EFFECTIVENESS OF *FANYA CHINI* TERRACES ON SOIL PROPERTIES AND CROP YIELD IN THE NORTH-WESTERN PART OF THE ULUGURU MOUNTAINS, MOROGORO, TANZANIA

BY

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ABSTRACT

A field experiment was conducted in the north-western part of the Uluguru Mountains, Morogoro District, to determine the effect of *Fanya chini* terraces on selected soil chemical and physical properties and crop performance. Eighteen experimental plots of 12 m x 3 m were established on farmers' fields. Plots with *Fanya chini* terraces were compared with those with no conservation structures. Maize (*Zea mays* L.) was used as the test crop. No inorganic fertiliser was applied in order to reflect farmers' practices in the area. Soil samples from the experimental plots taken at the beginning (initial) and at the end (final) of the study were analysed to assess the changes in soil physical and chemical characteristics that had occurred during the cropping period.

Most of the observed soil chemical variables were slightly (but insignificantly) higher in plots that had no conservation structures (unconserved plots) and their magnitude tended to increase along the slope. Organic carbon, total nitrogen and exchangeable calcium showed a significant increase ($P = 0.05$) in unconserved plots in the final soil samples. There was a significant difference ($P = 0.01$) in PR between the *Fanya chini* terraced plots and unconserved plots both at the beginning and at the end of the experiment. *Fanya chini* terraced plots had mean PR value of 0.69 and 1.81 MPa compared to unconserved plots which had mean PR values of 0.78 and 1.71 MPa at the beginning and at the end of the experiment, respectively. Maize grain yield and biomass were not significantly different between the *Fanya chini* terraced and unconserved plots. However, grain yield and biomass were relatively higher in the unconserved plots and they tended to increase along the slope. The exposure and spread of the subsoil from the *Fanya chini* channels that were about 30 to 50 cm deep

may have resulted into the reduced soil fertility and the resultant lower yield observed under *Fanya chini* terraces. *Fanya chini* terraces are not the best soil conservation measure on steep slopes. Where they are already in place, *Fanya chini* terraces should be complemented with other soil surface management practices.

DECLARATION

I, Appia Paul Mkoba, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation in my own original work and that it has not been submitted for a degree award in any other university.

Signature: 

Date: 06/04/2001

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DEDICATION

This work is dedicated to my uncle Mr. P. F. Mkoba, my deceased aunt Ginsella and my deceased sister Aveline.

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LIST OF ABBREVIATIONS

ANOVA – Analysis of variance

Ca - Calcium

CEC – Cation exchange capacity

CSIRO – Commonwealth Scientific and Industrial Research Organisation

D_b – Bulk density

DMRT – Duncan's New Multiple Range Test

FAO – Food and Agriculture Organization of the United Nations

H_2SO_4 – Sulphuric acid

K - Potassium

m.a.s.l. – Metres above sea level

Mg – Magnesium

MPa – Mega Pascal

MWD – Mean Weight Diameter

Na – Sodium

NaOH – Sodium hydroxide

OC – Organic Carbon

PR – Penetration Resistance

NORAD – Norwegian Agency for Development Co-operation

SUA – Sokoine University of Agriculture

SCSRD – SUA Centre for Sustainable Rural Development

N - Nitrogen

P - Phosphorus

S - Sulphur

USDA - United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

The Uluguru Mountains constitute an important agricultural area of the land surface (Rapp *et al.*, 1972). The favourable climatic conditions have enabled the Uluguru Mountains to support a high population density. Many people have inhabited the hilly slope area for agricultural production. This has resulted into several land-related problems including massive deforestation and intensive cultivation leading to land degradation and low soil productivity (Kilasara and Rutatora, 1993). Soil erosion is the most important form of land degradation in the Uluguru Mountains. Agricultural practices such as shifting cultivation, rampant burning and other uncontrolled human activities have resulted in serious erosion. A study conducted by Lulandala *et al.* (1995) in Magadu and Towero villages revealed that most areas are intensively exploited for wood products; they are also repeatedly burnt each year and frequently cleared for growing food crops. The overall environment has remarkably deteriorated and soil erosion is rampant.

Over the centuries, people have developed strategies to protect and rehabilitate land. Conservation practices such as contouring, terracing, ridging and inter-cropping help to reduce degradation and, hence, maintain the fertility status of the soil. Soil and water management has the potential to substantially contribute to reducing degradation of the productive capacity of the land, consequently increasing yield (Hatibu *et al.*, 1993). Terracing, for example, was reported to increase beans and maize yield by 56% and 61%, respectively, in Machakos district, Kenya (Tjernstrom, 1992). Soil and water conservation are mainly aimed at obtaining the maximum

sustainable level of production from a given area of land while reducing soil loss (Manyatsi, 1998).

The colonial rulers before independence first introduced soil conservation measures in the Uluguru Mountains. The colonial authorities launched huge soil conservation schemes such as the Uluguru Land Usage Scheme of the 1950s (Critchley *et al.*, 1992). Unfortunately, these conservation efforts failed due to several reasons such as lack of clear objectives, lack of experimental work and demonstration plots and inadequate extension services (Young and Fosbrooke, 1960).

Small holder farmers are not interested in soil and water conservation *per se*. They are always after immediate economic returns, mostly in the form of higher yields, in order to sustain their living. For any conservation programme to be effective, every effort must be made to develop practices that not only conserve the soil but also provide short-term tangible benefits to the farmers (Sanders, 1990). Short-term benefits include opportunity costs of resources needed to install conservation practices, changes in yield due to different cropping and management practices and changes in production costs (Marc *et al.*, 1989). Unfortunately, there are few data with which to estimate these benefits.

Currently the question of soil and water conservation measures has become of increasing interest in the Uluguru Mountains. The increased awareness of soil erosion and its related problems have been a driving force towards increased efforts in introducing appropriate soil and water conservation strategies. Various soil and

conservation measures such as intercropping, terracing, agroforestry and grass strips have been introduced.

In the north-western part of the Uluguru Mountains, level *Fanya Chini* terraces originating from Kenya (Thomas *et al.*, 1980) are the dominant terraces used by small holder farmers as the soil conservation measure mainly for vegetable growing but also for fields under food crops such as maize. These were introduced in the area by the Uluguru Mountain Integrated Soil Conservation Project (Lulandala *et al.*, 1995). Grasses such as elephant grass (*Pennisetum purpureum*) are planted on the ridge to stabilise it and for fodder. Bench and ladder terraces are exclusively used for growing vegetables. Currently, the SUA Centre for Sustainable Rural Development (SCSRD) is undertaking research to quantify the suitability of *Ngoro* pit system of cultivation in controlling runoff and soil loss in the north-western part of the Uluguru Mountains.

Although level *Fanya chini* terraces have been reported to be successful in Kenya (Hudson, 1995), it has been difficult to recommend them as being the best soil and water conservation technique for all situations in terms of their enhancing crop yield. Different soil and water conservation techniques have different impacts on soil properties depending on soil type and topography of the land. There has been limited research and shortage of information on the impact of *Fanya chini* terraces on soil properties and crop yield in the north-western part of the Uluguru Mountains. The study reported herein was conducted to fill this knowledge gap.

Main objective

The main objective of the study was to determine the effectiveness of level *Fanya chini* terraces on soil properties and crop yield in the north-western part of the Uluguru Mountains.

Specific objectives

- To examine the influence of level *Fanya chini* terraces on soil physical and chemical properties.
- To determine the impact of level *Fanya chini* terraces on maize yield.

CHAPTER TWO

LITERATURE REVIEW

The soil is a reservoir for water and chemicals including plant nutrients and provides a medium to support plants (Schwab *et al.*, 1995). In Tanzania there is a large and growing problem of decline in soil fertility due to erosion and other processes of soil degradation.

Soil erosion alters the physical, chemical and biological properties of the soil that regulate the processes that determine the fertility status of the soil. Erosion causes losses of productive topsoil, organic matter, nutrients and water (Rapp, 1986). It also results into degradation of soil structure and alteration of clay content (Weesies *et al.*, 1994) that ultimately cause reduced productivity. Misana (1992) revealed that soil erosion and compaction in Ismani Division, Iringa Region, resulted in the decline of maize yield from the recorded 35 bags/ha in the early 1950s to 12 bags/ha in 1971 and only an average of 7 bags/ha in 1992. One bag weighs approximately 90 kg.

Many management practices have the potential both to control erosion and to check other forms of soil degradation (Young, 1989). One method of decreasing erosion in agricultural land is through the adoption of soil and water conservation techniques. With the growing demand for increased crop production, concern for soil and water conservation has become of greater importance. Many conservation practices are being applied to reduce or control soil loss. The effects of these conservation practices appear to be a major reason for their acceptance or non-acceptance.

being applied to reduce or control soil loss. The effects of these conservation practices appear to be a major reason for their acceptance or non-acceptance.

It has been noted that many erosion-productivity studies that have been conducted do not provide a sufficient level of quantification of erosion's impact on productivity. According to Pierce and Lal (1994) the primary goal of soil-erosion related research world-wide has been the quantification of the forms, rates and extent of erosion. As a result much more is known about the erosion process than the consequences of erosion or, indeed, effective methods of controlling it.

Small-scale farmers have been relying on agriculture as their main source of income. As a result they do not have time to adopt new and risky practices to tackle land degradation. Soil conservation will only work effectively when farmers can see some immediate benefits. Thus, there is need for developing and introducing effective and profitable conservation measures. Conservation practices should increase yields, reduce risks and/ or provide other direct benefits such as taking the drudgery out of farm work, improve the nutritional status of a community (Sanders, 1992). Moreover, they should be appropriate to local conditions and capable of being integrated into local farming systems while at the same time preventing or controlling erosion (Hudson, 1995).

