter strip type, long rains 1991.

The figures shown on the graphs are again to two decimal places so as to show the slight difference in soil loss reduction between some of the treatments though no significant difference was found. The efficiency of soil loss reduction by the napier, setaria and brachiaria filter strips were 75.6%, 67.4% and 92.8% respectively. This still shows tremendous improvement when compared with the performance during the long rains of 1990. These results also indicate that the efficiency of the filter strips in reducing soil loss was slightly lower than during the short rains of 1990. This can be explained to be due to the more, bigger and generally more intensive storms during the long rains of 1991 as previously shown in Table 2. The short rains of 1990 had only two storms generating run-off and none of the two had a substantial amount of rainfall. The rainfall intensities of the two storms were also very low. This therefore greatly contributed to the very high soil loss reduction efficiencies during that season. The run-off generating storms during the long rains of 1991 were generally less intensive when compared with those of the long rains of 1990. The former also had lesser run-off. This explains the much lower soil loss for the control during the long rains of 1991.

The statistical analysis on soil loss reduction during this last season showed a significant difference between the grass filter strips and the control. However, there was a significant difference between the filter strips of setaria and the brachiaria i.e the brachiaria one was evidently superior. The brachiaria filter strip therefore, systematically showed higher performance in terms of run-off and soil loss reduction as seen from the results of the three seasons.

4.4 Crop Height And Yield

The effect of planting grass filter strips on the crop planted was monitored through measurement of crop height and yields. However, though crop height may not be a very reliable indicator of the actual crop yields, it was measured so as to have an indication of the expected crop yields. For example, competition for moisture and nutrients was expected to result in a stunted crop. Such crop height measurement is therefore useful especially where the crop might not reach the final harvesting stage. Crop height measurement for the maize planted during the long rains of 1990 was measured only once. This was when the crop was mature such that no further increase in height was expected. The edge effect of the grass filter strips on the height of the crop mentioned is as seen in Fig. 9 below:

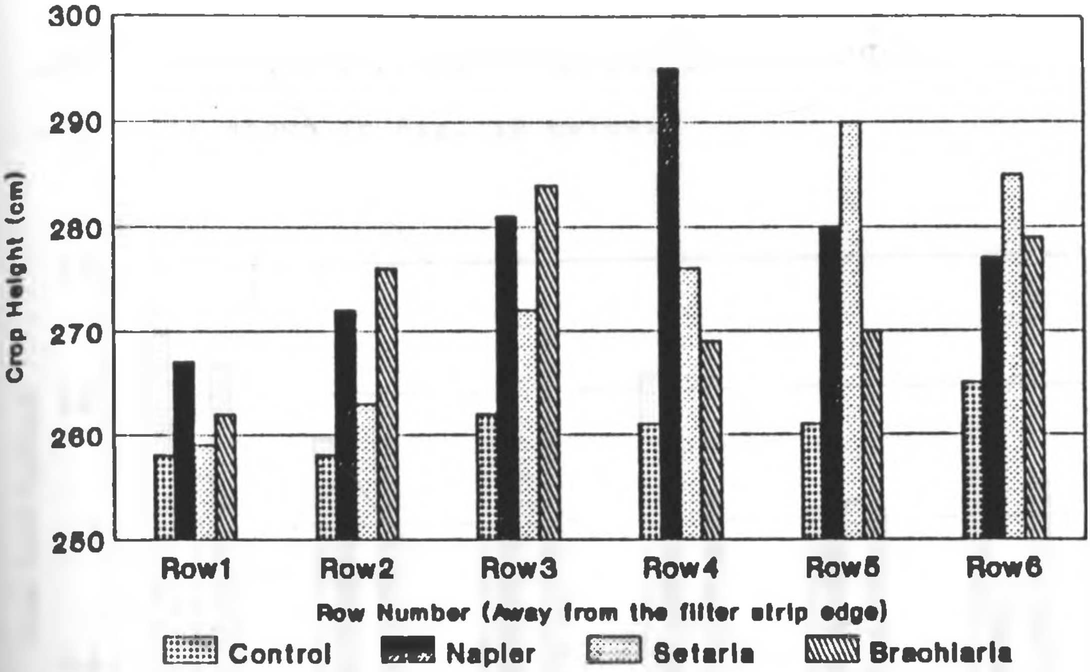

Fig. 9. Filter strip edge effect on the height of the adjacent maize crop, long rains 1990.

As seen from Fig. 9 above, the maize crop tended to increase in height away from grass filter strips edge. However, the crop near the filter strips tended to be higher than for the control. This is because the strips could prevent washing away of some of the plant nutrients carried by the run-off from the crop area of the plots. The control plot hand no such barrier. The strips at this time of early establishment were also not expected to significantly compete with the adjacent crop especially on nutrients uptake. However, the maize crop on the control tended to be more or less of the same height i.e. there was not much change in height. The edge effect of the grass filter strips on the maize crop yields is shown in Fig. 10 below:

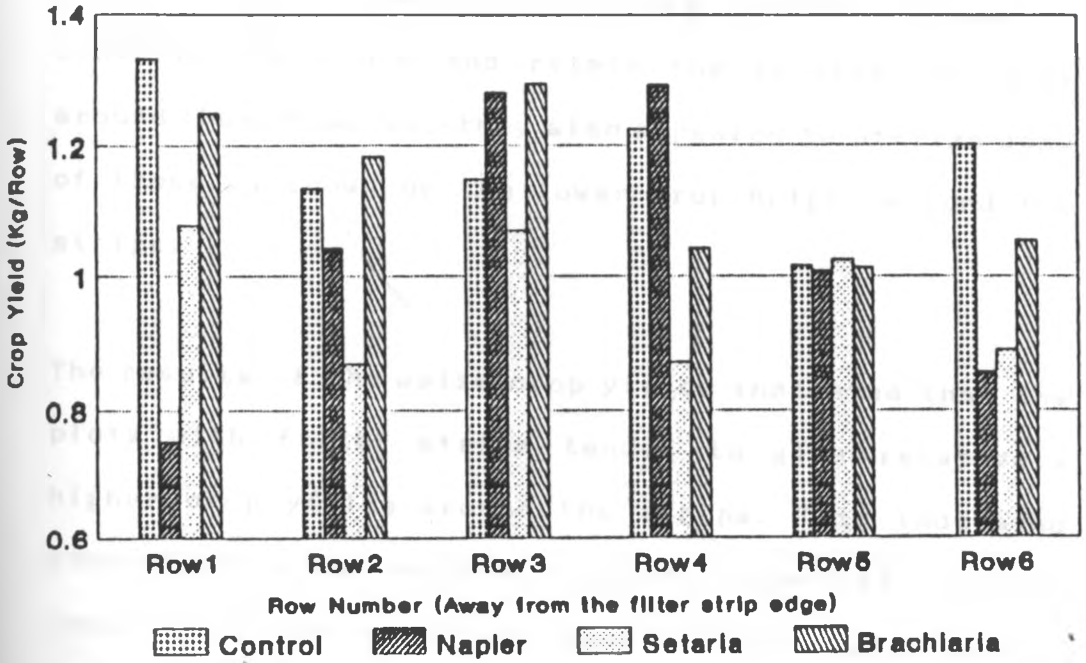

Fig. 10. Filter strip edge effect on the yields of adjacent maize crop, long rains 1990.

The two figures above show that the crop height does not necessarily indicate the expected final crop yields. For example, there was a tendency of the crop to increase in height away from the filter strip edge. However, the crop yields tended to increase towards the filter strips except for the case of the napier grass. It was only the first row of the maize whose yield was prominently lowered by the napier. However, in general the competitive effect of the filter strips was not very well magnified during this season. This indicates that there is a critical height for the crop yields to be affected significantly by soil moisture or nutrient insufficiency. The filter strips however tended to conserve moisture and retain the fertile top soil around them. However, they also appeared to utilize some of these as shown by the lower crop height around the strips.

The results of the maize crop yields indicated that the plots with filter strips tended to give relatively higher crop yields around the strips. This indicated some moisture and fertile top soil conservation on the immediate upstream of the strips. The napier filter strip however, exhibited lower crop yields on the immediate upstream indicating possible competition with the adjacent maize crop. The control in general gave more or less the same crop yield for the various rows shown in Fig. 10 i.e there was little variation between the rows.

The overall maize yields for the long rains of 1990 from the control and the plot with a napier filter strip was 16.4 Kg (7.1 t/ha) and 15.5 Kg (6.7 t/ha) respectively. The plots with setaria and brachiaria strips gave 13.7

Kg (5.9 t/ha) and 14.8 Kg (6.4 t/ha) respectively. This is as seen in Fig. 11:

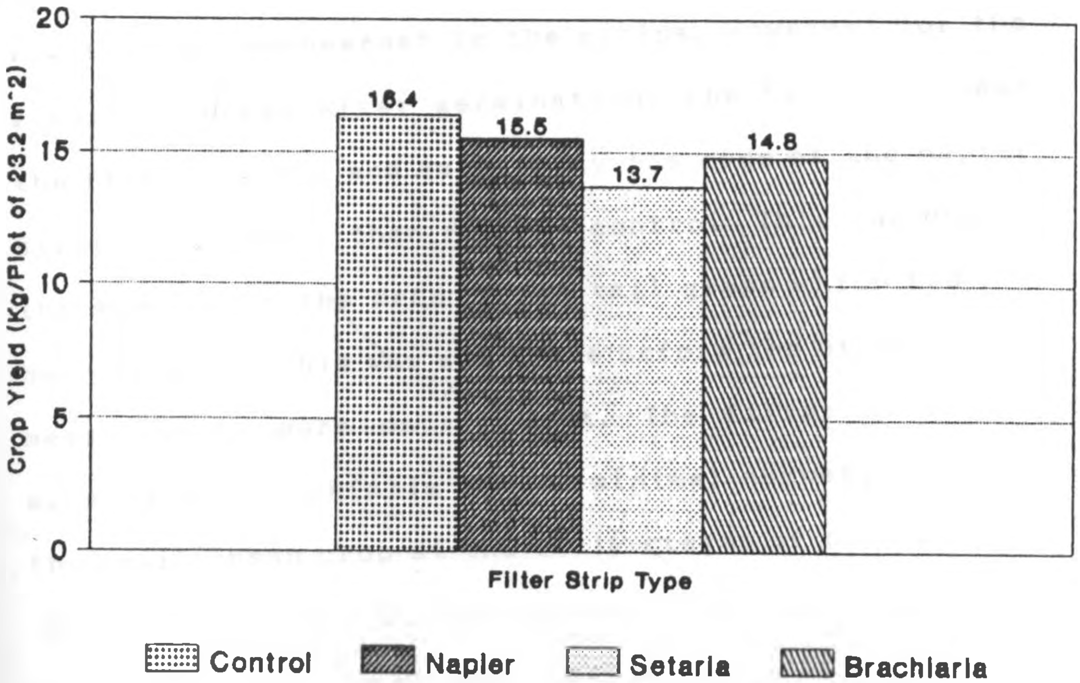

Fig.11. Maize crop yields versus the filter strip type on the plot, long rains 1990.

Though the control plot showed higher yields than the plots with filter strips, there was no significant difference between the four treatments when an F-test, at 5% level, was carried out. This implies that the crop area taken up by the grass filter strips was minimal. It also indicates that the adverse edge effect of the strips on crop yields was little. However, this trend could change with time since the filter strips were still young and not fully established.

