SOIL CONSERVATION EXPERIMENTS ON CULTIVATED LAND IN THE MAYBAR AREA, WELLO REGION, ETHIOPIA

A Thesis

Presented to

School of Graduate Stuedies

Addis Ababa University

In Partial Fulfillment

of the Requirements for the Degree

of Master of Arts in Geography

by

Mulugeta Tesfaye

June, 1988

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

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by

Mulugeta Tesfaye

(College of Social Sciences)

Approved by

Hans Hurni (Dr) ______________________

advisor

Ermias Bekele (Dr) ______________________

Examiner

K. N. Singh (Dr) Kailash Nath Singh

Examiner

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ABSTRACT

Soil conservation experiments consisting 6 plots (five of them treated and one untreated control plot) were established in 1986 in the Maybar area to identify the most suitable soil conservation measure(s) for the area and other similar areas in Wello region. The plots (each 30m long and 6m wide) are placed side by side on a 28% slope with a well-drained, highly stony, HAPLIC PHAEOZEM of about 60 cm depth. The treatments are Level Bund, Graded Bund, Level Fanya juu, Graded Fanya juu and Grass Strip.

Soil loss and runoff measurements from the experimental plots were made during 65 rainfall events with a total rainfall amount and erosivity (EI_{30}) of 2098mm and 876 Joules m^{-1} h^{-1}, respectively. 41 of the 65 rainfall periods having a total rainfall amount and EI_{30} value of 1291mm and 516 Joules m^{-1} h^{-1} respectively were monitored in 1986. The rest (24 rainfall events with rainfall amount and EI_{30} of 807mm and 360 Joules m^{-1} h^{-1}, respectively) occurred in 1987.

The observed annual soil loss values from all experimental plots are below the tolerance level. Yet, significant differences exist between experimental plots. The graded Bund showed distinctively

higher soil loss in both 1986 and 1987 amounting to 5.15 tons/ha and 1.66 tons/ha, respectively. The three level soil conservation measures (Level Fanya juu, Grass Strip and Level Bund) consistently showed significantly lower annual soil loss values in both the years amounting to 0.49, 0.84 and 1.04 tons/ha, respectively in 1986 and to 0.15, 0.40 and 0.54 tons/ha in 1987. The control plot showed an annual soil loss of 2.02 tons/ha (which was less than half of the annual soil loss of the Graded Bund) in 1986 and of 1.1 tons/ha in 1987.

Crop cover (as the major factor), high surface stoniness of the experimental plots which encouraged infiltration of rainwater into the soil and the dominance of low - erosivity rains during the study period were observed to have resulted in very low soil losses during individual rainfall events.

Under the rainfall conditions observed in 1986 and 1987, vegetative cover together with the high surface stoniness on the experimental plots have been sufficient to reduce soil loss from the plots to values below the tolerance level. However, soil loss data collected from test plots in the Maybar area showed that extreme years will produce upto 100 times more erosion than during the study period.

As a result of the experiments, it is concluded that in the Maybar area and in the whole eastern escarpment of Wello, the choice should be for agronomic soil conservation measures. These have to be supported by physical soil conservation measures (Level Fanya juu, Grass Strip and Level Bund) on steep slopes (15 to 50%) since test plot data have shown that extreme years will result in soil losses much higher than those observed during the study period. However, even where the physical meaures are applied, the stress should be on reducing inter-terrace erosion by means of agronomic measures.

1. INTRODUCTION

1.1 Definition

The terms 'soil erosion' and 'soil loss' are defined by Mitchell and Bubenzer (1980: 17) in the following way: "Soil erosion is the gross amount of soil moved by drop detachment or runoff. Soil loss is the soil moved off a particular slope or field."

In this paper, the term 'soil loss' is used as it is defined above. 'Soil erosion', however, is considered here to have the same meaning that the term 'accelerated erosion' has in the literature of soil erosion. It is understood as the removal of soil at rates faster than its formation and is mainly attributable to man and his agricultural activities. Through continuous tillage, man disturbs and loosens the soil on slopes. When splashing and runoff occur, the soil is removed downslope at rates exceeding its regeneration. Accelerated soil erosion is therefore a man- induced process that causes serious damages to agriculture wherever it is not effectively controlled.

1.2 The Problem of Soil Erosion in Ethiopia

Soil erosion continues to be a major agricultural problem in Ethiopia, particularly in the highlands (defined as areas above 1500m asl) which constitute 43% of the total area of the country. The

Ethiopian Highlands contain 88% of the country's 46 million people, 67% of its livestock population and over 90% of its permanently cultivated area (Constable, 1985).

Since their formation, the Ethiopian Highlands have been subject to fluvial erosion with geological events playing a major role in shaping the landscape for millions of years. The problem of accelerated soil erosion did not exist during that period because the soil resource was not yet exploited for sedentary farming.

The situation changed when farming became a basic and constant activity since the fourth millennium B.C. (Galperin, 1981). Since then, more and more parts of the highlands were brought under tillage and as the practice was further intensified and extended in time and space, the natural process of soil erosion was accelerated. This in turn led to severe land degradation. Already by the first century A.D. soil erosion had gained a firm grip in the northern highlands to become one of the major causes for the downfall of the Axumite Kingdom (Butzer, 1981). Land degradation due to soil erosion is also believed to be one of the causes for the downfall of the civilization of Lalibela in the 14^{th} century and of Gonder in the 17^{th} century (Hurni, 1987: 8).

From the highlands in the north, sedentary farming (and therefore soil erosion) has spread to the south, to the east and to the west and as Kifle (1972) observed, by the 1970's soil erosion also became a serious problem in the areas where mechanized farming is practised. Today, the Ethiopian Highlands have become, in the words of Hurni (1983)," ...one of the largest areas of ecological degradation in Africa, if not in the world."

Reports of the Soil Conservation Research Project (SCRP) and of the Ethiopian Highland Reclamation Study (EHRS) confirm the above quotation. The former has recorded soil loss rates (on cultivated lands) upto more than 200 tons/ha/yr from test plots, the highest being 282 tons/ha/yr from a 22% slope planted with teff in Gojam Research Unit in 1985. Most of the test plot measurements made in the research units of SCRP from 1981 to 1986 show soil loss rates of more than 20 tons/ha/yr for various crop covers (cf. Grunder, 1986:7f).

Estimates of soil erosion rates for various land use types are also currently given by Hurni (1986a:9) in which the erosion rate from all types of land uses for the highlands as a whole is estimated at 1,493,000,000 tons per year. Nearly half of this (672,000,000 tons) is from cropland which constitutes only 13.1 % of the total area of the country. The average rate for the cropland is estimated at 42 tons/ha/yr. On the other hand, estimated soil formation rates for cultivated land range from 5 to 11 tons/ha/yr (Hurni,1986a:10). The two differing rates show the accelerated nature of the erosion process existing in the highlands. Constable (1984) also estimates that in general, an area 270,000 km^2 in extent (about half of the total area of the highlands) is significantly eroded of which 140,000km^2 is very seriously affected.

Many research works on erosion-soil productivity relations in both temperate and tropical environments have documented loss in soil productivity as a result of soil erosion. A review of the research into erosion - productivity relationships made in different environments in the world is given in Stocking (1984).

In Ethiopia, a reduction of barley yields by 25kg/ha for 1 cm of soil loss on HUMIC ANDOSOL in the Debre Birhan area in Northern Shewa is reported by Hurni (1985b). The same study indicates that with a soil loss rate of 66 tons/ha/yr for that area, the shallow soil (average soil depth of the area is 45 cm) will be completely eroded in about sixty years time from now while crop production will decrease by 35% during the first twenty years, by 50% during the second twenty years and by 100 % during the last twenty years.

This finding and the historical evidence from Butzer (1981) suggest that the great quantities of soil that has been removed from cultivated areas in the Ethiopian Highlands for thousands of years and the high soil loss rates from slopes in the highlands have been accompanied by erosion - induced crop production declines and continuously depressed yields.

