

**IMPACT OF SOIL CONSERVATION MEASURES ON THE PROPERTIES
AND PRODUCTIVITY OF VOLCANIC SOILS ON THE SLOPES OF
MOUNT MERU, ARUSHA, TANZANIA.**

BY

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ABSTRACT

A study was conducted to examine the effect of soil conservation measures on soil properties and productivity of volcanic soils on the slopes of Mount Meru, Arusha Region. The experiment was conducted on 27 plots in two agroecological zones namely: medium (1,400-metres above sea level (m.a.s.l.) and high (1,700 m.a.s.l.) altitude zones. Two commonly used soil conservation measures, *Fanya Juu* and Contour bunds, were tested against non-conserved plots. The effect of soil conservation measures on soil properties was examined by collecting and analyzing soil samples from all treatments. The effect of soil conservation measures on soil productivity was assessed by planting common beans (*Phaseolus vulgaris* var. Lyamungo 85) as the test crop. Soil conservation measures had no significant effect on the surface soil chemical properties namely: pH, CEC, exchangeable bases, total nitrogen, available phosphorous and organic matter. The depth of Ap horizon in the conserved plots was not significantly different from one another ($P=0.05$). However, unconserved plots registered the lowest topsoil depth and they were significantly different from conserved plots. Bean yield differed significantly ($P=0.05$) due to the effect of soil conservation measures. There was no interaction ($P=0.05$) between conservation treatments and their respective position in the agroecological zone. Mean bean yield ranged from 0.789 Mg ha⁻¹ in unconserved to 1.367 Mg ha⁻¹ in *Fanya Juu* terraced plots. *Fanya Juu* treatments significantly out-yielded ($P=0.05$) Contour bund plots by 0.127 Mg ha⁻¹. A similar trend was observed for dry matter yield. Dry matter yield differed significantly ($P=0.05$) due to treatment effect. *Fanya Juu* terracing resulted in two folds grain yield compared to control. The highest dry matter yield was registered in *Fanya Juu* plots, followed by that from Contour bund

plots while unconserved plots produced the lowest yield. Multiple regression analysis showed that depth of topsoil (Ap-horizon) significantly affected bean yield ($P=0.01$, $r^2=0.64$). Depth of topsoil and surface available phosphorus were regressed against bean yield and it was found that the thickness of the Ap horizon had higher impact on bean yield compared to surface available phosphorus ($P=0.01$ and $R=0.78$). Soil moisture profile (0-90 cm) in conserved plots differed significantly ($P=0.05$) from that in unconserved plots. Conserved plots had higher profile moisture content throughout the growing season. However, soil moisture profile did not differ significantly ($P=0.05$) between *Fanya Juu* and Contour bund plots. This suggests that the two conservation measures have similar effect on soil water conservation. The results from this study confirm the importance of soil conservation measures on Ap horizon development, water holding capacity and crop yield.

DECLARATION

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

Signature..........

Date.....08. November 2001.....

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This work is dedicated to my parents: my father Mr. Thabit Kassim Ngatoluwa and my mother Juliana Kigenda Kalo for their role as parents; Mr. Hija Kassim Ngatoluwa for his tireless encouragement and assistance during my secondary and post secondary education without which I would not have reached this level. I also wish to dedicate this work to my late young brother Shaibu Ngatoluwa whose departure was so sudden and my late grand mother mama Ketty (may their souls rest in peace).

TABLE OF CONTENTS

ABSTRACT..... II

DECLARATIONIV

COPYRIGHTV

ACKNOWLEDGEMENTSVI

DEDICATION VII

TABLE OF CONTENTS.....VIII

LIST OF FIGURES..... XIV

LIST OF APPENDICES XV

LIST OF ABBREVIATIONS XVI

CHAPTER ONE 1

INTRODUCTION 1

1.1 Background..... 1

1.2 Justification..... 3

1.3 Hypothesis..... 3

1.4 Objectives..... 3

1.4.1 General objective3

1.4.2 Specific objectives: 4

CHAPTER 2	5
LITERATURE REVIEW.....	5
2.1 Background.....	5
2.2 Soils of the Highlands	6
2.3.1 Physical properties	7
2.3.2 Impact of depth of topsoil (Ap) on soil productivity	8
2.3.3 Bulk density and soil compaction	9
2.3.4 Soil porosity	10
2.3.5 Soil organic matter	10
2.3.6 Soil structure and texture	11
2.4 Soil Conservation Strategies.....	11
2.4.1 Terracing	13
2.4.2 Grass strips	15
2.4.3 Soil management.....	16
2.5 Soil Conservation Measures on the Slopes of Mt. Meru.....	16
2.6 The Impact of Soil Erosion on Soil Productivity.....	17
2.7 Bean Yield in Tanzania.....	17
CHAPTER THREE	19
MATERIALS AND METHODS	19
3.1 LOCATION OF THE STUDY AREA	19
3.1.1 Climate	19

3.1.2 Soils of the experimental sites.....	19
3.1.3 Experimental design.....	20
3.2.2 Treatments.....	21
3.3 Land Preparation, Planting, Thinning and Weeding.....	21
3.4 Insect-Pest and Disease Control.....	22
3.5 Soil Moisture Measurement	22
3.5.1 Gravimetric method	22
3.5.2 Volumetric soil moisture content determination.....	23
3.5.3 Weighted mean profile water content	23
3.6 Crop development assessment	24
3.6.1 Seedling emergence and plant height determination.....	24
3.6.2 Harvesting	24
3.7 Methods of Soil Analysis.....	25
3.7.1 Sample preparation.....	25
3.7.2 Chemical analysis.....	25
3.9 Physical analyses	26
3.9.1 Particle size analysis	26
3.9.2 Bulk density determination	27
3.9.3 Total porosity determination.....	27
3.10 Statistical Analysis	28
CHAPTER FOUR.....	30
RESULTS AND DISCUSSION.....	30
4.1 Soil characterization	30
4.1.1 Texture of the surface soil.....	30
4.1.2 Bulk density	30

4.1.4 Total nitrogen	32
4.1.5 Available phosphorous.....	33
4.1.6 Organic carbon	33
4.1.7 Cation exchange capacity.....	34
4.1.8 Exchangeable bases.....	34
4.2 Effect of Soil Conservation Measures on Soil Physical Properties.....	35
4.2.1 Effect of soil conservation measures on soil texture.....	35
4.2.2 Effect of soil conservation measures on depth of Ap-horizon, organic matter and bulk density	36
4.3 Effect of Soil Conservation Measures on Soil Chemical Properties.....	39
4.3.1 Effect of soil conservation measures on surface (0-20 cm) exchangeable bases and cation exchange capacity	39
4.4 Effect of Soil Conservation Measures on Soil Water Content	40
4.4.1 Effect of sampling depth and sampling time on soil moisture content	41
4.5 Impact of Soil Conservation Measures on Crop Performance	45
4.5.1 Seedling emergence	45
4.5.2 Effect of soil conservation measures on plant height and pod production...	46
4.6 Crop Yield.....	49
4.6.1 Bean grain yield	49
4.6.2 Above ground biomass.....	50
4.7 The Impact of Ap Horizon Thickness on Bean Yield	51
CHAPTER FIVE	54
CONCLUSIONS AND RECOMMENDATIONS	54

5.1 Conclusions	54
5.2 Recommendations	54
5.3 Future studies	55
REFERENCES	56
APPENDICES	64

LIST OF TABLES

Table	Title	Page
1	Physico-chemical properties of the three sites before the experiment started.....	31
2	Mean effect of soil conservation measures on surface (0-20cm) particle size distribution at the two agroecological zones.....	35
3	Mean effect of soil conservation measures on the topsoil depth, organic carbon content and bulk density at the two agroecological zones.....	37
4	Mean impact of soil conservation measures on soil moisture content in a 0-90 cm profile at two agroecological zones.....	41
5	Mean effect of sampling time and depth on gravimetric moisture content at the two agroecological zones.....	42
6	Effect of soil conservation measures on seed emergence on two agroecological zones on the slope of Mt. Meru.....	45
7	Mean effect of soil conservation measure on plant height	47
8	Effect of interaction between location and soil conservation measures on plant height at the two-agroecological zones.....	47
9	Effect of soil conservation measures on pod production in medium and high altitude agroecological zones of Mt. Meru.....	48
10	Mean effect of soil conservation measures on bean grain yield and above ground biomass yield at the two zones.....	50
11	Variation of bean yield as affected by soil conservation measures at the two agroecological zones.....	51
12	Multiple regression analysis result at the two agroecological zones	52
13	Relationship between topsoil depth and bean grain yield.....	52
14	Relationship between soil available phosphorous and bean grain yield...	53

LIST OF FIGURES

Figure	Title	Page
1a	Effect of soil conservation measures on surface (0-20 cm) gravimetric water content in high altitude site 1.....	43
1b	Effect of soil conservation measures on surface (0-20 cm) gravimetric water content in high altitude site 2.....	44
1c	Effect of soil conservation measures on surface (0-20 cm) gravimetric water content in medium altitude.....	44

LIST OF APPENDICES

1	Effect of soil conservation measures on surface (0-20 cm) pH, total nitrogen, and available phosphorous.....	64
2	Effect of soil conservation measures on surface (0-20 cm) exchangeable bases and cation exchange capacity and base saturation.....	65
3	Some soil physical properties in high altitude site 1.....	66
4	Some soil physical properties in high altitude site 2.....	67
5	Some soil physical properties in medium altitude.	68
6	Soil moisture profile (cm) during 1999/2000 cropping season in the high altitude site 1.....	69
7	Soil moisture profile (cm) during 1999/2000 cropping season in the high altitude site 2.....	70
8	Soil moisture profile (cm) during 1999/2000 cropping season in the medium altitude.....	71

LIST OF ABBREVIATIONS

FAO	Food and Agriculture Organization of United Nations
BS	Base Saturation
CV	Coefficient of Variation
CEC	Cation Exchange Capacity
L ha ⁻¹	Litres per hectare
HPA	High Potential Area
LPA	Low Potential Area
LSD	Least Significant Difference
MAFS	Ministry of Agriculture and Food Security
m.a.s.l.	metres above sea level
MAFS	Ministry of Agriculture and Food Security
Mg ha ⁻¹	Mega grams per hectare
Mt.	Mountain
NSS	National Soil Service
RSCU	Regional Soil Conservation Unit
SARI	Selian Agricultural Research Institute
SCAPA	Soil Conservation and Agroforestry Project Arusha
TARP-II	Tanzania Agricultural Research Project Phase II
USA	United States of America
USDA	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.1 Background

The slopes of Mt. Meru in Aru-Meru District, Arusha Region offer favourable climatic and agroecological conditions for agriculture than the surrounding lowlands (Food and Agriculture Organization (FAO), 1997). As a consequence the district is the most densely populated in the region with 110 persons per square kilometre (Regional Soil Conservation Unit (RSCU), 1994). The slopes of Mt. Meru have been used for crop production for many years. These slopes are intensively used to produce both perennial and annual crops such as vegetables, beans, maize, fruits, coffee and banana. The increased pressure on the use of this fragile ecosystem has led to land degradation including serious soil erosion. In response to land degradation, several efforts have been made to conserve the soils on these slopes. An intensive soil conservation program "Soil Conservation and Agroforestry Project Arusha" (SCAPA) started in 1989 to arrest the situation (RSCU, 1994). The overall goal of this program was to increase crop production by adopting appropriate soil and water management techniques for sustainable crop production (RSCU, 1994).