For the short rains of 1990, the bean crop height around the grass filter strips tended to remain lower than that of the control plot. This was mainly so for the first row i.e the row nearest to the strips. However, for the first two weeks after germination, the bean crop near the filter strips and especially the case of the napier strip, was higher than for the control. This was due to the shading of the crop by the tall grass which had not been trimmed. This was soon done before the other height measurements were carried out. The filter strips of setaria and brachiaria showed minimal competition with the nearby bean crop at the early stages of crop growth. It was observed that the adverse effect of the strips on the adjacent bean crop was mainly concentrated on first two rows though the first row was the most affected. The control systematically showed more or less similar crop height and yields for the various rows. All this is shown in Figures 12, 13, 14, 15 and 16:

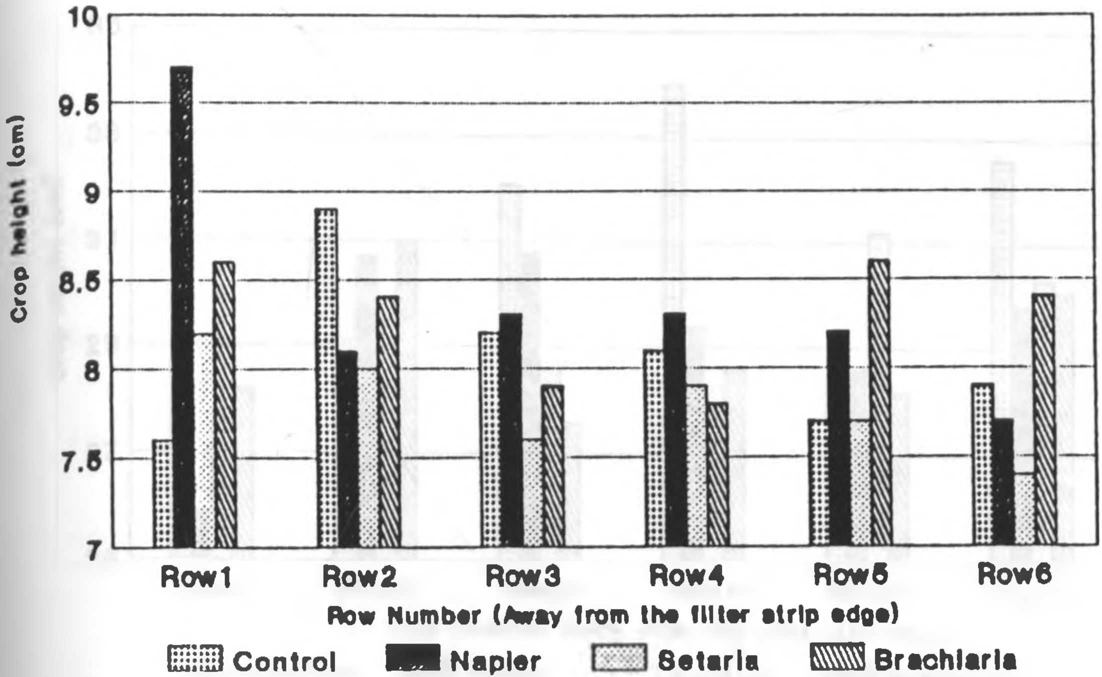

Fig. 12. Filter strip edge effect on the height of the adjacent bean crop, 2 Wks after germination, short rains 1990.

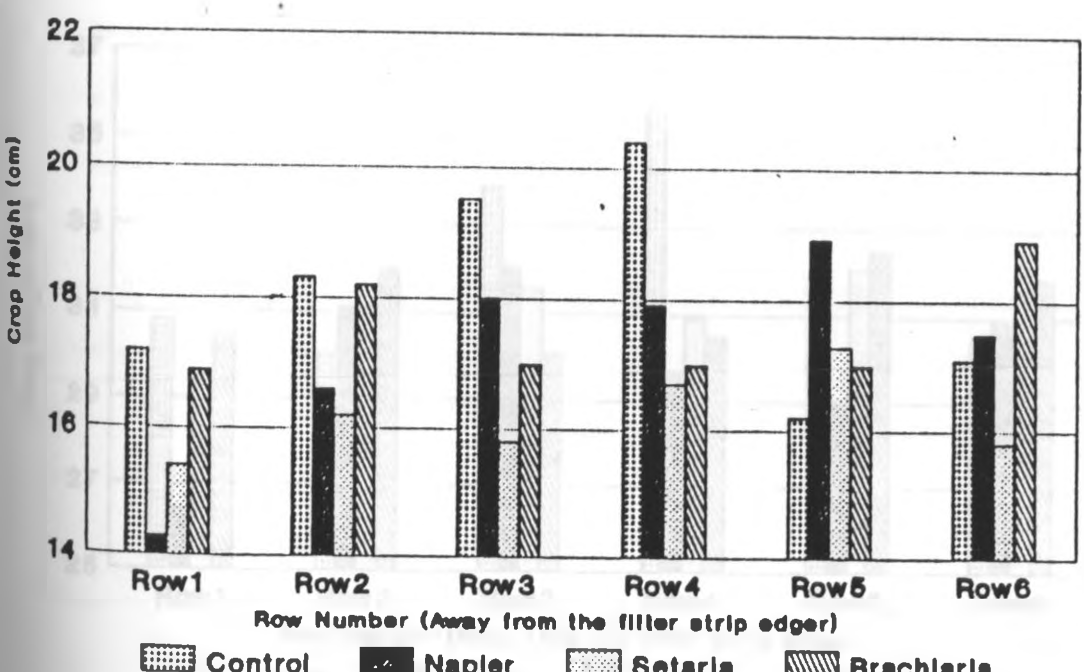

Fig. 13. Filter strip edge effect on the height of adjacent bean crop, 4 Wks after germination, short rains 1990.

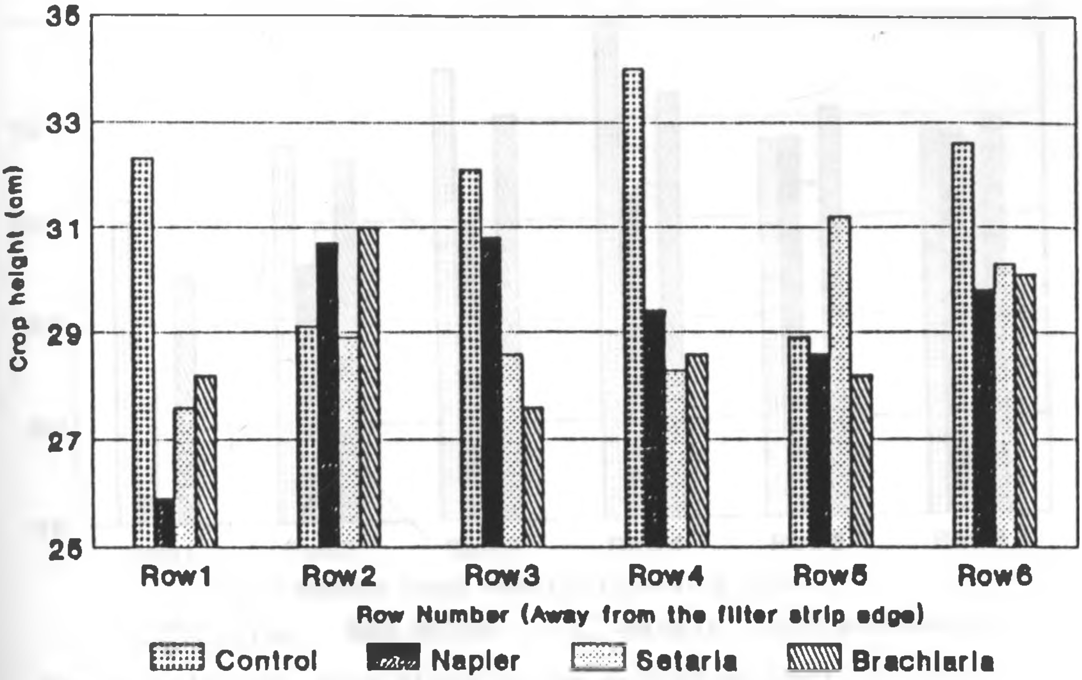

Fig. 14. Filter strip edge effect on the height of adjacent bean crop, 6 Wks after germination, short rains 1990.

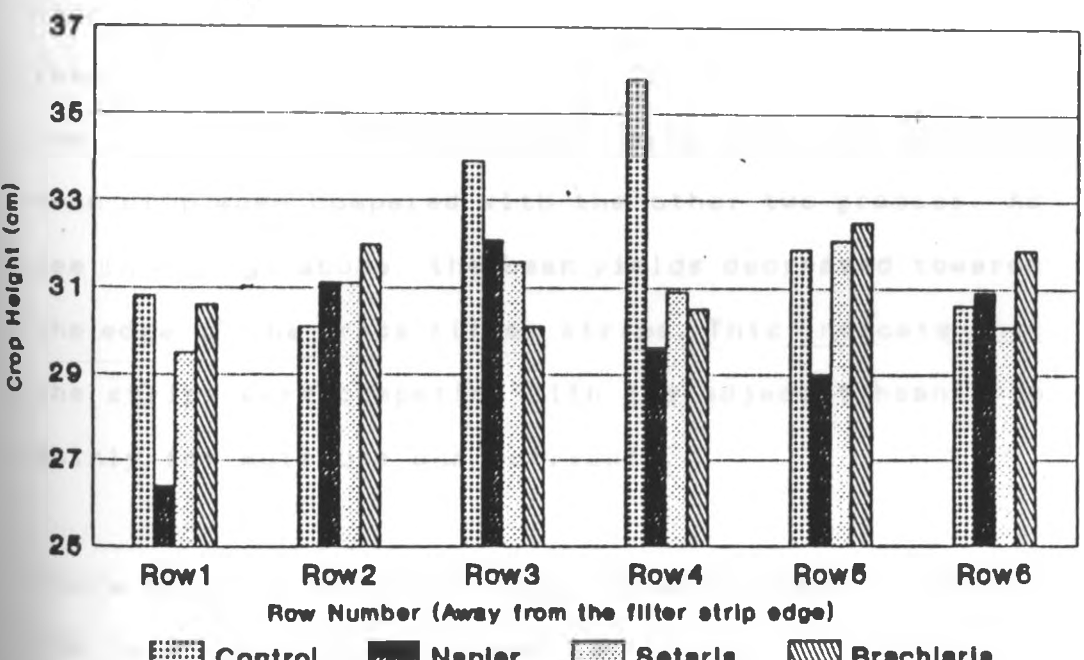

Fig. 15. Filter strip edge effect on the height of adjacent bean crop, 8 Wks after germination, short rains 1990.

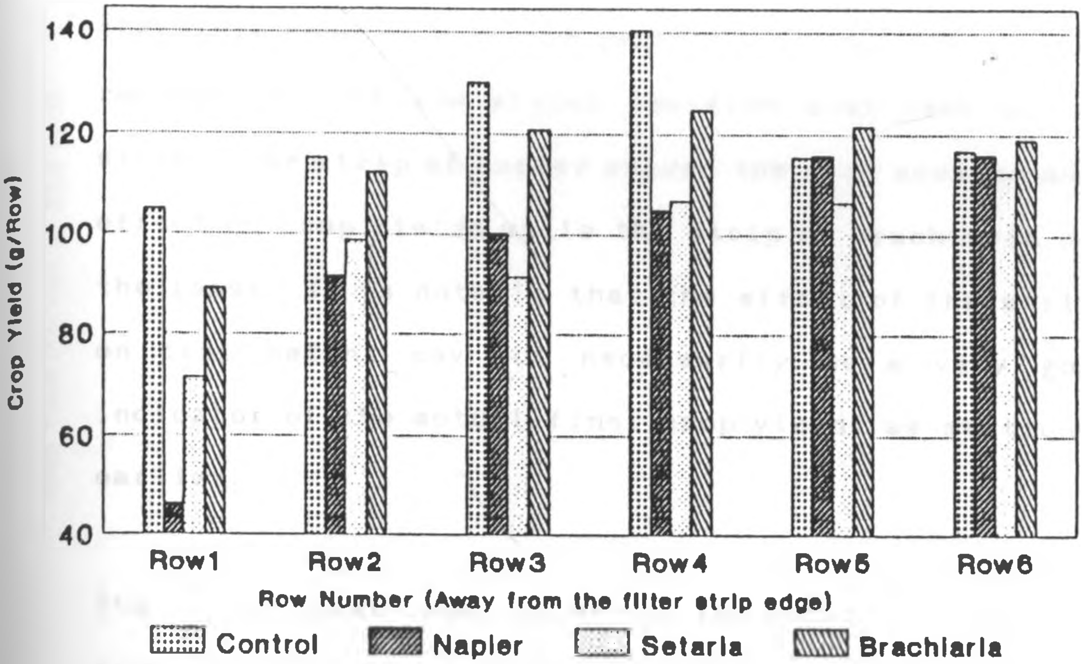

Fig. 16. Filter strip edge effect on the yield of adjacent bean crop, short rains 1990.