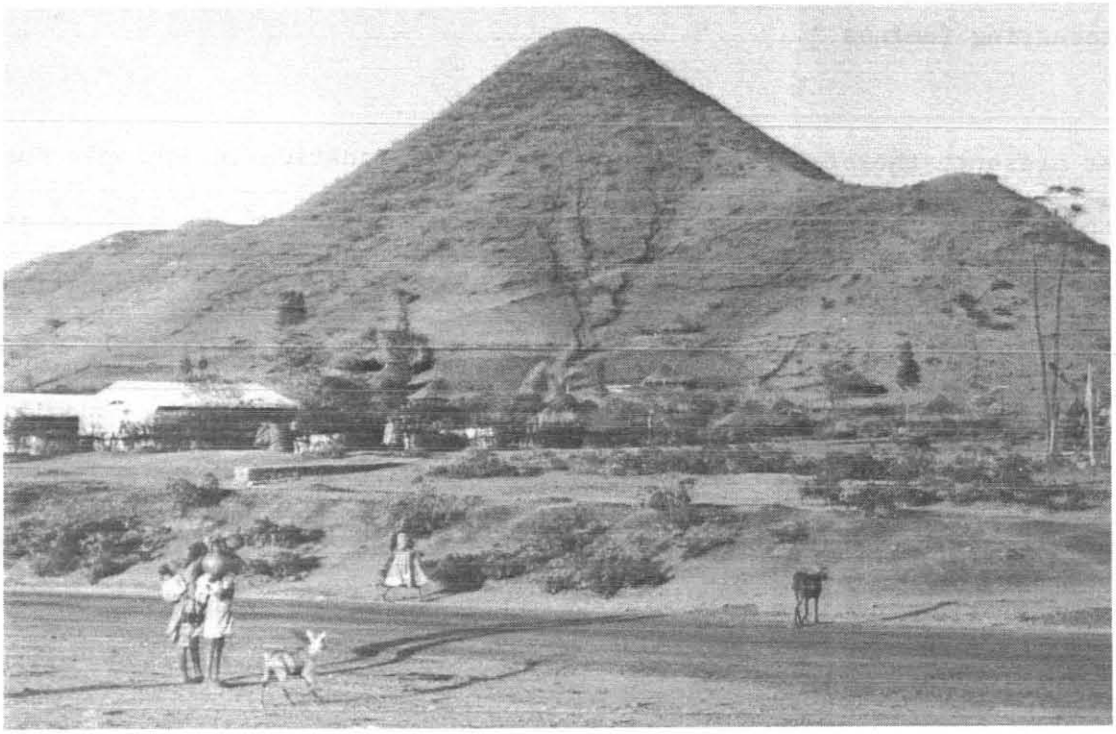


Figure 1: Famine and degradation - a vicious circle? Both elements are shown on this photo.

Some observers have indicated that degraded environments are the primary physical causes to the spread of deserts (U.N., 1977) and to famine (Cross, 1983). Although analyses based on sufficient data have not yet been done, there is a general consensus among planners and environmentalists that the recurring famines and the chronic food shortage problem in Ethiopia are also caused, among other things, by soil degradation. Hurni (1985b:2), for examople, states that the high soil loss rates in Ethiopia are "basic elements in understanding the recurring famines."

At present, therefore, the danger of land degradation in Ethiopia due to soil erosion is well documented. The seriousness of the problem is also highly recognized at government level. The Ten Years Perspective Plan gives priority to soil and water conservation activities and specifies their objectives and targets. The plan has a special provision for the implementation of catchment rehabilitation activities in the most seriously affected areas of Ethiopia. The constitution of the PDRE clearly states that the conservation of nature and natural resources especially forest, soil and water resources is also the duty of all Ethiopians (Article 55.3).

In the field a great deal of conservation activities are being made and encouraged in many parts of Ethiopia. Hurni (1985b:2) reports that the "... Ethiopian government is tackling the erosion problem with dedication, involving over 30 million peasant work-days per year for soil conservation..." However, he also recognizes that problems arise "due to uniform application of single measures to the different agroecological conditions..." This is the main reason why the conservation effort in the country has resulted in a much lower impact than expected (Grunder, 1986). Research directed to the development of conservation measures that are suitable for the different agroecological zones of Ethiopia has, therefore, become a very pressing task and an important aspect of the overall conservation movement in the country at the moment.

This study is devoted to the identification of the most suitable conservation measure(s) for the Maybar area and for other areas in Wello Region (and adjoining areas in Shewa) having topographic and climatic conditions similar to those of the Maybar area by making field plot experimental research.

1.3 Site Location of the Study

The Soil Conservation Research Project (SCRP) has established seven research units in several agroclimatic regions of the Ethiopian Highlands one of which is the Wello Research Unit (Maybar area).

In the Maybar area, which is defined by Weigel (1986a) as having a total drainage area of $9km^2$ (Figure 2), the Kori catchment ($1.16\ km^2$) was selected for soil conservation research. Abbo Ager Research Station (25 kms SSE of Desse) was built in the Kori catchment in 1981. The station is equipped with meteorological instruments including an automatic rainguage for measuring quantity and intensity.

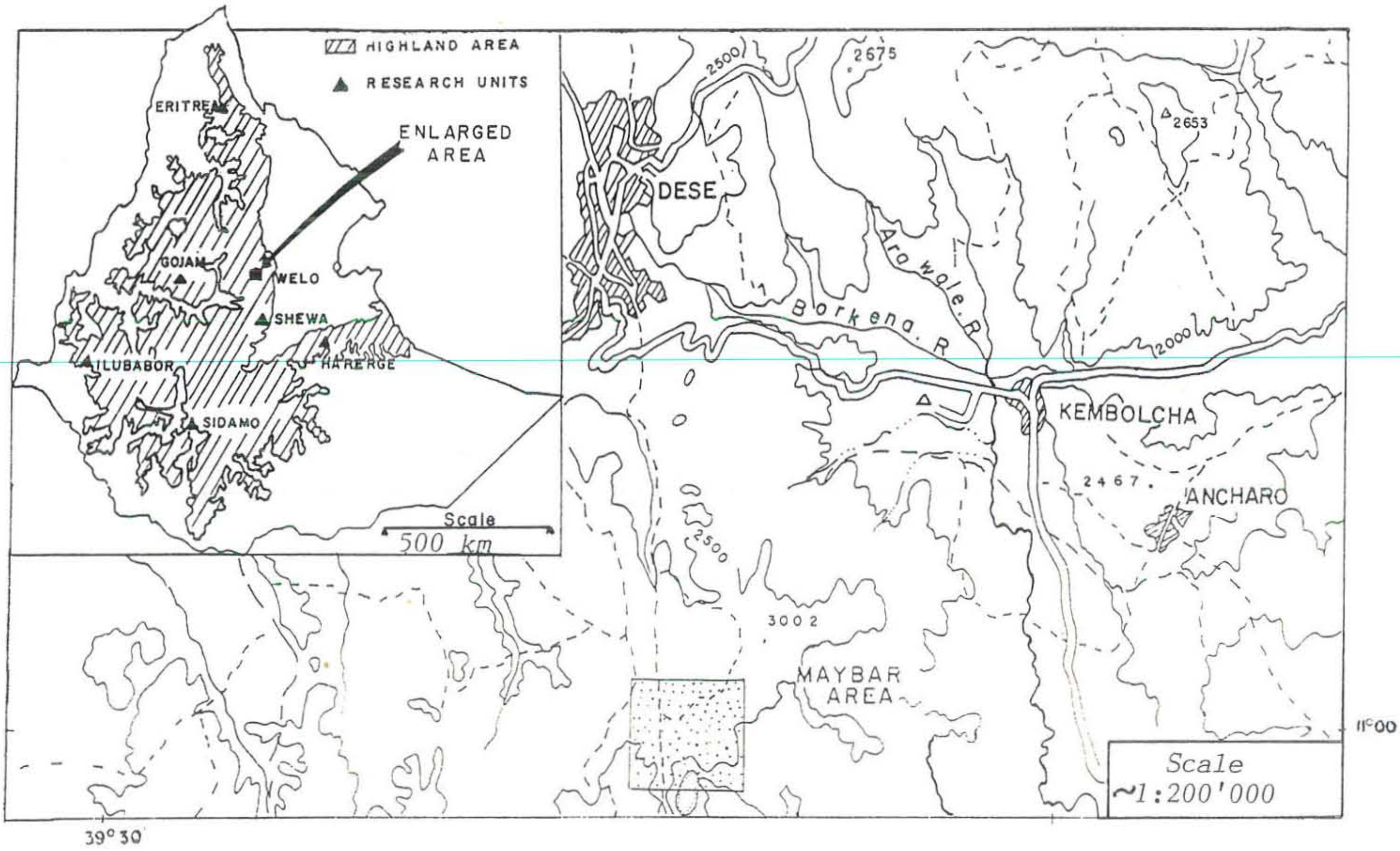
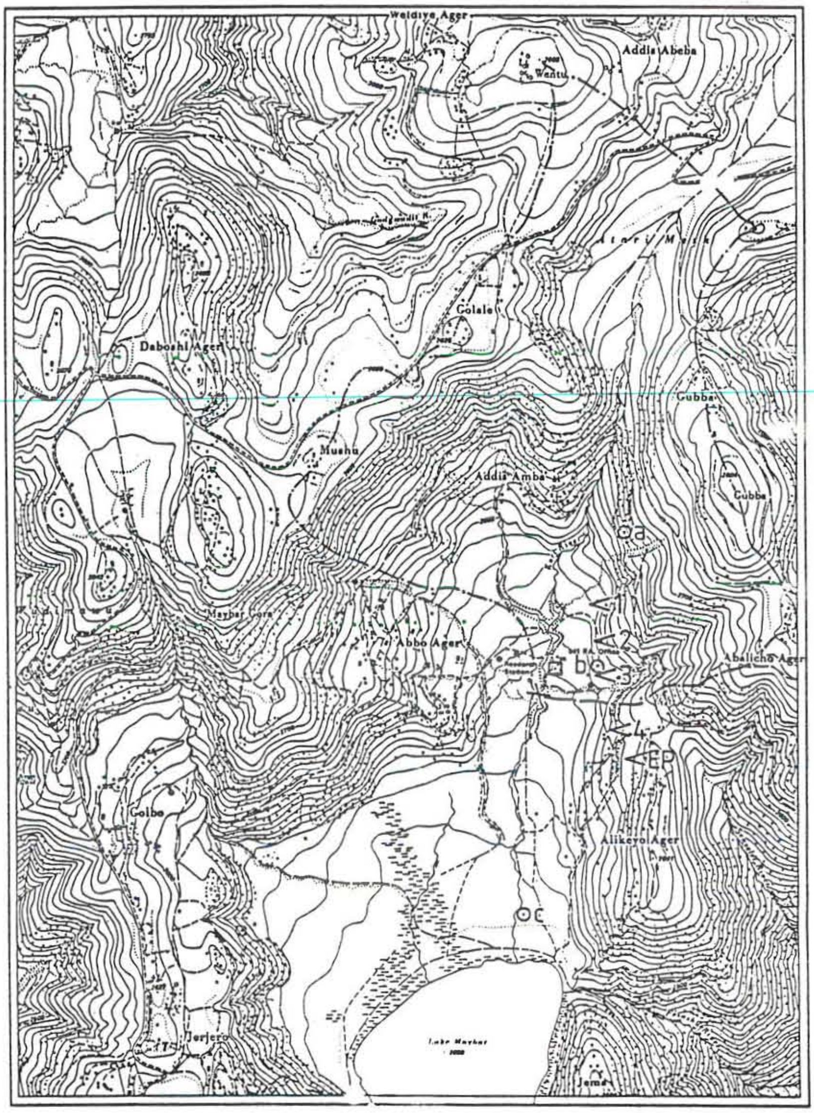