In the quest to halt environmental degradation and to achieve more sustainable agricultural practices, SCAPA programme has been putting a lot of emphasis on developing and refining an array of hillside soil management technologies that include hedgerows, mechanical structures such as *Fanya Juu* terraces and Contour bunds. The programme has been very successful and the performance of the major

conservation measures needs to be understood. Conservation measures which are used by small-scale farmers who form the majority of the farming population along the slopes of Mt. Meru need more attention and their usefulness in the different agroecological zones, soils and topographic conditions need to be studied. The effect of various conservation measures in reducing soil loss and surface runoff and increasing infiltration has been reported by many researchers (Dregne, 1990; 1992; Lal, 1990; Hudson, 1995). The general conclusion is that mechanical conservation measures can play a significant role in reducing losses of soil and nutrients as well as reducing surface runoff. But the critical question for conservation work on the slopes of Mt. Meru is to what extent the existing conservation measures have proved to be effective. Are terraces (*Fanya Juu*) more effective than other soil conservation measures? Ironically, no effort has been made to evaluate the comparative performance of the conservation measures on these slopes.

Volcanic soils characterized by high inherent fertility occupy the slopes of Mt. Meru. However, these soils are highly susceptible to erosion by water particularly when they are used for crop production (Rapp, 1975). Due to insufficient traditional soil conservation measures, serious soil erosion and other forms of land degradation threaten nearly all cropland in this fragile ecosystem. Declining crop yields on these slopes combined with subsistence agricultural systems make the population on the slopes of Mt. Meru vulnerable to shortages of food and, eventually, famine (FAO, 1997). This calls for a self-sustaining agricultural system that takes into account soil and water management practices.

1.2 Justification

For more than two decades now soil conservation activities have been undertaken on the slopes of Mt. Meru by different groups (RSCU, 1994). However, no attempt has been made to examine the influence of these conservation measures on the properties and productivity of these soils. This study, therefore, aims at providing quantitative information on the influence of soil conservation measures on soil properties and productivity. Such information will be useful for future detailed studies and improvement of the existing conservation strategies. This study was undertaken to examine the on-site effect of major soil conservation techniques on properties and productivity of the major soils in the respective agroecosystems.

1.3 Hypothesis

- i. Soil conservation measures do not significantly affect soil properties and crop yield.

- ii. Different soil conservation measures affect soil properties and crop production equally across the two agroecological zones.

1.4 Objectives

1.4.1 General objective

To evaluate the on site effects of the major soil conservation techniques on the properties and productivity of the soils on the slopes of Mt. Meru.

1.4.2 Specific objectives:

- i. To determine the physical and chemical properties of the soils under two conservation measures (*Fanya Juu* and Contour bund) in two agroecological zones: high and medium altitude

- ii. To evaluate crop yield under *Fanya Juu* and Contour bund soil conservation measures and recommend the most promising one.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

The colonial authorities in eastern Africa realized the problem of soil erosion and launched huge soil conservation schemes (Rapp, 1975). However, these schemes were often unsound and unwisely implemented. Farmers were forced to dig terraces without being educated about the need and benefit of such activities (Hudson, 1995).

Clearing forests in the tropics for settlement, overgrazing, lack of management of terraces together with increasing population pressure and settlements in drier areas, resulted in accelerated land degradation (Rapp, 1975; Sanchez, 1976; Darken, 1982; Lal, 1990;). Soil erosion increased with both on-farm and off farm consequences. Environmental problems such as rivers heavily loaded with sediments loads, siltation of dams, flooding and droughts soon reached alarming levels (Christiansson, 1981; Darken, 1982; Dregne, 1990). Concern about off-farm environmental effects of soil erosion rose during the 1960s and 1970s and several research projects on soil erosion processes, quantification of soil losses and sediment yields were conducted. The main objective of such studies was to obtain reliable data on the type, extent and contemporary rates of soil erosion and sedimentation in Tanzania as it was hoped that such information might form a more rational basis for future schemes of soil and water conservation in critical areas of Tanzania (Rapp, 1975; Darken, 1982). Semi arid regions of Tanzania have been plagued by problems of soil erosion since early

this century (Darken, 1982). Most erosion can be linked to the expansion of agriculture and the increased pressure of grazing (Rapp, 1975; Darken, 1982). Berry and Townsend (1972) wrote an excellent review of the history of conservation in semi arid regions of Tanzania. In review the authors concluded that increasing populations of both human and animals serve to steadily intensify the problem of the diminishing resource base in the plains. The reviewers further noted that the solutions demand a major reappraisal of the physical and human use of the land.

Soil erosion is a natural process that can be accelerated by human activities (Christiansson, 1981; Dregne 1990; Lal, 1990). Soil erosion has significant direct impacts on soil properties that affect soil productivity. Erosion removes the topsoil and exposes the sub-soil thereby affecting soil productivity. Once accelerated by human activities, erosion can threaten cropland potential. A risk of soil erosion exists on cultivated land when natural vegetation is removed. Erosion is exacerbated by farming on steep slope, cultivating up and down the slope, compaction of the soil through the use of heavy machinery and pulverization of the soil at seed bed preparation (Morgan, 1986; Hudson, 1995). The problem of soil erosion has been and still remains of great concern on most agricultural land in Tanzania (Rapp, 1975; Christiansson, 1981).

2.2 Soils of the Highlands

Predominant soils of sub-humid tropical uplands are alfisols, psamments, and inceptisols. Alfisols are comparatively fertile and less leached but are highly prone to

compaction and accelerated soil erosion. According to Lal (1990) most psammentic soils are coarse-textured and of alluvial origin. These soils are deficient in both macro and micronutrients. Because these soils often are underlain by hardened plinthite at shallow depth, they have shallow effective rooting volume (Lal, 1990) and they do not therefore, support ample vegetation cover. According to Food and Agriculture Organization (FAO) (1998) classification the soils of the study area are mainly Vitric Andosols, and according to United States Department of Agriculture (USDA) (1998) classification system these soils are classified as Durandepts (Lundgren and Lundgren, 1975)

The nature of soils on the slopes of Mt. Meru makes them very susceptible to erosion (Temple, 1975; RSCU, 1994). Several factors can account for this. In the first place the soils lack cohesion and the high silt content render the soils very prone to erosion (Lundgren and Lundgren, 1975). The second factor responsible for erosion problem on the slopes of Mt. Meru is the large percentage of land under annual crops, particularly maize and beans. Annual crops involve the risk of erosion during seedbed preparation and at early crop establishment stage when the most erosive rain is expected. Another factor contributing to erosion problem on these slopes is the general absence of conservation measures (RSCU, 1994).

2.3.1 Physical properties

Physical properties of the soil are indicators of the environmental impact of soil and crop management system (Warrick and Nielsen, 1980). Soil Physical properties of

tropical soils are also equally important in determining soil fertility and productivity (Lal, 1990; Dregne, 1990). Arrangement of soil particles strongly influences the air-water regime in the soil that significantly influences the root development of a crop. The change in environmental conditions causes many physical alterations of the surface, which in turn influence the ability of the soil to produce a crop. A good understanding of the physical properties of the soils of the slopes of Mt. Meru is therefore essential for planning sustainable crop production of this fragile ecosystem.

2.3.2 Impact of depth of topsoil (A_p) on soil productivity

Removal topsoil by erosion reduces soil fertility and water storage capacity of the soil resulting in declining crop yield. In the United States of America (USA) damage due to the removal of topsoil alone is estimated to cost \$ 250 million per year (Hudson, 1995). The damage is far worse in hill slopes of Tanzania such as the slopes of Mt. Meru where limited awareness of erosion problem, a low level of know how, and high population density for more land and food and limited allocation of resource to combat the problem abound (RSCU, 1994; Hudson, 1995).

Tracks of degraded land seen on the western parts of Mt. Meru are evidence of the seriousness of soil erosion on the slopes of Mt. Meru. Studies by Temple (1975) show high rates of sediment yield and siltation of reservoirs. It is evident that since erosion rates on these slopes are excessive, over time soil depth will be reduced at a drastic rate unless conservation measures are put in place.

Pierce (1991) found a strong positive relationship between crop yield and soil depth. Hudson (1995), Pierce (1991) and Dregne (1990) described effective soil depth as an important factor in crop yield realization because of its role as a major determinant of water storage capacity of the soil, while top soil depth determines productive capacity because it contains plant nutrients vital for plant growth. A thick Ap horizon and high organic matter content have a profound effect on soil hydrological properties and plant root growth and development (Sanchez, 1976).

2.3.3 Bulk density and soil compaction

According to Brady and Weil (1990) the normal range of bulk density for fine textured soil such as silt loam, clay, and clay loam is 1.0 to 1.55 Mg m⁻³ soil. When poorly developed soils are used for crop production, there is a decline in soil aggregation and soil becomes more compact with a consequent increase in bulk density. In a study where bulk density was used as a measure of compaction, potato yield was negatively correlated with bulk density for Hawaii latosols (Schertz *et al.*, 1989). The reduction in permeability due to compaction increases water runoff and erosion and reduces the amount of water available for the growth of crops. Under tropical conditions, the bulk density of the surface horizon of most soils is generally low especially if the soils are either cultivated by traditional methods or they have been under fallow for some time. In contrast, under mechanized cultivation, the bulk density increases significantly due to compaction induced by the use of the machinery (Warrick and Neisen, 1980; Thomas *et al.*, 1989). Fine textured soils such

as silt loams generally have lower bulk density than sandy soils (Brady and Weil (1990). Solid particles of the fine textured soils tend to be organized in porous granules, especially if adequate organic matter is present.