The bean crop near the filter strip of brachiaria showed higher crop yield than either the one near the edge of the setaria or napier filter strips. This indicates that the brachiaria was less competitive with the adjacent bean crop when compared with the other two grasses. As see in Fig. 16 above, the bean yields decreased towards the edge of the grass filter strips. This indicate that the strips were competing with the adjacent bean crop mainly for moisture and nutrients.

There was some moisture insufficiency observed during the late bean flowering and pod formation. This therefore coupled with the competition from the grasses resulted in the low yields realised just next to the strips. The strip of napier showed the most adverse edge effect on crop yields while the strip of brachiaria had the least. It is notable that the effect of the strips on crop height may not necessarily be a very good indicator of the actual final crop yields as mentioned earlier.

The overall bean crop yields for the short rains of 1990 from the control and the plot (each plot was 23.2 m^2) with a napier filter strip were 2.8 Kg (1.2 t/ha) and 2.5 Kg (1.1 t/ha) respectively. The plots with filter strips of setaria and brachiaria gave 2.3 Kg (1.0 t/ha) and 2.6 Kg (1.1 t/ha) respectively. This can be see in Fig. 17:

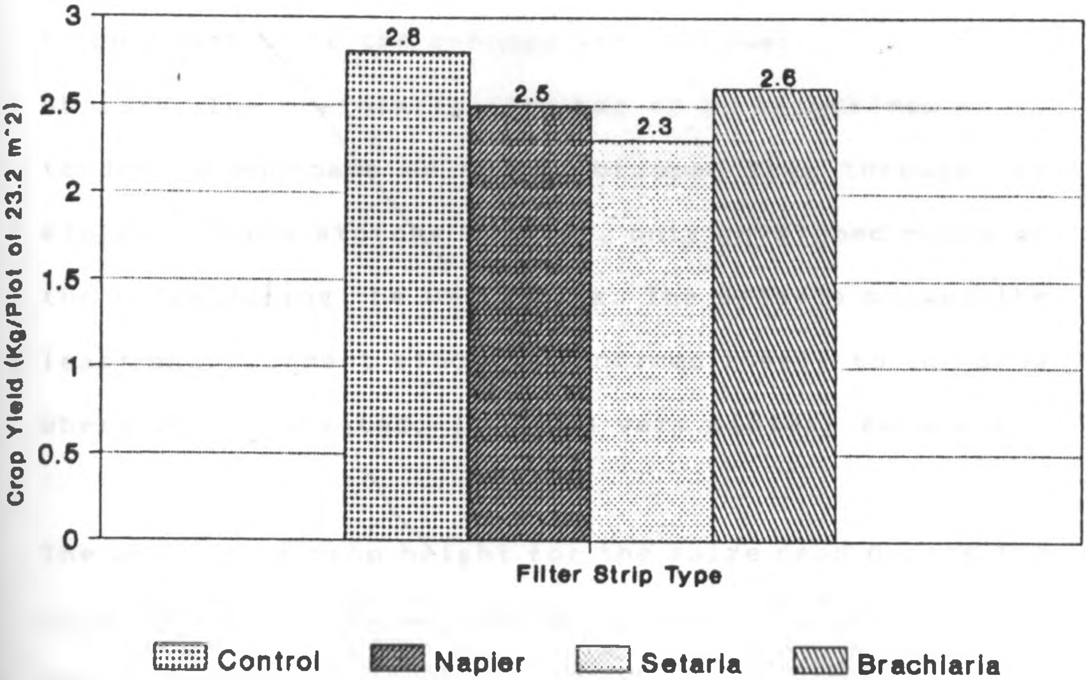

Fig.17. Bean crop yields versus the filter strip type on the plot, short rains 1990.

Again though the control plot gave higher yields compared to the plots with filter strips, there was no significant difference between the treatments when tested statistically (F-test, at 5% level). This again shows that the crop area taken by the filters is minimal and that the filter strip edge effect on adjacent crop was not considerable. As mentioned earlier, such a trend needs to be monitored for a longer duration because the competition may intensify with time. This is because the fully developed root systems of the grasses would be expected to have a more adverse effect on the crop near the filter strip. For example, the napier grass tended to encroach on to the cropped area through its tillering ability. The brachiaria also had to be maintained as it tended to encroach on to the cropped area through its stolons. These stolons however, only developed roots at the nodes during the wet spells. The setaria showed the least encroachment since it confined itself to the area where it was planted, i.e, had very minimal expansion.

The results of crop height for the maize crop during the long rains of 1991 are as seen in Fig. 18, 19, 20, 21 and 22 below:

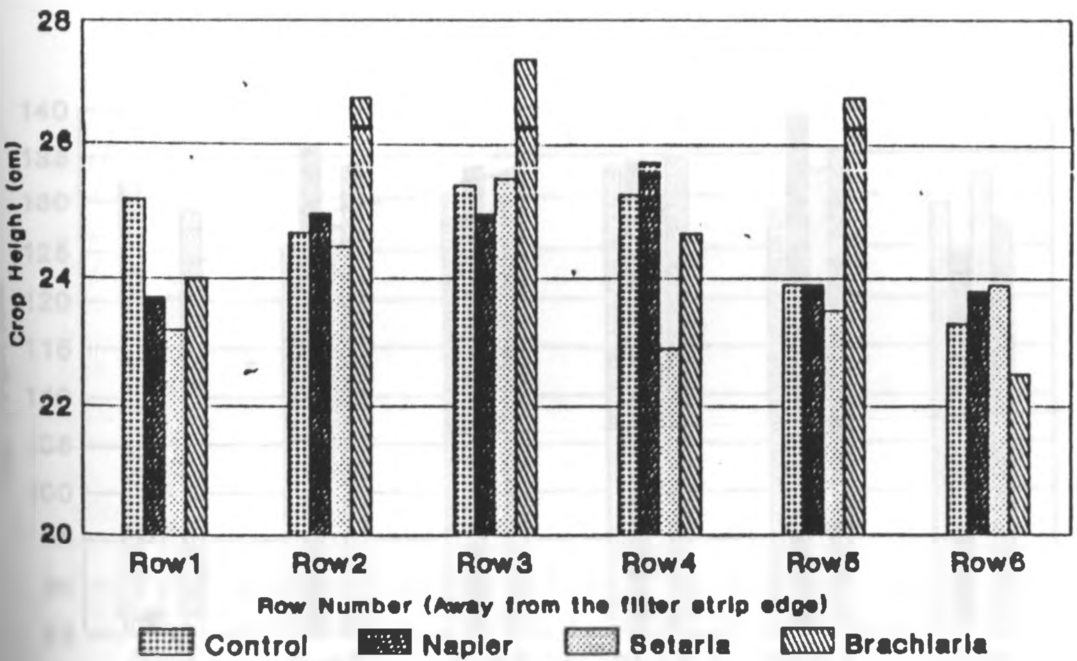

Fig. 18. Filter strip edge effect on the height of adjacent maize crop, 2 Wks after germination, long rains 1991.

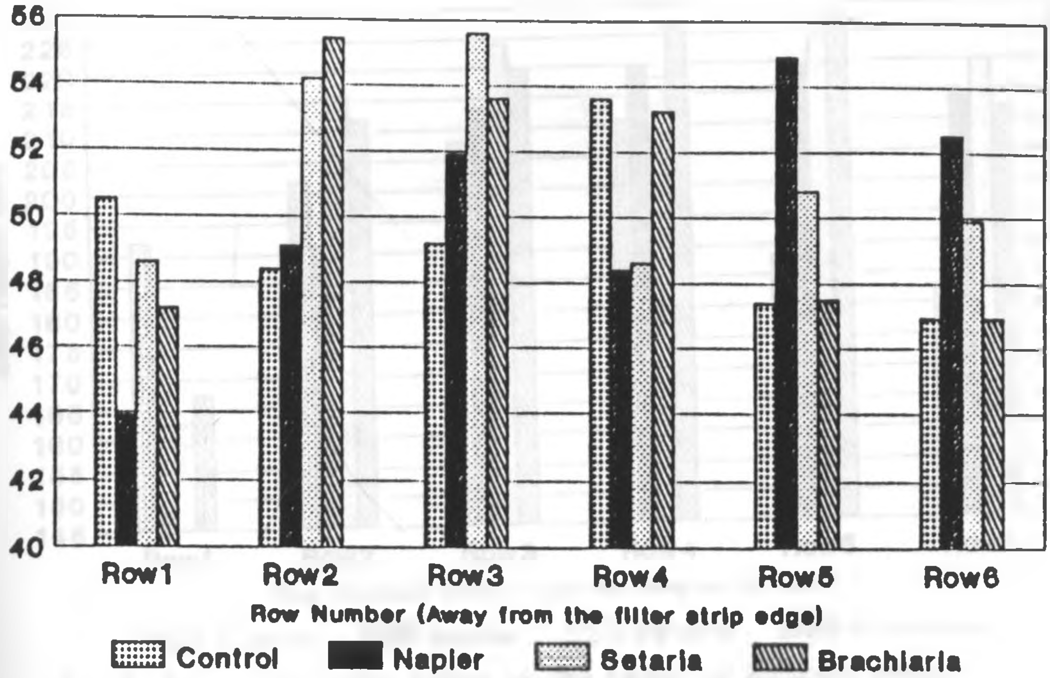

Fig. 19. Filter strip edge effect on the height of adjacent maize crop, 4 Wks after germination, long rains 1991.

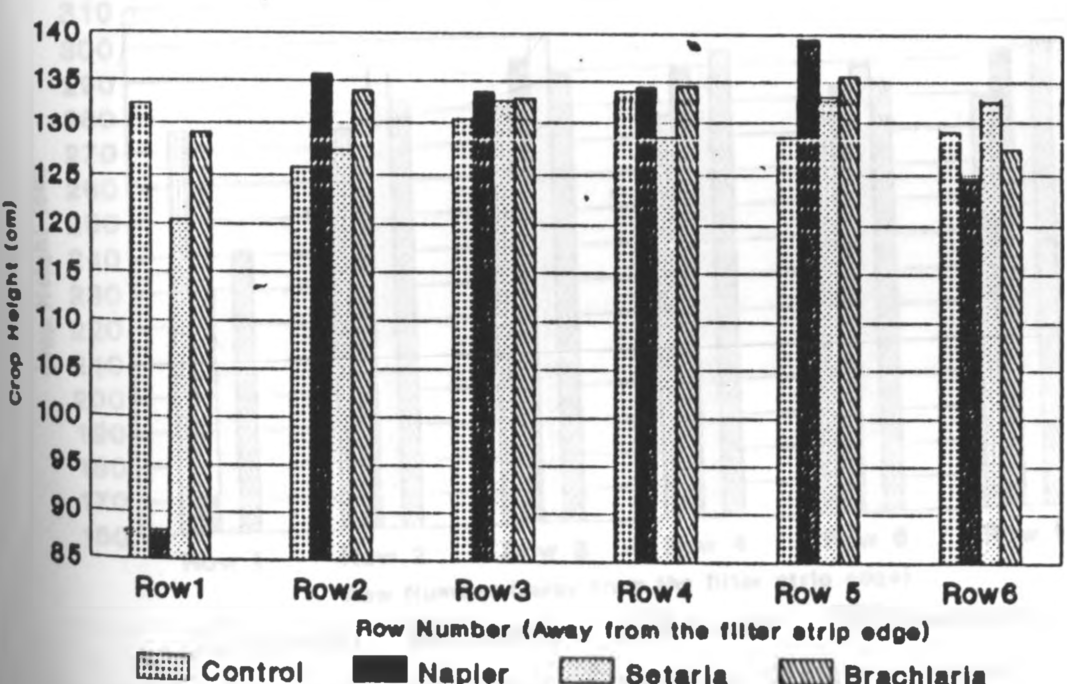

Fig. 20. Filter strip edge effect on the height of adjacent maize crop, 6 Wks after germination, long rains 1991.