Figure 2: Location of maybar area.

Sources : SCRP and Ethiopian Mapping Agency (EMA).

The soil conservation experimental plots (set up in 1986) are located at an altitude of 2625m above sea level, about 500 meters east of the site of the Abbo Ager Research Station (Figure 3). They lie on a hillside slope of 28%.



Legend:

• 2021	Spot height		Forest (newly planted: P)
• ▬	Local houses		Woodland (afforested: A)
	Mosque		Bushland
	Church	o	Big tree
	Moslem cementary	•	Small tree
	Christian cementary		Gully border
	Local school		Perennial stream
	All-weather road		Seasonal stream
	Dry-weather road		Swampy area
	Major trail		
	Local trail		
	Hedge		
•	Spring		

Contours are at 10 m vertical intervals, with intermediate 5 m contours if necessary. Elevations in metres.

N

—·—	*Watershed boundary*
	River station
□	*Research Station SCRP*
⊙a	*Soil profile pits*
< 3	*Testplots 2m x 15m*
<EP	*Experimental plots 6m x 30m*
<FE	*Field-Experiment 0.8 ha*

Source: Hans Hurni and Bruno Messerli, 1983: Maybar - Wello Region, 1:10'000. CFSCDD, MoA, Ethiopia

Scale: 0 — 500 m — 1 km

Figure 3: Location of the Abbo Ager Research station and the experimental plots in the Maybar area.

1.4 Soil Properties of the Experimental site

The soil on which the experimental plots are located is a well-drained, highly stony HAPLIC PHAEOZEM of about 60 cm depth (cf Appendix XII). It is sandy loamy in texture and dark brown in colour. According to Weigel (1986a:35) the soil is high in its soil moisture storage capacity and is characterized by medium nitrogen and phosphorous contents (0.16% and 10ppm, respectively) in the uppermost horizon. The organic matter content and the erodibility factor of the soil are given as 3.4% and 0.31 respectively.

1.5 Objectives of the Study

The study has the following objectives:

1. To compare runoff, soil loss and crop yield from six experimental plots in the Maybar area (Wello Research Unit), five of them treated with different conservation measures (see section 1.6) and one untreated control plot, during the four rainy seasons of 1986 and 1987.
2. To propose the most suitable conservation measure(s) for the Maybar area and for other areas in Wello Region which have environmental conditions (altitudes, rainfall, slope, soil) as well as human and animal population densities similar to those of the area in which the study is carried out (Maybar area).

1.6 Methods

Experiments consisting six plots were used to evaluate the effect of five conservation measures on runoff, soil loss, and crop yield. The design of the experiments is similar to that of the Anjeni experimental plots in Gojam, Ethiopia and to the design made by Hurni and Nuntapong (1983).

The treatments are Level Bund, Graded Bund, Level Fanya juu, Graded Fanya juu and Grass Strip (Figure 5). The spacing of conservation measures on the treated plots is 8 meters and the two graded structures have gradients of 1%. Figure 4 shows the cross-sections of the Grass Strip, the Level Bund and the Level Fanya juu (the cross sections of the two graded structures are not different from those of their counterparts - the two level structures).

The six plots (experimental plots) are equal in size, each 30m long and 6m wide placed side by side and separated from each other by corrugated iron walls. The corrugated iron walls are removable whenever the farmer wants to cultivate his farm land.

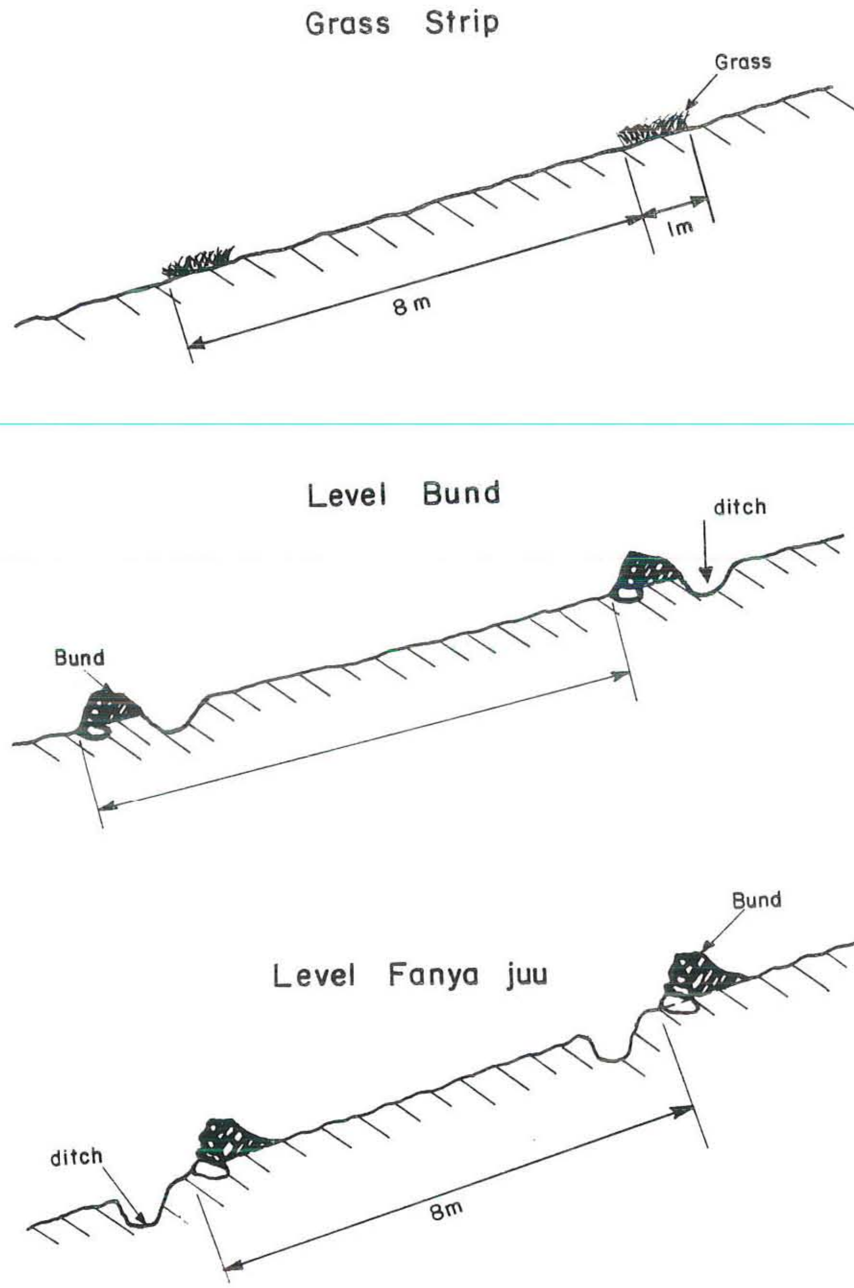


Figure 4: Cross sections of Grass Strip, Level Bund and Level Fanya juu. After Hurni, 1986b: 40f.