2.3.4 Soil porosity

Cultivation causes a decline in soil aggregation leading to soil becoming more compact (Schertz *et al.*, 1989; Thomas *et al.*, 1989). As a result, the total volume of pore space decreases and bulk density increases. Pressing practices together results in a decrease in the average pore size. Macropore spaces are reduced in size to micropores (Brady and Weil (1990). The result is an increase in volume of micro pore space. For a sandy soil this can be desirable, as the soil would retain more water. By contrast, the increase in micropore space in fine textured soil is generally detrimental because of reduced aeration and water movement (Schertz *et al.*, 1989; Thomas *et al.*, 1989).

2.3.5 Soil organic matter

Organic matter plays an important role in enhancing soil physical properties such as structure and aggregate stability, bulk density, porosity, infiltration capacity, and available water capacity (Young, 1986; Thomas *et al.*, 1989; Brady and Weil (1990). These properties are partly determined by basic condition of soil texture and iron minerals present, but are also substantially influenced by organic matter content (Schertz *et al.*, 1989). Lowering of soil organic matter normally leads to loss of

porosity, decline in aggregate stability, increased in bulk density and lowering of infiltration capacity. These in turn cause substantial reduction in crop yields (Schertz *et al.*, 1989; Thomas *et al.*, 1989)

2.3.6 Soil structure and texture

The long term effect of cultivation resulting from crushing of soil aggregates is a less well aggregated and more compact soil (Schertz *et al.*, 1989). Soil texture determine the rate and extent of many physical and chemical properties important in plant growth.

Soil structure is more drastically affected by cultivation than soil texture, and the effect is generally greater from mechanical than manual cultivation method. Textural properties of the soil are not immediately affected by the influence of a soil conservation strategy. However, soil textural properties especially on a newly installed conservation structure, surface texture is altered due to the removal of the surface horizon as result of conservation structure construction. Likewise, erosion from the soil bund and subsequent deposition to the cultivated area. There is a need therefore to understand the effect of soil conservation measures on the soil texture as well as soil structure.

2.4 Soil Conservation Strategies

Many of the soil conservation measures developed in United States of America involve

high level technology (Hudson, 1995) and may not be appropriate for traditional African farming systems on small holdings (Stocking, 1985; Dregne, 1990; Lal, 1990; RSCU, 1994). In order to combat the problem of soil erosion and other forms of land degradation that threaten the land resource base of the slopes of Mount Meru, it is necessary to introduce methods that are acceptable to small farmers, simple to implement and less labour and capital demanding (Hudson, 1995). Some of these methods are mentioned below.

Soil conservation refers to all activities aimed at covering the soil to protect it from rain drop impact, increasing the infiltration capacity of the soil to reduce runoff, improving the aggregate stability of the soil, and increasing surface roughness to reduce the velocity of runoff and wind (Stocking 1988; Hudson, 1995). According to Morgan (1986) the purpose and use of various conservation techniques can be described under the widely accepted terminology of agronomic measures, soil management and mechanical methods. Agronomic or biological measures utilize the role of vegetation to minimize erosion (Stocking, 1988). Soil management is concerned with ways of preparing the soil to promote dense vegetative growth and improve its structure so that it is more resistant to erosion. Mechanical or physical methods are concerned with manipulation of the land surface slope by constructing conservation structures such as terraces to control the flow of water. Mechanical methods attempt to control the energy available for erosion. Soil management aims at increasing resistance to erosion while agronomic measures provide a protective cover to soil.

2.4.1 Terracing

Terraces are earth embankments constructed across the slope to intercept surface runoff and convey it to a stable outlet at a non erosive velocity (Hudson, 1995). Terraces can be classified into three main types: diversion, retention and bench (Morgan, 1986; Hudson, 1995). A diversion terrace is designed to intercept overland flow and channel it across the slope to a suitable outlet. Retention terraces are used where it is necessary to conserve water by storing it on the hillside. These are normally recommended only for permeable soils on slopes of less than 5% (Morgan, 1986; RSCU, 1994; Hudson, 1995).

2.4.1.1 Bench terraces

Bench terraces consist of a series of alternating shelves and are employed where steep slopes, up to 30%, need to be cultivated. Level bench terraces are used where water conservation is also a requirement, as in loess soil of China and parts of Kenya (Fang *et al.*, 1981). Although bench terraces appear to be reasonably satisfactory as a conservation measure in Malaysia, they are not necessarily suited to all steep sloping land. According to Temple and Murray-Rust (1972) bench terraces are not suitable in the Uluguru Mountains because the soils are too shallow. The construction and maintenance of the bench terraces in the Uluguru Mountains encourages large volumes of water to be held on the hillsides and makes the soils saturated and likely to induce land slides. As an alternative conservation measure, the use of ladder/step terraces and *Fanya-Juu* is recommended. These consist of narrow shelves cut by hoe. Temple and Murray-Rust (1972) observed that very rarely do *Fanya Juu* terraces

break down under heavy rainfall. The effectiveness of terrace and waterway systems in reducing erosion can be illustrated by several studies of bench terracing as reported by Fang *et al.* (1981). On clay loam soil with 19% slope cropped to yams in Jamaica, annual soil loss was 1.7 kg m⁻² compared with 13.3 kg m⁻² without terraces. For a similar soil and slope, the soil loss under bananas was 1.7 kg m⁻² with terracing and 18.3 kg m⁻² without. On a 19% slope with loam to clay soils cropped to maize and beans in rotation in El Salvador, the annual soil loss was 3.0 kg m⁻² with and 10.0 kg m⁻² without terracing. The main reason for the reductions in erosion is the way the system manages the runoff (Fang *et al.*, 1981).

2.4.1.2 Contour bunds

These are earth banks, 1.5 to 2 m wide, where the soil is thrown across the slope to act as a barrier to runoff, to form a water storage area on their upper slopes side and to break up the slope into segments shorter in length than is required to generate overland flow (RSCU, 1994). Runoff hitting a permeable bund is slowed down, slowly penetrates the bund and partially leaves on its lower side. Thus, the area below a bund may be eroded whereas the area in front of the bund is sediment-enriched. This enhances small terraces formation in a few years. Contour bunds are suitable for slopes of less than 12% (Hurni, 1984; Nill *et al.*, 1996). Hurni (1984) calculated the effectiveness of contour bunds to control erosion in Wallo Province, Ethiopia, and showed that they would only reduce soil loss sufficiently on slopes less than 6%.

2.4.1.3 *Fanya Juu* terraces

Nill *et al.* (1996) described *Fanya Juu* terraces widely used in East Africa as a modified version of drainage ditches. The excavated soil is disposed of up-slope thereby forming an earthen bund that traps sediments. The principle of *Fanya Juu* is to build a bank by excavating a ditch and throwing the soil on the uphill side. Soil starts to build up above the bank as it is moved down slope by erosion. Planting grass on the ridge may accelerate this. *Fanya Juu* has proven to work very well in central Kenya where the soils are deep and have high moisture holding capacity (Hudson 1995; Nill *et al.*, 1996). If runoff does occur, there may be some risk of damage as it flows over the terrace bank, but this can be contained by planting vigorous grasses such as *Eugratis curvula* or *Panicum coloratum (makarikariensis)* on the bank (Hudson, 1995).

2.4.2 Grass strips

The use of grass strips developed simply from uncultivated strips of land or trash lines is one of a simple soil conservation technique that could be accepted by small farmers (Stocking, 1988). Although the use of grass strips was introduced in the slopes of Mt. Meru during the colonial time (Rapp, 1975) they were not widely adopted in contrast to the other soil conservation measures such as terracing most likely because conservation grass strips was found to be less effective as compared to mechanical conservation measures.

2.4.3 Soil management

Soil management has a profound effect on the physical and chemical status of the soil. The aim of sound management is to maintain the fertility and the structure of the soil. One way of achieving and maintaining a fertile soil is to apply organic residues. This improves the cohesiveness of the soil, increases its water retention capacity and promotes a stable aggregate structure (Temple, 1975).

2.5 Soil Conservation Measures on the Slopes of Mt. Meru

Temple (1975) carried out a study to measure runoff under different crop and soil conservation measures at Tengeru, Arusha. The study showed that when annual food crops such as maize were grown on the slopes of Mt. Meru, such fields lost over twice the amount of soil and 10% more water when compared to most effective conservation practices tested (grass cover). According to RSCU (1994) conservation work on the crop land on the slopes of Mt. Meru aims at conserving soil and water and maintaining or raising soil fertility in order to increase production. Structural measures which assist soil conservation include narrow grass strips, where soils are deep enough, as well as *Fanya Juu* terraces designed to retain water in situ and prevent runoff (Hudson, 1995). One of the long term benefits of *Fanya Juu* terraces is to speed up the natural process of bench terraces formation. The danger of water logging with retention type structures is not great if the soils are well drained.

2.6 The Impact of Soil Erosion on Soil Productivity

The impact of soil erosion on soil productivity depends primarily on how much of the original surface horizon (Ap or Ah) is remaining. This implies that soils that originally had a thin A horizon would be misinterpreted as being highly eroded (Thomas *et al.*, 1989). Verity and Anderson (1990) observed that an addition of as little as 50 mm of topsoil to a severely eroded soil increased yield by 45 to 58%. Ive and Shaykewich (1987) carried out a soil erosion simulated study on the effect of artificial erosion on the productivity as measured by crop yield and reported a substantial decline in yield with increasing depth of the soil removed. The investigators also concluded that large doses of fertilizer overcame the portion of yield decline but the original productivity of the soil was not restored. Soil erosion greatly changes the clay content of the soil (Verity and Anderson, 1990). In addition to changes in clay content, erosion results in changes in other chemical and physical properties, which are believed to affect soil productivity (Stocking, 1985).