2.1 Soil and water conservation in the Uluguru Mountains

Soil erosion in the Uluguru Mountains is worse because of shifting cultivation that dates as far back as the 1800s (Ahn, 1977). Other factors aggravating soil erosion in

the Uluguru Mountains include high human population density, steep slopes and highly erodible soils. Shifting cultivation was being practised along the slopes of the Uluguru Mountains up to when it was first interrupted by the first conservation measures in 1909 when an area of about 277 km^2 was declared as Forest Reserve. Consequently, however, the exploitation of the remaining non-reserve land increased. Greater proportions of steep slopes were cultivated leading to increased soil erosion (Temple, 1972).

During the 1920s limited conservation measures were put into operation. For example, around Mgeta area, local farmers began planting trees for obtaining firewood and preventing erosion. A new approach to soil and water conservation was again initiated in 1945 when the colonial authorities imposed a large conservation scheme, the Uluguru Land Usage Scheme, for rehabilitation of the eroded areas (Critchley *et al.*, 1992). The scheme mainly emphasised on the establishment of large terraces to control sheet erosion. For example, each household was forced to construct 500 m^2 of bench terraces (Ahn, 1977).

The Uluguru Land Usage Scheme collapsed in 1955 due to a number of factors. Among the reasons advanced to explain the scheme's failure included partial crop failure in some of the conservation sites, lack of well-trained and motivated field extension workers and provocation of riots and general disorders (Kilasara and Rutatora, 1993). All these were the outcome of lack of thorough investigation on the effect of bench terracing on crop yield prior to implementation of the scheme (Temple, 1972). Research conducted by Temple (1972) in the MorningSide valley,

on the north-western part of the Uluguru Mountains, showed that terraces were not effective and resulted into either total or partial crop failure. Moreover, an experiment conducted by Kisanga *et al.* (1992) in Mgeta revealed that bench terraces had less fertile soils with lowest values of soil pH, CEC, exchangeable Mg, total N and available P compared to ladder terraces and uncultivated representative soil. This was mainly because crops were planted in the exposed sub soil. Morgan (1986) recommended the use of ladder or step terraces (*Fanya juu*) as an alternative conservation measure in the Uluguru Mountains.

The concern about such environmental effects on the Uluguru Mountains arose again during the early 1980s. Studies on soil erosion processes were conducted and several soil and water conservation programmes were imposed. Lulandala *et al.* (1995) reported that in 1991, Sokoine University of Agriculture (SUA) initiated the Uluguru Mountain Integrated Soil Conservation Project (UMISCP). The aim of UMISCP was to determine the causes and extent of severity of land degradation and to begin environmental rehabilitation of the rapidly degrading Uluguru Mountains slopes above the main campus of SUA and on the north-western face of the mountains in general. The project stressed on tree planting. A total of 800,000 seedlings of different tree species were distributed. Farmers were trained especially in the construction of contour bunds and were told to plant a variety of grasses, leguminous tree species and fruit trees along the contour bunds. Apart from strengthening the contour bunds, they serve as a source of fodder for animals, as fuel wood and building poles and provide fruits to improve the nutritional status of the village. An evaluation conducted by Lulandala *et al.* (1993) revealed that the survival rate of

trees planted in the area was over 75%. From the project, it has become clear that more demonstration plots, afforestation activities and more farmer sensitization are the major issues in conserving the area (Verbesselt and Mertens, 2000).

2.2 Types of soil and water conservation techniques

There are many types of soil and water conservation techniques. These include Physical soil conservation measures such as stone barriers in gullies (Allan, 1965), terraces, cut-off drains and artificial waterways. Biological measures such as crop rotation, grass strips, mixed cropping and strip cropping (Per Assmo and Eriksson, 1994). Cultural measures such as Matengo pit system (Allan 1965), contour farming and mulching form the third type of soil and water conservation techniques.

2.2.1 Terrace farming

Cook (1962) defined a terrace as 'an embankment of earth constructed across a slope in such a way as to control water runoff and minimise erosion'. Terraces limit the water flow velocity (Rose, 1994), prevent formation of gullies and allow sediments to settle from runoff water (Schwab *et al.*, 1995). Hence, terrace farming generally aims at reducing soil loss and maintaining fertility status of the soil.

2.2.1.1 *Fanya chini/Fanya juu* terraces

Fanya chini terraces are channel terraces where the excavated soil used to build a bank is thrown down hill to establish an embankment. *Fanya chini* terraces can be

graded to discharge water or they can be level. Level *Fanya chini* terraces accumulate and retain runoff water in the terrace channel so that it infiltrates slowly and the sediments are allowed to settle in the terrace channel (FAO, 2000). Level *Fanya chini* terraces are in use in the north-western part of the Uluguru Mountains where rainfall is scanty. However, Per Assmo and Erikson (1994) noted that *Fanya chini* terraces are not suitable on steep slopes where soils are shallow. *Fanya chini* terraces require deep soils with high infiltration rate and the ground slope should not exceed 35%. In the north-western part of the Uluguru Mountains *Fanya chini* terraces are used on slopes exceeding 35% (see section 3.1).

Fanya juu terraces are channel terraces where the soil excavated from the ditch is thrown uphill to form a ridge (Hudson, 1995). These can also be graded or level. *Fanya juu* terraces have the advantage of leading to progressive natural terrace formation (Young, 1997). A bank formed on its upslope side encourages sediment deposition hence preventing soil loss. Kiome and Stocking (1993) indicated that by 1977 *Fanya juu* terracing had become the most popular method of developing bench terraces in Machakos district, Kenya, despite its high labour demand for construction and maintenance.

2.2.1.2 Influence of terrace farming on soil properties and crop yield

Terrace farming has been reported to show effect on erosion control and, consequently, on fertility status of the soil. In an experiment conducted in Andit-Tid, India, it was noted that soil loss from graded *Fanya juu* terraces was about 0.21

Mg/ha compared to the non-terraced plots which resulted into a soil loss of about 0.88 Mg/ha. Moreover, the same graded *Fanya juu* terraces had more barley yield and biomass than non-terraced plots by 6.70 and 8.51 Mg/ha, respectively (Michael, 1992).

Although terrace farming has been recommended on sloping areas where other conservation practices cannot be effective, Temple (1972) reported that terraces are unsuited to farming conditions in the mountainous areas of Tanzania because their construction exposes infertile subsoil, they require too much labour and result in soil saturation and landslides. Therefore, when applied, terraces do not appear to have adequately solved the problem of soil erosion on their own, nor to have given the anticipated yield increase. Their use may even reduce agricultural output (Shaxson, 1999). Research conducted by Kisanga *et al.* (1992) at Mgeta in the Uluguru Mountains revealed that bench terraces had low organic carbon content ranging from 0.5 to 2.6% (mean 1.48%) while ladder terraces, had organic carbon content ranging from 0.8 to 2.6% (mean 1.65%). Herweg (1993) quoted by Shaxson (1999) found that in Ethiopia, level and graded *Fanya juu* terraces that were one to four years of age, decreased maize yields by 73% and 24%, respectively. The respective decrease in beans yields were 36% and 52%.

It is clear from the above findings and observations by Cook (1962), that terracing alone is not an effective means of maintaining satisfactory yields. In order to improve and maintain sustainable crop performance and production, terrace farming should be supplemented with other conservation practices such as contour sowing, strip

cropping and soil cover (FAO, 2000). Additionally, application of organic matter, green or compost manure and inorganic fertiliser will compliment the use of terraces and ensure fertility increase (Kisanga *et al.*, 1992). Lal (1987) recommended that in general terraces are more effective for erosion control in orchards and plantation crops than in seasonal or annual crops. Since no evaluation has been made on the effectiveness of level *Fanya chini* terraces in the Uluguru Mountains, the study reported here-in attempted to fill in this gap.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental site

An experiment consisting of *Fanya chini* terraces and flat cultivation (unconserved plots) was laid at Gongo/Mgambazi and Mzingwi villages in the north-western part of the Uluguru Mountains during the 1999/2000 cropping season. The site is situated about 4 km south-east of SUA main campus. Gongo/Mgambazi village is situated on 52% slope, at 06°52'24" S latitude and 37°39'60" E longitude and at an altitude of about 906 metres above sea level (m.a.s.l.). Mzingwi village is located at latitude 06°51'62" S and longitude 37°39'78" E, an elevation of about 765 m.a.s.l. with the ground slope of 50%. Since it was an on-farm experiment, plots under *Fanya chini* terraces were to be adopted from farmers and, as a result, the first problem encountered was to find plots that were more or less homogenous.

3.2 Vegetation

The main vegetation communities of these areas are grasses, mainly *Pennisetum purpureum*, few shrubs dominated by remnants of the former Miombo forest and herbs. Most of the natural vegetation was removed when the area was brought into cultivation. Crops grown in the area include maize, cassava and legumes during the rainy season while vegetable growing by irrigation predominates during the dry season.

3.3 Soils

Kimaro *et al.* (1999) classified the soils of the study area as *Profondic Acrisol* and *Isohyperthermic, very deep, kaolinitic Typic Kandiustult*, according to FAO-World Reference Base (FAO, 1998) and USDA Soil Taxonomy (Soil Survey Staff, 1998), respectively. These soils are very deep, well-drained, red, clay soils. Generally they have low base saturation (<50%), and low CEC (<16 Cmol(+)/kg clay). Kaolinite and Fe and Al oxyhydroxides are the dominant soil fractions found in the area.

3.4 Climatic conditions

The climate of the study area belongs to the tropical savannah of the low altitude environment. It is characterised by three seasons. A long rainy season lasts from mid February to May. A short rainy season is experienced from November to January and a dry season normally extends from June to October. The average annual rainfall is 841 mm. The soil temperature regime and the soil moisture regime are *Isohyperthermic* and *Ustic*, respectively (Kimaro *et al.*, 1999). Table 1 shows monthly rainfall data for the study area from 1995 to 1999.

