SOIL PRODUCTIVITY EVALUATION UNDER DIFFERENT SOIL CONSERVATION MEASURES IN THE HARERGE HIGHLANDS OF ETHIOPIA

BY

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DECLARATION

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

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DEDICATION

This thesis is dedicated to my mother, Ayehu Kassegn; late father, Bedadi Woreka; brother, sisters, relatives and friends (especially, Lomita Bekurshe) all of who have contributed in various aspects to the success in my education.

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ACRONYMS

AAR	Africa Air Rescue
ANOVA	Analysis of variance
ASAE	American Society of agricultural Engineers
Avail.	Available
Cf.	Copied from
CFSCDD	Community Forests and Soil Conservation Developement Department
df	Degree of freedom
EC.	Electrical conductivity
EHRS	Ethiopian Highlands Reclamation Project
EP1	Control plot
EP2	Level bund
EP3	level fanya juu
EP4	Graded bund
EP5	Graded fanya juu
EP6	Grass strips
EPS	Experimental Plots
FAO	Food and Agriculture Organizations
Fcal	Calculated F value
Ftab	Tabulated F value(sometimes F critical)
FURP	Fertilizer Use Recommendations Project
K	Potassium
LSD	Least Significant Difference
LUPRD	Land Use Planning and Resourse Developement
m.a.s.l.	Metres above sea level
MOA	Ministry Of Agriculture
MS	mean sum of squares
NSSP	National Soil Service Project
O.C	Organic carbon
P	Phosphorous

ppm	Parts per million
SAREC	Swidish Agency for Research Cooperation
SCRP	Soil Conservation Research Program
sov	Source of variation
SS	Sum of Squares
SWMP	Soil and Water Management Program
T.N	Total nitrogen
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organizations
USDA	United States Department of Agriculture

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ABSTRACT

This study aimed at evaluating the different soil conservation measures namely, level and graded bunds, level and graded fanya juus and grass strips in soil conservation, nutrient retention and crop yields in the Hararge highlands of Ethiopia. The experiment was conducted on 6 m by 30 m soil conservation experimental plots. Runoff, soil loss and crop yield data which had been collected since the establishment of the soil conservation measures in 1986 and which had not been analysed were used in this study. In addition, soil samples were collected in 1997 in order to evaluate changes in soil properties since the establishment of the trials.

The soil conservation measures showed varied performance in controlling soil loss, retention of different soil properties and crop yields. Level bund and level fanya juu were significantly different (ANOVA; p=0.05) from the control in controlling runoff and soil loss. On the average, highest values of % clay (56 %), available phosphorous (P) (11.79 ppm), and available potassium (K) (86.48 ppm) were recorded from level fanya juu, grass strips and level bund respectively and that of total nitrogen (TN) (0.212 %) and organic carbon (OC) (1.54 %) from graded fanya juu. All soil properties tested except % clay were found to be lower at the upper positions of all the structural measures tested with an increasing trend down the terrace positions. In particular, total nitrogen, organic carbon and available phosphorous were significantly higher (ANOVA; p=0.05) in the lower positions when compared with the middle and upper positions of the interstructural spaces.

An average increase of 0.28 % and 0.16 % in OC and TN respectively was observed in 1997 as compared to the initial nutrient content determined at the site in 1983. Available K, % TN, % clay, grain and biomass yield are negatively correlated with soil loss with correlation coefficients (r) of -0.9, -0.4, -0.9, -0.4 and -0.6 respectively. Level bund, level fanya juu, graded bund, graded fanya juu and grass strips reduced soil loss by 99.5 %, 100 %, 67 %, 54 % and 60 % respectively as compared to the control plot. Grain yield was increased by 12.3 %, 4.2 %, 14.9 %, and 6.5 % on level bund, level fanya juu, graded bund and graded fanya juu respectively as compared to the control plot.

Level fanya juu, grass strips and graded bund ranked highest in soil loss reduction, nutrient retention and grain yield increase respectively. In general, all techniques tested at the research site reduced soil loss and all of them except the grass strip and graded bund increased grain yield and nutrient retention respectively as compared to the control plot. Level bund showed a relatively better overall performance than other techniques tested in the area in terms of all parameters considered i.e. soil conservation, nutrient retention and crop yield.

1. INTRODUCTION

1.1. Background information

Agriculture is the main economic sector generating income for the majority of the population and contributing substantially to Ethiopia's economy. Moreover, industrial raw materials for processing of consumer goods both for domestic market and export purposes are mainly provided by this sector. However, the country is characterized by low level of agricultural production. Some of the major reasons for the low productivity of this sector in Ethiopia include: eroded and truncated farmlands, lack of proper soil and water conservation practices, poor cultural practices of farming, lack of proper dissemination of research results, erratic distribution of rainfall and frequency of prolonged drought which makes rainfed agriculture a risky enterprise, lack of proper land use, shortage of skilled manpower for the effective management and use of natural resources and the poor economic condition of the country which has resulted from the combination of the effects of the above factors (Soil Conservation Research Programme, SCRP, 1996).

According to the 1984 census, the highlands of Ethiopia (altitude above 1500 m.a.s.l.) constitute 44% of the country and cater for 88% of the population at an average density of 64 persons per square kilometer.. Ninety five percent of the cropped area and two-third of the country's livestock occur in the highlands (SCRP, 1996).

1.2. Problem statement: Extent and severity of soil erosion

1.2.1 Global concern.

It is widely recognized that accelerated erosion is a serious global problem. The difficulty lies in precisely and reliably assessing the dimensions like- the extent, magnitude, and the rate of soil erosion and its economic and environmental consequences (Lal, 1988). The current rate of agricultural land degradation world wide by soil erosion and other factors is leading to an irreversible loss in productivity on about six million hectares of fertile land a year (Dudal, 1981; Lal, 1988). Kovda (1983) indicated that erosion has destroyed about 430 million ha of productive land since the beginning of agriculture. Buringh (1981) also estimated that the annual global soil loss of agricultural lands is about 3 million hectares due to soil erosion.

1.2.2. Extent and severity of soil erosion in Ethiopia

Most of the terrain within the highlands of Ethiopia have slopes of more than 16%. Twenty one percent of the highlands are seriously eroded. Four percent of the total highlands are so seriously eroded that they will not be economically productive in the future (Kruger, et al., 1995). Only 20% of the highlands is free from erosion hazard. Most of the productive topsoil in the highlands has been degraded, resulting in chronic food shortage and persistent poverty levels.

According to an estimation by the SCRP, about 1.5 billion tones of soil are eroded every year from the Ethiopian highlands (Hurni, 1984; Kruger, 1995). Past and present traditional practices have reduced the natural protection afforded by vegetation cover and as a result the land is being subjected to severe soil erosion (Barber, 1983; Hurni, 1984). This is mainly due to the increase in population pressure and ever rising demand for food forcing the rural community to cultivate more erosion prone lands.

1.3. Significance of the study

Soil erosion is considered to be a serious threat to food production over much of Ethiopia. However, its short and long term effect on crop production and soil fertility has not been fully investigated. Moreover, the establishment and maintenance of soil conservation measures is very expensive and hence requires an identification and characterization of an appropriate soil conservation measures for a given area based on the agro-ecological factors as well as the expected benefits.

The benefit gained from soil conservation may be lower than the expected or even discouraging especially when an appropriate soil conservation measure.and the purpose for which it is intended fails to suit the conditions of a given site. Therefore, an urgent need exists to assess the effects of erosion on soil productivity and the importance of soil conservation measures in maintaining soil fertility thereby reducing the rate of decline of productivity due to erosion.

Since the ultimate goal of soil conservation is to protect land against erosion and maintain soil productivity, crop yield was considered in this study as a major parameter for evaluation of different soil conservation measures. Although yield is affected by many soil physical and chemical properties and other agro-climatic variables, an attempt was made to determine nutrient retention by the soil conservation measures and the corresponding crop yield, other factors being kept constant.

1.4. Objectives

The overall objective of this study is to produce tangible information which will assist concerned bodies (e.g. land use planners, extension agents, farmers, etc.) in identifying appropriate soil conservation measures that minimize nutrient loss and optimize yield through maintenance of soil productivity at a reasonable cost for a given agroecological zone.

The study therefore aims at addressing the following specific objectives.

1. To compare the effectiveness of the different soil conservation measures in nutrient retention and soil loss reduction and determine how these affect crop grain yield.
2. To assess soil fertility variability within the inter-structural spaces of the different soil conservation measures
3. To determine the yield variation between the different soil conservation measures

2. LITERATURE REVIEW

2.1. Principles of soil conservation

Soil erosion by water occurs simultaneously in two steps: The detachment, which is principally caused by falling rain drops; and the transport of the detached particles. Therefore, soil erosion can be minimized by preventing the detachment and the transport of soil particles . A cover of vegetation and soil granulation helps to prevent the detachment of soil particles. The transportation of soil particles can be effectively minimized by mechanical structures to control the effect of runoff (Tripathi and Singh, 1993).

2.2. Types of soil conservation measures

Soil conservation measures can be classified into mechanical and biological. Mechanical soil conservation measures involve earth moving and soil shaping whereas the biological measures include all practices which influence and reduce erosion by the management of growing crops and animals. These two types of control measures are not alternative but are complementary and can be used together although each serving a separate purpose (Hudson, 1981). Mechanical soil conservation measures are expensive and time consuming. Therefore, they deserve careful thought and planning. Firstly because mechanical works are expensive and secondly man made earthworks are generally subject to constant wear and tear and their effectiveness would be short lived unless they are adequately repaired and maintained (Tripath and

Singh, 1993). They are also dangerous because they collect and concentrate runoff to few points resulting in the formation of small gullies and worsening the extent of soil loss which may even be severe if not managed properly.

Therefore, only high valued arable land would justify these costly mechanical measures. Mechanical measures however play a very vital role in controlling and preventing soil erosion on agricultural lands. They are adapted to supplement the agricultural practices (biological measures). These mechanical measures include: diversions, terraces (bunding), basins, waterways, etc. The naming of various kinds of earthworks and structures used to control erosion is complicated because in some cases the structure is called by different names in different countries, in other cases the same name is applied to different structures (Hudson, 1981).

Most soil conservation techniques result in the formation of terraces. Terraces are surface drains or channels constructed across the slope of rolling land and designed to conduct the water from the field in such a way that erosion is kept under control (Foster, 1965). They breakup the long slope into a series of short ones, each terrace controlling and collecting the excess water from a definite area of the slope above it. The water collected in the terrace channel may either be carried to protected areas where it will not cause damage or, if the soil is very absorptive, the terraces are built level and the water allowed to stand and soak in the ground. Terraces are needed on cropped land that have slopes as much as 2% and where the slope is longer than 90 -120 m. again depending on local conditions (Foster ,1965). Terraces can develop from bunds, fanya juus, and grass strips through time.

2.2.1. Level bund

A level bund is an embankment along the contour made of soil and/ or stones, with a basin at its upper side (Hurni, 1986). They are meant to retain all runoff and sediment between two bunds. The bunds reduce or stop the velocity of overland flow and consequently soil erosion. The soil which is eroded between the two bunds is deposited in the basin behind the lower bund. The dimensions of the ditches and the bunds are determined by the maximum volume of sediment and runoff that should be retained in the basin behind the bunds. The procedures recommended in fixing the dimensions of these structures and the spacing between the bunds are presented in the progress reports of the SCRP(SCRP 1984; Belay, 1992). According to Hurni (1986), the areas of applicability of level bunds in Ethiopia include: Moist Wurch, Moist Dega, Moist and Dry Weyna Dega and all Kolla agroclimatic zones (see Appendix 8 for description of the agro-climatic zones of Ethiopia) with slope ranges of 3-50% and soil depth of more than 50 cm. The height of level bunds could be about 50-75 cm with a width of 100-150 cm (Hurni, 1986). The vertical interval between two bunds could be about 1 m for slope gradients of less than 15% and two and half times the depth of re-workable soil for steeper slopes.

2.2.2. Graded bund

A graded bund is similar to a level bund except that the graded bund is slightly graded sideways, with a gradient of up to 1% towards a waterway or river to facilitate drainage of the surplus runoff if the retention of the bund is not sufficient. Most of the soil eroded between two bunds is deposited while some will be drained sideways during heavy storms and lost from the land. However, graded bunds are more effective in wet areas (annual rainfall >1400mm) as well as in moist areas(annual rainfall ranging from 900-1400mm) with clay soils (Hurni, 1986). The typical cross sections of graded bunds are similar to that of level bunds. The areas of applicability of this structure include: all Wurch (dry and wet), all Dega (wet and moist), wet and moist Weyna Dega and moist Kolla agro-climatic zones (Appendix 8) with slope ranges of 3-50% .(having clay soils in moist zones and all soils in wet areas).

2.2.3. Level fanya juu

A level "fanya juu" ("Throw uphill" in Swahili language) is an embankment along the contour made of soil and /or stones with a basin at its lower side (Hurni, 1986). It reduces or stops overland flow and consequently soil erosion. During the construction of a fanya juu, the soil is moved up slope and the water retention basin is situated at the lower side of the wall. The vertical interval specification of the level fanya juu is the same as that of level bund. The height of the fanya juu is about 50-75 cm and the ditch is about 50 cm deep. The space between the ditch and the berm is at least 25 cm. The width of the ditch depends on the fertility of soil. If the subsoil is fertile, it may be very wide and crops can be planted in the ditch. The areas of applicability of this structure is similar to that of the level bund in Ethiopia (Hurni, 1986)

2.2.4. Graded fanya juu

A graded fanya juu is similar to a level fanya juu except that a graded fanya juu is slightly graded side ways towards a water way, with a gradient of up to 1% to allow the surplus runoff to be drained if the retention of the fanya juu is not sufficient. Graded fanya juus retain small amounts of runoff above their wall and they drain excess runoff of heavy storms through the ditch below. The management of graded fanya juus is more difficult: careful design, supervision and maintenance are required in applying them. The vertical interval specification and typical cross section described under level fanya juu is also applicable for graded fanya juu (Hurni, 1986). Despite the difficulty in design and maintenance, graded fanya juus are effective in conservation and they do support development of bench terrace very well (Hurni, 1986). Dega, wet and moist Weyna Dega, and moist Kolla having slope ranges of 3-50% with all deep soils; in wet and deep clay soils and in moist agro-climatic zones are suggested to be areas of applicability of this structure.

2.2.5. Grass strips

A grass strip is a ribbon like band of grass laid out on cultivated land along the contour. They are mainly used to replace physical structures on soil with good infiltration (sandy or silty) on gentle slopes (Hurni, 1986). The use of narrow grass strips is developed simply from unploughed strips of land, trash lines, seeding or planting (Fisseha and Thomas, 1989). Although use of narrow grass strips was reported as early as the nineteen thirties, (Maher, 1938; 1939), they were not officially and widely recognized in contrast to the other soil conservation measures like terraces. However there seems to have been a return to their use in recent years (Kimutai, 1979; Wenner, 1980; Fisseha and Thomas, 1989). Recent surveys in some districts of Kenya show that Kenyan farmers tend to accept narrow grass strips as conservation support practices more readily than terraces (Tefera, 1983; Kimutai, 1979; Veirtmann, 1980). This could be due to the fact that grass strips are relatively cheaper to install than terraces. A simple fanya juu terrace at Kabete, Kenya, was estimated to cost about Kenyan shillings 10 per meter to construct (Fisseha and Thomas, 1989). Besides, structural methods require a considerable amount of labour which is not always available..