2.7 Bean Yield in Tanzania

In Tanzania it has been observed that the yield of common beans is low compared to that in other parts of the world where the crop is grown. Acland (1971) and Karel *et al.* (1980) observed that bean yields in East Africa ranged from 0.2 to 1.0 Mg ha⁻¹. However, in some parts of the world where improved bean varieties are grown with good crop husbandry practices coupled with appropriate diseases and pest control

measures, yields between 1.1 and 3.0 Mg ha⁻¹ have been recorded (Acland, 1971; Mushi and Edje, 1989; Mushi *et al.*, 1996). The low bean yields recorded in Tanzania would be attributed to various factors. Some of the factors include inadequate soil moisture, drought, pest and disease infestations, genetic variability in nutrient uptake, poor soil management as well as poor crop management (Mushi and Edje, 1989). Higher bean yields could therefore be realized in the slopes of Mt. Meru if the above constraints were given due consideration (Mughogho and Worthman 1988; Mushi and Edje, 1989; Mushi *et al.*, 1996).

Grain legumes have been reported to be more responsive to phosphorous application than cereal crops (Mughogho and Worthmann, 1988). Phosphate is important for leguminous plants because of its influence on the activity of nitrogen fixing bacteria.

CHAPTER THREE

MATERIALS AND METHODS

3.1 LOCATION OF THE STUDY AREA

The reported study was conducted on the slopes of Mount Meru in Arumeru District, Arusha Region. The district is situated in the north eastern part of Arusha region and lies between 35° to 37° east and 3° south. The study was carried out in two villages namely: Oldonyo-sapuk and Oli-kisongo. Oldonyo-sapuk is located in the highlands at an altitude of 1700 metres above sea level (m.a.s.l.). It is locally referred to as a high potential area (HPA). Oli-kisongo on the other hand, is located on the midslope position at an altitude of 1400 (m.a.s.l.) and it is locally described as a low potential area (LPA).

3.1.1 Climate

Mean annual rainfall in the study area is 900 mm (ranges between 800-1200 mm) and is bi-modal. The rains commence in March and continue until May. Following a short dry spell of approximately one month, the rain returns again in late August and continues until early November. The second dry season lasts from November to March

3.1.2 Soils of the experimental sites

The soils at the experimental site are fairly uniform based on the colour and texture. According to Food and Agriculture Organization (FAO) (1998) classification the soils of the study area are mainly Vitric Andosols, and according to United States

Department of Agriculture (USDA) (1998) classification system these soils are classified as Durandepts (Lundgren and Lundgren, 1975). The texture of the soil is fine with fairly uniform contents of sand, silt and clay throughout the profile. Sand content is less than 15% through all profiles while clay content ranges from 25-40%. The soils in the district are volcanic and are fertile especially in the lowlands but are very susceptible to erosion. The slopes of Mt. Meru offer favourable climatic and agroecological conditions for agriculture than the surrounding lowlands (FAO, 1997).

According to FAO (1994) the footslopes of Mt. Meru are classified according to the cropping systems into three agroecological zones: high altitude, medium altitude and low altitude zone. The study reported here was conducted on two zones: medium and high altitude to assess the impact of two soil conservation techniques, *Fanya Juu* and Contour bund on the soil properties and production potential.

3.1.3 Experimental design

A field experiment was conducted on existing four years old soil conservation structures on 27 plots during the 1999/2000 cropping season. The experiment was carried out using Randomized Complete Block Design (Gomez and Gomez, 1984). Each site was tested against two treatments namely: a *Fanya Juu* terrace, contour bunds and a control (no conservation measures) to assess the impact of the two soil conservation measures on soil properties and its production potential. In order to avoid border effects plots were located at the middle position between two consecutive structures.

The treatments were blocked into three homogeneous land units (blocks) commonly referred to as agroecological zones. In each block the treatments were replicated three times making a total of twenty 27-treatment combinations. The plot size was 15 m². Data were collected on the following variables: depth of Ap horizon, crop performance: date to 50% emergence (by counting), date to 50% flowering, crop yield at 13% moisture content and above ground biomass at 60% moisture content. Soil data including soil moisture and bulk density were determined at five depth intervals: 0-15, 15-30, 30-45, 45-60, 60-75 and 75-90 cm.

3.2.2 Treatments

The experiment was undertaken to evaluate contour bunds and *Fanya Juu* terrace during the 1999/2000 cropping season. Control treatment in this study is referred to as commonly used cultivation practice whereby the hand hoe is used to prepare a seedbed without forming ridges and where no conservation measures are used. This method is widely used by vegetable and cereal growers. The entire plot is tilled to create a weed free seedbed ready for planting. The process also involves the incorporation of crop residues from the previous harvested crop into the soil.

3.3 Land Preparation, Planting, Thinning and Weeding

Land preparation was done in March, 1999. This involved hand hoe tillage incorporating all previous crop residues. In proceeding seasons all sites were used for growing maize. Planting of beans was done on 13 March 1999. Four seeds were

planted per hill at a spacing of 0.20 X 0.50 m. Thinning to two seedlings per hill was done three weeks after emergence to give a plant population of 200,000 plants per hectare in all treatments.

The crop was weeded twice using a hand hoe. The first weeding was done four weeks after emergence while the second weeding was done four weeks later. The plots were kept weed free throughout the growing season by weeding the plots whenever necessary.

3.4 Insect-Pest and Disease Control

The study area is located in a high disease pressure area hence control measures were taken to prevent disease and pest attack. A mixture of Karate 5 EC and blue copper at a rate of 1 L ha⁻¹ and 2 kg ha⁻¹, respectively, was applied 4 weeks after crop emergence to control insect attack and fungal infection.

3.5 Soil Moisture Measurement

3.5.1 Gravimetric method

Soil samples weighing approximately 200 g were collected from 15 cm depth intervals of the soil profile to a depth of 90 cm which corresponds to a rooting depth of beans. Each soil sample was placed in an airtight container of a known weight and then weighed. The sample was then placed in oven and air dried at 105° C for 24 hours

with container cover removed. After drying, the soil and the container were again weighed and the weight of water (θ_g) determined (Blake and Hartge, 1986; Gardner, 1986).

3.5.2 Volumetric soil moisture content determination

The volumetric soil water content (θ_v) was determined from field soil sample by finding the product of gravimetric water content and the bulk density of the respective layer as follows (Blake and Hartge, 1986; Gardner, 1986).

$$\theta_v = \theta_g (\rho_b / \rho_w) \dots \dots \dots (1)$$

- Where:
- θ_v is the volumetric soil water content (cm^3/cm^3)
 - θ_g is the gravimetric water content (g.g^{-1})
 - ρ_b is the bulk density of the soil (Mg cm^{-3})
 - ρ_w is the density of water assumed to be 1.00 Mg m^{-3}

3.5.3 Weighted mean profile water content

The weighted mean profile water content from each treatment was calculated by the summation of the product between volumetric water content for each layer and respective depth (Blake and Hartge, 1986; Gardner, 1986) as follows:

$$\theta_p = \sum_{z_0} S^z \theta_v \delta z \dots \dots \dots (2)$$

Where: θ_p is mean profile water content (cm^3/cm^3) in the 0-15 cm depth
 δz is profile depth with similar textural class in which the matric potential and estimated water content is expected to be constant and i ranges
 z_0, z_i is depth integral from the surface
 θ_v is the soil volumetric water content

3.6 Crop development assessment

3.6.1 Seedling emergence and plant height determination

Seed emergence was determined by counting the total number of hills with emerged seedlings after 50% of seedlings had emerged. Plant height was measured at 90% flowering in all treatments. Heights of ten randomly selected plants were measured using a ruler. The measurements were taken from soil surface to the tip of the topmost leaf (Mushi and Edje, 1989).

3.6.2 Harvesting

After reaching maturity, from each treatment, the crop was harvested randomly from 4 plots of 10 m^2 each and mean for respective variable was computed. The pods were shreashed and seeds were dried to attain a constant moisture content of 13%. Immediately after drying and winnowing beans seed yield from each plot was determined using a sensitive balance and yields were recorded accordingly. Above

ground biomass was determined by cutting the plants from the ground surface level and air dried to a 60% moisture content and weighed.

3.7 Methods of Soil Analysis

Analysis of soil samples was done at the Selian Agricultural Research Institute laboratory. Soil variables that were analyzed and their respective methods of analysis are given in the following section.

3.7.1 Sample preparation

All samples were air dried, crushed and sieved through a 2 mm screen. Material larger than 2 mm was discarded.

3.7.2 Chemical analysis

Soil pH was measured in a soil to 0.01M KCl solution ratio of 1:2.5 on a Beckman Expandomatic SS-2 pH meter with a combination electrode as explained by McLean (1982).

Organic carbon was determined by the modified walkey-black combustion method (Nelson and Sommers, 1982). Total nitrogen was determined by semi-micro kjeldahl method and ammonia distillation (Bremner, and Mulvaney, 1982).

Cation exchange capacity was determined by ammonium acetate (1N adjusted to pH 7.0) and the displaced ammonium ions was determined by micro kjeldahl distillation technique (National Soil Service (NSS), 1991). Extractable cations were determined by the neutral ammonium acetate extraction technique followed by atomic absorption spectrophotometry as described by Thomas (1982).

Available P in the soil was determined following the Bray and Kurtz 1 procedure (Olsen and Sommer, 1982) and P in the extract was determined by ascorbic acid-molbdate blue method as described by McKeague (1978).

3.9 Physical analyses

3.9.1 Particle size analysis

Particle size was determined by the pipette method, using a constant temperature water bath and pre-treatment of the soil sample with hydrochloric acid and hydrogen peroxide (McKeague, 1978; Gee and Baunder, 1986).

3.9.2 Bulk density determination

Measurements of bulk density were made by collecting undisturbed soil samples of known volume and then drying the sample in an oven at 105° C for 24 hours to determine the dry weight fraction (Hillel, 1982). Then the dry weight of the soil (M_s) was divided by the known sample volume V , to determine bulk density ρ_b (Hillel, 1982)

$$\rho_b = M_s/V \dots\dots\dots(3)$$

Where: ρ_b = dry bulk density ($Mg\ m^{-3}$)

M_s = soil dry weight (g)

V = Known sample volume in cm^3)

3.9.3 Total porosity determination

Total porosity was determined by using relationship between bulk density and particle density as described by Brady and Weil (1990).

$$St = 1 - (\rho_b/\rho_p) \dots\dots\dots(4)$$

Where: St = is the total porosity (%)

ρ_b = dry bulk density ($Mg\ m^{-3}$)

ρ_p = particle density for most mineral soil is assumed to be $2.65\ Mg\ m^{-3}$ (Blake

and Hartge, 1986).