3.5 Experimental design and field plan

A Completely Randomised Design (CRD) experiment was conducted in Gongo, Mzingwi-1 and Mzingwi-2 villages. At each village six experimental plots of 12 m by 3 m were established on farmers' fields: three plots under *Fanya chini* terraces

Table 1: Five years monthly rainfall distribution at the area under study (1995 – 1999)

	Year (mm)				
Month	1995	1996	1997	1998	1999
J	-	81.1	28.1	228.2	80.6
F	-	171.9	68.5	357.3	33.5
M	-	206.6	176.5	108.4	237.2
A	337.81	336.3	246.7	269.4	307.6
M	612.1	202.3	59.5	67.2	180.6
J	0.5	10.4	82.2	39.6	73.8
J	3.1	10.2	21.5	9.8	81.4
A	49.4	0	5.6	14.4	49
S	18.2	0	2.1	17.6	27.4
O	105.5	25	63.1	12	17.2
N	1	12.3	81.9	21.4	98.5
D	126.3	0	292.7	18.2	153
Total	608	1056.1	1128.9	1163.5	1339.8

Source: Mzingwi village Agrometeorological station.

and three control plots with no conservation measure, making a total of 18 plots. The *Fanya chini* terraces in the study area had been practised for five and three years at Gongo and Mzingwi villages, respectively, before the establishment of the experiment. In Gongo village the *Fanya chini* terraced plots were under natural grass fallow for three years whereas unconserved plots were planted with cassava one year prior to the study. In Mzingwi village *Fanya chini* terraced plots had been under continuous maize cultivation since their establishment. On the other hand, unconserved plots had been under cassava one year prior to the study.

3.5.1 Construction of *Fanya chini* terraces

The principle of *Fanya chini* terracing is to build a bank by excavating a ditch and throwing the soil downhill side. Level *Fanya chini* terraces catch and store small flows of runoff water. Elephant grass (*Pennisetum purpureum*) is normally planted on the banks of *Fanya chini* in order to stabilise them; it is also used for cut-and-carry feeding in Morogoro.

The *Fanya chini* terraced plots adopted during the current experiment were about 15 to 20 m long and 4 to 5 m wide. The *Fanya chini* terrace channels were 40 to 50 cm wide and 30 to 50 cm deep. The narrow width between plots (4 – 5 m) made it necessary to spread some of the excavated subsoil onto the cropping area. Since the soils in the study area are shallow (8 to 10 cm deep), the spread of the subsoil on the cropped area resulted into 'decreased' topsoil depth and/or 'dilute' fertility, consequently reducing the general fertility of the soil under *Fanya chini* terraces.

3.6 Land preparation

During land preparation grass in the land earmarked for the study was slashed in December 1999 and left to dry on the plots up to the commencement of rains in mid February 2000. Cultivation was done twice using the hand hoe. The first land cultivation was done on 18/02/2000, whereas the second operation was carried out on 26/02/2000. The area was then divided into individual treatment plots of 12 m by 3

m, separated by a 1 m wide path. In *Fanya chini* terraced plots, the level channels occupied a path that was 1 m wide.

3.7 Trial planting

Composite maize, variety *Kito* that matures in 75 days was planted on 08/03/2000. Holes were made using a hand hoe and two seeds per hole were put that were thinned to one seedling per hole four weeks after sowing. The crop was planted in lines running across the slope at a spacing of approximately 40 cm by 75 cm within and between rows, respectively, achieving 4 rows per plot. This spacing gave a plant population of about 33,333 plants per hectare.

3.8 Trial management

3.8.1 Pest control, weeding and plant height determination

A rodent control chemical (Zinc phosphide) was applied two days before planting to curb the rodent problem. During the growing season, weeding was done twice using the hand hoe. The first and second weedings were done two and seven weeks after planting, respectively. Plant height from the soil surface to the top most leaf was measured 57 days after planting. No inorganic fertiliser was applied in order to reflect farmer s' practices in the study area.

3.8.2 Harvesting and grain yield

Harvesting was done on 27 June 2000 when all plants were dry. In each plot plants were counted before harvesting. An area of approximately 15.6 m^2, 2 central rows, free from border effects was harvested. Maize ears were then manually shelled and grain wet weight was determined. The grain was air dried for 7 days in the Soil Science Department drying shed to attain a moisture content of 13%. The dried grain was then weighed and the yield per net harvested area was determined which was later converted to yield per hectare.

3.8.3 Biomass

Harvesting of the biomass started by cutting the maize stalk flush with the soil surface. Then the maize cobs (ears) were separated from the stover and their separate weight was determined. After determining the weight of the cob, samples from the grain and stover were taken and weighed before drying them at 60 °C till they attained constant weight. The above ground biomass was obtained by summing up the weight of the dried stover and the cob and grain. The above ground biomass per net harvested area was later converted to biomass production per hectare.

3.9 Soil sampling and sample preparation

Soil samples were taken from the experimental plots before land preparation and at the end of the growing season for general analysis of soil physical and chemical properties.

Sampling was done at a depth of 0 - 20 cm in a zig-zag way at five points in order to make a composite sample from each plot. The composite samples were air dried, ground and sieved through a 2-mm sieve for laboratory analyses.

3.10 Soil analysis

Analyses of soil samples were performed for both chemical and physical properties.

3.10.1 Chemical properties

Parameters analysed included soil pH, total nitrogen (N), available phosphorus (P), exchangeable potassium (K), organic carbon (O.C) and exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}).

The soil pH was measured in soil-water suspension using a soil to solution ratio of 1:2.5 by mixing 10 g of air dry soil with 25 ml of water and determined by the glass electrode-calomel pH meter as described by McLean (1982). Total N was determined by the semi micro kjeldahl procedure as described by Bremner and Mulvaney (1982). Available P was determined by the Bray & Kurtz 1 method (Olsen and Sommers, 1982). An amount of 3 g air dry soil was shaken with 25 ml of extracting solution for 1 minute and immediately filtered through a Whatman No. 4 filter paper. Two ml of ammonium molybdate were added to 5 ml aliquot of the extract and made 40 ml with distilled water. Four millilitres of ascorbic acid were added and the final volume made to 50 ml. Organic carbon was determined by the Walkley-Black method as described by Nelson and Sommers (1982). Organic matter was obtained by

multiplying the value of organic carbon by the Van Bremmelen factor of 1.724. Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) were measured in neutral 1M ammonium acetate extract. One hundred ml of 1M NH_4COOCH_3 solution was added to 10 g air dry soil and shaken on a shaker for half an hour. The saturated soil was filtered on a buckner funnel and washed with 50 ml portion of NH_4COOCH_3 three times. The exchangeable cations were determined by atomic absorption spectrophotometry (National Soil Service, 1990). Cation exchange capacity (CEC) was determined after percolation with 1M ammonium acetate at pH 7.0 followed by ethanol and acidified 1M potassium chloride (KCl) and titration with 0.5 N sulphuric acid (H_2SO_4) following kjeldhal distillation of the filtrate with sodium hydroxide (NaOH) to determine adsorbed NH_4^{+} (National Soil Service, 1990).

3.10.2 Physical properties

The physical parameters analysed included Penetration resistance (PR), Soil moisture content, Particle size distribution, Bulk density, Aggregate stability and Infiltration rate.

3.10.2.1 Penetration resistance

The soil PR measurements were made at the beginning and at the end of the season. by the use of a field penetrometer (Manometer-type Hand Penetrometer; Eijkelkamp, 2000). At the beginning of the season PR measurements were made 16 days after planting and at the end of the season PR measurements were taken after harvesting

the crop. The penetrometer was fitted with a cone with a 15° semi-angle, 129-mm^2 end area and had a recessed shaft. The shaft was pushed vertically downward into the soil at a steady rate to the desired depth (Bradford, 1986). The readings in cone indices were taken at 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40 and 40-45 cm depth. These readings were later converted to force in MPa.

3.10.2.2 Soil moisture content

Two separate soil samples at a depth of 0 - 20 cm and 20 - 40 cm were collected 11 times from each plot using an auger and placed in moisture boxes for gravimetric soil moisture content estimation during the growing season. The samples were weighed in the laboratory before oven drying at 105 °C for 24 hours. The moisture boxes with soil samples were cooled in a dessicator then weighed with and without the soil material. The gravimetric soil moisture content, expressed in percentage, was then estimated from: $W_1 - W_2/W_2 - W_3 * 100$----------(1)

Where: W_1 = the weight of moist soil + moisture box (g).

W_2 = the weight of dry soil + moisture box (g).

W_3 = the weight of empty moisture box (g).

3.10.2.3 Particle size distribution

Samples for particle size distribution were taken at 0 – 20 cm depth before land preparation. Particle size distribution was determined using the hydrometer method

as described by National Soil Service (1990). The textural triangle nomograph of FAO (1990) was used for textural classification of the soils.

3.10.2.4 Bulk density

Bulk density of the undisturbed soil in the study area was estimated through core sampling using 5.6 cm x 4 cm cores. The samples were weighed in the laboratory before oven drying at 105 °C to constant weight. The cores were cooled in a dessicator then weighed with and without the soil material. The bulk density of the soil expressed in Mg/m^3 was then estimated from: W_1/W_2----------(2)

Where: W_1 = Oven dry weight of soil (g), then converted to Mg.

W_2 = Bulk volume of the soil (cm^3), then converted to m^3.

3.10.2.5 Aggregate size distribution

Samples for aggregate size distribution were collected before land preparation and after harvesting. Soil samples were taken at a depth of 0 – 20 cm with a hand hoe and placed into plastic bags. Soil samples were air dried in the sample-drying shed. A wet sieving method (Kempler and Rosenau, 1986) was used to separate aggregates into different size groups. A soil sample of 300 g (air dried) was saturated in distilled water overnight. Sieves of mesh size 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0.063 mm were nested in 3 sisal ropes designed for holding them. A saturated sample was placed on the top sieve. The nest of sieves was raised and lowered in the bucket of water at an average speed of 30 cycles/min for 10 minutes. The particles

each sieve were oven dried at 105 °C until the water has evaporated. The particles retained in the respective sieves were weighed to determine the percentage of it with respect to total weight as indicated in the formula below:

$w_i = y/x * 100$----------(3)

Where: x = total sample weight (g)

y = weight of particles in respective sieve (g)

w_i = percent retained in each size fraction

Mean weight diameter (MWD) was estimated using the following equation:

$MWD = \Sigma x_i w_i$----------(4)

Where: x_i = mean diameter of each size fraction (mm)

w_i = the proportion of the total sample weight occurring in the corresponding size fraction (percent retained in each size fraction).