Each plot is connected to a cemented collection ditch and to a two-chambered runoff and sediment collection tank both situated at the down slope end of the plot (Figure 6). Each collection tank has a volume of $1m^3$.

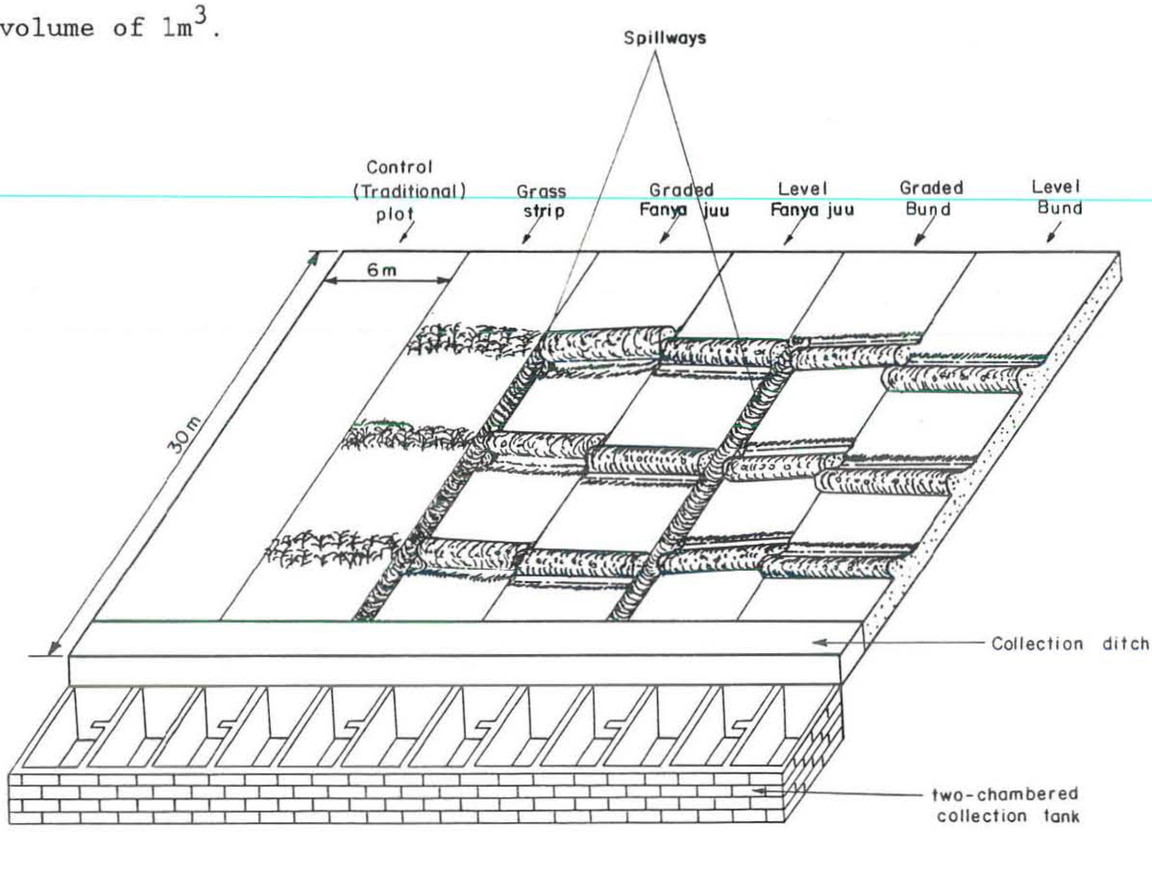


Figure 5 : Set-up and dimensions of the experimental plots.

Between the first and the second tank of each plot, there is a slot divisor with ten holes designed in such a way that only one-tenth of the overflow from the first tank enters the second one whenever a heavy storm with much runoff occurs. This method enables measurement of runoff and soil loss for even the rarely occuring heaviest storms. All tanks have corrugated iron covers so that raindrops do not enter them directly. Each tank has two outlet tubes for draining the water and cleaning the tanks after each measurement.

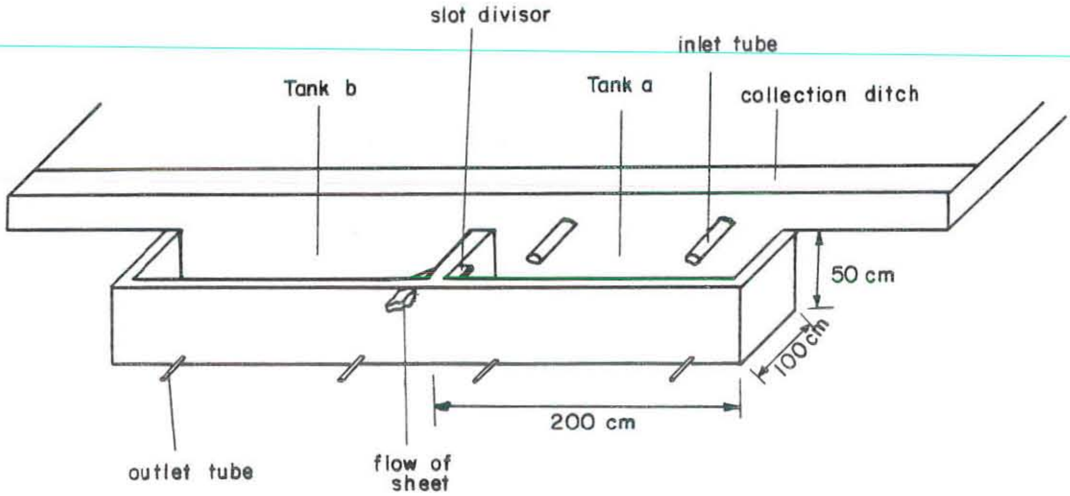


Figure 6 : Collection tanks at the downslope end of each experimental plot.

After Werner, 1986 : 19.

After each rainfall period (event), the depth of the water in the collection tanks was measured. The plot runoff in millimeters and the runoff as a percentage of rain for each plot were determined by a computer programme (cf. Appendix III). The runoff contribution from the cemented collection ditch was corrected.

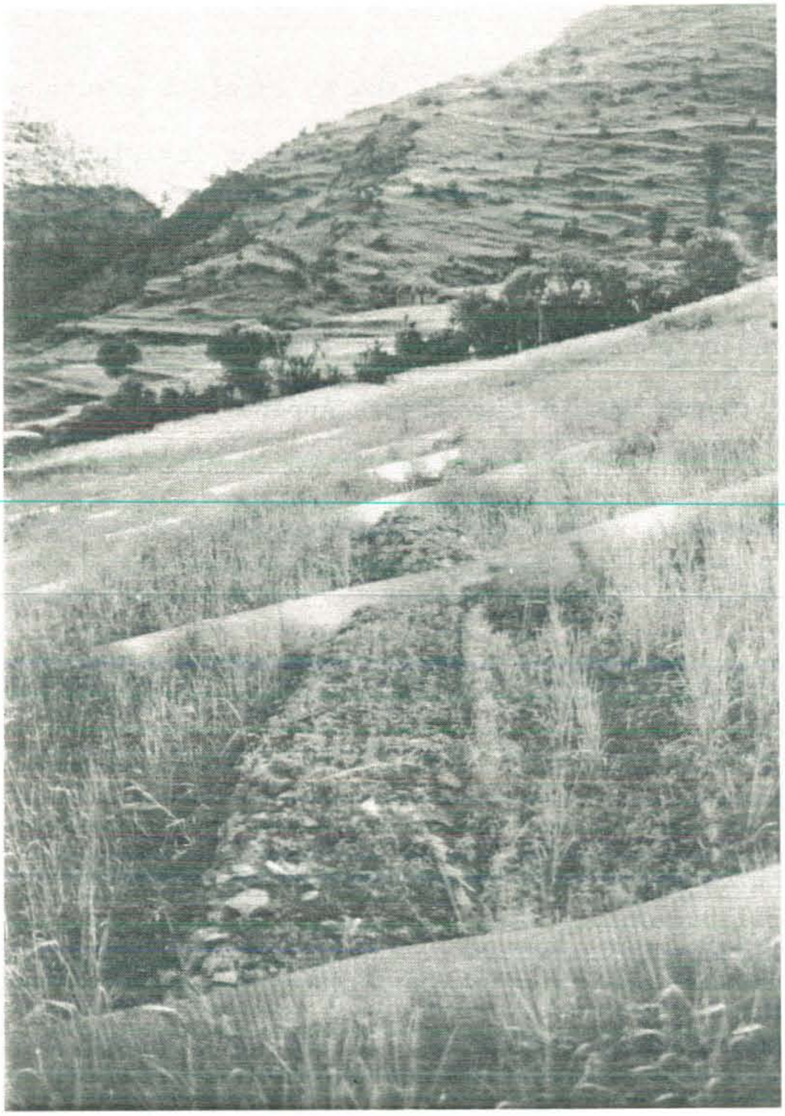


Figure 7: Partial view of the experimental plots.