Grass strips spread the flow of runoff thus reducing the velocity and causing the sediment to be deposited around and between plants (Fisseha and Thomas, 1989). Deposition is mainly due to mechanical obstruction which retards the flow velocity, causing most of the heavier aggregates to be trapped or to settle, but it is also due to adsorption of negatively charged clay particles to positively charged dead plant parts (Wilson, 1967). A number of soil hydraulic, topographic and grass factors affect sediment deposition. The hydraulic factors include depth of runoff and flow rate (Tollner, et al ,1976) while the soil factors include particle size of eroded sediment, sediment load (Tollner et al, 1976), and infiltration rate within the grass strips (Foster, 1982). Spacing between grass strips, strip width (Tollner et al, 1976) and density of grass elements (Hayes, et al, 1979) are among the major grass factors affecting sediment deposition.

It has been found that grass strips have a similar effect to that of graded terraces with 0.25% channel slope (Foster and Ferreira, 1981). Deposition of sediments in terraces mostly occurs in the terrace channels which retain about 80% of the soil moved (Wischmeier and Smith, 1978). The fact that structural soil conservation measures are costly to construct and require a trained man power makes the use of grass strips become very important in developing countries like Ethiopia because they are relatively simple and cheap to install.

Some requirements in selecting grass types for soil conservation according to Wilson (1967) include : deep root systems to resist scouring of swift current, dense well ramified top growth to trap sediments and to have yield economic return.

2.3. Effect of soil erosion

2.3.1. Soil chemical properties

Erosion reduces the fertility status of soils. The cause of loss in productivity has been demonstrated conclusively in many cases where fertilizer application at least partially restores yields on eroded soils. For example, Engelstand and Shrader (1961) found that N application allowed a topsoil and subsoil to yield similar amount of maize. Where no N was added, the exposed subsoil yielded approximately 3136 kg/ha less than the corresponding unaltered surface.

Progressive soil erosion increases the magnitude of soil related constraints to production. The constraints can be physical, chemical, or biological. Soil chemical constraints and nutritional disorders related to erosion include: low CEC, deficiency of plant nutrients (N, P, K,) and trace elements (Zn, S), nutrient toxicity (Al, Mn) and high soil acidity (Lal, 1988). Eck et al, (1967) reported that most land forming studies have shown that deficiencies of N, P and K were principally responsible for reduced yields from subsoil. Stocking (1984) has reviewed research on nutrient losses as related to erosion. Nutrient loss is one of the factors which causes productivity decline when erosion occurs. Nutrient loss by erosion is dependent upon the soil management practices. Soil erosion results both in loss of nutrients and degradation of soil physical properties. Massey et al,(1953) reported an average loss of 192 kg of organic matter, 10.6 kg of N and 1.8 kg of exchangeable K per ha in a Winsconsin soils on 11% slope. One of the major nutrients lost in the eroded sediments is applied Phosphorous (Lal, 1975). Andrew and Smith (1990) reported that the mean annual loss of total P in runoff from P fertilized watersheds is equivalent to an average of 15 %, 12 %, and 32 % of the annual fertilizer P applied to wheat, mixed crop and grass, and peanut - sorghum rotation practices respectively. Extensive loss of N in eroded sediments has also been reported by various workers (Massey et al ,1953, Lal, 1975).

2.3.2. Soil physical properties

Among the important soil physical constraints to production aggravated by erosion include: reduced rooting depth, loss of soil water storage capacity (Kilewe, 1988; Schertz et al., 1984; Office of Technology Assessment, 1982; National Soil Erosion - Soil Productivity Research

Planning Committee, 1981), crusting and soil compaction and hardening of plinthite (Lal, 1988). Erosion also changes soil surface colour and albedo. Moreover, erosion preferencially removes fine particles (ie clay and colloidal particles). This loss of clay particles influences soil tilth and consistency. Exposed subsoil is often of massive structure and harder consistency than the aggregated surface soil (Lal, 1988; USDA, 1981).

Development of rills and gullies may change micro-relief and render mechanized farm operations difficult. Another physical effect of erosion concerns the management and timing of farm operations. Achieving a desired seed bed with friable tilth necessitates a delay in ploughing until the soil is adequately watered (Lal, 1988).

2.3.3. Soil productivity

Quantifying the effects of soil erosion on crop yields is a complex task because it involves the assessment of a series of interactions among soil properties, crop characteristics, and the prevailing climate. The effects are also cumulative and often not observed until long after accelerated erosion begins (Lal, 1988). Furthermore, the magnitudes of erosion's effect on crop yields depends upon soil profile characteristics and management systems. Crop yield, an integrated response to many parameters is difficult to relate under field conditions to any individual factor. It is, therefore, difficult to establish a one-to-one, cause and effect relationship between rates of soil erosion and erosion induced soil degradation on the one hand and crop yield on the other (Lal, 1988).

However, information on erosion-productivity relationship is essential for future planning and for developing an effective land use policy. National, Soil Erosion Research Planning Committee, (1981), also indicated that accurate estimates of future soil productivity are important needs when planning for agricultural policy. The accuracy of such estimates greatly depends upon knowledge of the relationship between soil productivity and long term soil loss by erosion (Timilin, et al, 1986).

Soil erosion can reduce crop yields through loss of nutrients, structural degradation and reduction of soil depth and water holding capacity (Timilin, et al, 1986; Lal, 1988). In addition to reduced grain yield, erosion also increases crop production costs (Lal, 1988). Improved technology often masks the effect of lost fertility and water storage capacity making the effects difficult to quantify (Schertz, et al 1984, Lal, 1988).

Generally, fertility and soil structure can be restored through management practices that include addition of plant nutrients and crop rotation. However restoration of water holding capacities and soil depth is not economically feasible. In a rain-fed agronomic systems, yield reduction due to changes in these characteristics can be permanent (Frye, et al, 1982)

Loss of production in eroded soil further degrades its productivity, which in turn accelerates soil erosion. The cumulative effect observed over a long period of time may lead to irreversible loss of productivity in shallow soils with hardened plinthite or in soils that respond only to expensive management and to additional inputs (Lal, 1988).

The National Soil Erosion - Soil Productivity Research Planning Committee, (1981), presented a thorough review of erosion and soil productivity problems, past and current research, and research approaches to define the relationship between erosion and soil productivity. Numerous researchers are quoted who have found that when top soils are removed, yields are reduced 20-75% compared to control plots. In addition, they note that erosion reduces crop yields slowly and may escape detection until crop production is not economical.

2.4. Effect of soil conservation measures

2.4.1.Terrace development

Physical as well as biological soil conservation measures greatly facilitate the formation of bench terraces. They reduce erosion by cutting the gradients and breaking the otherwise long and steep slopes. Grass strips were able to form terraces over a period of five years in Kabete which would be best described as bench terraces with slight forward slope (Orina, 1996). Bench terraces allow greater and uniform infiltration of rain water and thereby minimize the generation and build up of runoff to erosive levels. Thus the structures that allow faster development of terraces are highly valued in any soil conservation effort. Belay (1992) observed that the greater the bank height (i.e. the height of the structures along the riser slope) the better the terrace development. He also pointed out that the bank height is increased tremendously and the structural slope reduced considerably from the very beginning of the construction of fanya juu bunds.

2.4.2. Soil productivity

Soil conservation measures generally promote increased crop yield by reducing water, soil and fertility losses. For the whole of Ethiopian highlands, Aggrey-Mensah (1984) assumed crop yield increases of 5% for the first five years and 10% for the years thereafter as a result of construction of soil conservation measures. This assumption, however, is contemptible because it appears to suggest that a continuous increase in yield is possible following the construction of soil conservation structures. But this is not always true because one has to expect a reduction in crop yield for the first few years due to the farm land taken by the conservation structures and the disturbance of the most fertile topsoil during the construction of the mechanical soil conservation measures. Again, it is impossible to assume a simple average figure for the whole of the Ethiopian highlands. Because of the wide variations in topographical, pedological and climatic conditions in the highlands, yield increases that may result from soil fertility and moisture conservation may vary greatly.

Hurni (1989) points out that in the steep slopes of Jinbar valley in the Simen Mountains, a yield increase of up to 50% can be obtained following construction of bunds and terracing. He argues that this increase is possible not only because of reduced runoff and soil losses but also because of the effective protection of seeds from being washed away by the powerful runoff that could be generated on the steep slopes. Furthermore, yield increase cannot be uniform over the whole field because of the variable increases of erosion and deposition on soil moisture, fertility and productivity within the interstructural space (the cultivated area between the structures). Generally, the soils above the bunds receive more moisture and fertile soil materials and are more productive than the other segments of the interstructural positions of the slope. Moreover, yield is expected to show greater increment in 15 or 20 years because both soil fertility and top soil depth (which improve the rooting depth and moisture retention capacity) improve in time (Belay, 1992).

Alemayehu (1989) reported that the soil loss, which was estimated to vary between 27 and 94 tons/ha/ year before implementing any conservation measure, can be reduced to 14.5 t/ha/year for the maximum 85 m terrace intervals, whereas on terraces with 40 m spacing, it can be reduced to 10 t/ha/year/. Kohnke and Bertrand (1959) also reported that terracing reduces erosion on cultivated lands to one-fifth or even one-tenth of what it would be if no control measures were used.

3. MATERIALS AND METHODS

3.1. Description of the study area

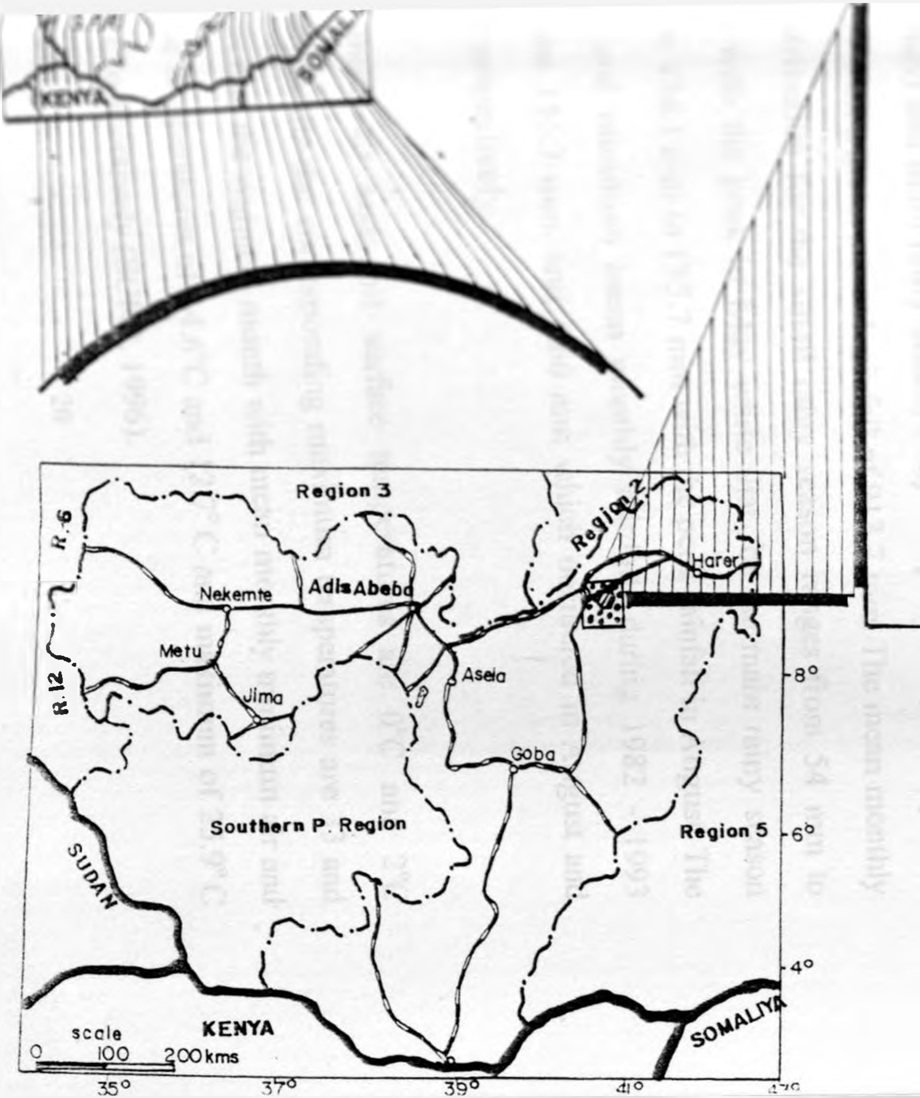
3.1.1. Location and Topography

Hunde Lafto research station is one of the six research stations established by the SCRP in Ethiopia and Eriteria. It is located in the West Harerge zone at about 350 km east of Addis Ababa and 20 km NE of Asebe Teferi, the capital city of West Harerge. The research station is part of the Agucho catchment which forms part of the Awash river basin. The catchment has an area of 234 ha and lies between 9°05` to 9°08` north and 40°57' to 41°01' east with altitude ranging from 1965 - 2320 m.a.s.l (see Fig. 1)

The topography of the research station is hilly and mountainous with moderately steep (10-15%), steep (15-40%) and very steep (40% and above) slopes which are either convex, concave or linear. Striking elements of the landscape include V-shaped valleys and gullies, partly flatter terraces and alluvial fans with gully formation; ridges and hills which form the north-western, the northern and the north-eastern limits of the catchment (SCRP, 1996; Bono and Seiler, 1983).

3.1.2. Geology and Soils

Lithologically, the research unit consists of granite and gneiss which are covered by deposits of Mesozoic sedimentary rocks (limestone and sandstone), (Geological Survey of Ethiopia, 1973; Mohr, 1971).


KENYA
Region 3
R.6
Adis Abeba
Nekemte
Metu
Jima
R.12
Region 2
Harer
Asela
Goba
Southern P. Region
Region 5
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scale
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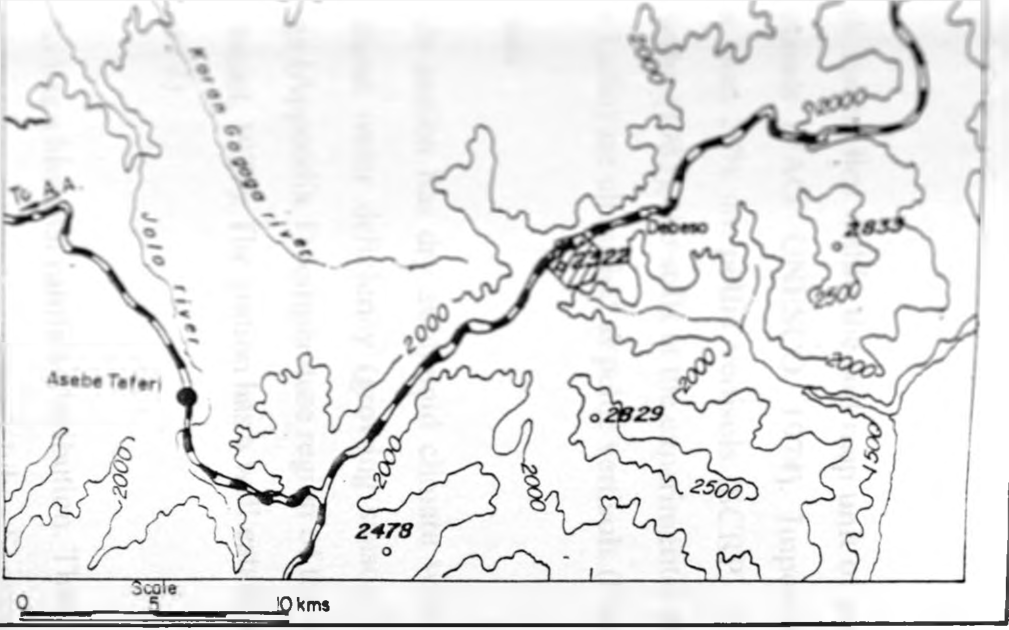


LEGEND

- International boundary
- Region boundary
- All weather road
- River
- Project area
- SCRP station (Hunde Lafto)
- ~2000~ Contour line 500m. V.I.
- o 2829 Spot height

The research station lies within the soil map unit of eutric cambisols and chromic luvisols (FAO/ UNESCO, 1974). Important inclusions that occupy less than 20% are pellic vertisols (SCRP, 1996). According to Bono and Seiler (1983), the soils at the experimental plots of the research site (Hunde Lafto) are classified as pellic vertisols (Plate 1).