3.10.2.6 Infiltration rate

Infiltration rate measurements were done using a CSIRO-type tension infiltrometer (permeameter) shown in Figure 1, developed by Perroux and White (1988). The principle behind this technique is that the infiltration/flow rate of water from the disc into the soil is measured. Adding or withdrawing water from the bubbling tower using a plastic syringe with a length of thin tubing connected to it sets the potential. Principally, the initial potential set in the bubbling tower is not equal to the soil matric potential of the soil in which the measurement is taken. However, when the infiltration attains steady state or constant rate, the potential set equals the soil matric potential of

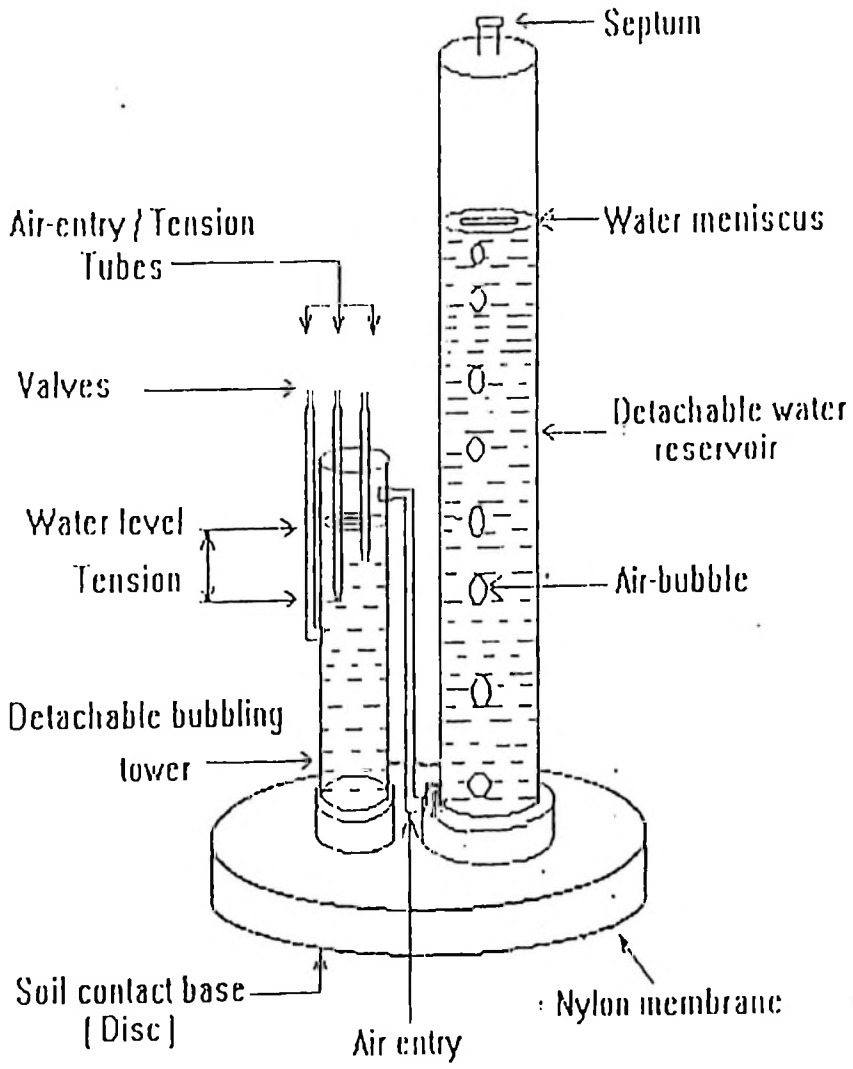

Figure 1: The disc permeameter for unsaturated measurements.

that area. Before setting the permeameter, the reservoir and air-inlet tubes were filled with water to the required volume and the potential was set in the bubbling tower. A thin layer of moist fine sand 1-cm thick was used as a contact material at each measuring location in a circular area equal to the diameter of the disc. The permeameter was then placed firmly on the levelled surface of the soil and initial water height recorded. The valve for the smallest negative pressure (5 cm) was then opened. The volume of the water drained from the reservoir and infiltrated through the area of disc was recorded from fall of water level in the reservoir in 5 minutes time interval, until the flow appeared to be steady. After reaching the steady state, the 7 cm valve was opened and 5 cm tension valve was closed. The procedure for determining steady state infiltration with this tension and the 10 cm tension was the same as that of tension 5 cm.

3.11 Statistical analysis

Data were analysed using MSTAT-C (Nissen, 1990) and Microsoft EXCEL computer programmes. Analysis of variance was used to determine the effect of *Fanya chini* terraces on soil properties. Treatment means were separated using Duncan's New Multiple Range Test. Paired t-test comparisons were used to determine the effect of *Fanya chini* terraces on soil properties and crop yield. Simple regression analysis was used to identify the different soil chemical properties that had impact on grain yield, biomass and shoot height.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Influence of *Fanya chini* terraces on soil chemical and physical properties

The soil chemical and physical properties of the experimental sites taken at the start and at the end of the experiment are summarised in Appendices 1a and 1b.

4.1.1 Soil chemical properties

Treatment average soil chemical properties are indicated in Table 2a, while Tables 2b and 2c present data on soil chemical properties on the upper, middle and lower part of the plots for each treatment.

4.1.1.1 Soil pH

The soil pH for the initial and final soil samples ranged from 6.1 to 6.9. These pH ranges are categorised as medium (Landon, 1991). There was no significant difference in pH ($P = 0.05$) between the *Fanya chini* terraced and unconserved plots for both sampling periods (Table 2a). However, both treatments showed an increase in pH over time. Although *Fanya chini* terraced plots showed slightly lower soil pH values than unconserved plots, their percent increase in pH was higher by 0.3%

Table 2a: Influence of *Fanya chini* terraces on soil physical and chemical properties (0 – 20 cm depth) of the study area at the beginning and at the end of the season presented by the mean, standard error and CV% (in parentheses)

	Initial sampling				Final sampling			
	fc	fl	Dif.	t_{tl}	fc	fl	Dif.	t_{tl}
pH (H_2O)	6.50±0.037 (1.7)	6.58±0.068 (3.1)	0 08	ns	6.71±0 039 (1.7)	6 77±0.029 (1.3)	0.06	ns
P (mg/kg)	2.41±1.606 (200)	5.24±2.714 (155)	2.83	ns	1.28±0.372 (87)	4.13±1.669 (121)	2.85	ns
TN (%)	0.09±0.007 (22.5)	0.11±0.005 (14.4)	0 02	ns	0.09±0.005 (15)	0.11±0.004 (9.8)	0.02	**
OC (%)	1.38±0.139 (30.1)	1.59±0.088 (16.6)	0.21	ns	1.33±0.069 (15.5)	1.58±0.065 (12.3)	0.25	*
CEC(Cmol(−)/kg	13.02±1.073 (25)	14.02±0.693 (15)	1.00	ns	15.49±0.694 (13)	16 58±0.331 (6)	1 09	ns
Exch. Bases								
Cmol(+)/kg								
Ca^{++}	3.62±0.286 (23.7)	4.26±0.245 (17.2)	0.64	ns	5.81±0.313 (16.2)	6.70±0.356 (15.9)	0.89	*
Mg^{++}	4.04±0.379 (28.2)	4.27±0.341 (23.9)	0 23	ns	5.03±0.56 (27.8)	5.87±0.453 (23.1)	0.16	ns
K^{+}	0.43±0.043 (29.4)	0.49±0.029 (17.7)	0.06	ns	0 41±0.058 (42.4)	0.49±0.026 (15.9)	0.08	ns
Na^{+}	0.13±0.006 (13.5)	0.14±0.012 (25.9)	0.01	ns	0.12±0.009 (20.5)	0.14±0.005 (10.8)	0.02	ns
$D_b(g/cm^3)$	1.29±0.027 (6.2)	1.29±0.033 (7 7)	00	ns	1.32±0.033 (7.5)	1.30±0.026 (5.9)	0.02	ns

fc = *Fanya chini* terraced plots

fl = unconserved plots

* = significantly different (P = 0.05)

** = significantly different (P = 0.01)

ns = non significant

compared to unconserved plots (Table 2b). The high percent increase in pH in *Fanya chini* terraced plots may be attributed to the high percent increase of Ca^{2+} and Mg^{2+} contents in these plots. The percent increase in Calcium and Magnesium contents were higher in *Fanya chini* terraced plots by 1.3 and 5.7%, respectively, than unconserved plots (Table 2b). Thompson (1957) indicated that soil pH increases as the Ca and Mg contents increase. According to Lisuma and Mrema (1999) the high content of Ca and Mg in the soil reduces the activities of Al^{3+} and H^{+} and thus increasing soil pH.