The soil accumulated in the sediment tanks was weighed wet. The 500 gm of wet samples (in some cases less than this) collected after each rainfall event were sun dried in the station and taken to the soil laboratory in the SCRP's office in Addis Ababa for oven dry weights and for calculating the total dry soil loss (cf. Apendex IV).

Erosivity of each of the 65 rainfall events monitored during the study period was calculated using the Wischmeier and Smith (1978) method. For comparison, the KE > 25 index (Hudson, 1981:70), which is an erosivity index consisting of the total kinetic energy of all the rain falling at greater than 25 mm per hour, was also calculated for each rainfall event(cf. Appendix I & II).

Pearson's Correlation Coefficient is used to see the strength of relation between runoff and soil loss (dependent variables) and rainfall amount, energy, I_{30} (maximum intensity in 30 minutes), the EI_{30} (the product of the kinetic energy of the rain and the 30-minute intensity, Wischmeier and Smith, 1978), and the KE > 25 (independent variables). The same statistical method is used to observe the relationship between runoff and soil loss as well as between crop growth (height) and soil loss during the four cropping seasons. Measurements of crop height and observation of soil moisture conditions were done once every week. The oneway analysis of variance is employed to find out whether the observed variations in soil loss and runoff between the plots are significant or not.

The percentage of ground covered by stones on each experimental plot was determined by simple random sampling using grids of wire on $1m^2$ (each grid being 20 cm x 20 cm). Each plot was sampled six times which gave a total of 150 samples (6 x 25 grids) per plot. From these, the mean percentage of ground covered by stones on each experimental plot was calculated.

Identification of the wider areas in Wello and adjoining areas in Shewa to which physical soil conservation measures are recommended is done by overlapping the rainfall map of Ethiopia (1:2,000,000, enlarged to 1:1,000,000), the average slope map of Ethiopia (1:1,000,000) and the topographic map of Ethiopia (1:1,000,000). The overlapping was done by taking only those areas to which the recommendation is made.

2. LITERAURE REVIEW

2.1 Soil Erosion Research

Soil erosion research originated in the United States in the 1920's. Since then, much knowledge about the causes of soil erosion and, for some areas and regions, about its magnitude, extent, measures of control and its effects on soil productivity has been acquired. Belpomme (1977) observes that in the 1970's alone, over 10,000 studies on soil erosion phenomena have been published throghout the world.

Most of this research output, is concentrated in the United States, Europe and in a few other countries with active research centers whereas there is a scarcity of research in large areas of the world (Hudson, 1981; Stocking and Peake, 1985).

In general, three major themes of research on soil erosion can be identified: assessment of potential and actual erosion damages by direct surveys; identification of the factors that cause soil erosion, assessing their relative strength in causing soil erosion and developing models for estimating soil losses; and investigation of the effect of soil erosion on soil productivity.

Assessment of potential and actual erosion damages has involved the use of qualitative descriptions, small scale maps, questionnaires, areal photographs and nowadays remote sensing techniques.

Such methods of assessing erosion hazards have been criticized for being unrealistic (Young, 1977). However, because the delineation of affected areas even in the most generalized form was found out to be useful for planning remedial measures, local, regional, national and even international surveys of actual and potential erosion damages were carried out since the 1920's by governments, international agencies and by individual researchers.

De Boodt and Gabriels (1977) report that erosion damages have been mapped in the United States and in the majority of European countries revealing that erosion is a hazard in many countries of Europe including Britain, Belgium and Germany and in the United States.

However, as indicated by Blaikie (1985) in these countries, the impact of soil erosion on agricultural production is concealed by yield-increasing technologies.

Soil erosion is a serious problem particularly in the developing countries due to "a complexity of human and physical factors which undermine not only development projects but present day subsistence" (Stocking, 1981:383). Quoting FAO sources , Lal (1977) states that vast areas of the highlands in Ecuador, Columbia and in the Andes have been either destroyed or seriously damaged by erosion. Another FAO (1983) report also indicates that 13% of the cropland of Argentina, 27% of the total area of India and 11.6% of the total area in Africa north of the equator is affected by water erosion. Nigeria's soil erosion problem is described by Blaikie (1985) as being extremely serious. According to Lal (1977) the areas that are particularly susceptible to rainfall erosion in West Africa include Gabon, Cameroon, Nigeria, Ghana, Ivory Cost, Liberia and Sierra Leone. In general, in West Africa, water erosion particularly of the sheet type, is more widespread than wind erosion (Okigbo, 1977). Ahn (1977) also indicates that soil erosion is a serious hazard in East Africa.

Identification of the major variables that determine soil erosion and developing quantitative methods for estimating (predicting) soil losses which is yet another theme of soil erosion research, has been receiving the attention of several researchers particularly since the 1950's. A group of U.S. scientists used laboratory and field experiments to test and formulate each of the major factors that cause soil erosion and the result of several years of research endeavour is the evolution of the Universal Soil Loss Equation (USLE) in the late 1950's (quoted from Hudson, 1981).

The basic equation runs as follows:

$A = RKLSCP$ Where

A = the predicted soil loss in t/ha/yr

R = the rainfall erosivity factor in 1MJ mm $ha^{-1}h^{-1}$

K = the soil erodibility factor in t ha h ha^{-1} MJ^{-1} mm^{-1}

L = the slope length factor

S = the slope gradient factor

C = the cropping management factor

P = the conservation practice factor.

Although criticized by some as being not universal because it was developed for situations in the Eastern United States (Mitchell and Bubenzer 1980:22) and for not including all relevant factors of erosion (Morgan, 1977), the equation has been widely used in many countries and environments for estimating soil loss rates that could be used for planning conservation activities on cultivated areas. Hurni(1985a) has provisionally adapted some factors of the equation for Ethiopia (eg. R-factor in J $m^{-1}h^{-1}$).

Recent investigations in this theme of research are focussed on modifying the USLE so that it is used for a greater range of conditions such as predicting sediment yields from individual gullies and watershades (Mitchell and Bubenzer, 1980: 47ff). A brief but an important review of experimental research on one of the factors of the USLE (rainfall erosivity) is given in Morgan (1986: 41f).

In another aspect of the same theme, soil losses during individual rainfall events are also observed and the studies of several authors indicate the dominance of a single or a few heavy storms in erosion losses.

Edwards (1985 : 476) reports that a single runoff contributed more than 50% of the total annual losses in eighteen out of the thirty years of observation in two research sites in Australia. In their study of the effects of four conservation measures on runoff and soil loss mentioned in section 2.2 below, Sheng et al. (1981 : 31) also found that six storms yielded 88% of the soil loss from the control plot. Hudson (1981) as well states that in his research in Zimbabwe, more than 50% of the total amount of soil loss recorded was the result of one or two heaviest storms. Here in Ethiopia, two storms were observed accounting for 99% of the total annual soil loss from Test Plot - 4 in 1984 in the Abbo Ager Research Station (cf. SCRP, 4th Progress Report, 1984). As will be shown in section 4.2.5, a similar situation was observed in the present study.

The third theme of research investigates the consequences of erosion on soil productivity expressed mainly in the form of nutrient losses and crop yield declines. This research theme has been the list investigated until the 1970's. Since that time however, it is becoming increasingly important as demonstrated by the fact that out of the total number of 195 research works on erosion productivity relations collated by Stocking & Peake (1985) 127(65%) were done in the 1970's and 1980's. 85% of the research is carried out in the U.S., and the rest in Australia, Europe, Africa, Latin America and Asia. Methods of research include field experimentation (both under natural and under simulated erosion conditions) and model building. A review of all the research into erosion-productivity relation is made by Stocking (1984), Stocking and Peake (1985) and by Peake (1986). Discussions of research results in these reviews clearly show reduction of the productivity- potential of soils due to soil erosion.