3.10 Statistical Analysis

Analysis of variance as described by Snedecor and Cochran (1980) was performed for bean yield, plant height, number of pods per unit area, plants per unit area, profile moisture content, soil physical and chemical properties to determine the treatment effect of these variables. The statistical model used was as described by Gomes and Gomez (1984) and is shown below.

$$\mu_{ij} = \mu + T_i + \beta_j + (\beta T)_{ij} + \xi_{ij}$$

Where μ = the general mean common to all observations

T_i = Treatment effect

β_j = Block effect

$(T\beta)_{ij}$ = interaction effect of treatment and block

ξ_{ij} = random error

MSTAC computer statistical package (Lund, 1991) was used to perform analysis of variance. Mean separation was performed using Least Significant Difference (LSD). Means were ranked to compare treatment effects on grain yield, plant height, pod counts, and on surface and profile moisture content.

Regression analysis was carried out to test the relationship between soil properties that influence crop. Various soil variables were regressed and correlated with yield to determine their relationship with bean yield.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Soil characterization

Soils data for selected physical and chemical properties of the soils of the study area are presented in Table 1, and in Appendices 1 to 5.

4.1.1 Texture of the surface soil

The surface texture around the study area was silt loam characterized by high silt contents ranging from 60 - 61% and low sand content ranging from 12 to 17% (Table 1). The soils had relatively high clay content ranging from 23 to 27%. This texture pre-disposes the soils in the study area to erosion (Christiansson, 1981).

4.1.2 Bulk density

There was a general decrease in bulk density with depth in all sites as indicated in Appendices 3, 4 and 5. This may be attributed to gradual decrease in silt content with depth as shown in Appendices 2 and 3. The soils have low bulk density ranging from 0.73 to 0.75 Mg m⁻³ and a large volume of pore space of about 72%. Relatively high proportions of pore space to solid have resulted into lower bulk density in these soils than those that are more compact and have less pore space (McKeague *et al.*, 1990; McKeague and Modestus, 1991). McKeague *et al.* (1991) reported that fine textured

Table 1. Physico-chemical properties of the three sites before the experiment started

Parameter	Unit	Mean ^a , SD		
		High altitude Site 1	High altitude Site 2	Medium Altitude
Texture				
Clay	%	22.9 ± 1.9	24.1 ± 1.9	27.1 ± 0.1
Silt	%	60.6 ± 1.3	61.8 ± 1.5	60.6 ± 0.5
Sand	%	16.5 ± 3.2	13.6 ± 2.1	12.3 ± 0.4
Textural class		Silt Loam	Silt Loam	Silt Loam
Bulk density	Mg m ⁻³	0.73 ± 0.02	0.75 ± 0.02	0.73 ± 0.02
pH 1:2.5 H ₂ O		5.4 ± 0.2	5.4 ± 0.4	5.7 ± 0.1
pH 1:2.5KCl		4.7 ± 0.3	4.5 ± 0.3	5.1 ± 0.2
Organic carbon	%	3.7 ± 0.3	3.9 ± 0.3	4.2 ± 0.1
Total nitrogen	%	0.38 ± 0.04	0.38 ± 0.1	0.42 ± 0.01
CN ratio		10	10.3	10
Available phosphorous	mg kg ⁻¹	7.5 ± 0.5	7.3 ± 0.5	10.2 ± 4.6
Exchangeable cations	Cmol (+) kg ⁻¹			
Calcium		14.7 ± 2.4	14.8 ± 2.4	14.6 ± 2.6
Magnesium		3.5 ± 1.3	3.5 ± 1.1	3.7 ± 1.2
Sodium		2.3 ± 0.05	2.3 ± 0.2	2.5 ± 0.1
Potasium		0.73 ± .05	0.74 ± 0.1	0.83 ± 0.1
Cation exchange capacity	Cmol (+) kg ⁻¹	52.2 ± 0.9	58 ± 2.3	52.2 ± 2.8
Base saturation	%	40.8 ± 2.9	36.7 ± 1.5	41.6 ± 2.4

a = Avarage of three samples

SD = Standard deviation

soils such as silt loams generally have lower bulk density than sandy soils. Solid particles of these fine textured soils were organized in porous granules, due to adequate organic matter content Landon (1991)

4.1.3 Soil pH

The $\text{pH}_{(\text{water})}$ of the soils in the high and low altitude areas were fairly similar and is classified as slightly acidic with pH values ranging from 5.4 to 5.7 (Table 1) (Landon, 1991). This range falls within the preferred range for most field crops (Landon, 1991). Soils in the high altitude area were slightly more acidic than those in medium altitude. Relatively higher precipitation (See section 3.1.1) has contributed to low pH value through leaching of basic cations in this area. This is in agreement with findings by other workers (Sanchez, 1976; Brady and Weil, 1990) who reported that low pH values are expected in high rainfall areas.

4.1.4 Total nitrogen

Total nitrogen was fairly uniform in the high altitude sites with N content value of 0.38%. The medium altitude site registered slightly higher total nitrogen level than the high altitude sites (Table 1). According to Landon (1991) total nitrogen was rated as medium and ranged from 0.38 to 0.42% (Table 1). Such nitrogen level can be considered to be sufficient for bean production in the area (Samki and Harrop, 1984; Flor and Thung, 1989; Landon, 1991).

4.1.5 Available phosphorous

Phosphorous content ranged from 7 to 10 mg kg⁻¹ (Table 1). Although phosphorous content was generally low in the study area, phosphorous content in the medium altitude was relatively higher than that in the high altitude. However, according to Flor and Thung (1989) these soils contained too low phosphorous contents for bean production. Phosphorous contents were relatively higher in the surface horizon while the lower horizons contained relatively small portion.

4.1.6 Organic carbon

There was a general decrease in organic carbon content with depth in the two agroecological zones (Appendix 2&3). Surface (0-15 cm) organic carbon ranged from 3.7 to 4.2% (Table 1). Organic carbon level was nearly the same in the high altitude sites. Organic carbon content was slightly more in the medium altitude than that of high altitude. The organic carbon was rated medium to high according to Landon (1991) in all sites. Low soil organic matter can be linked to relatively limited returns of organic residues into the soil after crop harvest. This was further supported by the fact that nearly all crop residues are utilized as animal feed in these highlands. Similar observations have been reported by Brady and Weil (1990) that low crop residues return into the soil leads to low soil organic matter content in most tropical soils.

4.1.7 Cation exchange capacity

Cation exchange capacity (CEC) was rated very high $>52.2 \text{ Cmol (+) kg}^{-1}$ according to Landon (1991). Exchangeable cations (Ca, Mg, Na and K) has contributed about 37-42% of the total CEC. Such high CEC values could most likely be associated with relatively high organic carbon content. This is supported by the findings by (McKeague *et al.*, 1991) from similar volcanic soils near Arusha who reported that high CEC of volcanic soils near Arusha was associated to high organic carbon and high charge clay minerals.

4.1.8 Exchangeable bases

Soils around the study area were characterized by low a base saturation ranging from 37 to 42%. The base saturation was fairly uniform in the two agroecological zones. However, one site at the high altitude zone had relatively low base saturation of about 37% as compared to that of 41% of the neighbouring site in the same zone. The reason for this variation was not established from the current study. Among the exchangeable bases, Ca^{2+} was the most abundant followed by Mg^{2+} , Na^+ and lastly K^+ for all sites (Table 1; Appendix 2). McKeague and Modestus (1991) have reported similar observations for volcanic soils around Arusha.

4.2 Effect of Soil Conservation Measures on Soil Physical Properties

4.2.1 Effect of soil conservation measures on soil texture

Data on mean effect of *Fanya Juu* terracing and Contour bunds on surface soil texture

at the two agroecological zones are presented in Table 2. Mean surface sand content of *Fanya Juu* terraced and unconserved plots in the two agroecological zones were significantly higher ($P < 0.05$) than those of Contour bund plots. The mean sand content ranged from 17 to 20%. Contour bunded plots had the lowest sand content. Similar trends were observed for silt content. Silt content on the *Fanya Juu* and Unconserved

treatments were not significantly different ($P < 0.05$) while silt content of the Contour bund plots was significantly higher ($P < 0.05$) than that of *Fanya Juu* and Unconserved plots. Again the clay content of the Contour bund treatments was significantly higher ($P < 0.05$) than that in *Fanya Juu* terraced plots.

Table 2. Mean effect of soil conservation measures on surface (0-20 cm depth) particle size distribution at the two agroecological zones

Conservation Measure	*(%)		
	Sand	Silt	Clay
Contour bund	17 b	59 a	24 a
<i>Fanya Juu</i>	20 a	57 b	23 b
Unconserved plots	20 a	57 b	23 b
LSD ($P=0.05$)	1.2	1.4	1.0
CV (%)	4.9	2.2	3.5

Means within the column followed by the same letter are not significantly different ($P < 0.05$); *Mean of three blocks; n=9 for each mean

However, control plots had statistically the same clay content as in *Fanya Juu* treatments. The reason for variations in silt and clay content in the two treatments could not be established from this study.

4.2.2 Effect of soil conservation measures on depth of Ap-horizon, organic matter and bulk density

The overall relationship between soil conservation measures and topsoil depth, soil organic matter, dry bulk density and total porosity for the two agroecological zones is given in Table 3.

4.2.2.1 Thickness of Ap horizon

The depths the of Ap-horizon in conserved plots were not significantly different ($P < 0.05$) from each other. However, unconserved plots registered the lowest topsoil depth and they were significantly different ($P < 0.05$) from conserved plots. The significantly thicker Ap horizon may be attributed to progressive natural formation of bench terraces on conserved plots. Similar observations were made in Kenya where Contour stone bunds were found to have a terracing effect as a result of progressive soil erosion and subsequent deposition of soil particles on the lower terrace (Hudson, 1995). Ap horizon development is one of the positive impacts of *Fanya Juu* terraces and Contour bunds.