Table 2b: Treatment effect on soil properties

	Fanya chini terraced plots			Unconserved plots		
	I	II	% increase/decrease	I	II	% increase/decrease
pH (H_2O)	6.50	6.71	3.1	6.58	6.77	2.8
P (mg/kg)	2.41	1.28	-88.3	5.24	4.13	-26.9
TN (%)	0.09	0.09	0.00	0.11	0.12	8.3
OC (%)	1.38	1.33	-3.8	1.59	1.58	-0.6
CEC(cmol(+)/kg	13.02	15.49	16.0	14.02	16.58	15.4
Exch. Bases						
cmol(+)/kg						
Ca^{++}	3.62	5.81	37.7	4.26	6.70	36.4
Mg^{++}	4.04	6.03	33.0	4.27	5.87	27.3
K^{+}	0.43	0.41	-4.9	0.49	0.49	0.0
Na^{+}	0.13	0.12	-8.3	0.14	0.14	0.0
$D_b(g/cm^3)$	1.29	1.32	2.3	1.29	1.30	0.78

I = Initial soil samples
II = Final soil samples

4.1.1.2 Available phosphorus

Available P of the soils ranged from 0.16 to 25.10 and 0.46 to 15.47 mg/kg of soil for soil samples taken at the beginning and at the end of the experiment, respectively. Statistically, there was no significant difference in available P content (P = 0.05) between plots with *Fanya chini* terraces and unconserved ones for both sampling periods (Table 2a). Non-homogenous handling of the fields by the different farmers could be the major reasons for the observed higher variations in available P content between the plots. This assumption is supported by the very high CV values indicated in Table 2a. Although unconserved plots had slightly higher though non-significant available P contents, both treatments showed a decrease in available P content over time. However, *Fanya chini* terraced plots had higher percent decrease in available P content than flat cultivated plots (Table 2b) that may be attributed to the higher decrease in organic carbon content in these plots due to subsoil exposure. Kaihura *et al.* (1999) reported a decline in soil organic carbon and available P content with a decrease in topsoil depth. Analysis of variance on the interaction effect between the treatment and slope position showed non-significant difference in available P content on both sampling periods due to the high variations among the plots. However, plots of the lower slope had slightly higher available P contents for both treatments and sampling periods (Table 2c). It can be surmised that fine soil materials and organic matter from upper slopes that were transported by runoff water and in turn deposited as they were moving along the slope could have caused this apparent increase in P on lower slopes. These results conform to the findings of Kisanga *et al.* (1992) in Mgeta area where a trend of increasing available P along the

Table 2c: Soil pH, available P, organic carbon and Total nitrogen on different slope positions between the *Fanya chini* terraced and unconserved plots for the initial and final soil samples

	pH				Avail. P (mg/kg)				%OC				% TN			
	I	II	dif.	t_H	I	II	dif.	t_H	I	II	dif.	t_H	I	II	dif	t_H
1a	6 57	6.77	0.20	**	0.64	1.13	0.49	ns	1.17	1.31	0.14	ns	0.08	0 09	0.01	ns
1b	6.43	6.73	0.30	*	1.04	0.82	0.22	ns	1.33	1 25	0.08	ns	0.09	0.08	0 01	ns
1c	6.50	6.63	0.13	ns	5.54	1 90	12 26	ns	1.64	1.43	0 21	ns	0.11	0 10	0 01	ns
2a	6.63	6.77	0.14	ns	2.62	2.37	0.25	ns	1.67	1.58	0 09	ns	0 11	0.11	0 00	ns
2b	6.60	6.80	0.2	ns	4.02	3.92	0.10	ns	1.61	1.68	0.07	ns	0.11	0.11	0.00	ns
2c	6.50	6.73	0.23	ns	9.09	6.10	4.10	ns	1.48	1 49	0.01	ns	0.11	0.11	0.00	ns
CV%	2.5	1 56			185.18	146 17			24.1	14.54			18.73	13 04		

I = initial soil samples
II = final soil samples
* = significantly different (P = 0.05)
1 = *Fanya chini* terraced plots
2 = unconserved plots
a = upper slope
b = middle slope
c = lower slope
ns = non significant (P = 0.05)
** = significantly different (P = 0.01)

slope in ladder and bench terraces was reported. Phosphorus is considered to be less soluble and thus tends to be removed in suspension with the eroded soil particles.

4.1.1.3 Soil organic carbon

The organic carbon content of the soil samples ranged from 0.83 to 2.17% at the beginning of the experiment and 1.11 to 1.92 percent at the end of the experiment. Landon (1991) classifies organic carbon contents below 2 percent as very low. Comparison between the *Fanya chini* terraced and unconserved plots showed a significant difference (P = 0.05) in organic carbon content at the end of the experiment. At the beginning of the experiment, the difference was not significant (Table 2a). However, both treatments showed a decrease in organic carbon content over time though unconserved plots had a relatively lower percent decrease. Unconserved plots had 0.6% decrease in organic carbon content compared to *Fanya chini* terraced plots which had 3.8% decrease (Table 2b). The spread of the subsoil that has a lower organic carbon content from the channels (see section 3.10.1) must have resulted into the high decrease of organic carbon content in the *Fanya chini* terraced plots. Malhi *et al.* (1994) noted that as topsoil removal increased from 0 to 18 cm, total carbon decreased to less than half the original quantity. Unger *et al.* (1990) revealed that land surface modification for soil and water conservation might result into changes in soil characteristics such as inherent fertility. These may have detrimental effects to soil conditions and crop yields. These findings agree with the conclusion by Temple (1972) that terraces are unsuited to farming conditions in mountainous areas of Tanzania because they expose infertile subsoil. Organic carbon

had a clearly defined trend along the slope in *Fanya chini* terraced plots (Table 2c). Organic carbon tends to increase down the slope. This could be due to the transportation and deposition of organic material down the slope by rainwater as they were moving along. In unconserved plots there was no consistent trend for the organic carbon content along the slope. Kisanga *et al.* (1992) reported an increase in organic carbon content along the slope in ladder terraces.

4.1.1.4 Total nitrogen

The total N content of the soil samples ranged between 0.06 to 0.13 and 0.08 to 0.13 percent for the initial and final soil samples, respectively. These are ranked as very low to low for soil samples with total nitrogen content of less than 0.1 to 0.2 and one percent, respectively (Landon, 1991). Total nitrogen content of the soil samples followed a similar trend to the organic carbon content. Unconserved plots had relatively higher total nitrogen than *Fanya chini* terraced plots for both sampling periods. Initially there was no significant difference in total N content between the *Fanya chini* terraced and unconserved plots. Unconserved plots had significantly higher total N content ($P = 0.01$) at the end of the season (Table 2a). The high total nitrogen content in the unconserved plots is attributed to the relatively high organic carbon content observed in these plots. Organic matter has been recognised as being beneficial in supplying most of the nitrogen in unfertilised soils (Sanchez, 1976). Moreover, the spread and exposure of the subsoil onto the plots under level *Fanya chini* terraces led to low organic carbon content in these plots (Temple, 1972; Shaxson, 1999). There was a clearly defined trend in total N down the slope in

Fanya chini terraced plots (Table 2c) that could be due to the deposition and decomposition of organic materials that were transported from the upper slopes. However, unconserved plots had the same total N content down the slope.

4.1.1.5 Exchangeable calcium

The exchangeable calcium content of the soils ranged from 2.66 to 5.95 Cmol(+)/kg at the beginning of the experiment and 4.69 to 8.55 Cmol(+)/kg at the end of the experiment. These calcium ranges are categorised as low (<4 Cmol(+)/kg) to medium (4 to 10 Cmol(+)/kg) (Landon, 1991). Although unconserved plots had relatively higher Ca^{2+} content both at the beginning and at the end of the season, their percent increase in Ca content was lower than that in *Fanya chini* terraced plots (Table 2b). However, unconserved plots had significantly higher Ca^{2+} content ($P = 0.05$) at the end of the season (Table 2a). The significantly higher increase in Ca^{2+} content in unconserved plots may be attributed to the relatively higher organic carbon content in these plots. Though both treatments showed a decrease in organic carbon content at the end of the season (Table 2b), the percent decrease was lower in unconserved plots (0.6%) than in *Fanya chini* terraced plots (3.8%). Lisuma and Mrema (1999) and Kaihura *et al.* (1999) revealed that exchangeable bases increase with the increase in soil organic carbon content.

4.1.1.6 Exchangeable magnesium

Magnesium contents were medium to high ranging from 2.22 to 5.56 and 3.51 to 8.11 Cmol(+)/kg for the initial and final soil samples, respectively. Statistically, there

was no significant difference (P = 0.05) in Mg^{2+} content between the *Fanya chini* terraced and unconserved plots both at the beginning and at the end of the season (Table 2a). However, both treatments showed an increase in Mg content over time. *Fanya chini* terraced plots had a higher percent increase in Mg content (5.7% higher) (Table 2b). There was a significant increase (P = 0.05) of magnesium content in the final soil samples in both treatments (Table 2d). Both trends cannot be explained and merit further study especially because there was a relatively higher decrease in organic carbon content in these plots.

4.1.1.7 Exchangeable sodium and potassium

Exchangeable sodium was low for both treatments and for both sampling periods ranging from 0.09 to 0.20 and 0.09 to 0.17 Cmol(+)/kg at the beginning and at the end of the experiment, respectively. There was no significant difference in the sodium content between the *Fanya chini* terraced and unconserved plots both at the beginning and at the end of season (Table 2a).

Exchangeable potassium ranged from 0.27 to 0.61 Cmol(+)/kg for the initial sampling and 0.16 to 0.64 Cmol(+)/kg for the final samples. These are ranked as low (<0.2 Cmol(+)/kg), medium (0.2 to 0.6 Cmol(+)/kg) and high (>0.6 Cmol(+)/kg) (Landon, 1991). The *Fanya chini* terraced treatment did not differ significantly from the unconserved one (Table 2a) in so far as exchangeable potassium is concerned. *Fanya chini* terraced plots showed a relative decrease in both Na and K contents at the end of the season (Table 2b). The decrease in both elements may be attributed to

Table 2d: Exchangeable Ca, Mg, K and Na (in Cmol(+)/kg) on different slope positions between the *Fanya chini* terraced and unconserved plots for the initial and final soil samples

	Ca				Mg				K				Na			
	I	II	dif.	t_H	I	II	dif.	t_H	I	II	dif.	t_H	I	II	dif.	t_H
1a	3.34	5.76	2.42	*	4.20	6.12	1.92	ns	0.38	0.34	0.04	ns	0.13	0.11	0.02	ns
1b	3.54	5.88	2.34	ns	3.87	5.80	1.93	*	0.38	0.41	0.03	ns	0.01	0.12	0.01	ns
1c	3.97	5.79	1.82	ns	4.05	6.18	2.13	*	0.54	0.48	0.06	ns	0.14	0.14	0.00	ns
2a	4.72	6.84	2.12	*	4.35	5.82	1.47	*	0.54	0.46	0.08	ns	0.14	0.13	0.01	ns
2b	4.05	6.94	2.89	*	4.20	6.04	1.84	*	0.43	0.48	0.05	ns	0.12	0.13	0.01	*
2c	4.01	6.34	2.33	*	4.28	5.76	1.48	*	0.50	0.55	0.05	ns	0.17	0.15	0.02	ns
CV%	21.62	18.61			29.69	29.48			21.9	31.45			17.77	17.47		

I = initial soil samples
II = final soil samples
*= significantly different (P = 0.05)

1 = *Fanya chini* terraced plot
2 = unconserved plots

a = upper slope
b = middle slope
c = lower slope

ns = non significant (P = 0.05)

spread of the subsoil on these plots.