3.1.3. Climate

The research station has dry subhumid climate with approximately 4-6 months without water deficiency (growing season). It falls within the Weyna Dega (Appendix 1) temperature region of the eastern highlands of Ethiopia (Daniel, 1977). The station has a well established meteorological station (Plate 2)

Hunde Lafto has a bimodal rainfall distribution. That is, small rainy seaon (March - May) and main rainy season (July - September) (see Appendix 2.1 and 2.2) with a mean annual rainfall of 913.7 mm. The mean monthly rainfall distribution for the small rainy season ranges from 54 mm to 126.7 mm with the peak in May while that for the main rainy season ranges from 134.1 mm to 155.7 mm with the peak rainfall in August. The maximum and minimum mean monthly rainfalls during 1982 - 1993 periods were 155.7 mm. and 5.60 mm which occurered in August and September respectively.

The minimum air and soil surface temperatures are 0^oC and 2^oC respectively while the corresponding maximum temperatures are 33 and 39^o C. March is the warmest month with mean monthly minimum air and soil surface temperatures of 14.6^oC and 12.7^o C and maximum of 25.9^o C and 31.9^o C respectively (SCRP, 1996).

Plate 1. A road cut soil profile about hundred meters from the experimental plots

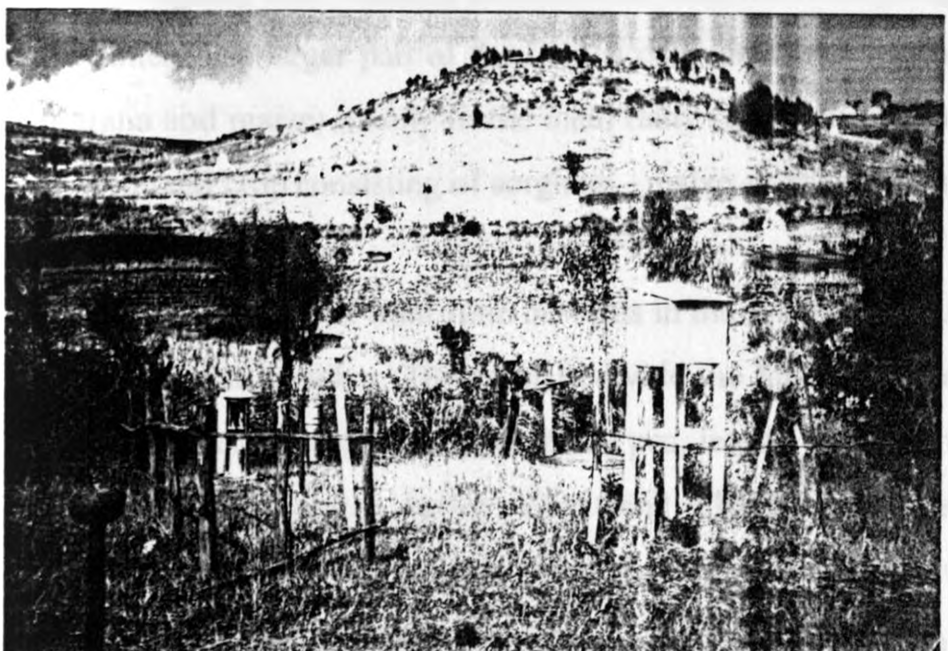


Plate 2. Meteorological station of the research station

3.1.4. Agriculture and land use

Agriculture is the main economic sector for the Oromos who inhabit the area. The farmers divide the agricultural year into four seasons:

Season	Period	Description
Bega	Dec. - Feb.	Dry season
Belg	March - May	small rainy season
Kremt	June - August	main rainy season
Tseday	Sept.- Nov.	end of rainy season

Land preparation begins after the harvest of sorghum in .Dec./Jan. (i.e. Bega). Before sowing, the land is initially dug with the help of digging tools (Dongora) after which it is cultivated with the oxen-plough two to three times. The larger part of the field is cultivated with the main crops (sorghum and maize) mainly in the main rainy season. It is customary to grow a mixed crop consisting of sorghum - maize - haricot beans.

Haricot beans are sown from June onwards in the mixed crop culture and are harvested in October. The farmers divide the land into small pieces and grow different crops like horse bean, pea, lentils, barley, linseed and tef. Harvesting of maize, barley, wheat and different pulses is done in November while that of sorghum (the most important crop grown in the area for subsistence followed by maize, haricot bean, barley, emmer wheat, peas, sweet potatoes and others like tef, lentil, linseed and horse beans) takes place in late December - January (Kuno, 1985). The summary of sowing and harvesting period for the most commonly grown crops in the area are given below:

Crop type	Land preparation	Sowing period	Harvesting period
Sorghum	Jan.-Feb.	Mar.-May	Dec.-Jan.
Maize	jan.-Feb.	Mar.-June	Nov.-Dec.
Haricot bean	Apr.-May	June-Aug.	October

The natural vegetation has almost disappeared and the only testimonies of the former forest are remnants like *Podocarpus, Juniperous* and *Acacia* (Speck, 1982). Few reafforestations especially with eucalyptus, have been carried out. Steep slopes and areas with shallow soils are covered by grassland, bushland or wood land. Most of the catchment is used as arable land and pasture (Bono and Seiler, 1983).

3.2. Data acquisition

The data used in this thesis have been acquired mainly from two sources:

(a). *Primary data*: Refers to the data collected by the author specifically the nutrient status of the soils at the experimental plots of the Hunde Lafto research site during the research work (1997).

(b). *Secondary data*: This refers to the data collected by the SCRP of Ethiopia since the establishment of the research site (1982) but which has not been analysed so far. The secondary data includes: runoff and soil loss, grain and biomass yield, and initial physical and chemical properties of soils at the research site .

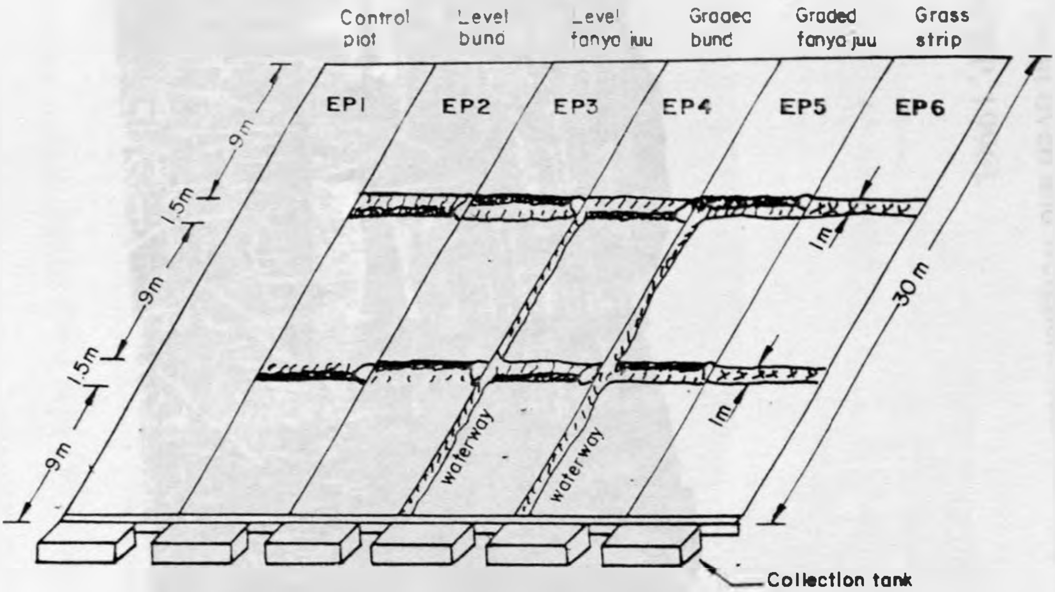
3.3. Experimental setup and data collection by SCRP

The conservation experiment is being conducted on 6 m x 30 m plots which is the standard size of conservation experimental plot in the SCRP, Ethiopia (SCRP, 1996). The field is considered to be homogenous in terms of slope, previous erosion, soil type and top soil depth. A total of six plots have been considered; of which five are treated with different soil conservation measures and one is left as a control plot (fig. 2). The types of conservation treatments being tested on separate plots are bunds (level and graded), fanya juus (level and graded) and grass strips. The same type of crop has been grown for a given cropping season in all the conservation measures.

3.3.1. Runoff and soil loss data collection

Individual storm or storm period data on runoff and soil loss from different soil conservation measures tested on plots of 180 m^2 (6 x 30 m.) each were assessed. Corrugated iron borders were installed to separate adjacent experimental plots (Plate 3). They were inserted 10 cm in the ground and erected 20 cm above the ground to enable the runoff to be collected in the tank through the inlet tube. Runoff and sediments were collected in two tanks of 250 litres capacity each (Plate 4). The first tank took most of the sediment from the plot. The second tank took 1/10 of the overflow from the first tank through a slot diviser. The volume of runoff water was measured directly from the sedimentation tanks.

Fig. 2 Layout of on farm soil conservation experiment



Representative runoff and soil loss samples were taken for laboratory analyses. For soil losses, 500g of soil and 1 litre of suspended sediment were sampled from the sedimentation tank and the overflow tank when necessary. After each sampling, the collection tanks were emptied and cleaned for subsequent storms. In the station, the 1 litre sample taken for sediment assessment was filtered and dried. The 500g sample taken from each plot was also dried in an oven and weighed. Soil loss was calculated on a per hectare basis (SCRP, 1996).

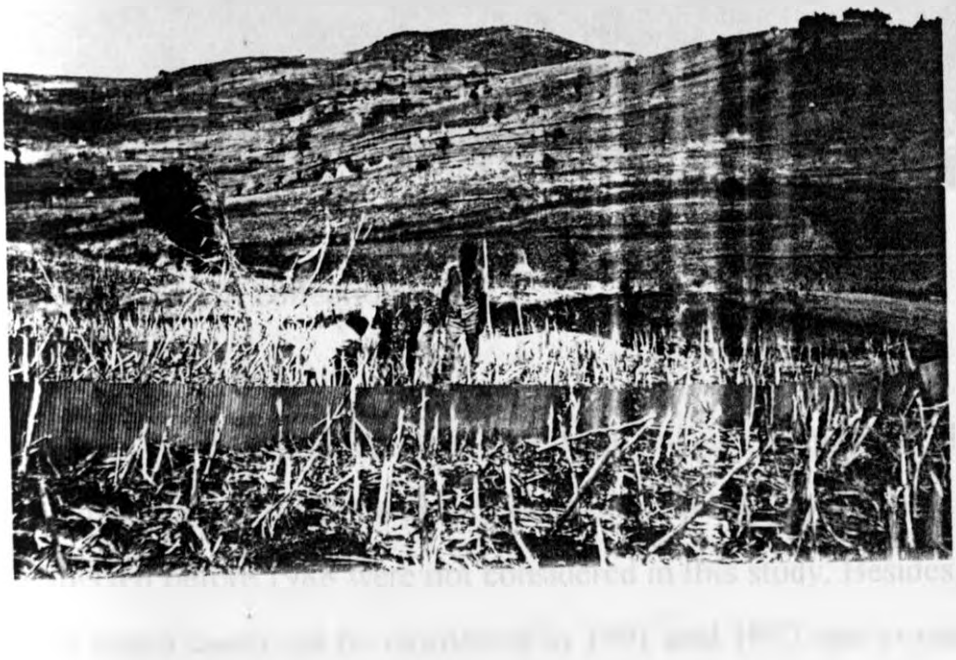


Plate 3. Corrugated iron sheets used for bordering the adjacent experimental plots

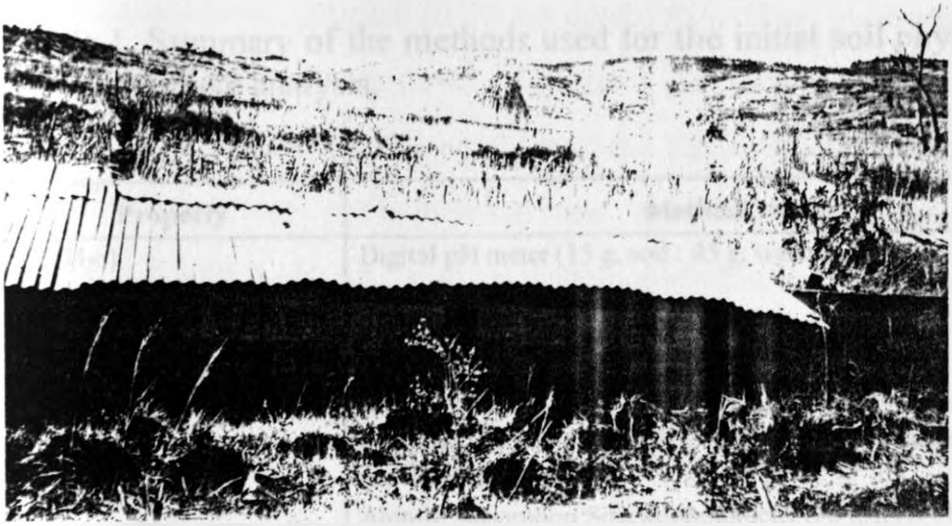


Plate 4. Runoff collection tanks

The data collected before and after 1988 are not comparable due to the reconstruction of the experimental plots in 1988. Hence, the data collected before 1988 were not considered in this study. Besides, soil loss and runoff could not be monitored in 1991 and 1992 due to war (SCRP, 1996). Therefore, runoff and soil loss data collected in 1989, 1990 and 1993 were considered for this study.

3.3.2. Initial soil physical and chemical properties of the research site

The methods used by Bono and Seiler (1983) for physical and chemical analysis of the soils have been summarised in Table 1.

Table 1. Summary of the methods used for the initial soil physical and chemical analysis.

Property	Methods used
pH (H_2o)	Digital pH meter (15 g. soil : 45 g. water)
$CaCO_3$ and dolomite	Complexometric titration
Nitrogen (N %)	Kjehldahl method
Carbon (C%)	Oxidation under standardised conditions with potassium dichromate in sulphuric acid. Organic matter was calculated by multiplying with 1.72.
Exchangeable bases (Ca, Mg, K and Na)	Atomic Absorption Spectrophotometer (AAS); (1N NH_4AC)
Phosphorous	Method of Dirks/Scheffer using extraction water which is saturated with carbon dioxide
CEC (Cmol/kg)	Determination of exchangeable ions: Na, K, Ca, and Mg by the amount of 0.1N HCl which is required to get an equivalent with the soil and exchangeable H-ions with 1N Ca-acetate; the sum of which is CEC (Cmol/kg). Both procedures use titration method
Pore space and pore size distribution	Method developed by Gupta and Larson (1979) to compute water content at various matric potentials.

Source: Bono and Seiler, 1983

3.3.3. Determination of grain and biomass yield at the experimental plots

When the crop in the experimental plots was ready for harvest, it was cut and collected from each of the entire plot. The above ground biomass was determined by taking the sun dry weight (exposed for about 20 days in the sun) of the crop collected from each plot and the value was extrapolated to estimate the total biomass per hectare basis. The grains were weighed and recorded as grain yield in tonnes per hectare.