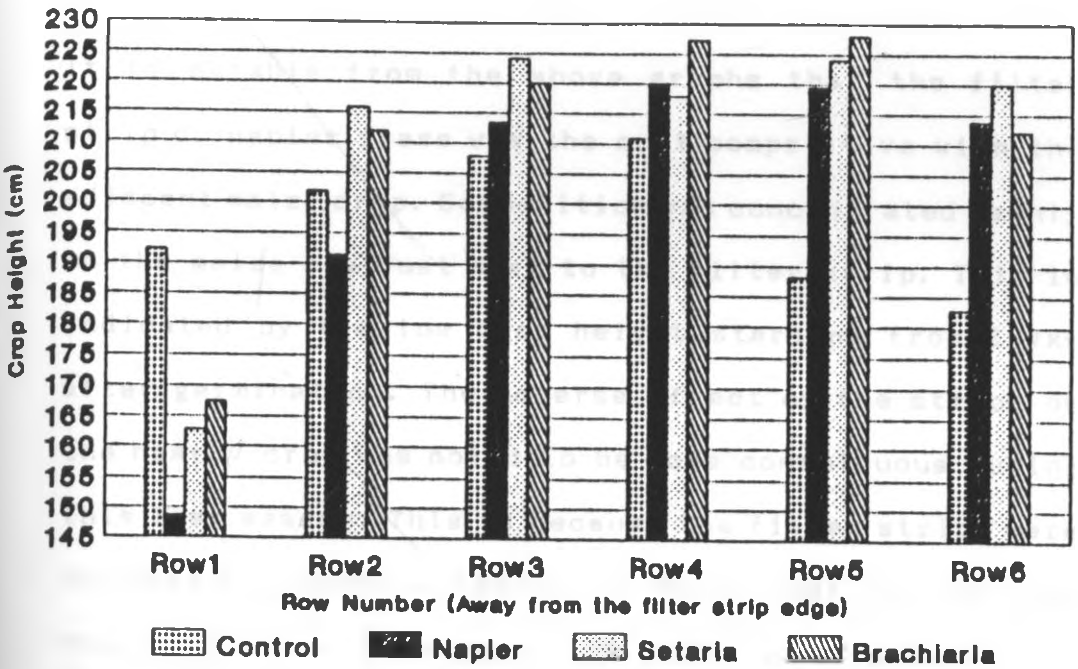

Fig. 21. Filter strip edge effect on the height of adjacent maize crop, 8 Wks after germination, long rains 1991.

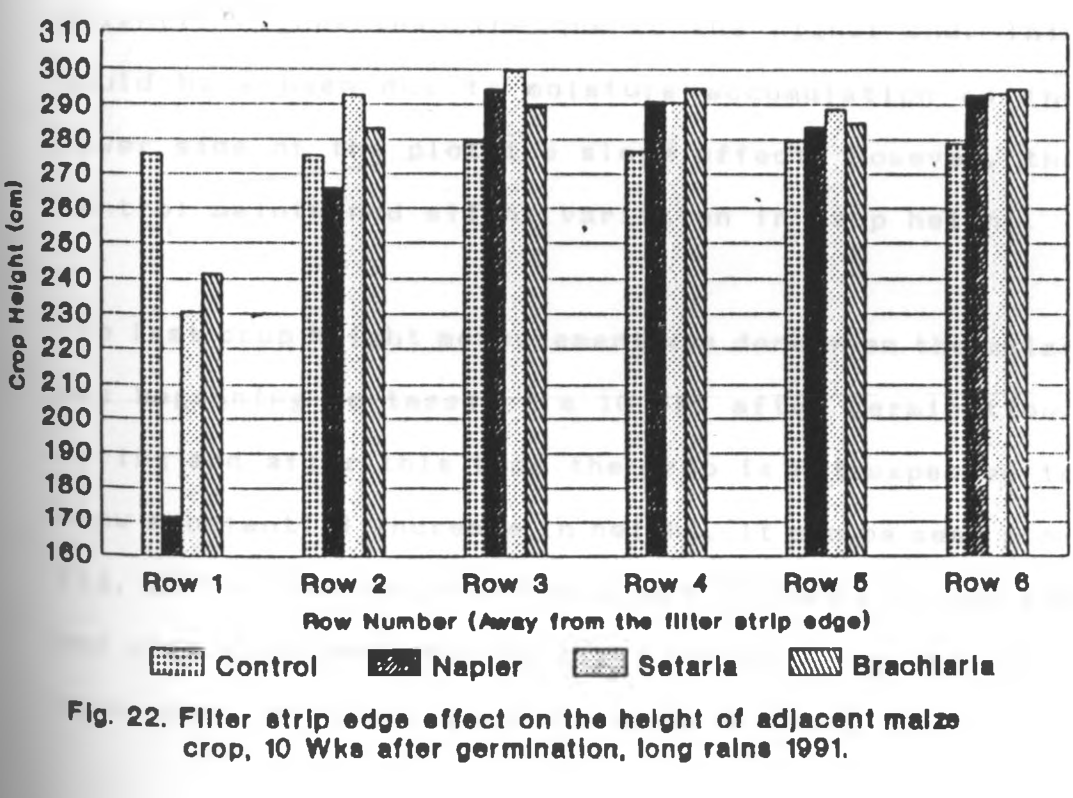

Fig. 22. Filter strip edge effect on the height of adjacent maize crop, 10 Wks after germination, long rains 1991.

It is notable from the above graphs that the filter strip of napier grass was the most competitive with the adjacent maize crop. Competition was concentrated mainly on the maize row just next to the filter strip. This is indicated by the low crop height starting from 2 Wks after germination. The adverse effect of the strips on the nearby crop was noted to be more conspicuous during this last season. This is because the filter strips were now more and better established. Their root systems were therefore more developed. The adverse effect of the filter strips on the maize crop was also more pronounced in the early stages of growth. There was a tendency of the crop near the lower end of the control plot to be slightly higher than the one to the higher end. This could have been due to moisture accumulation on the lower side of the plot i.e slope effect. However, the control maintained slight variation in crop height.

The last crop height measurement was done when the maize was beginning to tassel i.e 10 Wks after germination. During and after this time the crop is not expected to show substantial increase in height. It can be seen from Fig. 22 that the competitive effect of the filter strips was only prominent for the first row of maize. This was even more conspicuous in the case of the plot with a napier filter strip.

4.5 Soil Moisture Profile

The soil moisture profile at the upstream side of the filter strips was monitored through gravimetric sampling. This was done twice when there was no crop in the plots. The first sampling was done on 28/1/91. This was after harvesting the short rains 1990 bean crop. The second gravimetric sampling was done on 26/3/91. This was during a more dry period and it was just a few days before the planting of the maize for the long rains of 1991. The soil moisture content (on dry weight basis) results for the two gravimetric samplings is as indicated in Fig. 23, 24, 25, 26, 27 and 28 below:

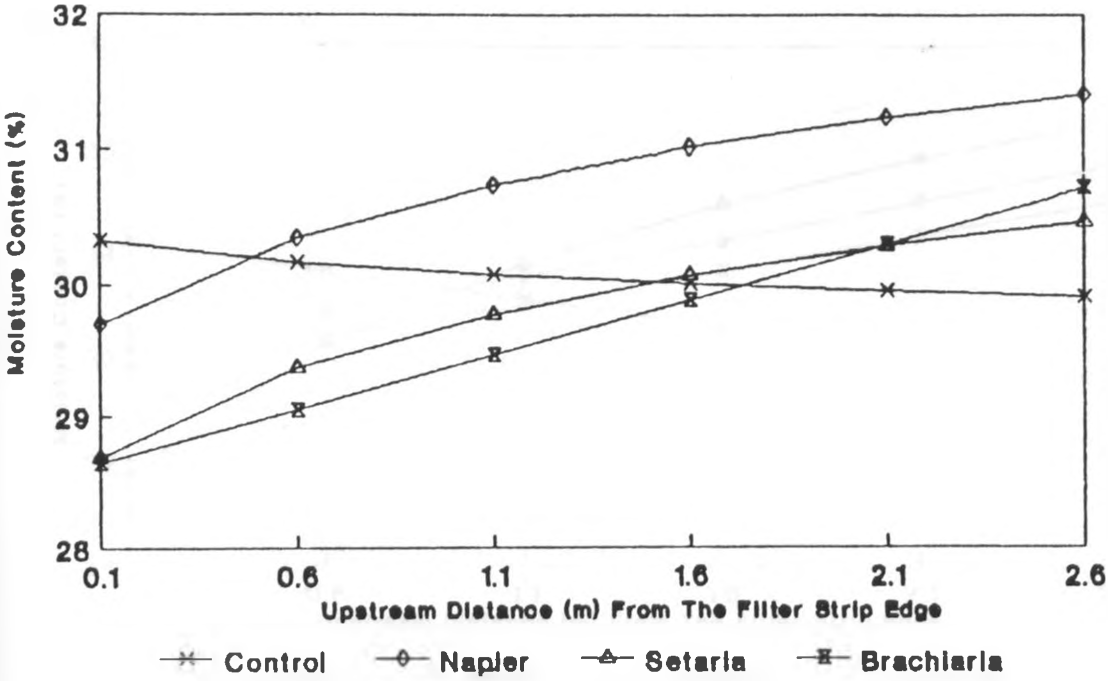

Fig. 23. Soil moisture profile upstream of the filter strips at 40cm depth, first gravimetric sampling.

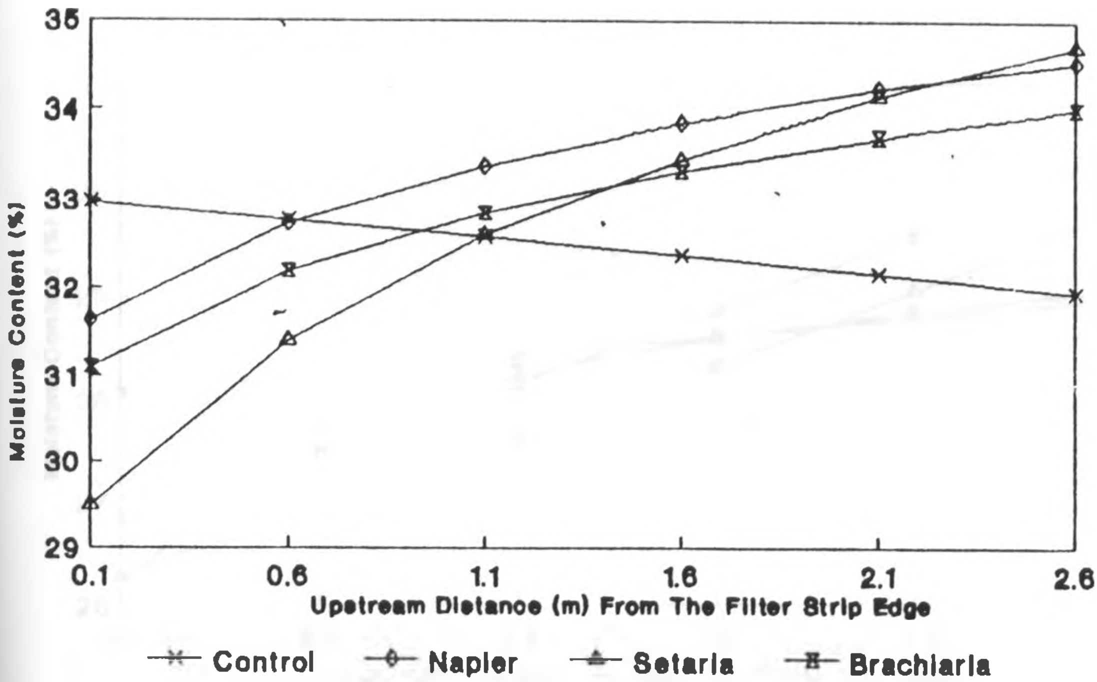

Fig. 24. Soil moisture profile upstream of the filter strips at 80cm depth, first gravimetric sampling.