4.1.1.8 Cation exchange capacity (CEC)

Fanya chini terraced plots had CEC ranging from 9.60 to 20.60 Cmol(+)/kg (mean 13.02 Cmol(+)/kg). In unconserved plots, the CEC ranged from 10.60 to 17.40 Cmol(+)/kg (mean 14.02 Cmol(+)/kg). There was no significant difference in CEC between *Fanya chini* terraced and unconserved plots (Table 2a) for both sampling periods. However, both treatments showed an increase in CEC over time. *Fanya chini* terraced plots had 0.5 percent higher increase in CEC (Table 2b) than unconserved plots that may be attributed to the observed higher percent increase of Ca and Mg contents in these plots.

4.1.2 Soil physical properties

4.1.2.1 Bulk density: D_b

The influence of *Fanya chini* terraces compared with flat cultivation on soil bulk density is shown on Appendices 1a and 1b. Initially, both *Fanya chini* terraced and unconserved plots had mean bulk density of 1.29 Mg/m^3. The final measurements showed that unconserved plots had mean bulk density of 1.30 Mg/m^3 while the mean bulk density for *Fanya chini* terraced plots was slightly higher, at 1.32 Mg/m^3. These ranges fall within the limits of 1.00 to 1.60 Mg/m^3 identified by Brady and Weil (1996) for clay, and Landon (1991) for clay loam and silt loam topsoil. Statistically,

bulk density did not differ significantly (P = 0.05) between the *Fanya chini* and unconserved treatments both at the start and at the end of the experiment (Table 2a). The slight increase in mean bulk density observed in *Fanya chini* terraced plots may be due to the decrease in soil organic carbon content. Kaihura *et al.*, (1999) reported an increase in bulk density due to the decrease in aggregation of soil particles because of decline in soil organic carbon content.

4.1.2.2 Soil penetration resistance

Penetration characteristics of the topsoil (0 – 45 cm depth) for both treatments and sampling periods are shown in Figure 2. The penetration resistance values at the beginning of the experiment were taken 16 days after planting whereas the final PR measurements were taken after harvesting the crop. Mean PR values for both treatments at the beginning and at the end of the experiment are shown in Appendix 1d. The results show significant difference in PR (P = 0.01) between the two treatments both at the beginning and at the end of the experiment (Table 3). At the beginning of the experiment *Fanya chini* terraced plots had significantly lower PR values than unconserved plots. This could be due to the relatively higher moisture content observed in *Fanya chini* terraced plots than in unconserved plots, (see section 4.1.2.3; Figure 3). It has been shown that PR depends on the soil water content. Kempler and Rosenau (1984) indicated that PR increases with decreasing soil water content due to increasing cohesion. In addition, the soil that was removed from the terrace channel and spread on the terraced plot ensured that there was an initial uncompacted soil layer. Uncompacted soil is easily penetrable. The high PR

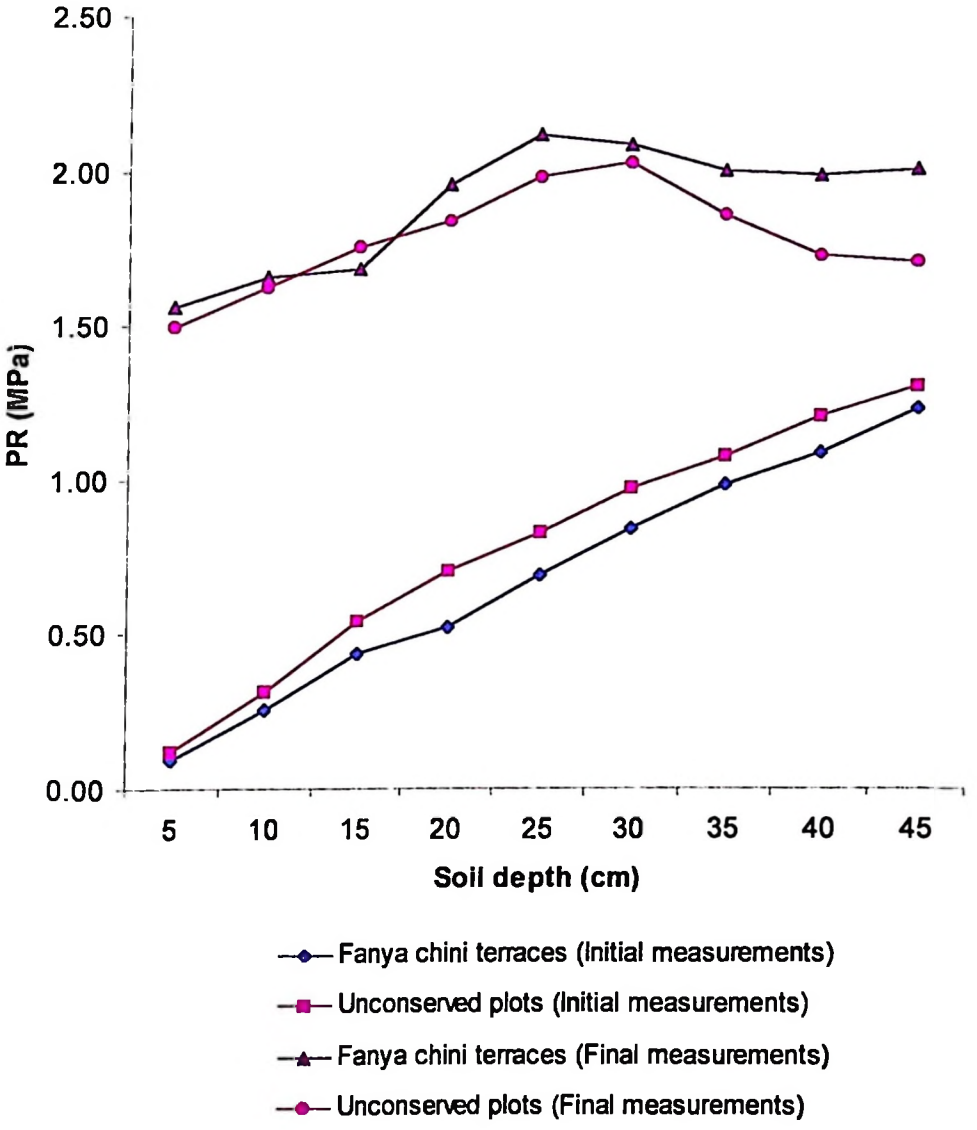

Figure 2: Effect of *Fanya chini* terraces on soil penetration resistance as influenced by soil depth at the beginning and at the end of the experiment

values in *Fanya chini* terraced plots at the end of the experiment could be due to the decrease in soil moisture content in addition to the observed slight increase in bulk density in that treatment. Hadas and Schmulewich (1990) reported that bulk density is one of the factors affecting soil resistance to penetration. However, at the beginning of the experiment mean PR values were less than 2 MPa for both treatments, which is the established critical level of resistance that will stop root growth (Materechera and Mloza-Banda, 1987). This critical value was equalled or surpassed only at two depths (25 cm and 30 cm) in the *Fanya chini* treatment in the final measurements. This generally indicated that root impedance due to penetration resistance may not be a great problem in the study area.

Table 3:Influence of *Fanya chini* terraces on mean penetration resistance (MPa) (0 – 45 cm depth) at the beginning and at the end of the experiment

	Fanya chini terraced plots	Unconserved plots	Dif.	t_H
Initial measurements	0.69	0.78	0.09	**
Final measurements	1.81	1.71	0.10	**

** = Significantly different (P = 0.01)

4.1.2.3 Soil moisture content

Results on mean soil moisture content for both treatments are shown in Figure 3. The mean moisture content throughout the season ranged from 102 to 162 mm/40 cm in *Fanya chini* terraced plots and 101 to 157 mm/40 cm in unconserved plots. The soil moisture content was not significantly different (P = 0.05) between the *Fanya chini* terraced and unconserved plots. However, from Figure 3 it is seen that in 10 out of the 11 observations, *Fanya chini* terraced plots had their moisture content equal to or greater than that in unconserved plots. The level channels in *Fanya chini* terraced plots probably accumulated moisture and allowed it to slowly infiltrate thus increasing the general moisture content of the soil in this treatment (Shaxson, 1999).

4.1.2.4 Infiltration rate

Results on infiltration rate are shown in Appendix 1c and summarized in Table 4. There was no significant difference in infiltration rate between the two treatments for all tensions (Table 4). At the lower tensions (5 and 7 cm) *Fanya chini* terraced plots tended to let more water infiltrate than did the unconserved plots. At the 10 cm tension, however, unconserved plots had a higher infiltration rate.