3.4. Determination of soil physical and chemical properties after the establishment of soil conservation measures

Soil samples were collected (0-30 cm depth) from three positions (Fig. 3) (upper, middle and lower parts of a terrace for each experimental plot) (Plate 5). A total of 18 soil samples, three for each experimental plot, were collected and their physical and chemical properties (% TN, available P and K, % OC and pH) were analyzed at the National Soil Service Programme (NSSP), Addis Ababa.

Total nitrogen was determined by the Kjeldahl procedure (Jackson, 1958), organic carbon by the Walkley-Black dichromate method (Walkley and Black, 1954; Metson, 1971), phosphorus by sodium bicarbonate extraction method (Olsen, et al., 1954) and available K by Flame Photometer (Hesse, 1971; Metson, 1971). Soil pH was determined by glass electrode in a 1:2.5 soil-water suspension (Metson, 1971). Soil texture was determined by the hydrometer method (Day, 1965).

Plate 5. Soil sampling technique at the experimental plots

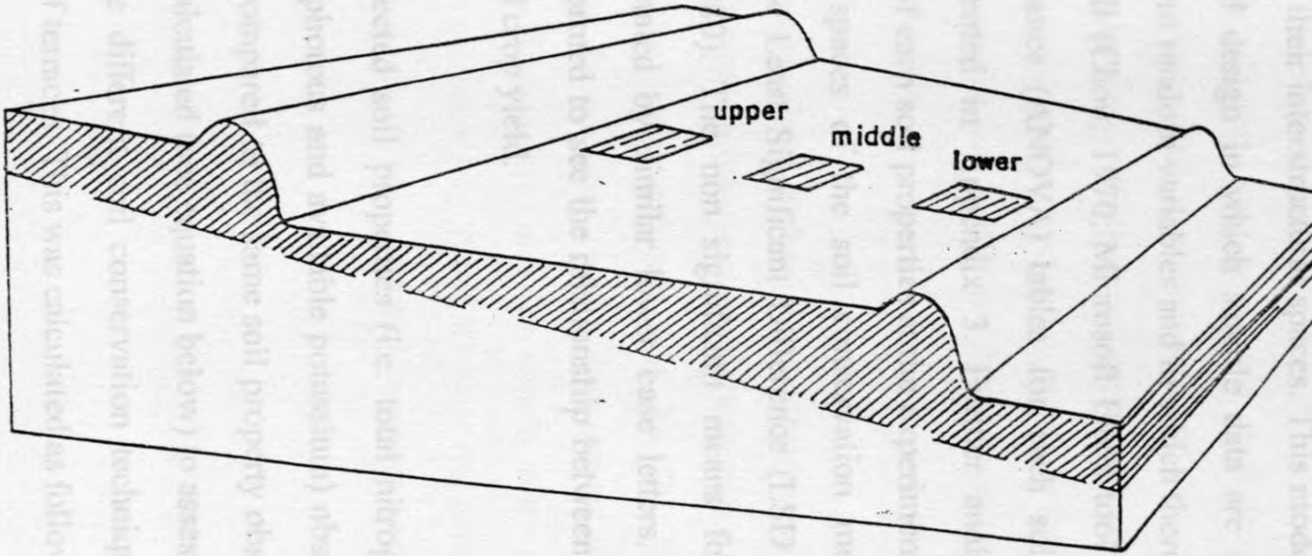


Fig. 3. Arrangement of catenary sampling in experimental plots

3.5. Statistical analysis and data interpretation

Completely Randomized, Two Variable classification without replication model was used to test the significance of selected soil properties in the experimental plots and their interstructural spaces. This model refers to a completely randomized design in which sample data are classified in terms of two independent random variables and in which there is only one observation in each cell (Chou, 1970; Microsoft Excel tool Pak, 1992). The Analysis of Variance (ANOVA) tables for each soil properties considered were presented in Appendix 3. Further analysis of the significance of means of each soil properties at the experimental plots and at the interstructural spaces of the soil conservation measures was conducted by using the Least Significant Difference (LSD) technique (Steel and Torrie, 1980). The non significant means for each soil properties were designated by similar lower case letters. Correlation analysis was also performed to see the relationship between runoff, soil loss, soil properties and crop yield.

The percentage of selected soil properties (i.e. total nitrogen, organic carbon, available phosphorous and available potassium) observed in the experimental plots as compared to the same soil property observed in the control plot was also calculated (see equation below) to assess changes in these properties in the different soil conservation techniques and the interstructural spaces of terraces. This was calculated as follows:

$$A = \frac{(B-C)\,X100}{C}$$

where, A= percent of a soil property at a plot or at a given position of a plot to that of the same soil property at the control plot

B= Soil property at the experimental plot

C= Soil property at the control plot

The mean annual runoff and soil loss was calculated for each experimental plot and these values were compared to that of the control plot by calculating the percentage deviation of each parameter (runoff and soil loss in this case) at each soil conservation measure from that of the control plot. Similar analysis was performed for the grain and biomass yield at the experimental plots.

Besides, the past (as determined before the establishment of the soil conservation structures,1982) and the present (as determined in 1997) soil properties of the site for some nutrients (e.g. % TN, % OC) were compared by calculating the deviation (past minus present nutrient status of the soil) for each soil properties and the results were presented by using bar graphs. Other nutrients (e.g. P and K) were not compared due to discrepancies. in the methods of soil chemical analyses used during the two periods.

4. RESULTS AND DISCUSSION

4.1. Runoff and soil loss

On average, highest runoff (20.0 mm) was recorded in EP5 (graded fanya juu) which was followed by 15.9 mm for EP4 (graded bund) (Fig. 4) (Table 2). Graded structures (both graded bund and fanya juu) result in more soil losses than level structures. This is because graded structures are intentionally designed to facilitate the removal of surplus runoff by slightly grading the structure sideways with a gradient of up to 1% towards a waterway or river. On the other hand, the lowest amount of runoff (0.6 mm) was observed in EP3 (level fanya juu). The reason for the lowest runoff and soil loss on the level fanya juu structure could be attributed to the nature of construction of this structure. Fanya juus are constructed by throwing the soil uphill to form a ridge (Hurni, 1986; Belay, 1992). Throwing the soil uphill to make a terrace causes a reduction in slope which in itself makes a major contribution in reducing erosion on steep land. Throwing the soil down slope as in bunds to form a ridge tends to increase the slope of the cropped area. Runoff was found to be lower than that of the control in the level structures and grass strip (i.e. EP2, EP3, and EP6) (Table 2). However, in EP4 and EP5, it exceeded that of the control plot (Fig. 4). This could be due to the graded nature of the later two structures which were meant to drain excess water from the area during heavy rainfall (see sections 2.2.2 and 2.2.4).

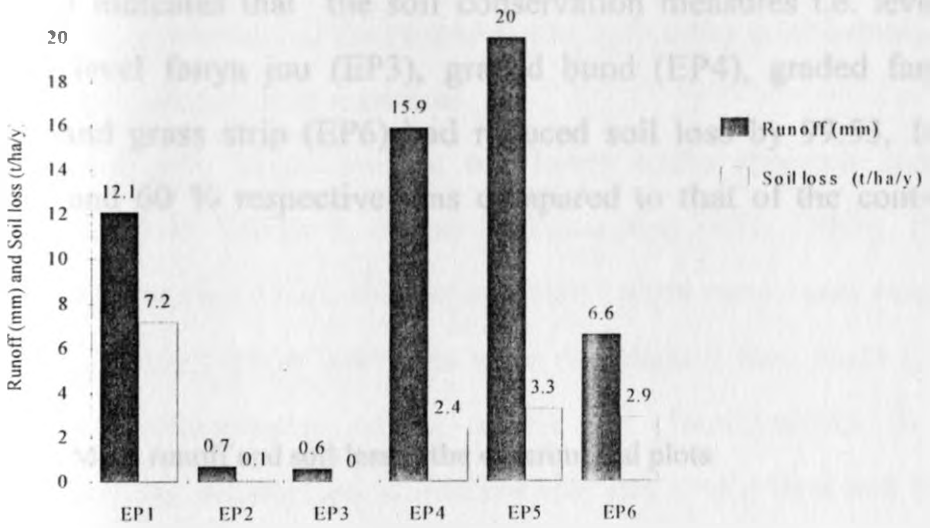
Table 2. Mean annual runoff and soil loss at Hunde Lafto experimental plots

Parameters	**Experimental plots***	**Years**			**mean**
		1989	1990	1993	
Runoff (mm)	EP1,	17.4	18.2	0.8	12.1
	EP2	1.6	0.4	0	0.7
	EP3	1.1	0.1	0.5	0.6
	EP4	23.3	23.0	1.3	15.9
	EP5	26.2	27.8	6.1	20.0
	EP6	12.4	7.2	0.3	6.6
Soil loss (t/ha/y)	EP1	16.3	5.2	0	7.2
	EP2	0	0.1	0	0.03
	EP3	0	0	0	0
	EP4	4.6	2.5	0	2.4
	EP5	6.3	3.5	0	3.3
	EP6	7.4	1.2	0	2.9
Rain fall (mm)		1039	1015	1121	1058
Crop type**		mz***	sg/hb	sg***	

* EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strips

** mz = maize; sg = sorghum; hb = haricot beans
*** Maize and sorghum were the only crops grown on the plots in 1989 and 1993 respectively

Despite the higher runoff values on the graded structures, (both graded bund and graded fanya juu) than the control plot, soil loss was found to be lower than that of the control plot at all conservation structures. Minimum runoff and soil loss was recorded at the level fanya juu structures (i.e. 0.6 mm and 0 t/ha/y respectively) (see Fig. 4). Similar findings were made by Belay (1992) at Gununo research station. Belay found that both runoff and soil loss were relatively higher in the graded structures than level structures and grass strips, although not higher than what was observed in the control plot. He also observed lowest mean annual runoff and soil loss in level fanya juu. This was attributed to the reduction in slope during construction of fanya juus which by itself contributes to reduction in runoff and soil loss.



EP1 = control; EP2=level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

Fig. 4. Mean values of runoff and soil loss at the experimental plots of Hunde Lafto

Table 3. Mean annual runoff and soil loss as percentage of the control plot at Hunde Lafto experimental plots.

Year	Runoff (% of control)						Soil loss (% of control)					
	EP1	EP2	EP3	EP4	EP5	EP6	EP1	EP2	EP3	EP4	EP5	EP6
1989	100	9.20	6.32	133.91	150.57	71.26	100	0	0	28.22	38.65	45.40
1990	100	2.20	0.55	126.37	152.75	39.56	100	1.92	0	48.08	67.31	23.08
1993	100	0	62.55	162.50	762.50	37.50	100	0	0	0	0	0
mean	100	5.49	4.67	130.77	165.11	54.67	100	0.47	0	33.02	45.58	40.0
% Dev*	0	94.51	95.33	-30.77	-65.11	45.33	0	99.53	100	66.98	54.42	60.00

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip
** Percent deviation from the control plot*

The grass strips were found to be intermediate between the level structures and the graded structures in controlling soil loss.

Table 3 indicates that the soil conservation measures i.e. level bund (EP2), level fanya juu (EP3), graded bund (EP4), graded fanya juu (EP5) and grass strip (EP6) had reduced soil loss by 99.53, 100, 67, 54.42, and 60 % respectively as compared to that of the control plot (EP1).

Table 4. Mean runoff and soil loss at the experimental plots

EPS	Runoff (mm)	Soil loss(t/ha)
EP1	36.4[c*]	7.2[a]
EP2	2.0[e]	0.0[b]
EP3	1.7[e]	0.0[b]
EP4	47.6[b]	2.4[ab]
EP5	60.0[a]	3.4[ab]
EP6	19.9[d]	2.9[ab]
LSD (α=0.05)	10.4	5.7

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

**Plots indicated by the same letter down the column are not significantly different at p = 0.05.*

All experimental plots except EP2 and EP3 were significantly different from each other in controlling runoff (Table 4). The two soil conservation techniques (i.e. EP2 and EP3) were found to reduce runoff better than other treatments tested at the site, the latter showing the best result. The same treatments i.e. EP2 and EP3 were also significantly different from the control (EP1) in reducing soil loss (Table 4).

4.2. Assessment of soil nutrient content of the research site

4.2.1. Characteristics of the research site before the establishment of the soil conservation measures

The initial site characteristics of Hunde Lafto research station are summarised in Tables 5, 6 and 7 (Bono and Seiler 1983). The soils represent the site where the experimental plots have been established. The soil conservation measures were established four years (in 1986) after the determination of the initial site characteristics (in 1982). Therefore, the assumption is that the changes in physical and chemical properties of the site which might have occurred during the four years may not have changed before the establishment of soil conservation measures. Soil properties determined at the site before the establishment of soil conservation measures (Table 7) show that very fine pores tend

Table 5. Initial site characteristics of the experimental plots before the establishment of the soil conservation measures

Position of profile	rolling plain (accumulation area)
Slope gradient	strongly sloping
Land use	arable land (sorghum)
Surface stoniness	very stony
Drainage class	3-4 (Appendix. 4)
Soil depth (Appendix 5.)	very deep (greater than 150 cm)
Elevation	1995 m
Aspect	SSE

Source: Bono and Seiler, 1983

to increase down the profile suggesting accumulation of fine particles (clay) in the lower horizons than in the topsoil. pH and % base saturation also increased down the profile. Low values of exchangeable bases were recorded in the topsoil than in the subsoil. Organic matter, total nitrogen, and available phosphorous were high in the topsoil than the subsoil.

The nitrogen content of the site before the establishment of the soil conservation measures was very low (< 0.05%) (Appendix 6). The soils at site may also be rated as having slight to moderate levels of organic matter content (see Appendix 7).

Table 6. Soil profile characteristics of the experimental area (pellic vertisols)

Depth(cm)	Horizon	Description
0-40	Ap	Black (5Y 2.5/1) moist; clay; strong medium and coarse angular blocky; very firm moist; many very fine pores and few fine and medium pores; frequent fine and few coarse root; very few fine gravels; wavy boundary; no nodules observed; many cracks (1-2 cm diameter); continuous clay skin.
40 - 80	B_1	Dark brown (7.5 YR 3/2) moist; clay; moderate medium angular blocky; firm moist; many very fine pores; few fine and medium pores; few fine and very few medium roots; presumed boundary to differentiate from the lower part; many cracks (2 - 3 cm diameter) with dark material (10YR 3/1) from the upper parts; broken and continuous clay skin on ped faces.
80 - 120	B_2	Black (5Y 2.5/1) moist; clay; strong, medium and coarse angular blocky; very firm moist; many very fine pores and few fine and medium pores; frequent fine and few coarse roots; few coarse gravel and stones, slightly rounded at edges, no nodules observed; many cracks (1-2 cm. diameter) continuous clay skin .