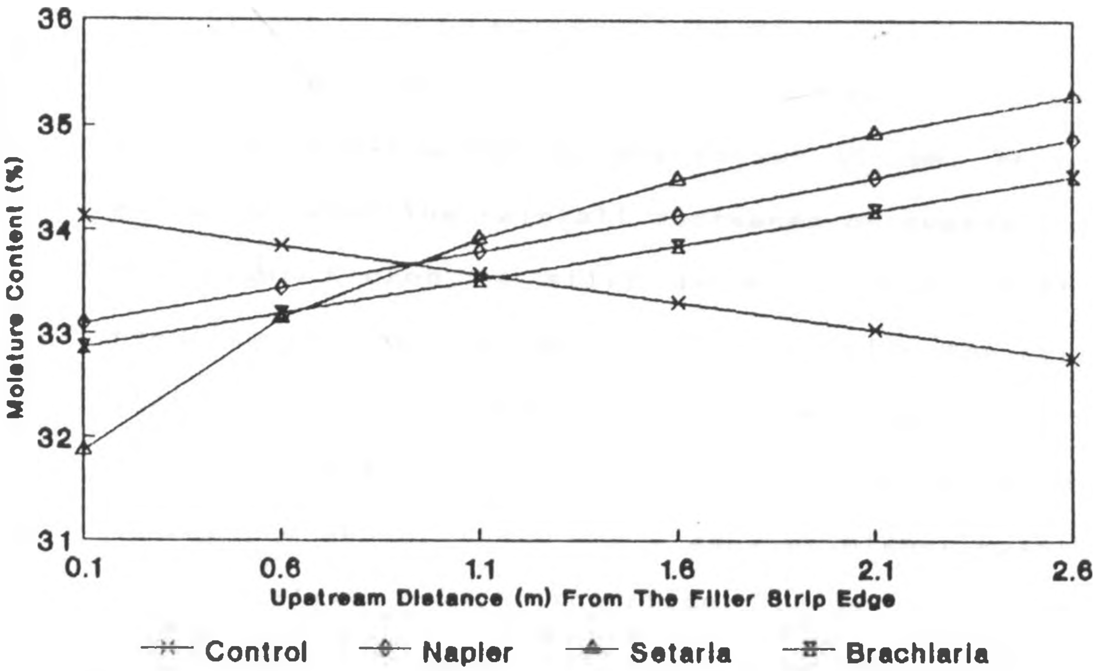

Fig. 25. Soil moisture profile upstream of the filter strips at 120cm depth, first gravimetric sampling.

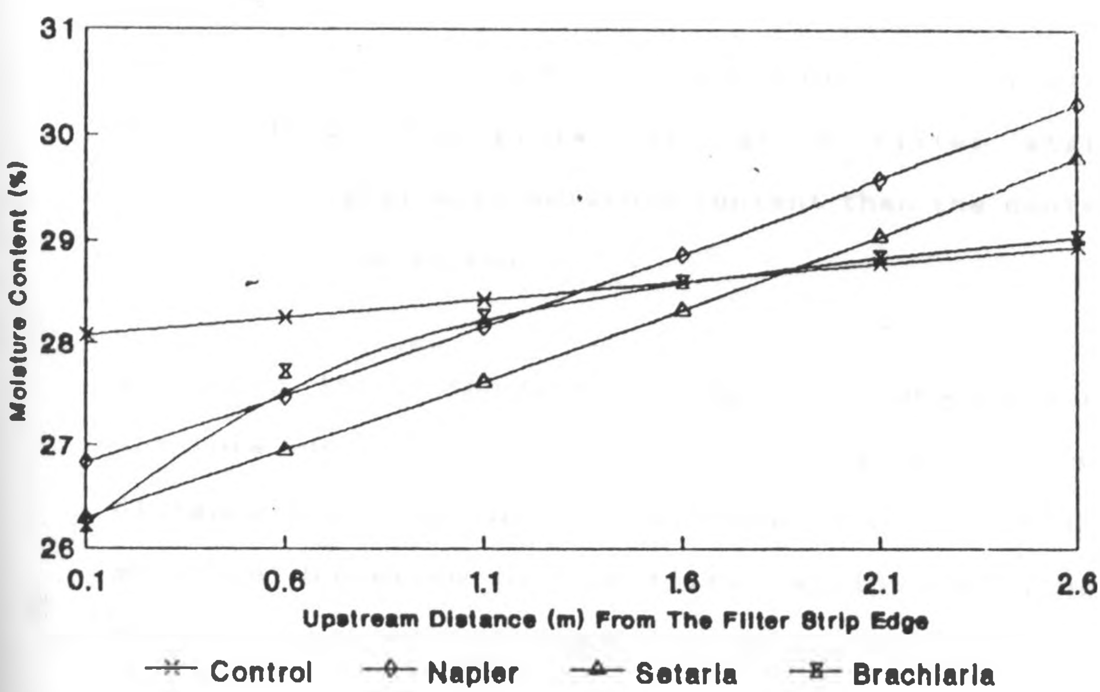

Fig. 26. Soil moisture profile upstream of the filter strips at 40cm depth, second gravimetric sampling.

The purpose of monitoring the soil moisture profile on the upstream side of the filter strips was to detect any moisture conservation by the filter strips. This is essential when the rainfall decreases or ceases while the planted crop is still in a critical moisture requirement stage. The moisture conserved by the filter strips can greatly assist in minimising any moisture deficit facing the crop planted. As it can be seen in the graphs above, there was a zone of higher moisture on the upstream side of the filter strips. However, the strips tended to utilize some of the moisture conserved during the dry spell. This can be seen from the lower moisture content just next to the strip edge when compared with the control i.e the control had overall higher moisture contents. This was approximately so for the first 0 m to 1.3 m away from the filter strip edge. Beyond this, the plots with grass filter strips exhibited higher soil moisture content than the control at the various depths.

Therefore, though the filter strips utilized some of the moisture conserved, they conserved more after a short distance from the edge of the strip. The zone of soil moisture depletion by the filter strips was longer during the second gravimetric sampling as seen in the graphs above. This can be explained to be due to more dry conditions and the more extensively developed grass root systems by the second sampling.

An interesting observation as seen from the graphs was that the difference in the soil moisture conserved between the control and the plots with grass filter strips increased with corresponding increase in soil depth. This can be explained to be due to evaporation of the soil moisture near the soil surface in to the atmosphere and hence the less difference at the upper soil layers. Then there is also the cumulative effect with time of the moisture conserved by the filter strips. This conserved soil moisture accumulates in the lower soil depths where minimal escape in to the atmosphere can occur. To monitor the soil moisture content during the crop growing season, one would have to employ methods that do not disturb the plots considerably e.g the neutron probe, gypsum blocks etc.

4.6 Fodder Potential Of The Grasses

The green fodder and dry matter yields from the filter strips of the three grasses was measured during the period of the research project. The nutrient content of the harvested grasses was also monitored. This was done for the most important parameters, namely the crude protein (CP), crude fibre (CF) and the nitrogen free extract (NFE). These nutrients are expressed as a percentage of the dry matter (DM).

For the four harvests done between March 1990 and January 1991 (more or less an annual yield) the green fodder and dry matter yields were as shown by the bar graphs in Fig. 29, 30, 31, 32, 33, 34, 35 and 36 below:

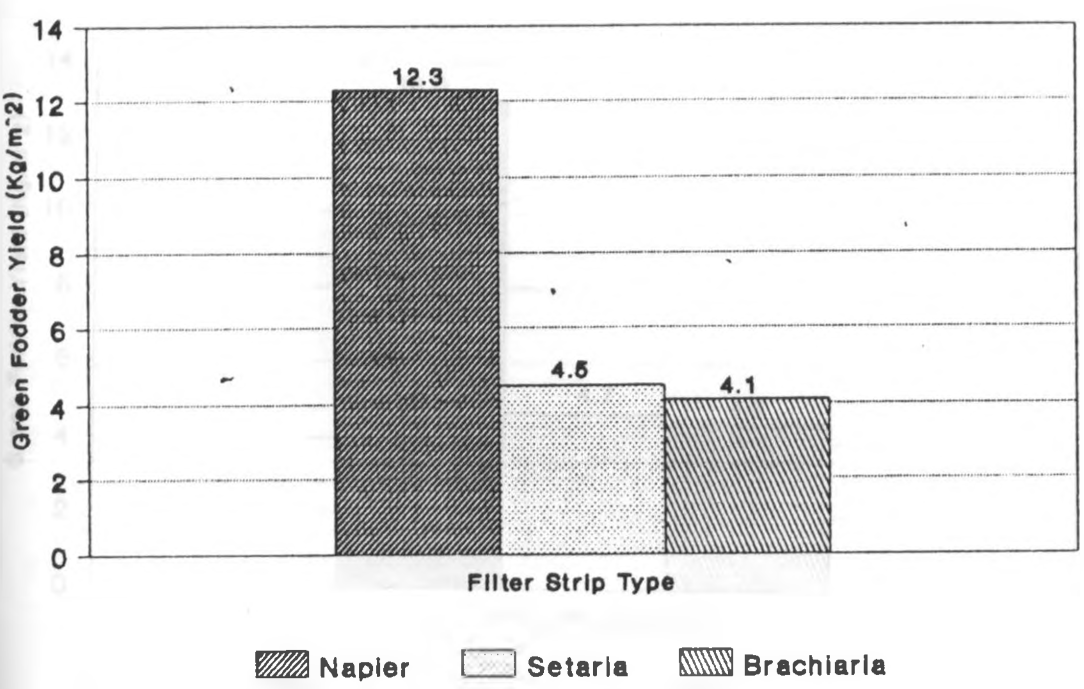

Fig.29. Green fodder yields versus the filter strip type,first harvesting.

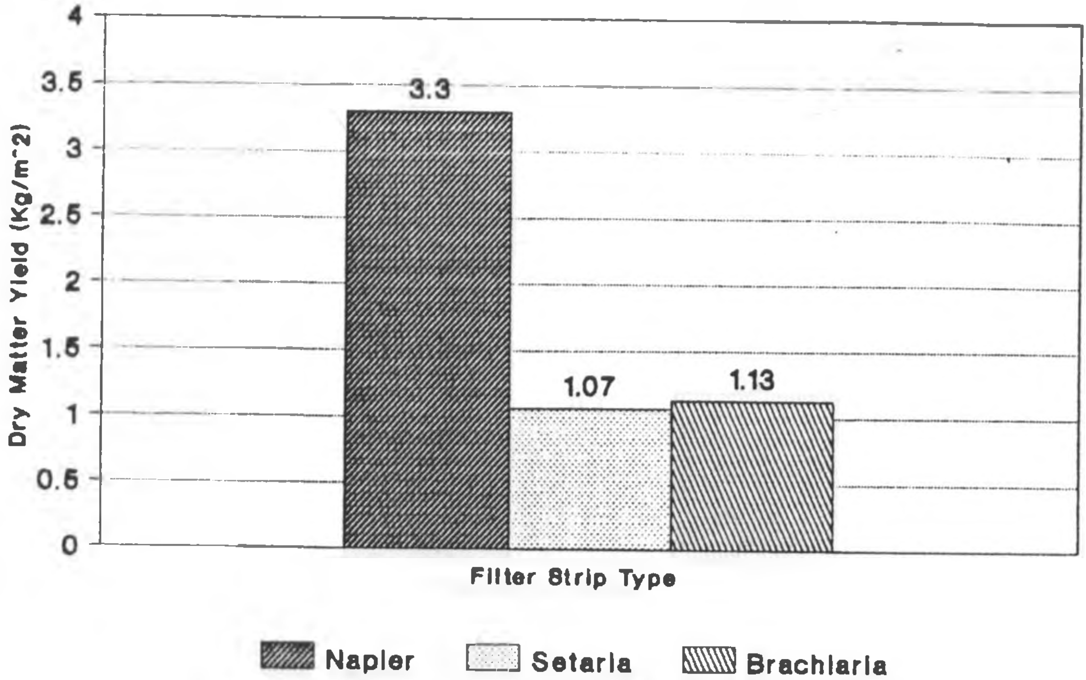

Fig.30. Dry matter yields versus the filter strip type, first harvesting.