4.1.2.5 Aggregate stability

Mean percentage of aggregates of different sizes for the initial and final measurements are shown in Appendix 1e. Initial measurements for aggregate stability were taken before land cultivation whereas the final measurements were

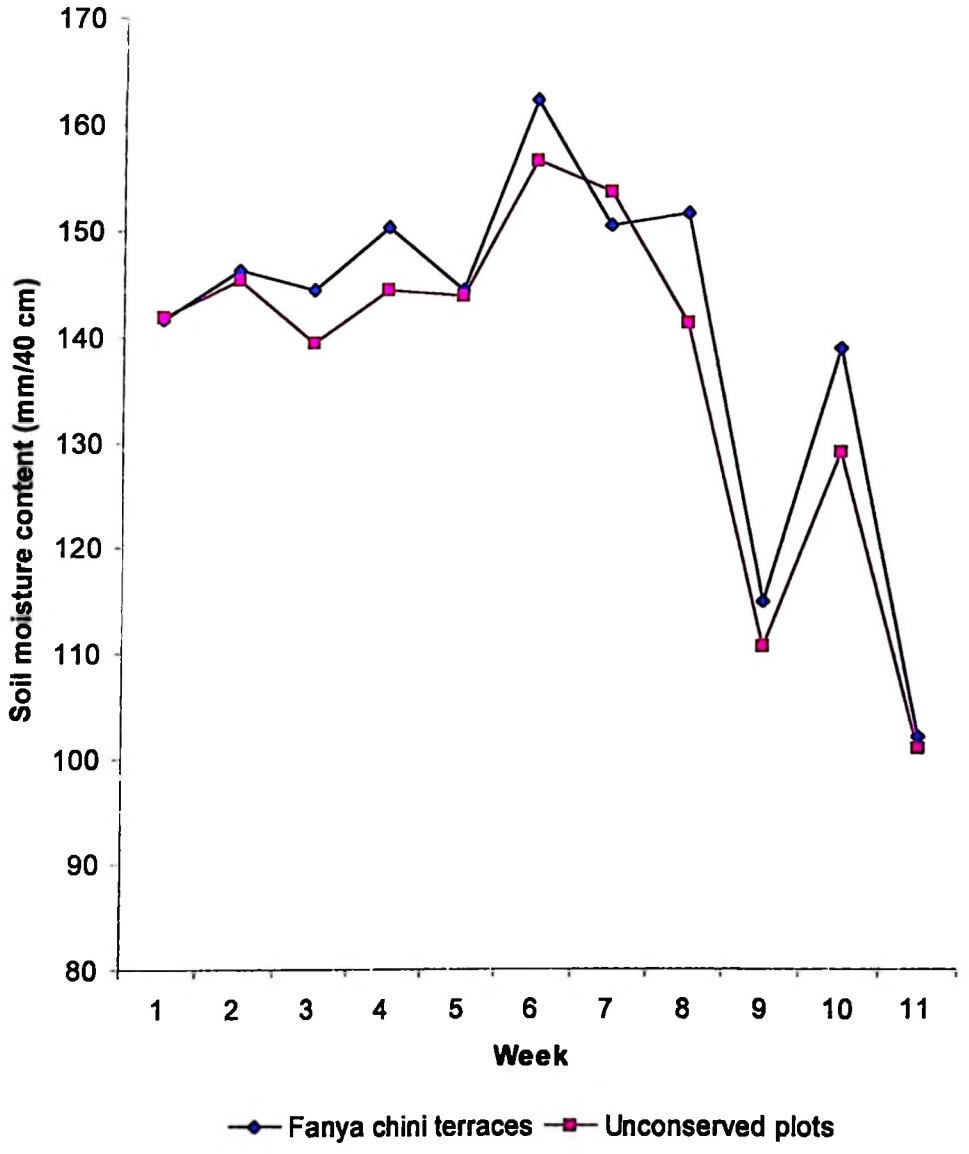

Figure 3: Effect of *Fanya chini* terraces on mean moisture content

Table 4: Influence of *Fanya chini* terraces on infiltration rate (cm/h)

Tension (cm)	*Fanya chini* terraced plots	Unconserved plots	Dif.	t_H
5	6.3	6.0	0.3	ns
7	3.9	3.5	0.4	ns
10	1.9	2.3	0.4	ns

ns = non significant (P = 0.05)

taken after harvesting. There was no significant difference (P = 0.05) in aggregate size distribution between plots with *Fanya chini* terraces and the control in both sampling periods. The Mean Weight Diameter (MWD) at the beginning and at the end of the experiment was 50 and 36 mm for *Fanya chini* terraced plots and 46 and 52 mm for plots under no conservation, respectively. The lower MWD in *Fanya chini* terraced plots may be attributed to the relatively lower organic carbon content observed in *Fanya chini* terraced plots at the end of the season. Other studies e.g. Mochoge and Mwonga, 1989; Carter, 1992 have also reported a decrease in MWD with a decrease in organic carbon content. Moreover, *Fanya chini* terraced plots had relatively higher percentages of aggregates < 0.063 mm (Appendix 1e) that may also be attributed to the low organic matter content observed in these plots. Organic matter promotes soil aggregation because it acts as a binding material of the soil separates to form stable aggregates (Reichert and Norton, 1994). In addition, in the study reported herein there was surface seal formation in *Fanya chini* terraced plots

that may have resulted from the higher percentage of aggregates of < 0.063 mm. Unger *et al.* (1998) indicated that fine soil particles, especially those < 0.125 mm, are primarily responsible for surface seal formation.

4.2 Shoot height, grain yield and biomass

Results on shoot height taken 57 days after planting are depicted in Figure 4. Plants were 56 to 92 cm tall (mean 79 cm) for *Fanya chini* terraced plots and 79 to 112 cm

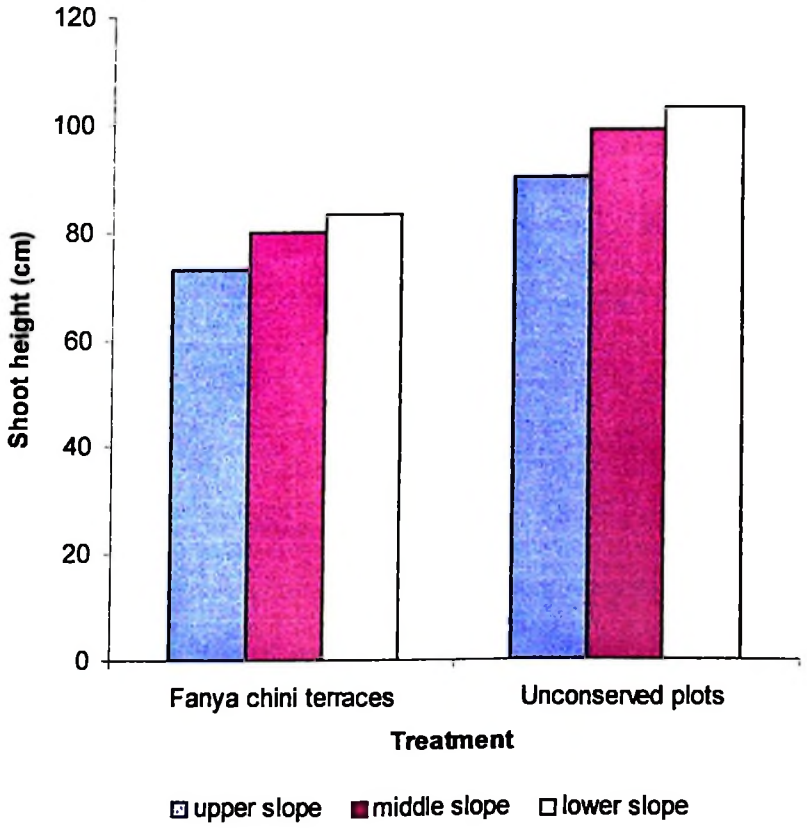

Figure 4: Effect of *Fanya chini* terraces and slope position on shoot height (cm)

tall (mean 97 cm) for plots under no conservation. Shoot height in *Fanya chini* terraced plots was significantly lower than that in unconserved plots (Table 5). This could be due to the influence of most observed chemical variables that were slightly higher in unconserved plots than in *Fanya chini* terraced plots (Table 2a). Generally, plant height tended to increase along the slope. A simple regression analysis showed a high correlation between percent organic carbon, total N and shoot height ($r = 0.65$ and 0.51, respectively) (Table 6).

Results on maize grain yield and above ground biomass for both treatments are shown in Appendix 1f. The mean maize grain yield for *Fanya chini* terraced and unconserved plots was 1.12 and 1.28 Mg/ha, respectively and was not statistically different ($P = 0.05$, Table 5). Biomass output showed a similar trend to the grain yield. Mean above ground biomass yield for *Fanya chini* terraced plots was 2.8 Mg/ha while that from unconserved plots was 3.1 Mg/ha. Again, the difference in biomass yield between the two treatments was not significant ($P = 0.05$) (Table 5).

Although not significantly different, the grain yield and biomass were relatively slightly higher in unconserved plots and tended to increase along the slope (Table 5). A simple regression analysis showed high correlation between percent organic carbon and grain yield and biomass ($r = 0.54$ and 0.53, respectively) (Table 6).

These yield results are similar to the trend shown in most soil properties observed in the experiment reported here. Reduction in soil organic carbon content, low availability and amounts of soil nutrients in *Fanya chini* terraced plots due to the

Table 5: Influence of treatment position on grain yield, biomass and shoot height

	Fanya chini terraced plots			Unconserved plots				
	Upper slope	Middle slope	Lower slope	Upper slope	Middle slope	Lower slope	LSD value	CV %
Grain yield (Mg/ha)	1.00a	1.10a	1.27a	1.30a	1.20a	1.33a	0.54	25.61
Biomass (Mg/ha)	2.60a	2.73a	3.08a	2.93a	3.07a	3.33a	0.98	18.72
Shoot height (cm)	73c	80bc	83abc	90abc	99ab	103a	20.8	13.28

Means of the row followed by the same letter are not significant different at 0.05 probability level using DMRT

subsoil spread (cover) could be the reason for the observed shoot height and yield reductions. This is in agreement with the observation by Shaxson (1999) that when terraces are used on steep lands they do not appear to solve the problem of erosion on their own, or give the

Table 6: Effect of soil organic carbon content on grain yield, biomass and shoot height

Parameter	r	P	Regression Equation
Grain yield	0.54	0.022	Y = 0.25 + 0.65x
Biomass	0.53	0.025	Y = 1.23 + 1.19x
Shoot height	0.65	0.04	Y = 29 + 40.6x

r = coefficient of correlation

P = probability level

anticipated yield increase but they may even reduce agricultural output. The exposure and spread of the subsoil from the terrace channel to the topsoil on the cropped basin may have greatly diluted the topsoil in the current study.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The use of *Fanya chini* terraces on the slopes of the north-western part of the Uluguru Mountains has some positive and negative impacts on the soil chemical and physical properties and, eventually, crop yield. Consequently, the following conclusions may be drawn and recommendations made based on the findings of this study.