Source :Bono and Seiler, 1983

Table 7. Initial physical and chemical properties of soils at Hunde Lafto research site before the establishment of the soil conservation measures

Depth	Horizon	b.d	s.v	*pore space %				pH	O.M	N	C/N	Calc.	Dol
cm		kg/m^3	%	cp	mp	Fp	vfp		%	%		%	%
0-40	Ap	1170	37	4	4	11	44	6.8	2	.03	39	.3	1.7
40-80	B_1	1090	34	4	5	12	45	7.2	1	0		.2	3.7
80-120	B_2	1130	36	4	3	10	48	7.5	1	0		.2	2.7

Depth	CEC	B.S.	Exchangeable bases (ppm)				Phosphorous
cm	Cmol/kg	%	Ca	Mg	K	Na	(ppm)
0-40.......	79.9	98.6	7930	2041	374	70	62
40-80.......	78.5	98.8	8290	1945	594	98	10.5
80-120.....	79.8	99.2	8210	1817	542	120	18.4

Source: Bono and Seiler, 1983

** See Appendix 8 for description of pore size distribution*
calc = calcium carbonate; dol = dolomite

vfp = very fine pores; fm = fine pores; mp= medium pores; cp = coarse pores

s.v = sUbstance volume

4.2.2. Soil nutrient content of the experimental plots as determined in 1997

Soil properties, namely pH water (1: 2.5), EC (mmhos/cm), texture (% sand, % silt, and % clay), total nitrogen (%), organic carbon (%), available phosphorous (ppm) and available K (ppm) were determined at three positions (upper, middle and lower positions of a terrace) for each experimental plot (control, level bund, graded bund, level fanya juu, graded fanya juu and grass strips) at Hunde Lafto research station (Tables 8 and 9).

Table 8. Soil texture at the experimental plots as determined in 1997

Soil properties	Position	Experimental plots						mean
		EP1	EP2	EP3	EP4	EP5	EP6	
% sand	upper	23	17	17	13	17	15	17
	middle	31	23	19	19	21	17	22
	lower	33	15	17	19	27	19	22
	mean	29	18	18	17	22	17	
% silt	upper	28	30	26	36	32	30	30
	middle	30	28	22	22	30	30	27
	lower	30	32	32	32	28	32	31
	mean	29	30	27	30	30	31	
% clay	upper	49	53	57	51	51	55	53
	middle	39	49	59	49	49	53	51
	lower	37	53	51	59	45	49	47
	mean	42	52	56	53	48	52	

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

Table 8 shows that % sand was highest (in all positions) in the control plot when compared with the other treated plots. This could be due to the higher erosion /soil loss levels (see Table 2) in the control than the treated plots which resulted in loss of clay and colloids due to the preferential removal of fine particles from the soil surface (Lal, 1988).

From the particle size analysis, % clay was significantly different at 5% level from the control in the level fanya juu and the graded bund (Table 10). No other significant differences were observed among the experimental plots. The average % clay content was observed to be higher at the level fanya juu (56 %) and lowest in the control plot (42 %). This could be due to the low runoff and soil loss levels in level fanya·juu (Table 2) than the other plots. The average percent clay trend between the experimental plots is shown in Table 10.

Table 9. Soil chemical properties at the experimental plots as determined in 1997

soil properties	position	Experimental plots						mean
		EP1	EP2	EP3	EP4	EP5	EP6	
pH	upper	7.07	6.35	6.95	6.86	6.64	6.44	6.72
	middle	7.22	6.34	6.9	6.43	6.9	6.76	6.76
	lower	7.76	6.46	6.58	6.51	6.86	6.81	6.83
	mean	7.35	6.38	6.81	6.6	6.8	6.67	
EC (mmhos/cm) at 25°C	upper	0.04	0.03	0.04	0.08	0.07	0.08	0.06
	middle	0.05	0.05	0.04	0.06	0.05	0.04	.0.5
	lower	0.06	0.05	0.05	0.06	0.06	0.07	0.06
	mean	0.05	0.04	0.04	0.07	0.06	0.06	
TN %	upper	0.15	0.17	0.18	0.15	0.21	0.18	0.17
	middle	0.15	0.21	0.18	0.18	0.20	0.21	0.19
	lower	0.18	0.19	0.21	0.18	0.22	0.22	0.20
	mean	0.16	0.19	0.19	0.17	0.21	0.21	
O.C. %	upper	1.24	1.32	1.22	1.22	1.44	1.28	1.28
	middle	1.36	1.38	1.60	1.34	1.60	1.52	1.45
	lower	1.70	1.62	1.48	1.42	1.60	1.62	1.57
	mean	1.43	1.44	1.43	1.32	1.54	1.45	
Av.P (ppm)	upper	4.28	4.94	4.02	3.14	4.16	10.24	5.13
	middle	5.98	7.32	4.50	5.70	7.34	11.36	7.03
	lower	11.16	14.84	11.84	6.70	9.56	13.76	11.31
	mean	7.14	9.03	6.79	5.18	7.02	11.76	
Av. K(ppm)	upper	58.1	73	68	77.4	75.5	77.4	71.57
	middle	66	75	79.4	80.3	72	87.1	76.63
	lower	63	111.3	106.5	75.5	84.2	92	88.75
	mean	62.37	86.43	84.63	77.73	77.23	85.50	

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

The pH of the different conservation measures ranged from 6.34 - 7.76. The lowest (6.34) and the highest (7.76) pH were recorded in the middle position of level bund and the lower position of the control plot respectively (Table 9). The mean pH at the control plot was significantly higher than those of the treated plots (Table 10). It was significantly lower at the bunds than fanya juus; the lowest being at the level bund which was significantly different (5% level) from all treatments. The relatively lower pH at the treated plots than that of the control plot may be explained by the difference in the extent of soil loss between the soil conservation measures and the control. The data on soil properties before establishment of the soil conservation measures (see Table 7) indicate an increasing trend of pH down the profile. Therefore, due to the higher amount of soil loss at the control plot than the treated plots (see Table 2), erosion might have removed the topsoil and exposed the subsoil to the surface resulting in a relatively higher pH in the control plot.

Table 10. Tests of significance of the average soil properties at the experimental plots

EPS	Mean of soil properties					
	pH	% clay	% OC	% TN	Avail. P (ppm)	Avail. K (ppm)
EP1	7.35^{a}	41.67^{a}	1.43^{ab}	0.16^{a}	7.14^{bc}	62.36^{a}
EP2	6.38^{c}	51.67^{ab}	1.44^{ab}	0.19^{b}	9.03^{ab}	86.43^{b}
EP3	6.81^{b}	55.67^{b}	1.43^{ab}	0.19^{b}	6.79^{bc}	84.63^{b}
EP4	6.60^{bc}	53.16^{b}	1.32^{a}	0.17^{a}	5.18^{c}	77.73^{ab}
EP5	6.80^{b}	48.33^{ab}	1.54^{b}	0.21^{c}	7.02^{bc}	77.23^{ab}
EP6	6.67^{b}	52.33^{ab}	1.47^{ab}	0.21^{bc}	11.79^{a}	85.50^{b}
LSD (α=0.05)	0.27	10.77	0.17	0.02	2.89	18.27

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

NB: Plots indicated by the same letter down the column are not significantly different at 5% level

Total nitrogen (%) in the different experimental plots ranged from 0.147 - 0.224 which can be rated as moderate to high (Appendix 6). In all the soil conservation measures, the % total N was found to be higher than that of the control plot suggesting that the soil conservation measures have retained some amount of nitrogen which would have otherwise been lost by erosion. The benefits of using soil conservation measures was also suggested by Belay (1992). Belay reported that organic matter and total nitrogen losses were reduced by about 69 and 26% respectively on graded bund, 84 and 86 % on graded fanya juu and 95 and 96 % on the grass strip treatments. Total nitrogen in all experimental plots except the graded bund was significantly different from the control at 5% level (Table 10).

On the average, all soil conservation measures except the graded bund had higher % organic carbon than that of the control plot. The lowest % organic carbon at the site was 1.13% which was recorded at the upper positions of level fanya juu and graded bund while the highest was 1.70% which was recorded from the lower positions of the control plot. The graded bund (EP4) and graded fanya juu (EP5) were found to be significantly different from each other at 5% level of significance in organic matter content (Table 10). This could have resulted from the differences in the construction of bunds and fanya juu structures. In bunds, the soil is thrown downhill (see section 2.2.1 and 2.2.2) during construction forming a ridge at the lower slope position of the ditch (Appendix 9). Therefore, a relatively high amount of organic carbon could probably be washed away from the interstructural spaces of bunds and be accumulated in the ditch at the lower position of each interstructural space of bunds. On the other hand, the construction of graded fanya juus involves throwing the soil uphill (see section 2.2.4) whereby the ridge is located at the upper slope position of the ditch. Hence, whatever is eroded from the upslope position of the terraces would be tapped by the ridge resulting in deposition of materials high in organic matter. This is in line with the findings of Belay (1992) who observed a relatively lower loss of organic matter (177 Kg/ha) by erosion from graded fanya juu than graded bund (338 Kg/ha). The same reason could be suggested for the significant difference in % TN in these plots.

The available P content of the site was rated as low to moderate (Appendix 10). The lowest (3.14 ppm) and highest (14.84 ppm) available phosphorous was recorded in the upper positions of the graded bund (EP4) and the lower positions of the level bund (EP2) respectively. Phosphorous in the grass strip (EP6) was significantly different from the other plots except the level bund (EP2). The relatively higher amount of available P in the grass strips than other plots may probably be due to the addition of organic matter to the soil system by the grass strips. Tisdale, et al., (1990) suggest that organic anions of various sources can reduce P fixation by forming stable complexes with iron and aluminium of the soil components. Hence, the relatively higher organic matter content might have contributed to the increased availability of P in the grass strips (see correlation between organic carbon and available P in Table 17). Moreover, the difference in P content in level bund and graded bund could also be related with the difference in organic matter contents of these plots.

Available K was highest in the lower position of level bund (111.3 ppm) and lowest in the upper positions of the control plot. On average, all soil conservation structures had higher values of available K than the control plot. The highest average available K was recorded in the level bund (86.43 ppm) followed by the grass strips with 85.5 ppm. Available K was significantly different from the control in the level structures (i.e.

level bund and level fanya juu) and the grass strip at 5% level of significance (Table 10). The graded structures (i.e. graded bund and graded fanya juu) had lower available K as compared to the other structures. This could be due to the relatively high amount of runoff and soil loss which occurred in the former structures. The available K status of the experimental plots was negatively correlated with the amount of runoff recorded in the plots (see Table 17). Lower amount of available K was observed on plots where higher runoff was recorded. This might imply that most of the available K was lost through runoff. Evidence of the substantial effects that soil moisture have on K transport in soil has been reported by Skogley (1981) at Montana State University. Tisdale, et al., 1990 also observed that increasing soil moisture from 10 to 28 % increased total K transport by up to 175 %. Moreover, Belay (1992) reported that potassium constituted the highest concentration in runoff.

In general, the performances of different soil conservation measures were different in retaining different soil properties. The percentage of selected soil properties in each experimental plot and that of the same soil property in the control plot was calculated (Table 11). This form of presentation compares the overall effectiveness of the experimental plots (soil conservation measures) in nutrient retention despite the fact that the units of measurements of each soil properties are different.

On the average, there was an increase of soil nutrient retention of about 21.1, 12.73, 15.84, and 33.19 % in the level bund, level fanya juu, graded fanya juu and grass strip respectively. Hence, all soil conservation measures except the graded bund were found to retain a relatively higher amounts of nutrients than the control plot suggesting long term benefits of carrying out soil conservation measures. The highest soil nutrient losses from graded bund was also reported by Belay (1992) in Gununo research station. The reason for the lowest soil nutrient content of the graded bund could be that most of the soil nutrients might have been washed away from the plot by runoff because of the waterway constructed (in graded structures) to facilitate the removal of excess water.

Table 11. Chemical properties of the experimental plots expressed as percent to the control plot

soil properties	position	Experimental plots						mean
		EP1	EP2	EP3	EP4	EP5	EP6	
T.N (%)	upper	100	114.29	123.81	100	142.86	123.81	117.69
	middle	100	142.86	123.81	123.81	138.1	142.86	128.57
	lower	100	103.85	115.39	100	123.08	121.98	110.99
	mean	100	118.87	120.13	106.92	133.33	128.93	
O.C. (%)	upper	100	106.47	98.38	98.38	116.09	103.23	103.8
	middle	100	101.47	117.61	98.53	117.61	111.72	107.81
	lower	100	95.23	86.98	83.41	94.05	95.23	92.53
	mean	100	100.49	100	92.52	107.90	101.61	
Avail. P.	upper	100	115.42	93.93	73.36	97.2	239.25	119.86
	middle	100	122.41	75.25	95.32	122.74	189.97	117.56
	lower	100	132.98	106.09	60.03	85.66	123.30	101.34
	mean	100	126.47	95.09	72.55	98.32	165.13	
Avail. K.	upper	100	125.65	117.04	133.22	129.95	133.22	123.18
	middle	100	113.64	120.30	121.67	109.09	131.97	116.11
	lower	100	176.67	169.05	119.84	133.65	146.03	140.87
	mean	100	138.58	135.69	124.62	123.82	137.09	
Overall mean of % to control	nutrients	100.	121.10	112.73	99.16	115.84	133.19	
% Dev.*		0	+21.10	+12.73	-0.84	+15.84	+33.19	

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

** % deviation of the overall mean of nutrients from the control plot*

(+) sign stands for increase; (-) stands for a decrease in nutrient retention as compared to the control plot

4.2.3. Comparison of the 1982 and 1997 soil nutrient contents of the research site for some soil properties

The changes in nutrient content (Table 12) for some soi properties were calculated by subtracting the initial nutrient content of the site, as determined in 1982 from those determined in 1997. Hence, the negative sign in Table 12 indicates the reduction in nutrient content whereas the positive sign stands for an increase in that particular nutrient.

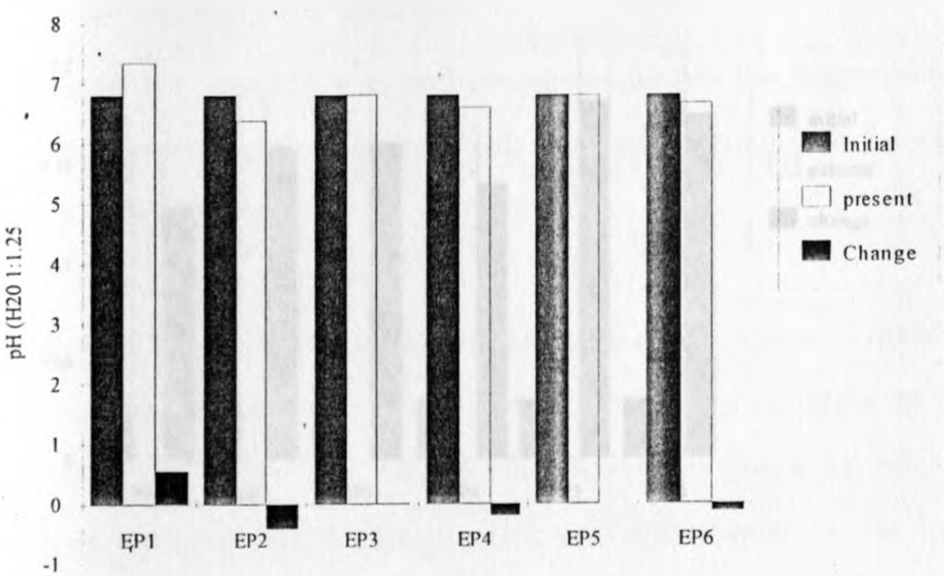
Table 12 and Figures 5-7 refer to the changes in some soil properties before and after the establishment of the soil conservation measures. Soil pH (H_2O) was higher in 1997 than that of 1982 in the control plot. Slight decline in soil pH was observed in bunds and grass strips (Fig. 5) whereas no changes were observed in the fanya juu structures during the 1982 - 1997 period. The increase in soil pH at the control plot could be attributed to the high soil loss levels(Table 2) in this plot which exposed the subsoil having higher initial soil pH, (Table 7) to the surface. This observation does not agree with the ones reported by Gachene (1995) and Belay (1992) who observed a decline in soil pH with increasing soil loss.

Table 12. Comparison of the initial and current soil nutrient content of the research site.