2.2 Soil Conservation Research

The problems associated with soil erosion - land degradation, widespread famine in developing countries and others - have long prompted interest in soil conservation research. The world soil conservation research has been geared towards the development of three complementary erosion control measures known as mechanical (physical), agronomic (biological) and soil management measures.

In the research directed towards the development of agronomic (biological) measures, the aim is to reduce soil erosion through the help of vegetative cover. Research on soil management measures is concerned with influencing the erodibility of the soil by improving its structure (and hence its infiltration capacity) so that it is more resistant to erosion. The research on mechanical methods seeks to develop measures which involve earth moving and soil shaping practices for reducing the velocity of runoff.

According to Hudson (1981) the pioneer research on agronomic conservation was by the German soil scientist, Wollny, who used small plots to observe the effects of vegetation and surface mulches on the interception of runoff in the late 19th century. A nine-year experiment done by Hudson in 1957 in Zimbabwe showed that the mean annual soil loss and runoff from a tilled, continuously weeded plot was 127 and 13 times more, respectively, than from a continuously weeded plot having the same soil type and slope gradient but covered with a wire guaze which simulated a full vegetative cover (reported by Elwell and Stocking, 1976).

Quoting from the research done by Lal in Nigeria, Greenland and Lal (1977) also indicate that the runoff from the bare fallow plots was 16 times more than that from the plots treated with 6 tons/ha mulch. The mean annual soil loss from the treated plots was 730 times less than those from the bare fallow plots. In the same country Aina et al. (1976) studied the effect of mixed cropping systems on runoff and soil loss. They reported that mixed cropping system decreased soil loss and runoff compared with a mono-cropping system, regardless of slope gradients.

Marston and Perrens (1981) compared the effect of zero - tillage and stubble incorporation to tillage on runoff using simulated rain in the northeastern wheat belt of Australia. They found out that the zero-tillage (and retention of crop residue) significantly reduced runoff velocity and therefore soil loss.

Comparison and development of physical measures of soil conservation has also received the attention of some research workers. Quoting from Fourner's research in Upper Volta, Greenland and Lal (1977) indicate that the runoff from field ridging was only 0.9% of the rainfall as compared to 12.2% of runoff from flat cultivation. Sheng et al. (1981) studied the effects of four types of structures - bench terraces, intermittent terraces (terraces in which every third bench is actually constructed, the intermediate land being untreated), hillside ditches, contour bunds and of an untreated control plots on runoff and soil losses in Thailand. Results show that runoff was highest from bench terraces and lowest from the untreated plots. All structure reduced soil loss by about half as compared to the control plot, but no significant difference in soil loss was found out between the structures.

Hurni and Nuntapong (1983) compared runoff and soil loss from six plots in Thailand. Plot I was planted with traditional upland rice; plot II was fallow with some weeding; plot III to VI were planted as agroforestry plots with a mixture of trees, coffee, drainage ditches across the slope, lemon grass strips along the contour and one or two out of the three basic crops (upland rice, maize, peanuts) in each plot. One year results show that all agro-forestry plots reduced soil losses to annual totals of 22,13,10 and 10 t ha^{-1} respectively compared to annual total of 89 t ha^{-1} from the traditional plot. However, soil loss from the fallow test plot was less than that from the traditional plot since the fallow test plot was not kept in continuous fallow with tillage up and down the slope.

The soil conservation research works quoted so far belong into any one of the three approaches to soil conservation (agronomic, soil management and mechanical methods) mentioned earlier. However, the emphasis henceforth should perhaps be on studying the effect of combined measures on runoff and soil losses. It should also be pointed out that unlike many of the studies reviewed above, the runoff and soil loss data of the present study was generated from the

Figure 8: Traditional farming practice on the experimental plots.

conservation experiments under natural rainfall conditions and under traditional farming practices (Figure 8). Results obtained from this kind of experimentation are therefore expected to be nearer to the real situations.

2.3 Soil Erosion and Soil Conservation Research in Ethiopia

Soil erosion and conservation research is quite young in Ethiopia. Scientific approach to the problem was rare before the 1970's (Hurni, 1986a). Pereira (1968) proposed a rather detailed plan for conservation works and warned of the danger of soil degradation. Gunnar (1969) gives a brief qualitative treatment of the process of soil erosion and relates this to actual situations in Chilalo Awraja. Other cases of soil erosion study in Ethiopia include El Hassanin (1985) who studied the problem of soil erosion on the Awash Valley and Assefa Kuru (1986) who assessed the degree and extent of soil erosion using MSS LANDSAT method of data interpretation. His study recognizes six soil erosion severity classes (1 to 6) in Ethiopia, 1 denoting least severity and 6 highest severity. However, the method itself has serious limitation because it was not supported by ground verification. Because of this, the whole province of Desse Zuria (in Wello Region), for example, is classed in the highest degree of soil erosion severity (in class 6) although in reality there are extensive areas such as the Tossa Fellana Plain and the Gerado Plain where the soil erosion hazard is least.

A more marked transformation of soil erosion and conservation research in Ethiopia from qualitative approach to the experimental-quantitative approach came with the initiation of SCRP in 1981 within the framework of the then Soil and Water Conservation Department (SWCD) of the Ministry of Agriculture.

The main objectives of SCRP are "to provide the Ethiopian soil conservation with necessary basic data for the proper implementation of soil conservation measures, to test the applied and to plan adapted measures, and to train local as well as international personnel in this field of study" (SCRP, 1984:9). To this end, seven research stations were set up in a wide range of agroecological zones since the year 1981 and besides other activities basic data on erosion processes were generated from test plots (cf. Grunder, 1986:7). The data on soil loss rates collected by SCRP up to 1986 range from 0 to 282 tons/ha/yr showing high variation in soil loss rates in the Ethiopian Highlands due to variation in topographic, land use and climatic conditions (for soil formation rates in the highlands, see section 1.2).

The high soil loss rates on cultivated areas indicate the need for conservation measures to be applied to a wide range of ecological zones in Ethiopia. Hurni (1985b:2), underlining the need for research in this direction writes: "...present day soil and sediment losses from slopes and in rivers amount to horrifying quantities... Conservation activities, including aiming at a better understanding of the situation, and a contribution to its improvement, belong to the heart of development efforts..."

The quotation clearly calls for the need of intensive research in two closely related aspects of the problem of soil erosion. First, research directed towards "... a better understanding of the situation" that is estimating soil and sediment losses from cultivated areas and rivers using standard methods of research; second, research that leads to the solution of the problem, or "a contribution to its improvement" which means the development of efficient conservation measures to reduce runoff and soil loss in different ecological zones in Ethiopia. Reports prepared by SCRP (1984, 1986) and remarks made by Thomas (1984a, 1984b) and by El-Swaify et al. (1982) indicate that, so far, relatively more research work has been done in the first aspect of the problem.

Underlining the importance of research in the second aspect of the problem, Hurni (1985b) writes: "... Research will have to be application oriented, foccussing more on conservation and development problems, while the assessment of the status quo should be kept rather as a monitoring unit than a target for itself..." As already indicated in section 1.2 the research reported by this paper is a contribution in this direction.

3. GEOGRAPHICAL BACKGROUND OF THE MAYBAR AREA

3.1 Geology

Geologically, Maybar is part of the Afar margin and the tectonics are dominated by graben faulting (Pilger and Roessler, 1975). The rocks outcropping in this area are mainly alkaline olivine basalts, tuffs and porphyrites which belong to the Ashangi groups of the trap series (Ministry of Mines, 1973). The Ashangi basalts are attributed to Paleocene Oligocene - Miocene flows and are believed to be over 30 million years old (Justin - Visentin and Zanettin, 1974). The chemical characters of these rocks are very similar to the rocks of the same volcanic sequence of the Ethiopian plateau or of other zones of the Afar margin. They all show a definite alkaline character.

3.2. Climate

Figure 9 shows the climatic data (temperature and rainfall) and the altitude of Abbo Ager, Desse and Kembolcha stations. The data for Abbo Ager is based on 6 years observation. The temperature and rainfall data for Kembolcha station are based on 33-year and 21-year observation, respectively, and those of Desse on 14-year and 21-year observation.

According to Hurni's (1986b) agroclimatic zonation, the altitude, mean annual temperature and mean annual rainfall for the Moist Dega Agroclimatic Zone range from 2300 to 3200m asl, 12 to 18$_{o}$C and 900 to 1400mm, respectively. Abbo Ager and Desse stations therefore represent climatic conditions of the broad Moist Dega Agroclimatic zone.