Table 3. Mean effect of soil conservation measures on the surface 0-20 cm topsoil depth (Ap), organic carbon, dry bulk density and total porosity at the two agroecological zones

Conservation Measure	*Depth of Ap (cm)	*Organic Carbon (%)	*Bulk density (Mg m ⁻³)	*Total Porosity (%)
Contour bund	25 a	4.2 a	0.75 a	72 a
Fanya Juu	26 a	4.1 a	0.73 b	72 a
Control	21 b	4.1 a	0.73 b	72 a
LSD (P0.05)	1.4	0.2	0.004	3.2
CV (%)	4.4	3.5	1.1	1

Means within the column followed by the same letter are not significantly different (P<0.05)

*mean of three blocks, n = 9

4.2.2.2 Bulk density

The bulk density in the Contour bunds treatments was significantly higher than that in either *Fanya Juu* or unconserved plots (Table 3). However, there was no significant difference in dry bulk density between unconserved plots and *Fanya Juu* plots. The results from this study could not reveal the possible cause of higher bulk density in the Contour bund treatments. Although contour bund plots had statistically higher bulk density it did not pose any agronomic problem to the crop. Generally, the soils in the study area had low bulk density as compared to other volcanic on the lower slopes of Mt. Meru with bulk density ranging from 1.0 to 1.3. Under ideal soil condition bulk density of most tropical soil ranges from 1.0 to 1.3 Mg cm³ (Brady and Weil, 1990).

4.2.2.3 Organic carbon content

There were no significant differences ($P < 0.05$) in organic carbon content in all treatments (Table 3). Organic matter content decreased substantially with depth (Appendices 3,4 & 5) in the two agroecological zones. Mean organic carbon content was about 4.2%. The soils are rated as having medium organic carbon (Landon, 1991; Brady and Weil, 1990). The relatively high organic carbon content is due to the regularly application of farm yard manure, which is a common practice in these areas. Similar results were reported by Grimes and Bishop (1971; Thomas *et al.*, (1989) and Dregne (1990) that high soil organic matter was reflected in cropping system that returns more organic residues and farm yard manure into the soil.

4.2.2.4 Total porosity

Total porosity was not significantly affected by conservation measures in the two agroecological zones ($P < 0.05$) (Table 3). The mean total porosity for the two agroecological zones was about 72%. High total porosity in these soils was caused by relatively low soil bulk density and high organic matter content associated with these soils. This in agreement with Cassel and Nelson (1985) in their study which revealed that high total porosity values are a result of low bulk density and relatively high content of organic matter. Similar results were also reported from ferratic soil of Senegal; on Grisword silt loam soils by Cassel and Nelson (1985); Datiri and Lowery (1991) and Unger and Casel, (1991).

4.3 Effect of Soil Conservation Measures on Soil Chemical Properties

Effects of soil conservation measures on surface (0-20 cm) pH, total nitrogen and available phosphorous at the two agroecological zones is summarized in Appendix 1. There were no significant differences ($P < 0.05$) among treatments on surface pH, total nitrogen and available phosphorous. The surface soil reaction was generally medium acidic with a fairly uniform pH of about 5.2. Although phosphorous levels were not significantly different, unconserved plots registered the lowest amount of available phosphorous. The relatively lower concentration of available soil phosphorous in the unconserved plots has been attributed to loss of topsoil by erosion as reflected by relatively thin Ap-horizon (Table 3). This is in agreement with findings reported by Datiri and Lowery (1991) and Unger and Casel (1991) who reported decline in soil P as affected by soil erosion in similar soil type.

4.3.1 Effect of soil conservation measures on surface (0-20 cm) exchangeable bases and cation exchange capacity

A summary of effects of conservation measures on the surface (0-20 cm) chemistry of the soils on different treatments is given in Appendix 2. It was observed that soil conservation measures had no significant effect ($P < 0.05$) on CEC, exchangeable bases, and base saturation.

The soils are characterized by high CEC associated with low base saturation of about 36%. High silt content and organic carbon has contributed to relatively high CEC of these soils. Low base saturation suggests that most of the exchangeable bases have been removed from the soil profile most likely through leaching. This is in agreement

with observations reported by Nieuwenhusy *et al.* (1993). The authors observed low base saturation in andosols due to extreme leaching conditions in Holocene beach under humid tropical conditions. In the current study excessive leaching of basic cations seem to have greatly contributed to low soil pH and low base status of these soils (Table 1).

4.4 Effect of Soil Conservation Measures on Soil Water Content

Soil conservation measures significantly improved soil water content at the two agroecological zones. Contour bunds and *Fanya Juu* treatments had the highest water content and were significantly different ($P < 0.05$) from unconserved plots (Table 4).

The mean water content ranged from 148 to 179 mm m⁻¹. The high moisture content observed in the conserved plots may be partly attributed to increased infiltration time offered by the conservation structures. The presence of conservation measures breaks the slope into smaller segments that increase time for water to infiltrate into the soil. Low moisture content in unconserved plots is likely to be due to increased surface runoff and reduced infiltration. This was suggested by Young (1986) who reported reduced yields in eroded fields that were caused by increased runoff and subsequent reduced infiltration rate and not by erosion *per se*. Soil conservation measures substantially increased the periods during which the soil profile is close to field capacity, thus reducing moisture stress.

Table 4. Mean impact of soil conservation measure on soil moisture content in a 0-90 cm profile at the two agroecological zones

Conservation measure	^a Moisture content mm m ⁻¹
Contour bund	176 a
<i>Fanya Juu</i>	179 a
Unconserved	148 b
LSD(P=0.05)	15
CV (%)	14

Means within the column followed by the same letter are not significantly different (P<0.05), ^a = mean of three blocks, n = 9

4.4.1 Effect of sampling depth and sampling time on soil moisture content

Data on mean moisture content as affected by soil conservation measures, sampling time and sampling depth in the two agroecological zones are presented in Table 5. At planting time (Time 0) soil moisture content in the upper 15 cm was not significantly different (P=0.05) among treatments (Table 5; Figure 1a, Figure 1b). Mean moisture content ranged from 39 to 42 mm m⁻¹. During the first four weeks after planting gravimetric soil moisture content in the upper 15 cm layer was not significantly different in *Fanya Juu* and Contour bund treatments. From the second to the sixth week after planting, soil moisture content remained significantly higher in the conserved plots than in the unconserved plots (Table, 5).

Table 5. Mean effect of sampling time and depth on soil moisture content at the two agroecological zones

Treatment	Depth (cm)	Sampling time in weeks						
		0	2	4	6	8	10	12
Contour bund	0-15	41.33 a	41.33 a	40.33 ab	38.67 ab	25.67 abc	21.33 abc	9.66 c
	15-30	35.67 b	34.00 cde	37.00 bcd	34.00 cd	26.33 abc	21.00 abc	9.667 c
	30-45	32.33 bcd	32.00 e	36.00 cd	32.33 cde	27.67 ab	22.00 abc	13.00 a
<i>Fanya Juu</i>	0-15	41.67 a	41.67 a	42.00 a	41.00 a	28.33 a	23.33 a	11.00 b
	15-30	35.33 bc	38.00 b	38.00 abc	36.67 abc	26.33 abc	22.33 ab	11.67 b
	30-45	32.00 cd	35.33 bcd	36.33 bcd	34.67 bcd	25.00 abc	21.33 abc	13.00 a
Unconserved	0-15	39.33 a	36.33 bc	36.00 cd	33.67 cd	23.33 bc	16.33 c	8.00 d
	15-30	35.33 bc	33.00 de	33.00 de	30.67 de	22.00 c	16.67 bc	8.667 d
	30-45	30.33 d	32.33 e	31.00 e	28.67 e	23.67 bc	18.67 abc	9.667 c
LSD (P<0.05)	3.664	2.797	4.288	4.619	4.650	5.748	0.758	

Means within the column followed by the same letter are not significantly different (P<0.05)

CV (%) 14.29 for all treatments

The surface (0-15 cm) soil water content dropped considerably in all treatments from the 8th week onwards. However, moisture content in the conserved plots remained relatively higher than that in the unconserved plots. The significant drop in the surface soil moisture from the 8th week was most likely due to increased demand for water by the crop at that stage as well as offset of the rains. This coincided with flowering period and contributed greatly to lower crop yields (Table 10).

The effect of sampling depth on soil moisture content was more pronounced during the first two weeks after planting in all treatments. During the first 14 days soil moisture content decreased significantly with depth in all treatments as a result of the extended drought period that came in soon after the rain season that lasted for less than three weeks.

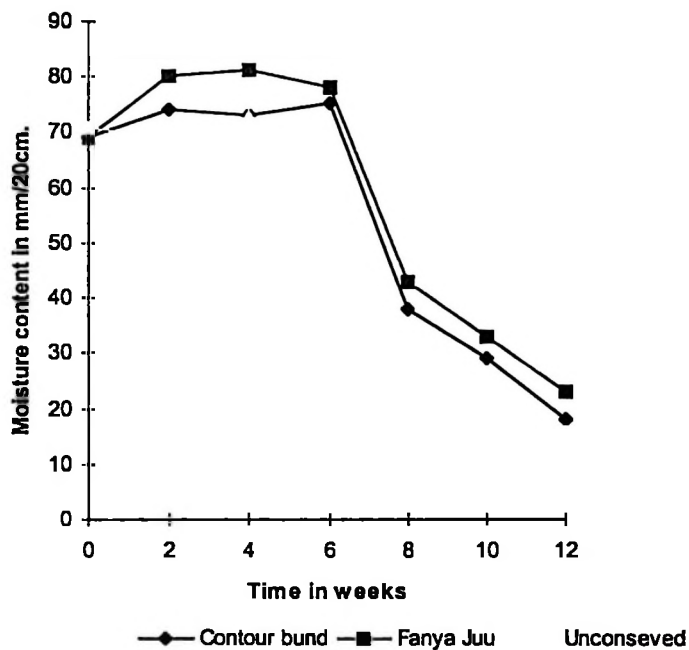


Figure 1a Effect of soil conservation measures on surface gravimetric soil moisture content in the high altitude site 1.

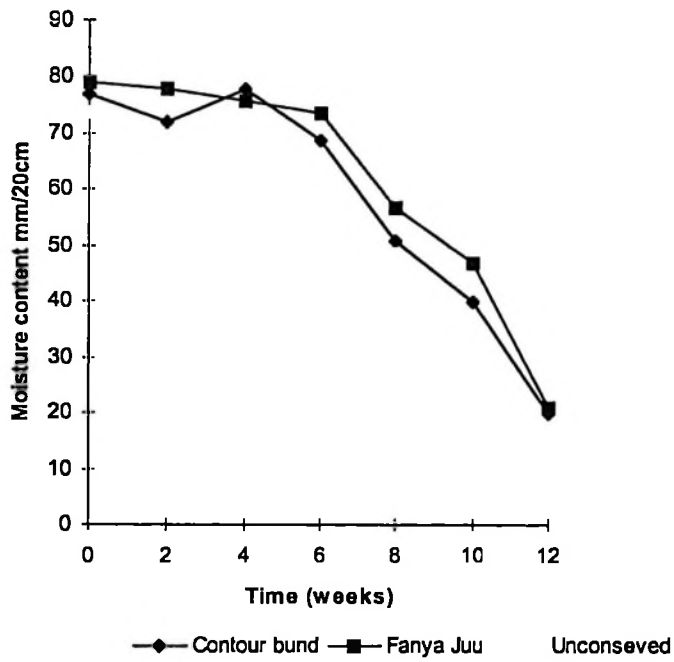


Figure1b Effect of soil conservation measures on surface gravimetric soil moisture content in the high altitude site 2.