Soil properties		EP1	EP2	EP3	EP4	EP5	EP6
pH	Initial	6.80	6.80	6.80	6.80	6.80	6.80
	present	7.35	6.38	6.81	6.60	6.80	6.67
	Change	+0.55	-0.42	+0.01	-0.20	0	-0.13
% O.C	Initial	1.16	1.16	1.16	1.16	1.16	1.16
	present	1.43	1.44	1.43	1.32	1.54	1.47
	Change	+0.27	+0.27	+0.27	+0.16	+0.38	+0.31
% T.N	initial	0.03	0.03	0.03	0.03	0.03	0.03
	present	0.16	0.19	0.19	0.17	0.21	0.21
	change	+0.13	+0.16	+0.16	+0.14	+0.18	+0.18

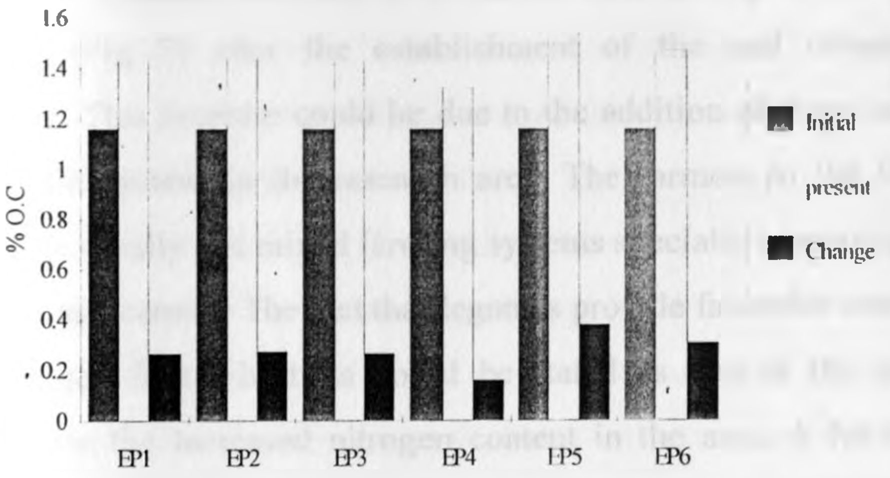
EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

NB: All experimental plots had similar soil properties before the establishment of the soil conservation measures. Hence, similar figures were indicated in each experimental plot for each initial soil property in Table 12. Therefore, the change in soil properties observed between the experimental plots is due to the difference in the present nutrient status of the experimental plots.



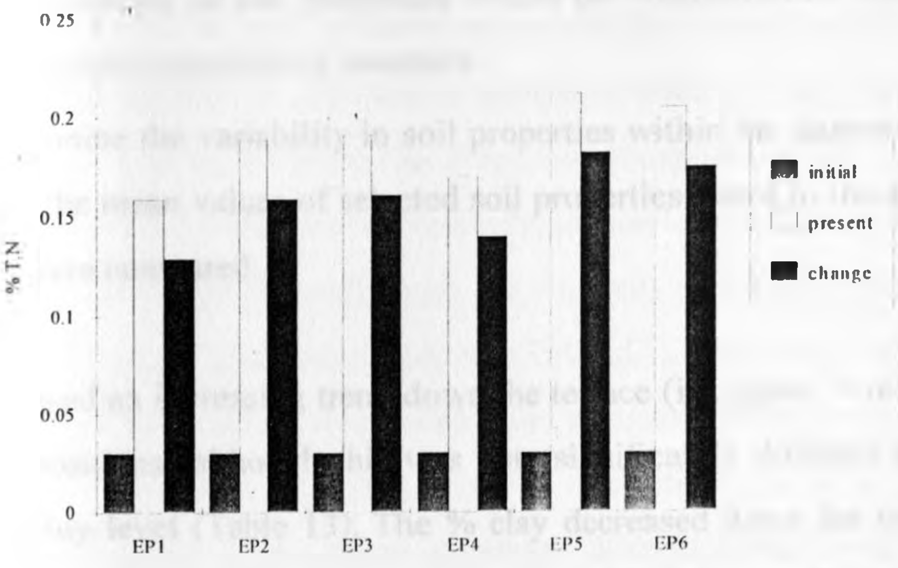
EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

Fig. 5. Soil pH before and after the establishment of the experimental plots



EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

Fig. 6. OC (%) before and after the establishment of the experimental plots



EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

Fig. 7. Total nitrogen (%) before and after the establishment of the experimental plots

There was a general increase in % organic carbon (Fig 6) and % total nitrogen (Fig 7) after the establishment of the soil conservation measures. This increase could be due to the addition of these nutrients to the soil system in the research area. The farmers in the Hararge highlands usually use mixed farming systems specially intercropping of legumes and cereals. The fact that legumes provide favorable conditions for nitrogen fixing bacteria could be stated as one of the possible reasons for the increased nitrogen content in the area. A lot of crop residues were visible in the plots during soil sampling in 1997 (Plate 5). This could possibly contribute to the relatively high organic carbon and nitrogen contents in the soils in 1997 as compared to the same soil in 1986.

4.2.4 Variability of soil properties within the interstructural spaces of the soil conservation measures

To determine the variability in soil properties within the interstructural spaces, the mean values of selected soil properties tested in the area (in 1997) were compared.

pH showed an increasing trend down the terrace (i.e. upper < middle < lower positions) although this was not significantly different at 5 % probability level (Table 13). The % clay decreased down the terraces; the highest being in the upper position and the lowest in the lower position. The pore size distribution determined before the establishment of the soil conservation measures (Table 7) indicated that very fine pores increased down the profile. This may suggest an increasing trend of fine particles in the lower than in the upper horizon of the profile which in turn suggests higher % clay in the lower than in the upper horizons. Hence, the possible reason for the relatively higher percent clay in the upper positions of terraces (as determined in 1997) than the lower positions could be that erosion might have removed more topsoil from the upper than the lower positions of the terraces whereby the lower horizons, with higher % clay had been exposed to the surface. Similar observation was made by Weigel (1986) who reported an increase in clay content caused by erosion in the upper segment of a slope between bunds in the adjacent catchment under conservation in a eutric nitisol of Gununo research station (quoted by Belay, 1992)

Total nitrogen (%) was significantly higher in the lower positions than that of the other positions and significantly lower in the upper positions at 5% probability level (Table 13). Organic carbon also had an increasing trend down the terrace (upper < middle < lower) and this was significantly higher in the lower positions than in the other two positions at 5 % level (Table 13). Available phosphorous had a similar trend to that of organic carbon. Similarly, available potassium increased down the terrace positions although this was only significantly different between the upper and lower positions (Table 13). The data in Table 13 indicate that soils in the lower positions of terraces generally experience a relatively higher pH, O.C (%), T.N (%), available P and K but less % clay as compared to the upper positions. Weigel (1986), reported a similar fertility redistribution at Gununo soil conservation research station, Ethiopia; the only exception being that of potassium which was reported to be lower at the lower positions.

Table 13. Soil properties in the interstructural spaces of terraces

Soil properties	Position on terrace		
	Upper	Middle	Lower
pH (H_2O)	6.72 [a*]	6.76 [a]	6.83 [a]
% Clay	52.67 [a]	51.33 [a]	47.33 [a]
% T.N	0.17 [a]	0.19 [b]	0.20 [c]
% O.C	1.28 [a]	1.46 [a]	1.57 [b]
Avail. P	5.13 [a]	7.03 [a]	11.31 [b]
Avail. K	71.57 [a]	76.63 [ab]	88.75 [b]

* *NB: Means of each soil properties across the rows indicated by the same letters are not significantly different at 5 % level.*

In general, erosion had resulted in a significant redistribution of soil materials and fertility within the interstructural spaces. Soil materials eroded from up slope are deposited at the lower positions (immediately above the bund) of the conservation structures. A similar finding was reported by Belay (1992) who observed that soils at the deposition site experience net gains in terms of soil fertility while those upslope undergo net losses. This soil fertility redistribution within the interstructural spaces of the soil conservation measures indicate that the upper terrace position is more vulnerable to erosion than the other two positions due to the slope effect. This may suggest different soil management practices, e.g. during fertilizer application, higher rate should be applied to the upper terrace position (to compensate for the loss due to erosion) with a decreasing rate down the terrace.

4.3. Crop production

4.3.1. Crop yield at the experimental plots

The mean annual grain and biomass yields (t/ha) have been calculated for each experimental plots based on the grain yield and biomass data for the years: 1989, 1990, 1991 and 1993 (Table 14). All the conservation measures had high yields than the control plot except in the grass strip which had a mean grain yield of 1.32 t/ha. The low grain yield recorded in grass strips could possibly be due to the competition for soil nutrients and moisture between the crops and the grass strips. Orina (1996) indicated that in all grass strips tested at Kabete, crop yields tended to increase away from the grass strips, the lowest yields being near the strips. Most of the farmers interviewed in his area of study, (i.e. 58% in Ikuma, 73 % in Gatei, and 80 % in Ngorongo) indicated that grass strips compete for nutrients and moisture with crops. Orina (Ibid) also indicated that grass strips also harbour pests and rodents (mainly moles and rats) which can eat the crops at various stages of growth resulting in a relatively low crop yield near the grass strips. The highest (1.58 t/ha) and lowest (1.32 t/ha) mean annual grain yield was recorded in the graded bund and grass strip with percentage deviation from the control of +14.49 and -4.35 respectively. This implies that the mean annual yield obtained from the graded bund was 14.49% more than that of the control plot whereas the yield obtained from the grass strips was 4.35% less than that of the control plot.

The highest and lowest mean annual crop biomass yields were 4.7 and 4.12 t/ha for the level and graded bunds respectively. The mean annual

Table 14. Crop grain and biomass production in the soil conservation experimental plots.

Year	1989	1990		1991			1993	Avg.	% Dev.*
SE	2	2	2	2	2	2	2		
Crop type	mz	sg	hb	sg	mz	hb	sg		
Grain yield t/ha									
EP1	1.65	1.00	0.34	0.41	0.39	0.72	0.99	1.38	0
EP2	1.77	1.36	0.32	0.79	0.40	0.61	0.93	1.55	+12.32
EP3	1.69	1.11	0.33	0.81	0.38	0.46	0.95	1.43	+3.62
EP4	1.87	1.50	0.29	0.64	0.54	0.56	0.92	1.58	+14.49
EP5	1.74	1.33	0.20	0.79	0.43	0.61	0.77	1.47	+6.52
EP6	1.36	1.28	0.22	0.72	0.43	0.47	0.79	1.32	-4.32
Biomass yield t/ha									
EP1	4:57	4.61	1.05	1.82	0.83	1.09	2.83	4.20	0
EP2	4.66	5.26	0.76	2.99	0.87	0.98	3.26	4.70	+11.90
EP3	4.97	4.24	0.74	3.31	0.81	0.78	3.16	4.50	+7.14
EP4	5.76	2.19	0.62	2.63	1.11	0.89	3.29	4.12	-1.92
EP5	4.93	5.18	0.45	3.03	0.83	0.77	2.66	4.46	+6.19
EP6	4.20	6.06	0.54	2.58	0.97	0.83	2.74	4.48	+6.67

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

*NB: * % deviation from the control*
The (-) and (+) signs in the % deviation indicate yield reduction and increase respectively as compared to the control.
mz = maize; sg = sorghum; hb = haricot bean; se = season

crop biomass yield in all the soil conservation measures except the graded bund was higher than that of the control plot (4.20 t/ha). Level bund had 11.9% more crop biomass yields than that of the control plot while graded bund had 1.92 % less biomass yield than that of the control plot.

In all experimental plots, the highest mean crop grain and lowest crop biomass yields were recorded on the graded bund. This observation on grain yield from graded bund seems to contradict,with the high soil loss (Table 2) and relatively low nutrient content (Table 9) observed in this structure. Level bund had the highest mean annual biomass yield and was second to the graded bund in mean annual grain yield.

4.3.2. Crop yield in the interstructural spaces of level bund structures

Grain yield mean values of the major crops (maize, sorghum, and haricot beans) collected from three different positions between bunds of the commonly used conservation structures in the catchment (Level bund) has been summarized in Table 15.

On average, the highest grain yield was obtained on the position immediately above the bund (lower position of a terrace) for all the major crops in Hunde Lafto research unit. This is possibly due to improvement in soil fertility in the lower terrace positions because of deposition of soil materials rich in soil nutrients which had been eroded from the upslope positions (see section 4.2.4). The mean yield of maize on the middle of the bunds and immediately below the bunds (i.e. upper terrace position) was almost the same which was also true for sorghum. On the other hand, the yield of haricot beans was higher in the middle of the structures than that of below the bunds (upper terrace position).

Table 15. Grain yield (t/ha) of the major crops at different positions of the most commonly used soil conservation measure (level bund).

Year	SE	Crop type								
		Maize			sorghum			Haricot beans		
		a	b	c	a	b	c	a	b	c
1986	2	1.19		1.00	1.37	1.95	1.91	0.53		.22
1987	1							0.33		
1987	2	1.03		1.19	1.68	1.09	1.74	0.42	.75	.40
1988	2	1.05	1.16	1.14	2.25	2.31	2.50	1.79	.62	.65
1989	1							0.85	.60	.94
1989	2	1.70	1.25	1.34	2.85	2.62	2.46	.47	.59	.54
1990	1							.87	.69	.42
1990	2	0.96	0.71	.76	2.46	1.82	1.57	.72	.68	.56
1991	1							.88	.86	.61
1991	2	1.56	1.24	1.07	2.27	1.42	1.23	.52	.59	.66
1992	2				2.41	1.92	1.84			
1993	2	1.03	0.87	0.84	1.74	1.46	1.39	.39	.41	.36
Total		8.52	5.23	7.34	17.03	14.59	14.64	7.77	5.79	5.36
Avg.		1.22	1.05	1.05	2.13	1.82	1.83	.71	.64	.54

NB (1). The blank spaces in the table above indicate that the data for that particular crop during the specified cropping season was not collected from the indicated position

a = Lower position of a terrace

b = position in the middle of the bund

c = Upper position of a terrace

SE = cropping season

4.4. Comparison of the performance of the soil conservation measures in soil conservation, nutrient retention and grain yield.

The mean values of some parameters considered for the study are summarized in Table 16 below (see also Fig. 10). Almost all parameters were negatively correlated with soil loss (which was significant with available K and % clay at $p = 0.05$, Table 17) indicating that when soil loss increases, there is decline in soil fertility which may in turn result in reduction of crop yield. Belay (1992) and Gachene (1995) reported a

Table 16. Summary of the mean values of runoff, soil loss, soil nutrient content, and yield at the experimental plots of Hunde Lafto research station after establishment of the soil conservation measures.