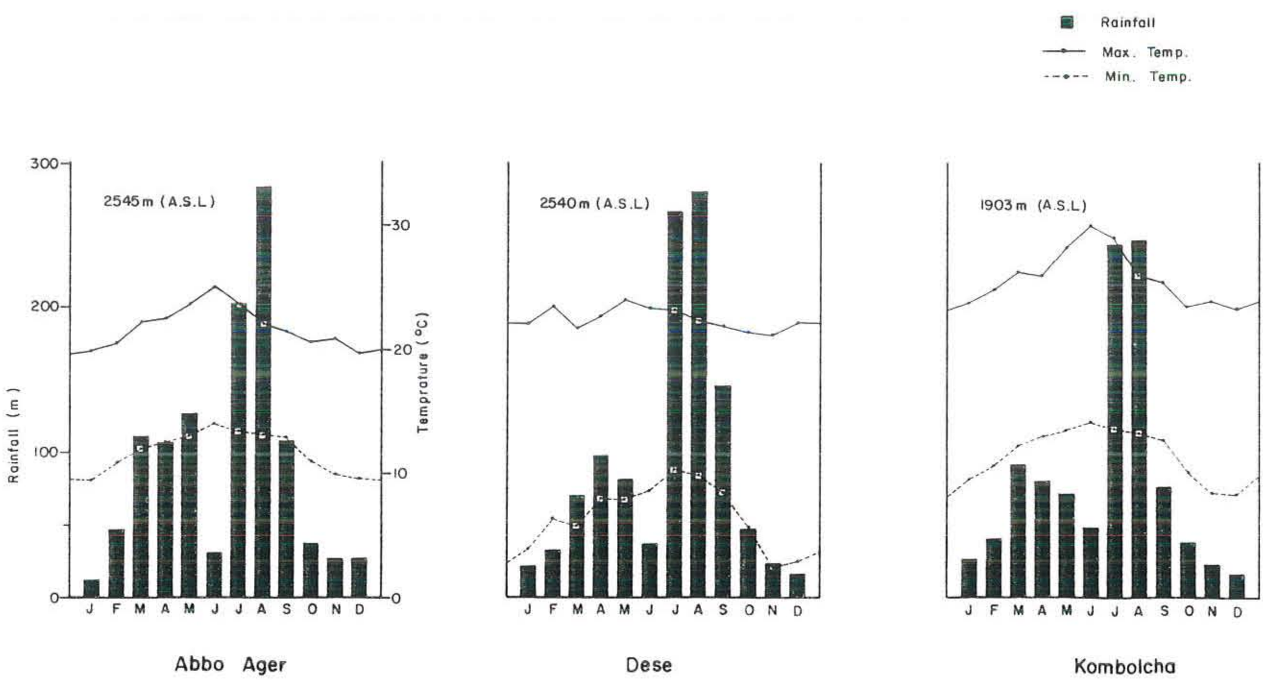


Figure 9: Climatic data of Abbo Ager, Desse and Kembolcha.

Sources : SCRP, 1982 - 1987.

National Meteorological Services Agency (NMSA), various years.

This also means that, in general, the long term observation in Desse is representative of the Maybar area (where Abbo Ager station is located) since both areas have similar topographic features and Abbo Ager lies only a short straigt line distance (about 10kms) from Desse. Although Kembolcha as well lies a short distance from the Maybar area, its altitude is too low to be representative of the Moist Dega Agroclimatic Zone.

The rainfall regime of the Maybar area shows alternating dry and rainy seasons. The small rainy season or Belg which is caused by on-shore southeasterly winds from the Indian Ocean, occurs from March to May. This is followed by a brief dry period in June. About 60% of the rain comes in the main rainy season or Kremt which extends from July to September. The Kremt season is caused by moist westerly winds from the Atlantic. The dry season from October to February is induced by northeasterly and easterly winds from the interior of Asia. The rainfall regime is therefore typical for the eastern escarpment region of Wello.

3.3 Vegetation, Topography and Soils

Vegetation

The natural vegetation of Maybar area consists of trees, bushes and grasses. The trees occurring on slopes, are remnants of a once dense evergreen forest and include species such as *Juniperus procera*, *Olea africana*, and *Hajenia abyssinica*. Bushes and scrubs are found on steep slopes and along river valleys. On the flatter ground near Lake Maybar, the vegetation consists of meadow grasses. Species of Lobelia are found along the ages of the lake and various mosses and linchens occur on rock outcrops.

Topography

Maybar area has quite marked topographic variation which is the result of both tectonic phenomena and fluvial erosion. Elevations in the area range from 2500m to a little more than 2800m asl. Steep and very steep slopes cover three-fourth of the total area (Table 1). The rest is made up of moderately steep slopes of colluvial deposites and sloping valley bottoms with alluvial deposites. Cultivation is done even on very steep slopes (> 55%) although some of these are currently closed for reafforestation purposes.

Table 1: Slope classes of the Maybar area.

Slope class	Slope angle(%)	Slope designation	% of total area	in % of cultivated area
1	0-2	flat or almost flat	-	-
2	2-6	gently sloping	-	-
3	6-13	sloping	6	8
4	13-25	moderately steep	20	44
5	25-55	steep	38	44
6	>55	very steep	36	18

Source: Weigel, 1986b : 30 after FAO, 1977:9.

In general, Maybar is typical of the dominant landform types found in the eastern escarpment region of Wello at large (Hurni, personal communication). Both Maybar and the eastern escarpement region are generally characterized by high altitude areas (above 2300m) with steep slopes and gentle bottom lands.

A prominent part of Maybar's topographic feature is Lake Maybar which lies at an elevation of 2500m asl. The lake has an approximate area of 1.5 km^2 (Ketema, 1980:28) and gets its water supply from runoff of small non-perennial streams and from small springs in the surrounding area. River Fellana, which drains eastward into the Broken Valley, is the outlet of Lake Maybar.

Soils

The Maybar area provides a living verification of the catena concept in the analysis of the relationship of soils and landforms. The concept holds that the properties and distribution of soils cannot be understood in isolation from the geomorphic systems of which they are an integral part (Gerrard, 1981:61ff). The study made by Weigel (1986a) bears out this strong relationship. His study indicates that the distribution of soils in the Maybar area is primarily controlled by geomorphic forms (relief) and the history of land use (soil erosion) with climate and parent rock having no recognizable impact on the distribution.

The influence of relief on soil distribution is indirect. On steep slopes runoff exceeds infiltration rate. Erosion processes dominate over the process of accumulation. The erosion processes operating on these landform units are accentuated by accompaning cultivation practices. Soil distribution on such slopes is therefore restricted to LITHOSOLS and very shallow HAPLIC PHAEOZEMS.

On gentler concave slopes and valley bottoms the processes of accumulation predominate over the process of erosion. This results in moderately deep to deep (soil depth 50-100cm) and very deep (soil depth > 100cm) fertile HAPLIC PHAEOZEMS and EUTRIC REGOSOLS on the gentler slopes. On the more flatter grounds near Lake Maybar, where water accumulates long, hydromorphic soils or MOLLIC GLEYSOLS are formed.

The influence of land use on soil distribution is also indirect. Deforestation and cultivation activities carried out on the steep slopes of Maybar have long accelerated the normal rates of soil erosion. This in turn has led to reduction in soil depths, soil nutrients and soil organic matter content on the same slopes. Throughout long time. land use practices in the Maybar area have led into severe degradation of the land.

The shallow to very shallow PHAEOZEMS and associated LITHOSOLS with soil depths of less than 50cm occur on more than 50% of the Maybar area (Weigel,1986a:41f). Since these soils are also used for cultivation, the soil depth which is too shallow to hold sufficient moisture for deficiency times is a serious limiting factor for higher crop yields. The moderately deep to deep HAPLIC PHAEOZEMS cover 19% of the area. These soils have sufficient rooting depth for crops but they occur on slopes where soil erosion is a limiting factor (For further information about the soils of the Maybar area, see Weigel, 1986a).

3.4 People, Land Use and Agriculture

The population and livestock densities for the Maybar area are 220 persons/km^2 and 350 TLU (Tropical Livestock Unit) per km^2 (Hurni, in preparation). This is similar to the figures for the eastern escarpment region of Wello which are given as 200 persons/km^2 and 300 TLU per km^2 by the same source.

Table 2 shows the human and livestock population found in the Kori catchment. The number of people who have lands in but live outside the catchment (together with their animal holdings) is given in the third column.

Table 2: Human and animal population in the Kori catchment, Maybar area.

Number of:	Inside the catchment	Out of the catchment
households	45	12
male adults	64	17
female adults	73	13
male children	45	14
female children	44	11
Total population	226	55
Average size of household	5	5
cows	56	16
bulls	28	6
oxen	53	13
young cattle (heifer)	39	4
horses	23	7
donkeys	26	9
mules	19	6
sheep	264	47

goats	19	15
Total animal population	527	123
Animal size per household	12	10

Source: SCRP, March 1987.