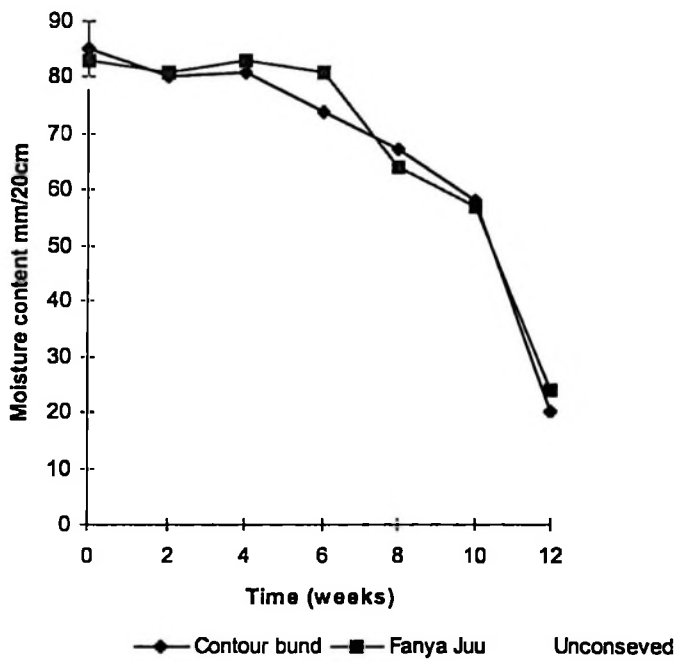


Figure1c Effect of soil conservation measures on surface gravimetric soil moisture content in the medium altitude

4.5 Impact of Soil Conservation Measures on Crop Performance

4.5.1 Seedling emergence

Effect of soil conservation measures on seedling emergence is summarized in Table 6. The impact of soil conservation measures on seedling emergence showed inconsistent results in the high altitude 2 site. The results from high altitude 2 revealed that there were significant differences in days to 50% emergence between *Fanya Juu* terraced plots and unconserved plots. However, there was no significant difference between contour bund plots and unconserved plots. Seedlings emerged one day earlier in contour bunds and unconserved treatments.

Table 6. Variation of seed emergence as affected by soil conservation measures at the two agroecological zones

Treatment	Number of days to 50% emergence		
	High altitude 1	High altitude 2	Medium altitude
Contour bund	8 a	7 b	7 b
<i>Fanya Juu</i>	8 a	8 a	7 b
Unconserved	8 a	7 b	7 b

Means within the column followed by the same letter are not significantly different (P=0.05),

LSD(P<0.05) 0.33 for all treatments, n = 9

c) CV (2.6%)

The reason for delayed seedling emergence in *Fanya Juu* terraced plots could not be established from the current study. It was further observed that regardless of the type of soil conservation measure used, there were no significant differences in number of

days to 50% seedling emergence in the two sites. In high altitude 1, the mean number of days to 50% seedling emergence was eight days from date of planting in all treatments. However, it was also noted that seed emerged one day earlier in the medium altitude zone.

4.5.2 Effect of soil conservation measures on plant height and pod production

Data on plant height as affected by soil conservation measures are presented in Table 7. Plant height was significantly affected by of soil conservation measures ($P<0.05$). Mean bean plant height varied between 24 to 28 cm. This is in disagreement with observation by Mushi and Edje (1989) who found that the mean plant height of Lyamungo 85 in northern Tanzania is 44 cm. Bean plants on unconserved plots were stunted and were significantly ($P<0.05$) shorter when compared to bean plants in *Fanya Juu* and Contour bund treatments. Plant height had a direct effect on the number of pods produced, such that Contour bunds, which had the taller plants, produced significantly more pods than the *Fanya Juu* treatment. Unconserved plots, which had the shortest plants, produced the lowest amount of pods. Stunted plant growth in unconserved plots is linked to low soil fertility status associated with the high degree of topsoil loss of these plots as reflected by significantly thin topsoil depth. Although plants height on conserved plots were significantly taller ($P<0.05$) than those were in unconserved plots (Table 7), soil conservation measures had similar impact on plant height in the two agroecological zones. The reason for relatively stunted plants in unconserved plots is linked more to soil moisture stress.

Table 7. Mean effect of soil conservation measures on plant height at the two agroecological zones

Conservation measure	*Plant height (cm)
Contour bund	28 a
<i>Fanya Juu</i>	28 a
Unconserved	24 b
LDS (P=0.05)	0.9
CV (%)	3.7

Means within the column/row followed by the same letter are not significantly different (P<0.05); *= Mean of three blocks; n = 9

Table 8 shows the effect of soil conservation measures at the two-agroecological zones on plant height

Table 8. Variation of plant height as affected by soil conservation measures at the two agroecological zones

Treatment	Plant height in centimeter		
	High altitude 1	High altitude 2	Medium altitude
Contour bund	28 a	28 a	28 a
<i>Fanya Juu</i>	28 a	28 a	27 a
Control	26 b	25 b	22 b

LSD (P<0.05) 1.7; CV (%) 3.8 for all treatments;

Means within the column followed by the same letter are not significantly different (P<0.05); n = 9

The average number of pods per unit area ranged from 52 to 92 pods per square metre (Table 9).

Table 9. Effect of conservation measures on pods production in medium and high altitude agroecological zones of Mt. Meru

Treatment	Pods/m ²		
	High altitude 1	High altitude 2	Medium altitude
Contour bund	63 b	62 b	62 b
<i>Fanya Juu</i>	92 a	91 a	81 a
Control	56 b	52 b	47 c

LSD (P<0.05) 10.17; CV (%) 8.67 for all treatments

Means within the column followed by the same letter are not significantly different (P<0.05), n = 9

The highest number of pods was recorded on contour bund plots followed by *Fanya Juu* plots. Unconserved plots produced the lowest number of pods per unit area. Significant differences (P<0.05) were observed between *Fanya Juu* terraced plot and contour banded plots on high altitude sites while the number of pods in the contour bund plots was not statistically different from that in the control in the high altitude zones. On the other hand, significant differences were observed between *Fanya Juu* terraced and contour banded plots on medium altitude. Both conservation measures were significantly superior to unconserved plots. The range of pod production observed is in agreement with observations by Mushi *et al.* (1996) where the authors obtained 75-80 pods/m² when the same bean variety was planted in Arusha and Kilimanjaro area. The relatively lower pods production in unconserved plots was probably due to low soil fertility particularly low available phosphorous and insufficient soil moisture encountered during the 8th week when the plant was at flowering (Figure 1a, 1b, 1c Table 5 and Appendix 1).

4.6 Crop Yield

4.6.1 Bean grain yield

According to Mushi and Edje (1989) the potential yield for the bean variety Lyamungo 85 is 2.5 Mg ha⁻¹. Bean yields obtained from the experiment reported herewith were relatively low when compared to its potential yielding ability. Such low yields most likely have been due to low available phosphorous and insufficient soil nitrogen levels (Table 1). Phosphorous is known to enhance root development (Sanchez, 1976) which in turn improves the capacity of the plant to forage for nutrients. Edje *et al.* (1975) obtained bean grain yield ranging from 2.2 Mg ha⁻¹ at 0 kg N ha⁻¹ to as high as 3.8 Mg ha⁻¹ at 200 kg N ha⁻¹ when results were averaged for two years. Bean grain yield was significantly affected ($P < 0.05$) by conservation measures in the present study. Mean bean grain yield varied between 0.80 and 1.24 Mg ha⁻¹ (Table 10, 11). The *Fanya Juu* treatment registered the highest bean grain yield, followed by Contour bunds while uncontrolled plots had significantly lower ($P < 0.05$) bean grain yield. The Control treatment produced only 64% and 58% of the bean grain yield recorded in the Contour bund and *Fanya Juu* treatments, respectively.

Table 10. Effect of soil conservation measures on mean bean grain and above ground biomass yield

Conservation Measure	Yield in (Mg.ha ⁻¹)			
	Bean	% of Control	Above ground dry matter yield	% of Control
Contour bund	1.24 b	155	3.6 b	171
<i>Fanya Juu</i>	1.37 a	171	4.2 a	200
Unconserved	0.8 c		2.1 c	
LSD (P=0.05)	0.05		0.12	
CV (%)	4.43		3.36	

Means within the column followed by the same letter are not significantly different (P<0.05); n = 9

4.6.2 Above ground biomass

Data above ground biomass yield as affected by conservation measures is presented in Table 10. Conserved plots produced significantly higher above ground biomass than unconserved plots (P<0.05, Table 10, 11). The trend in above ground biomass closely followed that of grain yield, with *Fanya Juu* producing significantly more biomass by two fold than in the control treatment. Contour banded plots out yielded the unconserved plots by 44%.

Table 11. Variation of bean yield as affected by soil conservation measures at the two-agroecological zones

Location/treatments	Yield in Mg ha ⁻¹	
	Bean yield	Above ground biomass
High altitude 1		
Contour bund	1.23 c	3.47 d
<i>Fanya Juu</i>	1.41 a	4.32 a
Unconserved	0.83 e	2.10 e
High altitude 2		
Contour bund	1.28 bc	3.73 c
<i>Fanya Juu</i>	1.33 ab	4.11 b
Unconserved	1.003 d	2.19 e
Medium altitude		
Contour bund	1.21 c	3.48 d
<i>Fanya Juu</i>	1.36 ab	4.03 b
Unconserved	0.56 f	2.03 e
LSD (P<0.05)	0.095	0.28
CV (%)	4.4	3.6

Means within the column followed by the same letter are not significantly different (P<0.05), n=9

4.7 The Impact of Ap Horizon Thickness on Bean Yield

Multiple regression analysis was used to identify soil parameters that had significant effect on bean yield. Bean grain yield was regressed against four soil variables namely: Ap-thickness, total nitrogen, available phosphorous and organic carbon. The result showed that the depth of topsoil (Ap-horizon) and available phosphorous significantly affected bean yield (P=0.01, r²=0.64, Table 12).