	EP1	EP2	EP3	EP4	EP5	EP6
Run off (mm)	12.13	0.67	0.57	15.87	20.03	6.63
soil loss (t/ha/y)	7.17	0.03	0.00	2.37	3.27	2.87
T.N %	0.16	0.19	0.19	0.17	0.21	0.21
O.C %	1.43	1.44	1.43	1.32	1.54	1.45
Avail. P (ppm)	7.14	9.03	6.79	5.18	7.02	11.79
Avail K (ppm)	62.37	86.43	84.63	77.73	77.23	85.50
% Clay	42	52	56	53	48	52
Grain yield (t/ha/y)	1.38	1.55	1.43	1.58	1.47	1.32
Biomass (t/ha/y)	4.20	4.70	4.50	4.12	4.46	4.48

EP1 = control; EP2 = level bund; EP3 = level fanya juu; EP4 = graded bund; EP5 = graded fanya juu; EP6 = grass strip

Table 17. Correlation coefficients of selected soil properties and crop parameters

	RO	SL	TN	OC	P	K	Y	B	% clay
RO	1								
SL	0.59	1							
TN	-0.03	-0.40	1						
OC	0.14	0.09	0.70	1					
P	-0.43	-0.07	0.5	0.36	1				
K	-0.56	-0.90	0.05	0.04	0.43	1			
Y	0.13	-0.40	-0.20	0.41	-0.60	0.17	1		
B	-0.63	-0.60	0.66	0.54	0.57	0.71	-0.04	1	
% clay	-0.46	-0.90	0.41	-0.28	0.07	0.88	0.29	0.36	1

Where, ***RO*** *= Runoff;* ***SL*** *= Soil loss;* ***Y*** *= Grain yield;* ***B*** *= Biomass yield*

very close relationship between soil properties and soil erosion in Ethiopia and Kenya respectively. Belay further observed a strong correlation between soil depth and crop yield.

There was a positive correlation (r = 0.59) between runoff and soil loss (Table 17) (although not significant at p = 0.05) which implies that high runoff could result in increased soil loss. The % clay was significantly and negatively correlated (p =0.05) with soil loss (r = -0.90) while available K was significantly and positively correlated with % clay (p =0.05; r = 0.88). This suggests that high amount of available K is lost with fine materials due to the preferential removal of these materials by soil erosion.

There was however, no much correlation between soil properties and grain yield. On the other hand, biomass yield was positively correlated with all soil properties considered. Similar findings were reported by Belay (1992) and Gachene (1995).

Table 18. Summary of comparison of the effects of soil conservation techniques on nutrient retention, soil conservation, and crop production

Conservation Techniques	Reduction in soil loss as compared to the control plot (%)	Effect on grain yield as compared to the control plot (%)	Effect on Nutrient retention (OC, TN, K, P) as compared to the control plot (%)
Level bund	99.50	12.3 0(increase)	21.1 (increase)
Level fanya juu	100	4.2 0(increase)	12.73 (increase)
Graded bund	67.00	14.90 (increase)	0.84 (decrease)
Graded fanya juu	54.40	6.50 (increase)	15.84 (increase)
Grass strip	60.00	4.2 0(decrease)	33.19 (increase)

All techniques tested at Hunde Lafto research station reduced soil loss (Table 18). All except the grass strips and graded bund increased grain yield and nutrient retention respectively as compared to the control.

The soil conservation measures, when evaluated separately using different parameters showed a variation in their performance. For instance, level fanya juu, grass strips and graded bund ranked the highest (Tables 18 and 19) in soil loss reduction, nutrient retention and grain yield increase respectively. The possible explanations for this was given in the previous sections. However, level bund, which ranked the highest in the net performance evaluation (Table 19), showed a relatively better overall performance than the other techniques tested in the area in terms of all parameters considered.

Table 19. Ranking of the soil conservation techniques in terms of their net performance in soil conservation, nutrient retention and crop yield

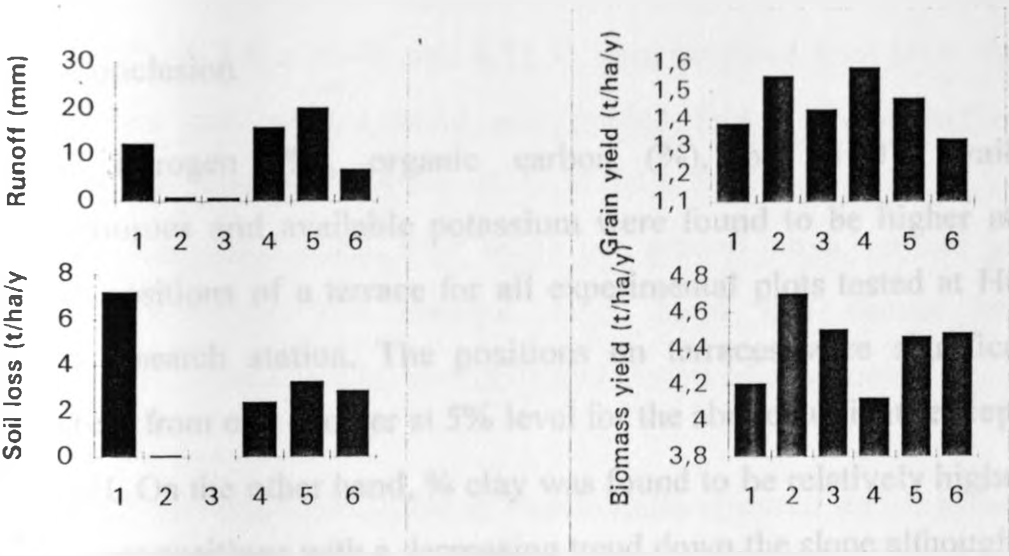
Soil conservation technique	**soil loss reduction % to max**	**grain yield % to max**	**Nutrient retention % to max**	**average**	**Net performance ranking**
Level bund	99.5	83	64	82	1
level fanya juu	100	28	38	56	2
Graded bund	67	100	-2.5	55	3
Graded fanya juu	54.4	44	48	49	4
Grass strips	60	-28	100	44	5

NB The percentage values in Table 19 were calculated with reference to the highest values in soil loss reduction, grain yield increase and nutrient retention indicated in Table 18 above. Hence 100 % was allocated to a soil conservation measure ranking the highest in each parameter.

The (-) sign stands for reduction as compared to the control

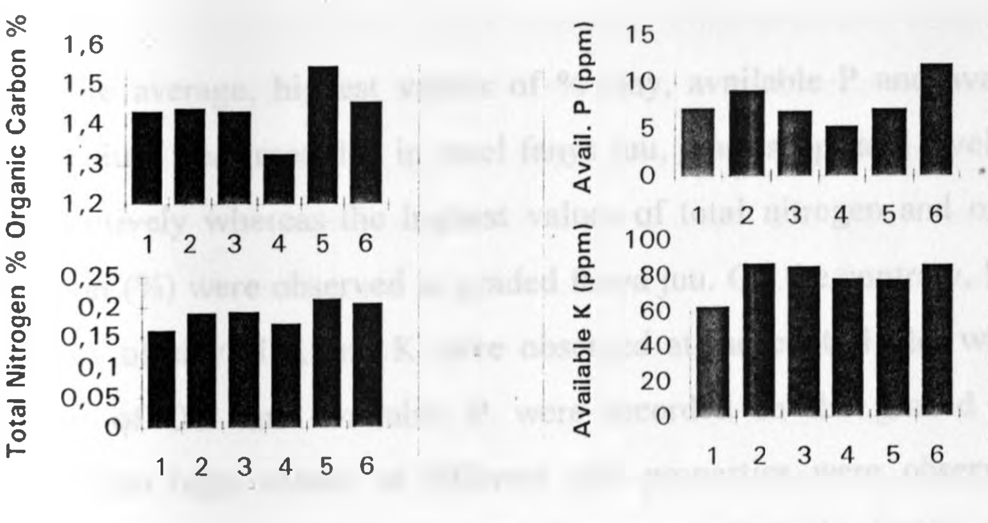
Hence, Level bund, which is the most commonly practiced soil conservation technique in the surrounding areas of Hunde Lafto research station can be recommended to be best suited for the area although further comprehensive research is required to justify this.

Fig. 8. Summary of the mean runoff, soil loss, soil properties, and crop yield at the experimental plots



Runoff and soil loss (mean of 1989, 1990,and1993)

Crop yield (mean of 1989, 1990, 1991 and 1993)



Selected soil properties (as determined in 1997)

NB: Numbers1, 2, 3, 4, 5 and 6 in the X-axis represent control, level bund, level fanya juu, graded bund, graded fanya juu and grass.strips respectively.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Total nitrogen (%), organic carbon (%), pH (H_2O), available phosphorous and available potassium were found to be higher at the lower positions of a terrace for all experimental plots tested at Hunde Lafto research station. The positions on terraces were significantly different from one another at 5% level for the above nutrients except for soil pH. On the other hand, % clay was found to be relatively higher on the upper positions with a decreasing trend down the slope although this variation was not significant.

On the average, highest values of % clay, available P and available potassium were recorded in level fanya juu, grass strips and level bund respectively whereas the highest values of total nitrogen and organic carbon (%) were observed in graded fanya juu. On the contrary, lowest values of clay, TN, and K were observed at the control plot whereas those of OC and available P were recorded in the graded bund. Although high values of different soil properties were observed at different plots, grass strips had shown a relatively better overall performance in retention of the soil properties investigated.

Higher % organic carbon and % total nitrogen were recorded in 1997 as compared to that of 1982.

The soil conservation techniques had resulted in a relatively higher grain yield and biomass production than that of the untreated plot except that grain yield and biomass values were lower in the grass strip and graded bund respectively than the control. An increases in grain yield of 12.32, 3.62, 14.49, and 6.52 % were obtained from level bund, level fanya juu, graded bund and graded fanya juu respectively. Moreover, a biomass increase of 11.9, 7.14, 6.19, and 6.67 % were obtained from level bund, level fanya juu, graded fanya juu and grass strips respectively. On average, level bund had shown better performance in maintaining productivity in terms of crop yield.

In general, all techniques tested at Hunde Lafto research station reduced soil loss and all of them except the grass strip and graded bund increased grain yield and nutrient retention respectively as compared to the control. The soil conservation measures, when evaluated separately using different parameters showed a variation in their performance. For instance, level fanya juu, grass strips and graded bund ranked the highest in soil loss reduction, nutrient retention and grain yield increase respectively. Nevertheless, level bund (which reduced soil loss by 99.5%, increased grain yield and nutrient retention by about 12.3 % and 21.1% respectively) showed a relatively better overall performance than other techniques tested in the area in terms of all parameters considered (i.e. soil conservation, nutrient retention and crop yield).

5.2. Recommendations

Based on the available information, the level bund, which is a widely practiced technique in the area, seems to perform better than the other soil conservation techniques tested at the site. However, the information obtained in this work may only provide a clue on the performance of the soil conservation measures at Hunde Lafto research station This is because the conditions under which the information was obtained were so specific (i.e. single slope percent, soil type, land use and microclimate) that it seems unfair to rely only on the available information and decide the type of soil conservation measure that best suits the Hararge highlands. This is due to the wide range of variability of these parameters within the catchment in particular and for the highlands in general. Therefore, further comprehensive research is required to investigate the soil conservation technique that best suits for the highlands.

Since both water deficit and excess water can alternate within a year at Hunde Lafto research station, water conservation is needed mostly during the Belg season (March - May) because this is a short rain cropping season when the area experiences water deficit hence requiring water conservation for optimum growth of crops grown during this season. Soil conservation is needed during Kremt season (June - August) due to the heavy rainfall occurring in this season. Thus a flexible approach of soil and water conservation is required to meet the demands of drainage during heavy rains and water conservation during low rainfall. It is thus difficult to meet these two conditions with a single static soil and water conservation measure. One of the possible approaches for this may be the inclusion of part time barriers such as tied ridges which will keep the water in place during water shortage but which will break or might be broken by hand during heavy rains to avoid damage of the structures by concentrated runoff.

Evaluation of the performances of different soil conservation measures for soil conservation, nutrient retention as well as yield improvement need to be done under varied conditions of land use, slope percentage, soil type, climate and socio-economics through time to reach at a conclusive remark about the type of soil conservation technique to be best implemented for a given area under the prevailing conditions.

The mixed farming system (especially of legumes and non legumes) which is widely practiced in the surrounding areas of this research site, is encouraging since it helps in sustaining or improving the fertility status of the soils.

6. REFERENCES

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7. APPENDICES

Appendix 1. Description of agroclimatic zones of Ethiopia

Altitude	Less than 900 mm	900 to 1400 mm	More than 1400 mm
More than 3700m			**HIGH WURCH** (No conservation) A: None (frost limit) C: None S: Black soils, little disturbed T: Mountain grassland
3700 to 3200m		**MOIST WURCH** A: only barley, one cropping season per year C: drainage rare S: Black soils, degraded T: Erica, Hypericum	**WET WURCH** A: only barley, two cropping seasons per year C: wide spread drainage ditches S: Black soils, highly degraded T: Erica, Hypericum
3200 to 2300m		**MOIST DEGA** A: Barle, wheate and pulses, one cropping season per year C: Some trditional terracing S: Brown clay soils T: Juniperus, Hagenia, Podocarpus	**WET DEGA** A: Barley, wheat, nug, pulses: two cropping seasons per year C: Drainage ditches wide spread S: Dark brown clay soils T: Juniperus, Hagenia, Podocarpus, Bamboo
2300 to 1500m	**DRY WEYNA DEGA** A: Wheat, tef, barley, maize C: Terracing wide spread S: Light brown to yellow soils T: Acaia trees	**MOIST WEYNA DEGA** A: Maize, sorghum, tef, Inset rare, wheat, nug, dagusa, barley C: Traditional terracing S: Red- brown soils T: Acacia, Cordia, Ficus	**WET WEYNA DEGA** A: Tef, maize, Inset in W. part, nug, barley C: Drainage wide spread S: Red clay soils, deeply weathered, gullies frequent T: Many varieties; Acacia, Cordia, Ficus, Bamboo
1500 to 500m	**DRY KOLLA** A: Sorghum rare, tef C: Water retention terraces S: Yellow sandy soils T: Acacia bushes and trees	**MOIST KOLLA** A: Sorghum, rarely tef, nug, dagusa, groundnut C: Terracing wide spread S: Yellow silty soils T: Acacia, Erythrina, Cordia, Ficus	
Below 500m	**BERHA** (NO conservation) A: None excepy irrigation areas C: None S: Yellow sandy soils T: Acacia bushes		

NB: On the vertical is the altitude increasing upwards. On the lateral is the annual rainfall increasing towards the right side