5.1 Conclusions

1. The relatively higher percent decrease of soil organic carbon content in *Fanya chini* terraced plots compared to unconserved plots could be the reason for the observed low amounts of soil nutrients.

2. There was no significant difference in grain and biomass yield between *Fanya chini* terraced and unconserved plots. But *Fanya chini* terraced plots had relatively lower grain yield and biomass compared to unconserved plots. In both treatments yield tended to increase down the slope, implying a fertility gradient.

3. It appears that it was not scientifically correct to advocate use of *Fanya chini* terraces on the foothills of the Uluguru Mountains where soils are shallow and slopes are steep.

5.2 Recommendations

1. *Fanya chini* terraces should not be advocated in the north-western slopes of the Uluguru Mountains since their performance is not superior to flat cultivation, at least during the first 5 years.

2. The use of the existing *Fanya chini* terraces should be complemented with other soil surface management practices such as agroforestry, cover crops and mulching so as to make them a viable soil and water conservation measure. At the same time soil fertility in the existing *Fanya chini* terraced plots should be enhanced through application of organic matter in form of farmyard-, green- or compost –manure and inorganic fertiliser.

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APPENDICES

Appendix 1a: Soil chemical and physical properties (0 – 20 cm depth) of the study area at the beginning of the experiment

	Gongo/Mgambazi						Mzingwi-1						Mzingwi-2					
	Fanya chini terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots		
	us	ms	ls	us	ms	ls	us	Ms	ls	us	ms	ls	us	ms	ls	us	ms	ls
PH (H_2O)	6.6	6.5	6.5	6.8	6.6	6.7	6.7	6.3	6.5	6.6	6.7	6.7	6.4	6.5	6.5	6.5	6.5	6.1
P (mg/kg)	1.01	2.13	15.16	4.47	10.64	25.10	0.63	0.43	0.33	3.06	1 09	2.02	0.27	0 55	1.14	0.33	0.33	0.16
TN (%)	0.08	0.09	0.10	0.12	0.13	0 12	0.09	0.06	0.10	0.10	0 10	0.12	0.08	0.12	0.13	0.12	0.10	0.08
OC (%)	1.09	1.24	1.32	1.49	1.57	1.44	1.30	0.83	1 44	1.65	1.71	1.96	1.12	1.90	2.17	1.86	1.55	1.05
CEC(cmol(+)/kg	11.8	10.60	9.60	14.8	11 80	10.60	12.40	13.40	13.60	13.60	17.40	13.20	11.00	14.20	20.60	14 60	14.00	16.20
Exch. Bases cmol(+)/kg																		
Ca^{++}	4.40	3.57	3.28	5.95	4 43	4.12	2.66	2.66	3.51	3 73	4 09	4.45	2.96	4.40	5.13	4.48	3.64	3.47
Mg^{++}	3.29	2.55	2.22	3.01	3.03	2.96	5.07	5.14	5.31	5.21	5.06	5.56	4.22	3.90	4.62	4.82	4.50	4.32
K^{+}	0.27	0.30	0.61	0.61	0.41	0.61	0.36	0.32	0.43	0.45	0.37	0.47	0.52	0.52	0.58	0.56	0.52	0.43
Na^{+}	0.14	0.11	0.16	0.15	0.12	0.20	0.14	0.10	0 14	0.12	0.09	0.20	0.13	0.13	0.13	0.15	0.14	0.12
Texture																		
% sand	41.0	49.0	49.0	37.0	43.0	45.0	31.0	23.0	27.0	33.0	37.0	39.0	19.0	33.0	29.0	23 0	29.0	27.0
%silt	14.0	12.0	16.0	18.0	18.0	22.0	18.0	20.0	20 0	18.0	14.0	14 0	16.0	12.0	16.0	16.0	12.0	12.0
% clay	45.0	39.0	35.0	45.0	39 0	33 0	51.0	57.0	53.0	49.0	49.0	47.0	65.0	55.0	55.0	61.0	59.0	61.0
Textural class	C	SC	SC	C	CL	CL	C	C	C	C	C	C	C	C	C	C	C	C
D_M(g/cm^3)	1.30	1.34	1.35	1.40	1.31	1.29	1.23	1.23	1.25	1.22	1.12	1.27	1.43	1.30	1.16	1.24	1.32	1.46

us = upper slope ls = lower slope
ms = middle slope

Appendix 1b: Soil chemical and physical properties (0 – 20 cm depth) of the study area at the end of the experiment

	Gongo/Mgambazi						Mzingwi-1						Mzingwi-2					
	Fanya chini terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots		
	Us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls
pH (H_2O)	6.8	6.7	6.5	6.8	6.8	6.7	6.9	6.7	6.7	6.8	6.8	6.9	6.6	6.8	6.7	6.7	6.8	6.6
P (mg/kg)	1.00	0.82	4.15	3.01	9.12	15.47	1.64	0.91	0.64	3.38	2.19	2.37	0.73	0.73	0.91	0.73	0.46	0.46
TN (%)	0.08	0.08	0.11	0.12	0.12	0.13	0.08	0.08	0.08	0.10	0.11	0.11	0.10	0.10	0.11	0.13	0.12	0.10
OC (%)	1.11	1.11	1.31	1.33	1.60	1.54	1.17	1.19	1.37	1.49	1.68	1.60	1.64	1.46	1.62	1.92	1.76	1.31
CEC(cmol(+)/kg	14.60	16.20	11.80	16.60	16.40	15.00	15.60	15.20	17.20	16.00	18.40	16.20	14.40	15.00	19.40	17.00	16.00	17.60
Exch. Bases cmol(+)/kg																		
Ca^{++}	7.21	7.12	6.17	8.55	8.38	6.85	4.76	4.69	5.07	5.53	5.93	6.09	5.30	5.82	6.13	6.43	6.51	6.07
Mg^{++}	5.06	4.30	3.51	4.23	4.43	4.20	8.11	7.51	7.97	6.86	7.66	7.50	5.17	5.60	7.07	6.38	6.04	5.59
K^{+}	0.15	0.19	0.38	0.42	0.49	0.45	0.32	0.41	0.44	0.51	0.39	0.62	0.53	0.64	0.63	0.43	0.55	0.58
Na^{+}	0.09	0.10	0.12	0.13	0.14	0.13	0.10	0.12	0.13	0.14	0.11	0.16	0.14	0.16	0.16	0.13	0.15	0.15
D_b(g/cm^3)	1.43	1.48	1.38	1.38	1.37	1.39	1.20	1.26	1.25	1.31	1.28	1.14	1.24	1.36	1.24	1.32	1.28	1.27

us = upper slope

ms = middle slope

ls = lower slope

Appendix 1c: Effect of *Fanya chini* terraces on infiltration rate (cm/h)

	Gongo/Mgambazi						Mzingwi-1						Mzingwi-2					
	Fanya chini terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots		
Tension (cm)	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls
5	6	4.8	4.8	6	6	4.8	7.2	7.2	7.2	6	7.2	6	6	7.2	6	6	6	6
7	4.8	3.6	3.6	4.8	3.6	1.2	3.6	4.8	2.4	3.6	3.6	3.6	2.4	4.8	4.8	3.6	3.6	3.6
10	2.4	2.4	2.4	2.4	2.4	1.2	1.2	2.4	1.2	2.4	2.4	2.4	1.2	2.4	1.2	3.6	2.4	2.4

us = upper slope

ms = middle slope

ls = lower slope

Appendix 1d: Mean PR values (MPa) for *Fanya chini* terraced and unconserved plots at the beginning and at the end of the experiment

	At the beginning of the experiment		At the end of the experiment	
Depth (cm)	*Fanya chini* terraced plots	Unconserved plots	*Fanya chini* terraced plots	Unconserved plots
0 – 5	0.09	0.12	1.56	1.50
5 – 10	0.26	0.31	1.66	1.63
10 – 15	0.44	0.54	1.69	1.76
15 – 20	0.52	0.71	1.96	1.84
20 – 25	0.69	0.83	2.12	1.98
25 – 30	0.84	0.98	2.09	2.03
30 – 35	0.99	1.08	2.00	1.86
35 – 40	1.09	1.20	1.99	1.73
40 – 45	1.23	1.30	2.01	1.71

Appendix 1e: Mean aggregate percentages of different sizes in *Fanya chini* terraced and unconserved plots

Aggregate size (mm)	*Fanya chini* terraced plots (Aggregate %)		Unconserved plots (Aggregate %)	
	Initial soil samples	Final soil samples	Initial soil samples	Final soil samples
>2	25.1	27.0	34.2	19.6
1 – 2	20.8	12.8	17.5	22.3
0.5 – 1	15.8	14.9	17.5	15.3
0.25 – 0.5	13.8	11.2	13.0	13.9
0.125 – 0.25	8.2	4.5	6.7	8.2
0.063 – 0.125	3.9	3.0	3.4	3.4
<0.063	12.0	26.7	4.4	17.4

Appendix 1f: Effect of *Fanya chini* terraces on maize grain yield, biomass and shoot height

	Gongo/Mgambazi						Mzingwi-1						Mzingwi-2					
	Fanya chini terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots			*Fanya chini* terraced plots			Unconserved plots		
	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls	us	ms	ls
Grain yield (t/ha)	0.7	1.2	1.1	0.9	1.1	1.1	1.1	1.2	1.3	1.0	1.2	1.3	1.2	0.9	1.4	2.0	1.3	1.6
Biomass yield (t/ha)	2.4	3.4	2.8	2.1	2.9	3.2	2.4	2.6	3.2	2.5	3.1	3.3	3.0	2.2	3.2	4.2	3.2	3.5
Shoot height (cm)	77	87	74	79	83	95	56	80	83	87	112	112	86	73	92	104	102	102