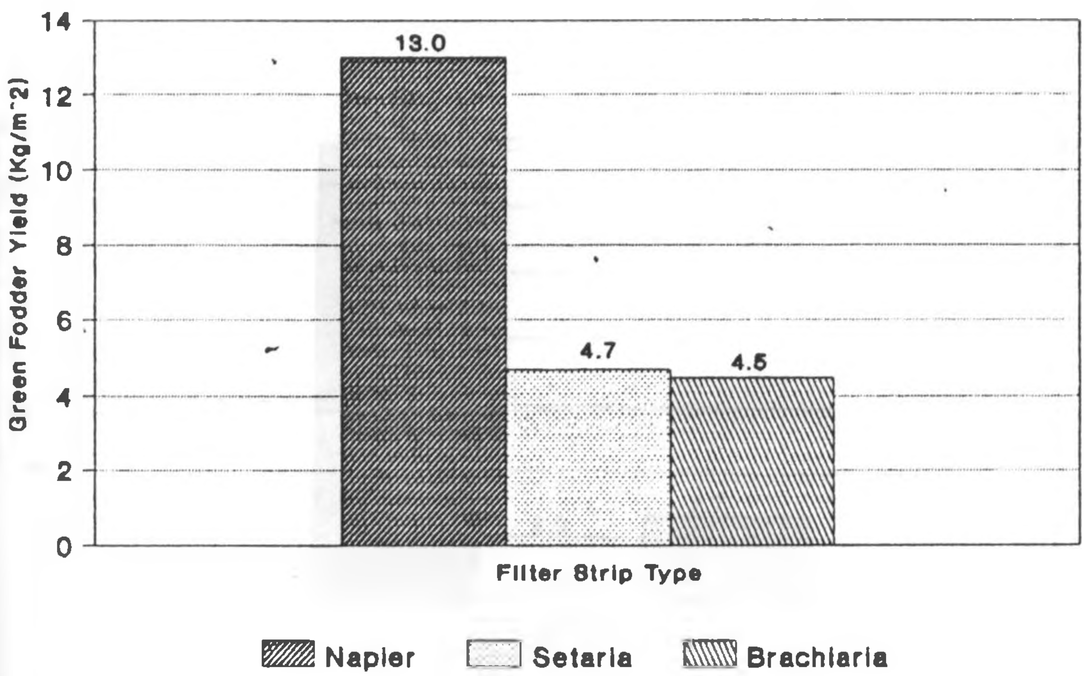

Fig.31. Green fodder yields versus the filter strip type, second harvesting.

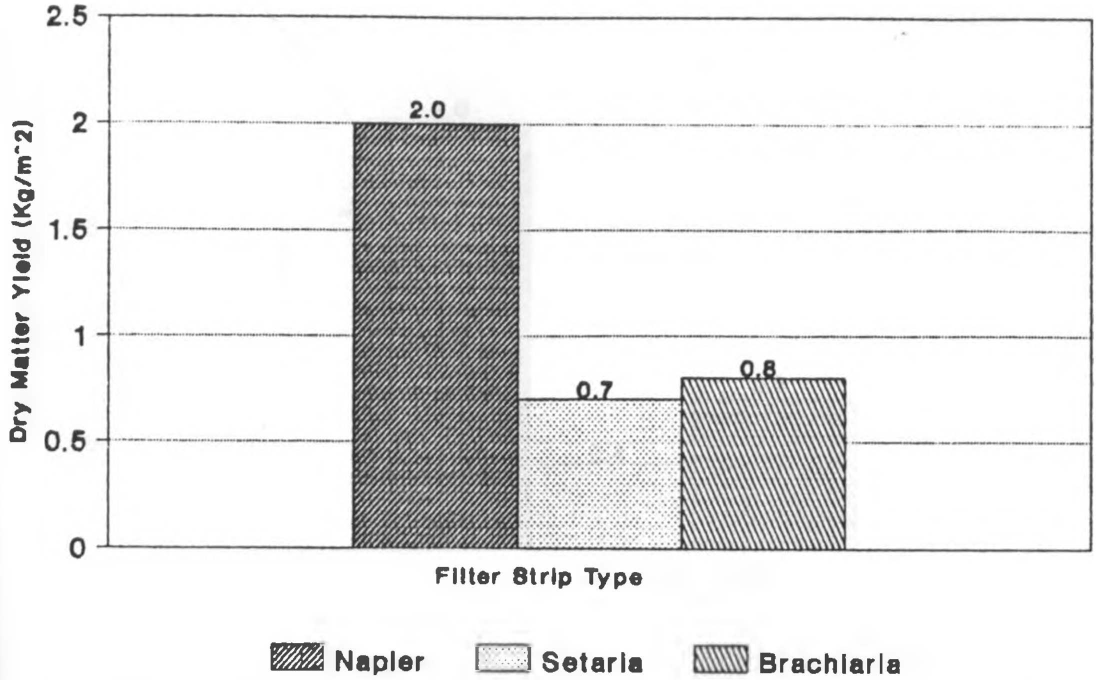

Fig.32. Dry matter yields versus the filter strip type, second harvesting.

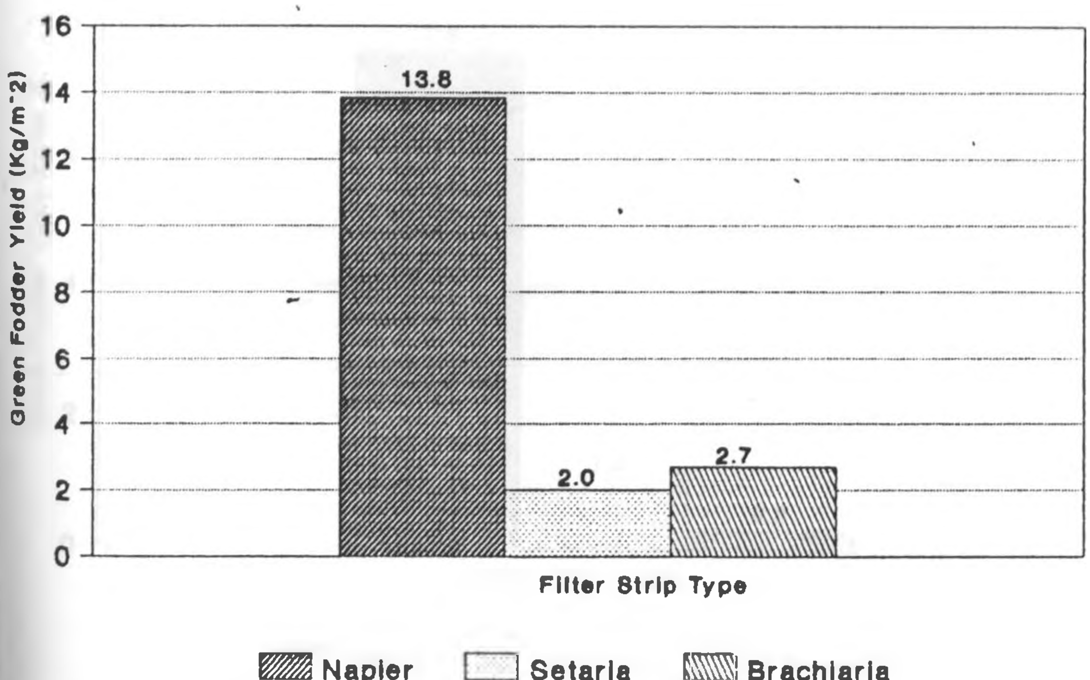

Fig. 33. Green fodder yields versus the filter strip type, third harvesting.

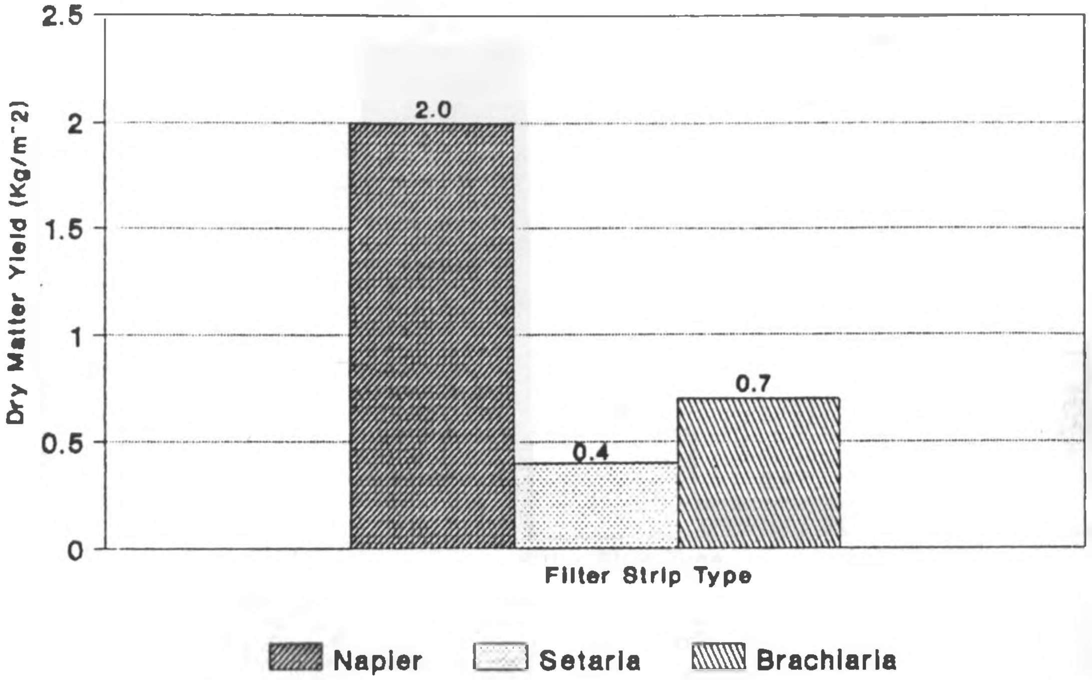

Fig.34. Dry matter yields versus the filter strip type, third harvesting.