Table 12. Multiple regression analysis results at the two agroecological zones

Variable	Regression Coefficient	Standard Error	Student T-Test	Probability
Ap depth (cm)	1.24e-001	2.04e-002	6.08	0.000
Organic carbon (%)	3.69e-002	3.08e-002	0.12	0.905
Total nitrogen (%)	-1.22e+000	2.44e+000	-0.50	0.621
Available phosphorous (mg kg ⁻¹)	2.08e-001	3.78e-002	5.50	0.000

n = 27; R² = 0.643; Intercept = -1.93

A strong linear relationship was observed between topsoil depth (Ap) and bean grain yield across the two agroecological zones ($P < 0.05$, Table 12). The most significant effect of topsoil depth loss (erosion) was observed in the medium altitude zone ($P < 0.01$, $R = 0.86$).

Table 13. Relationship between topsoil depth and bean yield (n=9)

Location	R	P-value	Regression Equation
High altitude 1	0.76	0.017	$Y = -0.630 + 0.079x$
High altitude 2	0.74	0.023	$Y = 0.278 + 0.036x$
Medium altitude	0.86	0.003	$Y = -1.339 + 0.099x$

Where: Y = bean yield in kg/ha, x = top soil depth in cm,

R = coefficient of determination

Total nitrogen, available phosphorous and exchangeable potassium, calcium and magnesium were regressed with yield to find out their impact on yield. Table 13 gives the summary of relationship between soil available phosphorous and bean yield.

A weak relationship between bean grain yield and level of available phosphorous was noted (Table 13). A Slightly strong relationship was observed in medium altitude plots ($R=0.57$). Although soil available phosphorous showed a weak relationship with bean yield, P is thought to be a major limiting element for high bean yield in this soil (Mushi and Edje, 1989).

Table 14. Relationship between soil available phosphorous and bean yield (n=9)

Location	R	P-value	Regression Equation
High altitude	0.23	1.00	$Y=1.036+0.012x$
High altitude	0.42	0.265	$Y=0.445+0.115x$
Medium altitude	0.57	0.110	$Y=-4.254+0.835x$

Where: Y = bean yield in kg ha^{-1} , x = soil available P (mg kg^{-1}),

R = coefficient of determination

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

On the basis of present findings, the following conclusions can be drawn:

1. Soil conservation measures had more pronounced effect on the thickness of the Ap horizon. Bulk density in the Contour bund plots was significantly higher than that in either *Fanya Juu* or unconserved plots.
2. Soil conservation measures tested had no significant impact on the surface (0-20 cm) soil chemical properties such as organic carbon, CEC, exchangeable bases, base saturation, pH, available P, and total nitrogen.
3. *Fanya Juu* and Contour bunds plots conserved more soil moisture than did unconserved ones.
4. There were significant differences in bean yield between conserved and unconserved plots. However, bean yields on contour bunds and *Fanya Juu* plots were not significantly different.

5.2 Recommendations

1. Soil conservation measures should be a pre-requisite for sound and sustainable land use on the slopes of Mt. Meru.

2. Both *Fanya Juu* and Contour bunds are recommended as suitable and effective means of conserving the soil for better crop yields since they perform equally well.

5.3 Future studies

1. Detailed study to investigate the water use efficiency on different soil conservation measures will be very useful if sustainable crop production is achieved.
2. A more detailed research is required to study soil fertility and nutrient uptake efficiency in areas where soil conservation measure have been introduced in the two agroecological zones

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APPENDICES

Appendix 1. Effect of soil conservation measures on surface (0-20 cm) pH, total nitrogen and available phosphorous

Treatment	pH (H ₂ O)	Total nitrogen (%)	Available phosphorous (mg.kg ⁻¹)
Contour bund	5.256	0.3544	8.467
Fanya Juu	5.267	0.3400	7.589
Control	5.289	0.3489	6.656
LSD (P=0.05)	0.1171	0.1804	2.069
CV (%)	1.71	2.38	20.89

Appendix 2.

Effect of soil conservation measures on surface (0-20 cm) exchangeable bases (Ca, Mg, Na, and K), cation exchange capacity (CEC) and base saturation

Treatment	Cmol (+)/kg					(%)
	Ca	Mg	Na	K	CEC	Base Saturation
Contour bund	12.73	3.267	0.8029	2.378	53.33	36.03
Fanya Juu	12.39	3.244	0.7979	2.367	52.91	35.58
Unconserved	12.02	3.356	0.8022	2.367	52.89	35.10
LSD (P=0.05)	1.817	0.2151	0.04139	0.1373	1.856	2.709
CV (%)	6.87	4.98	3.73	4.51	2.67	5.82

Appendix 3. Some soil physical properties in high altitude site 1

Depth (cm)	Organic	Bulk	Total	Sand (%)	Silt (%)	Clay (%)
	Carbon (%)	density (Mgm ⁻³)	Porosity (%)			
0-15	4.2	0.73	72	12.8	60.2	27.0
15-30	3.6	0.78	70	13.9	57.9	28.2
30-45	2.6	0.77	71	10.9	56.4	32.7
45-60	4.8	0.66	75	12.7	67.1	20.2
60-75	3.9	0.65	75	12.2	61.7	26.1
75-90	3.0	0.64	76	13.7	60.3	26.0
90-105	2.1	0.61	77	11.5	62.5	26.0

Appendix 4. Some soil physical properties in high altitude site 2.

Depth (cm)	Organic	Bulk	Total	Sand (%)	Silt (%)	Clay (%)
	Carbon (%)	Density (Mgm ⁻³)	Porosity (%)			
0-15	4.6	0.73	72	10.8	59.6	29.6
15-30	4.1	0.74	72	11.6	60.2	28.2
30-45	4.0	0.76	71	13.1	51.2	35.7
45-60	3.8	0.77	71	14.3	58.3	27.4
60-75	3.6	0.68	74	12.2	57.1	30.7
75-90	3.3	0.64	76	12.6	50.7	36.7
90-105	3.1	0.63	76	11.0	50.2	38.8

Appendix 5. Some soil physical properties in medium altitude

Depth (cm)	Organic	Bulk	Total	Sand (%)	Silt (%)	Clay (%)
	Carbon (%)	density (Mgm ⁻³)	Porosity (%)			
0-15	4.6	0.81	69	13.1	60.3	26.6
15-30	4.3	0.80	70	14.3	60.1	25.6
30-45	4.8	0.71	73	15.2	60.1	24.7
45-60	3.2	0.75	71	11.7	62.3	26.0
60-75	3.0	0.72	72	10.8	59.7	29.5
75-90	2.9	0.67	75	14.1	58.1	27.8
90-105	2.1	0.63	76	11.3	56.1	32.6

Appendix 6 Soil moisture profile (mm) during 1999/2000 cropping season in the high altitude site I (1400 m.asl.)

Depth (Cm)	1		2		3		4		5		6		7										
	Cb	FJ	Ctr	Cb	FJ	Ctr	Cb	FJ	Ctr	Cb	FJ	Ctr	Cb	FJ	Ctr								
0-15	39	39	38	41	41	36	37	42	38	39	41	36	18	20	18	14	15	10	9	11	8		
15-30	30	30	33	33	39	33	36	39	35	36	37	33	20	23	17	15	18	12	9	9	12	8	
30-45	25	26	25	34	38	33	35	38	34	35	34	34	22	19	19	17	22	17	13	13	11	11	
45-60	22	23	22	36	31	34	37	39	35	48	36	34	23	30	22	20	25	18	22	21	13	13	
60-75	51	44	34	51	45	31	34	34	31	34	31	29	23	21	22	19	22	19	24	26	16	16	
75-90	41	40	31	42	41	29	28	31	25	21	27	26	21	26	18	18	14	16	24	26	19	19	
Total	209	203	182	236	234	196	208	223	198	213	206	191	127	138	117	101	115	92	100	109	75	75	75

Cb=Contour bund, FJ=Fanya Juu, Depth interval in cm

Appendix 7. Soil moisture profile (mm)during 1999/2000 cropping season in the high altitude site 2 (1400 m.asl.)

Sampling time in weeks after planting

Depth	1		2		3		4		5		6		7							
	Cb	FJ	Ctr	Cb	FJ	Ctr	Cb	FJ	Ctr	Cb	FJ	Ctr	Cb	FJ	Ctr					
0-15	40	41	38	39	40	35	33	36	39	32	25	28	23	20	29	16	10	11	07	
15-30	37	38	36	33	38	33	34	33	35	32	26	29	26	20	18	17	10	10	09	
30-45	33	34	33	30	35	32	32	30	34	30	28	23	23	21	18	18	12	12	10	
45-60	40	33	30	32	33	30	32	30	32	31	30	32	24	24	22	20	22	14	14	
60-75	44	32	29	29	31	28	30	28	30	31	32	36	30	24	22	21	26	24	24	
75-90	38	26	21	22	24	21	18	21	22	22	28	31	28	23	21	18	23	24	24	
Total	231	205	187	185	201	179	179	177	191	178	169	179	154	133	130	109	102	95	88	70

Cb=Contour bund, FJ=Fanya Jua, Ctr=Unconserved plot, Depth interval in cm

Appendix 8 Soil moisture profile (mm) during 1999/2000 cropping season in the medium altitude 1400 m.asl.

Time in weeks after planting	1		2		3		4		5		6		7						
	Cb	FJ	Cb	FJ	Cb	FJ	Cb	FJ	Cb	FJ	Cb	FJ	Cb	FJ					
0-15	45	42	44	44	44	44	37	41	43	33	34	37	29	30	26	23	10	11	9
15-30	40	38	37	37	37	39	30	33	38	27	33	27	23	28	31	21	10	13	9
30-45	39	36	33	33	32	37	27	32	36	22	33	33	29	28	24	21	14	14	8
45-60	40	37	34	32	32	41	25	32	37	22	36	39	30	31	31	22	28	22	20
60-75	36	34	29	29	29	39	24	30	35	19	39	42	34	34	35	24	32	24	18
75-90	29	25	23	23	23	31	19	18	26	17	34	35	29	31	28	17	27	23	19
Total	229	215	197	187	188	228	162	186	214	140	208	214	173	181	176	127	120	106	81

Cb=Contour bund, FJ=Fanya Juu, Ct=Unconserved plot, Depth interval in cm