Each box represents one agroclimatic zone

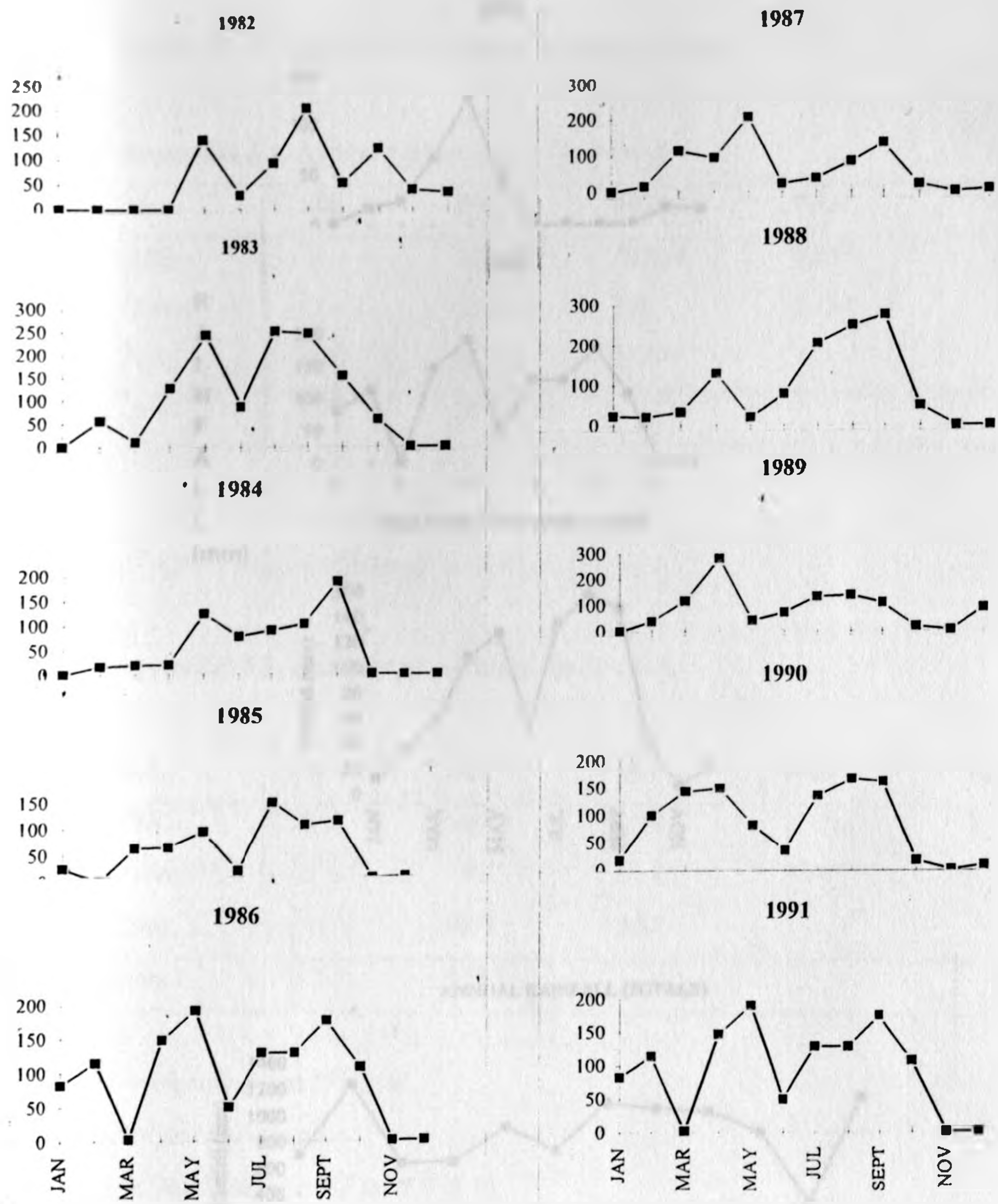
Legend:
A: Main crops
C: Traditional conservation
S: Soils on slopes
T: Natural trees

Source: Hurni, 1986

Appendix 2.1. Mean monthly and annual rainfall (mm) data of Hunde Lafto research site

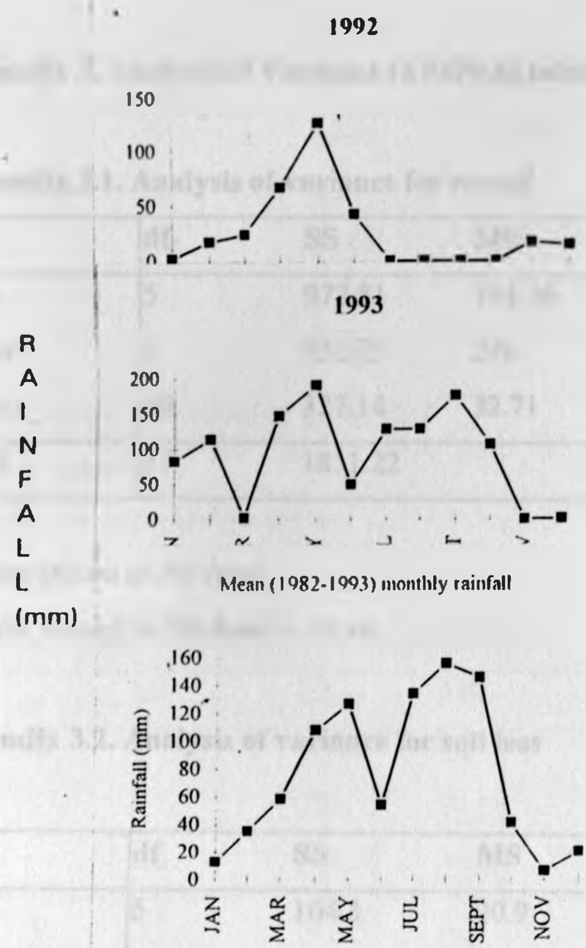
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL
1982	0	0	0	0	139.9	28.3	92.1	203.5	52.3	121.2	37.8	32.7	707.8
1983	0	56.1	10.6	128.4	244.1	87.2	251.7	246.7	154.2	58.6	0	0	1237.6
1984	0	15.7	18.7	20.3	124.1	77.4	90.1	102.9	188.7	1.4	0	0	639.3
1985	24.9	0.6	62	63.4	93.7	19.8	148.9	106.3	113.8	6.9	9.5	0	649.8
1986	0	26.2	49.7	106.2	175.3	118.3	117.4	144.9	132.3	30.4	3	3.4	907.1
1987	0	14.3	113.1	92.9	206.3	21.3	35.6	82.9	133	19.8	0	6.4	725.2
1988	23	20.6	32.7	129.4	20.1	78.3	204.2	249.1	275.2	48.5	0	0.6	1081.7
1989	0	38	116.9	281	41.7	71.8	132	137.4	108.5	17.8	4.5	89.1	1038.7
1990	17.7	99.3	143.4	148.9	81.4	35	135.2	166	160.7	17.6	1.1	9	1015.3
1991	3	19.7	127.6	110	77.2	19.4	140.3	145	107.6	23.5	0	85.2	858.5
1992	2.1	17.3	23.8	67	126.4	42.5	0	0	0	0	16.7	14.5	310.8
1993	82.1	113.9	1.6	146.7	190.1	48.7	128	128	174.9	106.4	0	0.9	1121.3

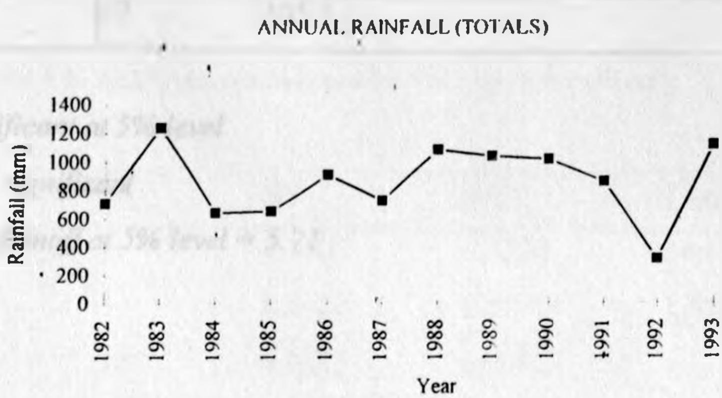
Appendix 2.2 Monthly and annual rainfall patterns inHunde Lafto



Values in the Y- axis are rainfalls in mm

...continued


1992
150
100
50
0
1993
200
150
100
50
0
RAINFALL (mm)
Mean (1982-1993) monthly rainfall
160
140
120
100
80
60
40
20
0
Rainfall (mm)
JAN
MAR
MAY
JUL
SEPT
NOV


ANNUAL RAINFALL (TOTALS)
1400
1200
1000
800
600
400
200
0
Rainfall (mm)
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
Year

Appendix 3. Analysis of Variance (ANOVA) tables

Appendix 3.1. Analysis of variance for runoff

sov	df	SS	MS	Fcal	Ftab (5%)
EPS	5	972.81	194.56	5.95 *	3.3
Years	2	552.25	276	8.44*	4.1
Error	10	327.14	32.71		
Total	17	1851.22			

** = significant at 5% level*

LSD for Runoff at 5% level = 10.40

Appendix 3.2. Analysis of variance for soil loss

Sov	df	SS	MS	Fcal	Ftab (5%)
EPS	5	104.3	20.9	2.12ns	3.3
Years	2	102.3	51.15	5.19*	4.1
Error	10	98.5	9.85		
Total	17	305.1			

** = significant at 5% level*

ns = not significant

LSD for Runoff at 5% level = 5.71

Appendix 3.3. ANOVA for soil pH at the experimental plots

SOV	df	SS	MS	Fcal	Ftab
EPS	5	1.457	0.2914	4.402*	3.3
Positions	2	0.04	0.02	0.03ns	4.1
Error	10	0.662	0.0662		
Total	17	2.159			

* = significant at 5%level of probability

ns = not significant

LSD for pH at 5% level = 0.27

Appendix 3.4. Analysis of variance for % clay

SOV	df	SS	MS	Fcal	Ftab(5%)
Positions	2	92.44	46.22	1.319ns	4.1
EPS	5	139.78	27.96	0.7984ns	3.3
Error	10	350.22	35.02		
Total	17	582.44			

LSD for % Clay at 5 % level = 10.765

Appendix 3.5. Analysis of variance for % organic carbon

SOV	df	SS	MS	Fcal	Ftab(5%)
Positions	2	0.2508	0.1254	14.106*	4.1
EPS	5	0.0728	0.01456	1.638ns	3.3
error	10	0.0889	0.00889		
Total	17	0.4125			

** significant at 5% probability levels*

ns = not significant

LSD for % O.C. at 5% level =0.172-

Appendix 3.6. Analysis of variance for total nitrogen (%)

SOV	df	SS	MS	Fcal	Ftab (5%)
Positions	2	0.003	0.0015	15*	4.1
EPS	5	0.006	0.0012	12*	3.3
Error	10	0.001	0.0001		
Total	17	0.01			

** = significant at 5% level*

LSD for T.N.(%) at 5% level = 0.0183

Appendix 3.7. Analysis of variance for available phosphorous

SOV	df	SS	MS	Fcal	Ftab
EPS	5	79.034	15.81	6.261*	3.3
Positions	2	120.21	60.11	23.81*	4.1
Error	10	25.25	2.53		
Total	17	224.49			

** = significant at 5% level*

LSD at 5% level = 2.89

Appendix 3.8. Analysis of variance for available potassium

SOV	df	SS	MS	Fcal	Ftab (5%)
EPS	5	1231.892	246.378	2.442ns	4.1
Positions	2	935.5	467.75	4.635*	3.33
error	10	1009.07	100.907		
Total	17				

ns = not significant

** = significant at 5% level*

LSD = 18.274

Appendix 4. Drainage classes

Class	Description
class 0	Very poorly drained
Class 1	poorly drained
Class 2	imperfectly drained
Class 3	Moderately well drained
Class 4	well Drained
Class 5	somewhat excessively drained
Class 6	excessively drained

Source: (FAO, !977)

Appendix 5. Description of soil depths

Class	soil depth
Rock / extremely shallow	<10 cm
very shallow	10-25 cm
Shallow	25-50 cm
Moderately deep	50-80 cm
Deep	80-120 cm
Very deep	> 120 cm

Source :Kenya Soil Survey, 1978 (Cf. Bono and Seiler, 1983)

Appendix 6. Rating for the total nitrogen content

% TN	Rating
> 0.5	very high
o.2 - 0.5	high
0.1 - 0.2	moderate
0.05 - 0.1	low
< 0.05	very low

Source: FURP, 1988.

Appendix 7. Rating of for organic matter content of mineral soils

% OC	Rating	
> 5.6	peat	
3.8 - 5.6	rich in humus	very high
1.5 - 3.8	very humic	high
0.75 - 1.5	moderately humic	moderate
0.4 - 0.75	slightly humic	low
<0.4	poor in humus	very low

Source: FURP, 1988.

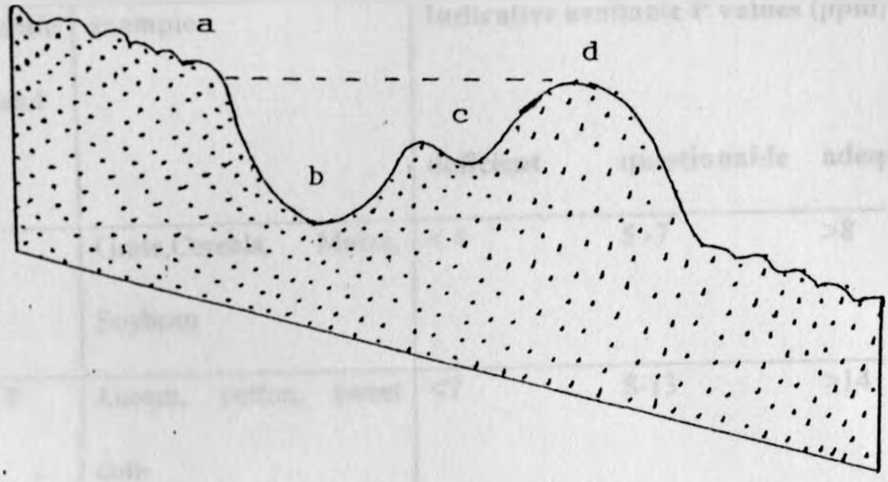
Appendix 8. Description of pore size distribution

Pores	diameter (mm)	metric potential(bar)
Coarse pores (cp)	> 0.05	< 0.1
Medium pores (mp)	0.05 - 0.01	0.1 - 0.33
Fine pores (fp)	0.01 - 0.0002	0.33 - 15
Very fine pores (vfp)	< 0.0002	> 15

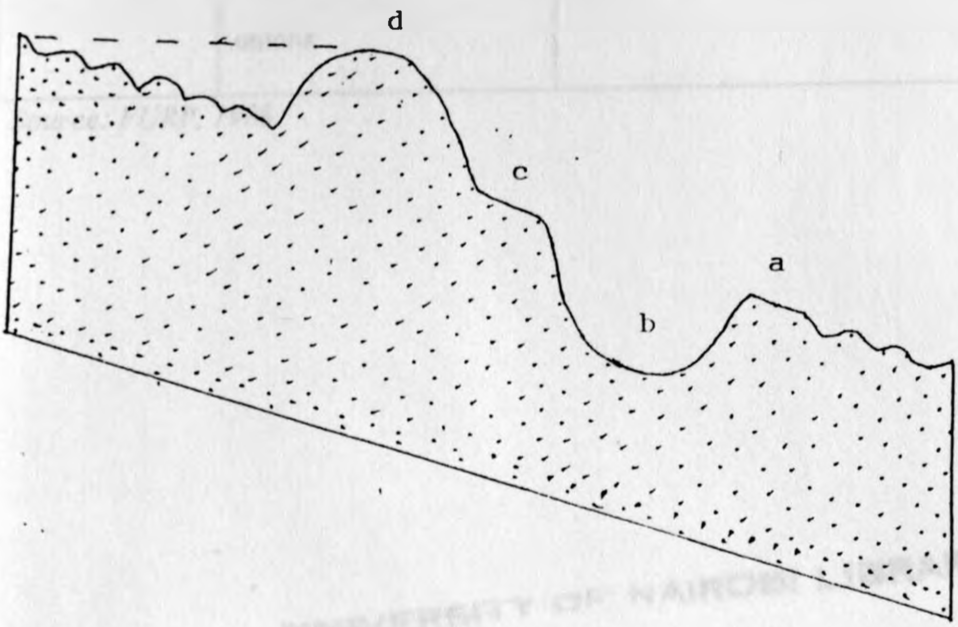
Source : Gupta and Larson, 1979 (Cf. Bono and Seiler , 1983)

Appendix 9. Cross sectional profiles of a bund (1) and a fanya juu (2)

(1)



(2)



The four elements of the structures are: (a) the ditch rim, (b) the ditch, (c) the berm and (d) the ridge

Appendix 10. Ratings for available phosphorous (Olson's Bicarbonate extraction)

Characteristic crop demand	**example**	**Indicative available P values (ppm)**		
		deficient	**questionable**	**adequate**
Low P	Grass,Cereals, Maize, Soybean	< 4	5 -7	>8
Moderate P	Lucern, cotton, sweet corn	<7	8-13	>14
High P	Sugarbeet, potatoes, onions	<11	12-20	>21

Source: FURP, 1988