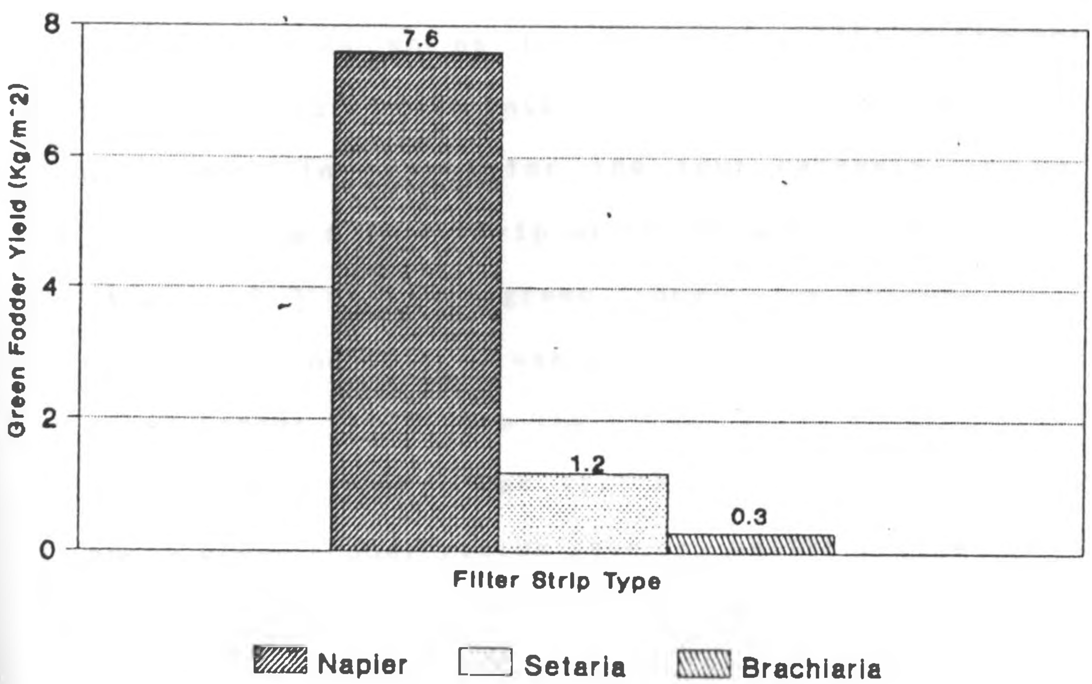

Fig.35. Green fodder yields versus the filter strip type, fourth harvesting.

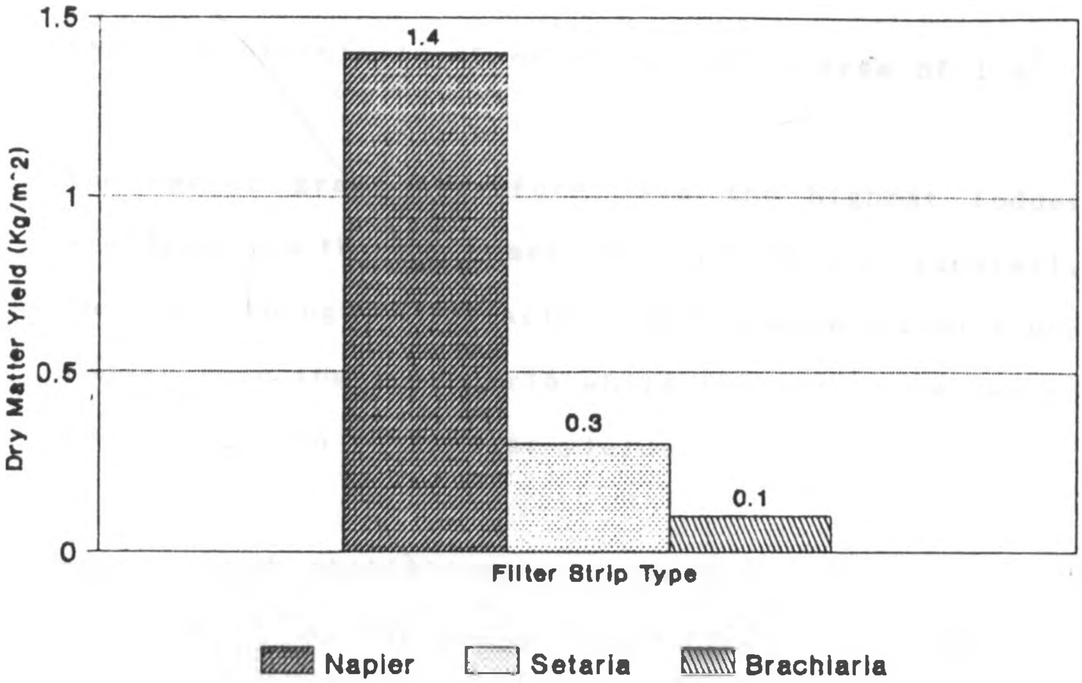

Fig.36. Dry matter yield versus the filter strip type, fourth harvesting.

The dry matter amounts shown in Fig. 30 are to two decimal places so as to show the slight different between some treatments though not significantly different. In total, for the four harvests (annual yields), the filter strip of napier grass yielded 46.7 Kg/m^2 (466.7 t/ha) of green fodder. The corresponding yield from the setaria was 12.4 Kg/m^2 (123.9 t/ha). The green fodder yield from the filter strip of brachiaria for the same period was 11.7 Kg/m^2 (117.1 t/ha). The above green fodder yields gave dry matter yields of 8.8 Kg/m^2 (87.7 t/ha) for the napier, 2.5 Kg/m^2 (24.6 t/ha) for the setaria and 2.7 Kg/m^2 (26.8 t/ha) for the filter strip of brachiaria. Each strip had an area of 1 m^2.

The napier grass therefore gave the highest fodder yields of the three grasses. The results also generally show that though the setaria tended to give higher green fodder than the brachiaria while the latter tended to be superior in dry matter yields.

When tested statistically, F-test at 5% level, the filter strip of napier was superior to the two grasses in both green fodder and dry matter yield. There was only a significant difference in green fodder and dry matter yield between the setaria and brachiaria during the third and fourth harvesting. During the third harvesting, the brachiaria gave higher green fodder and dry matter than the setaria though it was the dry matter which was significantly different. The fourth harvesting was done in one of the driest periods of the year i.e January 1991. This explains the low yields from the setaria and brachiaria filter strips during this fourth harvesting. However, the setaria was superior to the brachiaria in both green fodder and dry matter yields i.e there was a significant difference between the two during this last harvesting. These last two grasses were affected by the very dry spell of January to March

1991. It was however noticeable that despite the lower yield from the brachiaria during this very dry period, the foliage harvested was more green when compared with the mainly dry stalks from the setaria.

Therefore, as seen from the above results, the napier maintained high green fodder and dry matter yields during the wet and dry spells. The other two grasses had their growth considerably reduced during the dry spell. Though the brachiaria was second to the napier in terms of drought tolerance, its growth was minimal during the driest part of the year as the results of the fourth harvesting indicate.

The nutrient content of the three grasses during each of the harvesting is as shown in Table 3. below:

Table 3. Important nutrient contents of the three grasses.

Grass	harvesting time	%DM	%Water	%CP	%CF	%NFE
Napier	1st	26.76	73.24	9.75	34.77	38.10
"	2nd	15.38	84.62	13.53	31.90	33.25
"	3rd	14.79	85.22	14.40	34.83	30.14
"	4th	19.02	80.98	8.18	39.44	40.17
Setaria	1st	23.62	76.38	9.62	41.63	36.70
"	2nd	14.35	85.83	13.17	33.53	33.86
"	3rd	18.95	81.05	13.74	35.88	34.04
"	4th	29.02	70.98	10.08	38.83	33.77
Brachiaria	1st	27.36	72.64	11.11	32.89	42.43
"	2nd	17.66	82.44	13.85	28.78	38.72
"	3rd	24.93	75.06	12.73	30.68	40.23
"	4th	21.84	78.16	13.32	26.81	43.50

DM = Dry Matter, CP = Crude Protein, CF = Crude, NFE = Nitrogen Free Extract

The brachiaria therefore tended to maintain high CP content even as it aged before harvesting. The napier and the setaria had their CP lowered considerably as they passed their optimum harvesting time. This is well shown by the results of the delayed first harvesting. However, all the grasses maintained high and no much different CP content when harvested at suitable growth stages. It is also notable that the critical level of CP content is 7% and therefore herbages above this level are not significantly different interms of protein content. The freshly harvested material is also important since it is the one that is actually fed to livestock. In terms of CF, the setaria generally had the highest content while the brachiaria had the least. The brachiaria generally gave the highest NFE content followed by the setaria as seen from the above table.

The crude protein is important since proteins are responsible for high milk production. The NFE mainly comprises of soluble carbohydrates. These are utilized by microorganisms that assist foliage digestion in ruminants. The CF content is also critical because if it is very high, the foliage is less digestible. This is especially so if the lignin content is high. The dry matter is the most important since it is the one containing the nutrients dicussed above. Therefore, a grass having very high water content and low dry matter is not of high value to the farmer.

The fourth harvesting was done during a very dry spell when compared with time during the other harvests. However, during this harvest the brachiaria maintained high CP while the other two grasses had their CP substantially reduced. Despite that disadvantage, the napier filter strip had the biggest advantage of maintaining high green fodder and dry matter yields as mentioned earlier.

4.7 Economic Aspects

The value of the maize and beans harvested was estimated by the current prices offered by the National Cereals And Produce Board (NCPB), Kenya. The prices were for a 90 Kg bag of each of the produce. The price of maize was KSh 230 while the beans were KSh 520 per the 90 Kg bag. The green fodder yields were valued using the local price of approximately KSh 15 per a bag of approximately 27 Kg. However, the fodder value could rise up to about KSh 20 to KSh 25 during the very dry periods.

By planting the grass filter strips, one row of maize and two rows of beans were foregone annually. The value of the crop yields lost by having the above rows is shown in the table below:

Table 4. Value of crop lost on planting the grass filter strips.

Description	Yield (Kg)	Value (KSh)
1 row of maize (long rains)	0.9	2.22
2 rows of beans (short rains)	0.2	1.38
Total annual value		3.60

To be able to determine whether the fodder harvested from the filter strips was compensating for the crop foregone, the fodder harvested was valued as shown in the table below:

Table 5. Value of the green fodder harvested from the grass filter strips.

Grass type	Annual green fodder yield (Kg)	Fodder value (KSh)
Napier	46.67	25.93
Setaria	12.39	6.88
Brachiaria	11.71	6.51

The above computations show that the value of the fodder obtained from the crop area taken by the filter strips greatly surpasses the value of the crop foregone. Therefore, the advantages of the using the filter strips appeared to considerably outweigh the disadvantages. The fodder benefits could even be higher if considered in terms high milk production in areas where dairy is an important enterprise. There is the more important benefit of the grass filter strips conserving moisture and the fertile top soil as discussed earlier.

To have a general economic outlook of the effect of planting the grass filter strips, the value of the annual crop and green fodder yields from the plots used was determined as shown in the four tables below:

Table 6. Value of the maize yields from the long rains, 1990.

Treatment	Maize crop yield (Kg/Plot of 23.2 m^2)	Yield value (KSh)
Control	16.434	42.00
Napier	15.478	39.55
Setaria	13.696	35.00
Brachiaria	14.758	37.71

Table 7. Value of the bean yields from the short rains, 1990.

Treatment	Bean crop yield (Kg/Plot of 23.2 m^2)	Yield value (KSh)
Control	2.883	16.37
Napier	2.478	14.32
Setaria	2.276	13.15
Brachiaria	2.644	15.28

Table 8. Total value of the annual maize and bean crop yields.

Treatment	Yields Value (KSh)
Control	58.37
Napier	53.87
Setaria	48.15
Brachiaria	52.99

Table 9. Total value of the annual crop and fodder yields from each treatment.

Treatment	crop and fodder value (KSh)
Control	58.37
Napier	79.80
Setaria	55.03
Brachiaria	59.50

The above results therefore show that the value of the green fodder harvested generally exceeded the value of the crop lost on planting the filter strips. It is seen in table 8. above that the total value of the fodder and crop yields from the plots with the filter strips was generally higher than the value of the crop yields from the control plot. It was only the case of the plot with a filter strip of setaria that the combined value of the crop yields and fodder was slightly lower than the value of the crop from the control. However, the fodder from the setaria filter strip could still be more value in terms of high milk production and conservation benefits. The fodder is also expected to be more valuable during the driest months of the year.

Though it is difficult to value the benefits of soil and water conservation, the value of the soil conserved by the grass filter strips is of great importance. This is because soil formation is generally an extremely slow process and therefore any soil that is eroded is not easily replaced. Moreover, the soil productivity and the soil's response to fertilization is greatly reduced. It is also important to note that the above calculations exclude such inputs like filter strips planting materials, seeds, fertilizers, weeding labour, filter strips maintenance, etc. An important aspect to note here also, is that the computations above are based on a run-off plot unit and therefore are purely experimental. Therefore, in real life (actual terraces in the field) the situation may be different. For example, a terrace may be wider or even narrower than the plots used in the experiment. This is expected as the ground slope varies. Therefore, the economic aspect under consideration only suggests the economic implication of using such grass filter strips for conservation on crop land. This therefore suggests that more research on the economic implications of using such strips for conservation should be carried out in the future.

5.0 CONCLUSION

In terms of run-off control, the grass filter strips showed no significant difference when compared with the control during early establishment. The different types of filter strips also showed no significant difference between themselves in this early period of establishment. However, the run-off from the plots with filter strips was always on the lower side compared with the control. For this difference to be significant, the filter strips need to be well established. The different types of filter strips did not differ considerably in run-off control during the early stages of growth as shown by the results of the long rains of 1990. The filter strips of napier and setaria exhibited closer run-off reduction efficiencies than when compared with the brachiaria. This was especially so for the first two seasons and can be explained to be due to their tufted growth nature and slow establishment as discussed in the previous chapters.

In the case of soil loss reduction, the grass filter strips were substantially effective only after they were well established and provided good ground cover. This was because their sediment filtering ability improves tremendously over time. The run-off impedence capability of the strips also improved as mentioned above resulting in most of the eroded sediments settling on the upstream side and within the filter strip. An important aspect to note is that the brachiaria filter strip was the best of the three filter strips tested in terms of run-off and soil loss reduction. This filter strip gave the lowest amounts of run-off and soil loss during the three seasons of the experiment. The filter strip of napier was second best though it had a low performance during the early growth stages. The type of grass that is used to establish filter strips for soil and water conservation is therefore important. This is because grasses differ in their ability to impede run-off and to filter the eroded sediments.

Though the control and the plots with filter strips did not show significant difference in crop yields, this may change with time. For example, as more soil is eroded from the plot without a filter strip, the crop yields may be reduced considerably. The remaining and less fertile soil may also not be able to respond well to fertilizer application. As highlighted earlier, erosion of the fertile top soil also depletes the moisture storage capacity of the soil and degrades the soil texture. This may result into poor crop performance.

It can also be concluded that the grass strips had the disadvantage of competing with the adjacent crop for soil moisture. One would also expect the strips to compete with the nearby crop for nutrients. This was highly indicated by the filter strip of napier grass especially during the long rains of 1991. However, the strips conserve more soil moisture a short distance away from the strip edge. It is however notable that the degree of competition depends on the grass type used. This is because some grasses are more competitive than the others. The setaria and the brachiaria showed minimal competition with the nearby crop.

In terms of fodder potential where the three grasses are used for conservation purposes, the napier had the highest potential followed by the brachiaria. Since the fodder potential aspect is essential especially to small scale livestock farmers, the napier proved to be superior compared to the other two grasses. The brachiaria then follows and is also notable for its high efficiency in run-off control and soil loss reduction.

6.0 RECOMMENDATIONS

6.1 Recommendations For Further Research

Some aspects of this research study should be investigated further as discussed below.

(i) Though the grass filter strips were seen to conserve and also utilize some soil moisture on the upstream side, what happens on the downstream side should also be investigated. The soil moisture conservation by the filter strips should also be monitored through out the growing period of the crop planted. This may be useful to find out if the filter strips ensure that the crops get more moisture during dry spells and especially at critical growth stages. Such an undertaking would require soil moisture measurement methods that do not frequently disturb the soil unlike the gravimetric sampling method. It would also be important to find out whether such filter strips can reduce run-off and soil loss significantly at much steeper slopes. The long term behaviour of grass filter strips as a conservation measure on crop land should also be studied further.

(ii) The other important aspect that could be investigated is the effect of the filter strips on soil fertility. Some grasses could be depleting a lot of plant nutrients from the soil. Other grasses could have the benefit of adding more and recycling the nutrients. For example the brachiaria filter strip was observed to have lot of dead leaves which could be adding substantial amounts of organic matter into the soil.

(iii) The economic aspects considered in this experiment only applied to the unit run-off plot used in the study. Further economic investigations on bigger plots, steeper slopes and also on farmland should be carried out.

(iv) The essential aspect of the grass strips competition with the adjacent crop should be monitored over a long period. This should mainly involve measurement of crop height, crop yields, soil moisture content and also studying the root characteristics of the grasses.

(v) It would also be important to find out whether such filter strips can significantly reduce run-off and soil loss at much steeper slopes. The long term behaviour of the strips as a conservation measure should also be investigated. This was clearly suggested by the varying efficiencies of the strips in run-off and soil loss reduction with time.

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8.0 APPENDICES

8.1 Appendix I: Rainfall

Table 10. Mean monthly rainfall of the experimental site (Gachene, 1989).

Month	Mean rainfall (mm)
January	43
February	59
March	89
April	245
May	172
June	41
July	24
August	16
September	33
October	63
November	133
December	90
Total	1008

Table 11. Monthly and total rainfall at the experimental plots, 1990.

Month	Rainfall (mm)
January	52
February	62
March	195
April	263
May	283
June	4
July	5
August	13
September	16
October	75
November	138
December	63
Total	1169

Table 12. Monthly and total rainfall (mm) at the experimental plots, January to May 1991.

January	February	March	April	May	Total
47	0	77	153	285	562

8.2 Appendix II: Plates

Plate 1. The control plot, with no grass filter strip, long rains 1990. Note the young maize crop and the covered collector unit at the lower end.

Plate 2. The plot with a filter strip of napier grass, newly established, long rains 1990. Note the uncovered ground within the strip.

Plate 3. The plot with a newly established filter strip of setaria, long rains 1990. Note the large uncovered ground within the strip and the less growth when compared with the napier.

Plate 4. The plot showing the newly established filter strip of brachiaria, long rains 1990. Note the fast and carpet forming growth habit unlike the two grasses above.

Plate 5. The maize crop at the silking stage, 3 Wks after the long rains 1990. From the left, note the control and the now better established filter strips of napier, brachiaria and setaria respectively.

Plate 6. The short rains bean crop and the newly harvested grass filter strips. Note the two extra rows of beans where no filter strip is planted.

Plate 7. The control and the plots with the filter strips, long rains 1991. Note the maize row suppressed by the napier and the extra maize row where no filter is established.

Plate 8. The collector unit showing the end plate and the collecting trough, long rains 1991. The eroded sediments can be clearly seen on the end plate.

Plate 9. The main run-off storage tank, the small drum and the conveyor (the grey pvc pipe). Note the run-off with the eroded sediments in the small drum, long rains 1991.

Plate 10. Run-off and the eroded sediments measurement. Note the red graduated bucket, measuring cylinder and the sampling jar with a blue lid.

Plate 11. Napier grass being used to stabilise the embarkment of a fanya juu terrace, Mbari ya Hiti catchment, Murang'a district. Note the sweet potato and the healthy maize crop.

8.3 Appendix III: ANOVA (F-test at 5% level)

df = degrees of freedom.

SS = reduced Sum of Squares.

MS = Mean sum of Squares.

F = calculated F.

F5% = tabular F at 5% significance level.

ns = not significant.

* = significant at 5% level.

LSD = Fisher's Least Significant Difference.

Table 13. Run-Off, Long Rains 1990.

Source	df	SS	MS	F	F5%
Total	11	2272.27	206.57		
Treatment	3	165.75	55.25	1.25ns	4.76
Block	2	1841.17	920.59	20.81*	5.14
Error	6	265.35	44.23		

Table 14. Run-Off, Short Rains 1990.

Source	df	SS	MS	F	F5%
Total	11	6.81	0.62		
Treatment	3	1.72	0.57	7.13*	4.76
Block	2	4.64	2.32	29.0*	5.14
Error	6	0.45	0.08		
		LSD =0.51			

Table 15. Run-Off, Long Rains 1991.

Source	df	SS	MS	F	F5%
Total	11	53.32	4.85		
Treatment	3	41.10	13.70	52.69*	4.76
Block	2	10.69	5.35	20.58*	5.14
Error	6	1.53	0.26		
		LSD = 0.92			

Table 16. Soil Loss, Long Rains 1990.

Source	df	SS	MS	F	F5%
Total	11	14693.95	1335.81		
Treatment	3	455.62	151.87	0.61ns	4.76
Block	2	12746.21	6373.11	25.63*	5.14
Error	6	1492.12	248.69		

Table 17. Soil Loss, Short Rains 1990.

Source	df	SS	MS	F	F5%
Total	11	32.68	2.97		
Treatment	3	21.91	7.30	7.68*	4.76
Block	2	5.09	2.55	2.68ns	5.14
Error	6	5.68	0.95		
			LSD = 1.75		

Table 18. Soil Loss, Long Rains 1991.

Source	df	SS	MS	F	F5%
Total	11	37.01	3.36		
Treatment	3	35.15	11.72	40.41*	4.76
Block	2	0.11	0.06	0.21ns	5.14
Error	6	1.75	0.29		
		LSD = 0.97			

Table 19. Green Fodder Yields, 1^{st} Harvesting.

Source	df	SS	MS	F	F5%
Total	8	156.34	19.54		
Treatment	2	128.24	64.12	139.39*	6.94
Block	2	26.25	13.13	28.54*	6.94
Error	4	1.85	0.46		
			LSD = 1.28		

Table 20. Dry Matter Yield, 1^{st} Harvesting.

Source	df	SS	MS	F	F5%
Total	8	11.29	1.41		
Treatment	2	9.73	4.87	54.11*	6.94
Block	2	1.22	0.61	6.78ns	6.94
Error	4	0.34	0.09		
			LSD = 0.56		

Table 21. Green Fodder Yield, 2nd Harvesting.

Source	df	SS	MS	F	F5%
Total	8	157.54	19.69		
Treatment	2	141.15	70.58	235.27*	6.94
Block	2	15.21	7.61	25.37*	6.94
Error	4	1.18	0.30		
		LSD = 1.03			

Table 22. Dry Matter Yields, 2nd Harvesting.

Source	df	SS	MS	F	F5%
Total	8	3.78	0.47		
Treatment	2	3.23	1.62	81.0*	6.94
Block	2	0.49	0.25	12.50*	6.94
Error	4	0.06	0.02		
		LSD = 0.27			

Table 23. Green Fodder Yields, 3rd Harvesting.

Source	df	SS	MS	F	F5%
Total	8	266.22	33.28		
Treatment	2	261.41	130.71	165.46*	6.94
Block	2	1.67	0.84	1.06ns	6.94
Error	4	3.14	0.79		
		LSD = 1.67			

Table 24. Dry Matter Yields, 3rd Harvesting.

Source	df	SS	MS	F	F5%
Total	8	4.74	0.59		
Treatment	2	4.67	2.34	117.0*	6.94
Block	2	0.01	0.01	0.5ns	6.94
Error	4	0.06	0.02		
		LSD = 0.27			

Table 25. Green Fodder Yields, 4th Harvesting.

Source	df	SS	MS	F	F5%
Total	8	94.70	11.84		
Treatment	2	93.98	46.99	522.11*	6.94
Block	2	0.38	0.19	2.11ns	6.94
Error	4	0.34	0.09		
		LSD = 0.56			

Table 26. Dry Matter Yields, 4th Harvesting.

Source	df	SS	MS	F	F5%
Total	8	3.23	0.40		
Treatment	2	3.15	1.58	158.0*	6.94
Block	2	0.03	0.02	2.0ns	6.94
Error	4	0.05	0.01		
			LSD = 0.19		

8.4 Appendix IV: Main Project Activities

Table 27. Dates Of Major Operations/ Activities.

Operation /Activity	Date /Period
Grass strips planting	20/3/90
Planting of the 1st maize crop	22/3/90
1st grass harvesting	10/8/90
1st maize crop harvesting	26/9/90
Bean crop planting	23/10/90
2nd grass harvesting	16/11/90
3rd grass harvesting	7/1/91
Bean crop harvesting	21-23/1/91
1st sampling for soil moisture	28/1/91
4th grass harvesting	28/3/91
2nd sampling for soil moisture	26/3/91
2nd maize crop planting	27/3/91