The area of the Kori Catchment is $1.16km^2$. The population density is therefore 195 persons/km^2 (Table 2). This is quite similar to the population density for the Maybar area as a whole given earlier in this section.

The population is mainly composed of the young age group (Figure 10). 45% of the total population being below the age of 16 years.

Table 3 gives information on the land use pattern of the Kori catchment (with its implication for the Maybar area) in Belg 1986. 30% of the catchment was under cultivation in that season.

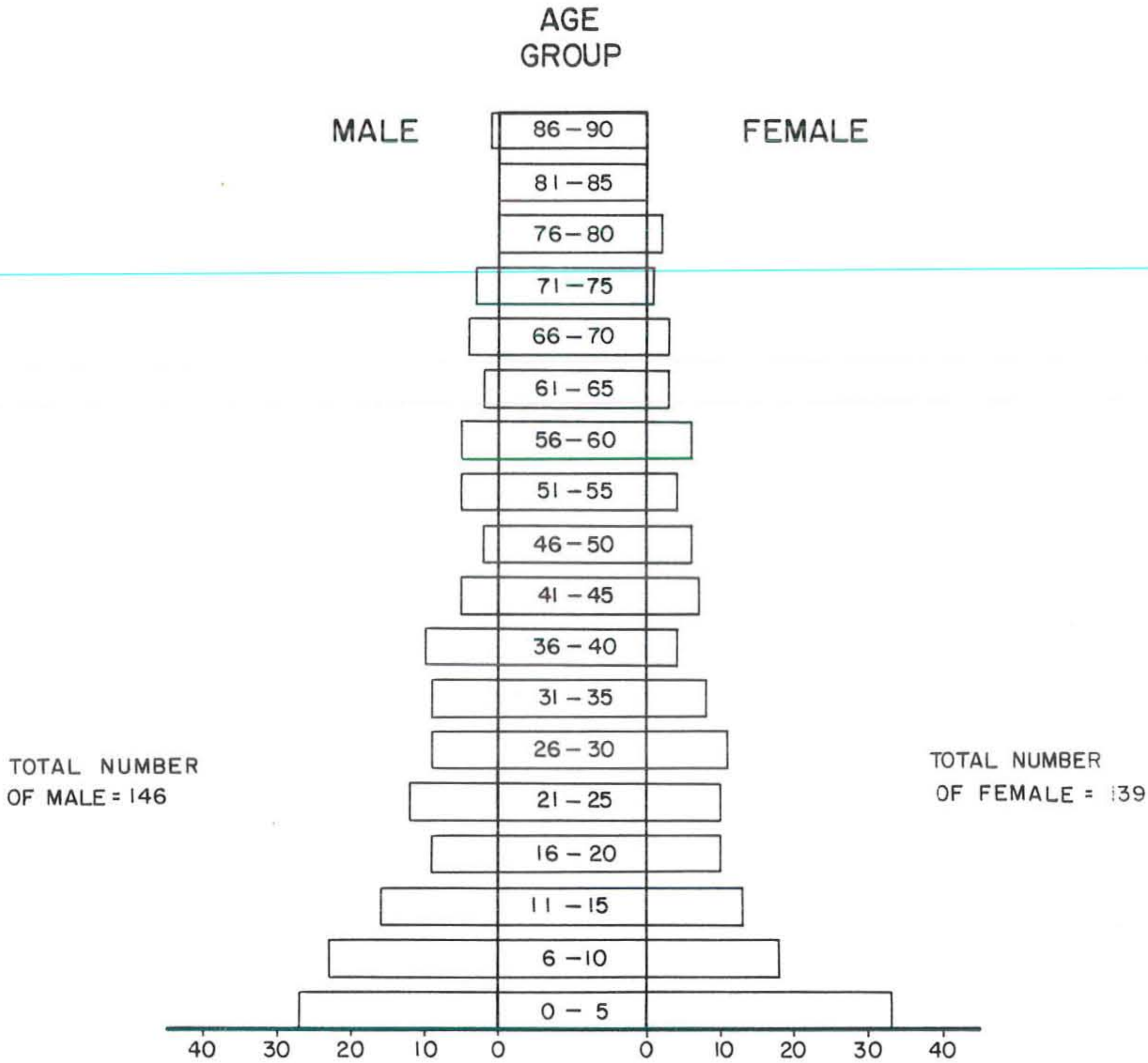


Figure 10 : Age and sex composition of the population in (and out of) the Kori catchment .

Source : SCRP, March 1987.

Table 3: Land use pattern of the Kori catchment in Belg 1986.

Land cover	ha	area % of catchment
grass + tree	41.2	35.5
grass + bush	0.61	0.5
fallow	19.50	16.8
bush	0.66	0.6
peas	0.39	0.3
teff	0.57	0.5
wheat	1.42	1.2
lentile	0.39	0.3
maize	13.97	12.0
grass	16.8	14.5
barley	12.1	10.4
emmer wheat	6.3	5.4
village	2.3	1.9
Total	116.2	99.9

Source: SCRP ; 1986.

In Belg 1982, it was 43%. The decrease in the area under permanent cultivation in Belg 1986 is due to the closure of very steep slopes for reafforestation purposes.

The major crops grown in the catchment (and in the maybar area as a whole) are maize, barley, emmer wheat, wheat, teff, horsebeans and peas all produced by traditional technology which is described as "grain plough complex" (Westphal, 1975). The typical crop rotation used in the Maybar area are given in Table 4.

Table 4: Crop rotation cycles in Maybar area.

On good Land

maize	barley emmer wheat	horse beans teff	maize	barley emmer wheat

On shallow soils, very steep land

barley horsebeans peas lentil emmerwheat	2-3 years fallow	barley horsebeans peas lentil emmerwheat

Source: Weigel, 1986a: 16.

The crop rotation cycles and the variety of crops listed above (all grown by traditional agricultural practices) are also typical for the eastern escarpment of Wello at large.

3.5 Soil Erosion Problem and Traditional Conservation in the Maybar Area

Situated in the northeastern highland area of Ethiopia, Maybar area has been settled by subsistence farmers for more than two thousand years. Charcoal particles in alluvial deposites which are believed to be the result of deforestation activities in the area were dated 2450 years BP (Hurni, 1985b). Soil erosion has therefore been a long-time problem in the area. The present soil distribution in Maybar which is characterized by very shallow to shallow soils (<50cm soil depth) on steep slopes and by thick accumulation on gentle slopes is the result of soil erosion. Weigel (1986b: 33) reports that 74% of the Maybar area has severe limitation for crop production due to soil erosion.

Nowadays, increasing population number and the closure of very steep slopes for reafforestation has eliminated the practice of fallowing on the flatter areas. Shortage of grassland area has also forced the farmers to remove crop residues (especially in the case of maize) for animal feeding. Cowdung is used mainly for fuel and there is hardly any application of manure on farms except in gardens. Crop rotation is insufficient and traditional terraces on steep slopes have proved ineffective due to lack of proper management.

However, the new conservation efforts made by the Ministry of Agriculture (MoA) in cooperation with SCRP and the local community has started to show positive results.

4. RESULTS AND DISCUSSIONS

4.1 Results

4.1.1. Precipitation and Erosivity

The average annual rainfall at Abbo Ager Research Station in the Maybar area for the years 1986 and 1987 was 1156 mm. This is similar to the four-year (1982 to 1985) annual average of 1114 mm at the same station and to the twenty one-year (1963-1984) annual average rainfall of 1130 mm observed at the meterological station in Desse which lies 25kms northwest of Abbo Ager (see Figure 3, section 1.3). The annual rainfall at Abbo Ager Station in 1986 was 1465 mm. In 1987, it was 847mm. The rainfall of the year 1987 was therefore considerably below average. Moreover, 46% of the amount came in spring or Belg (February to May) and only 48% in summer or Kremt (July to September) which means that there was less summer concentration of rain (the Kremt of 1987 was dominated by dry weather conditions) in the year 1987 as compared to the year 1986 when 69% of the total annual rainfall was in Kremt.

The annual erosivity (EI_{30}) for the Maybar area for the years 1986 and 1987 were 584 Joules $m^{-1}h^{-1}$ and 417 Joules $m^{-1}h^{-1}$, respectively. The annual erosivity value of 1986 was therefore nearly 1.5 times greater than in 1987.

Soil loss and runoff measurements from the experimental plots were actually made during 65 rainfall periods with a total rainfall amount of 2098 mm and a total EI_{30} value of 876 Joules m^{-1}.41 of the 65 rainfall periods having a total rainfall amount and (EI_{30}) value of 1291 mm and 516 Joules $m^{-1}h^{-1}$ respectively were monitored in 1986. The rest (24 rainfall events having a total rainfall amount and erosivity (EI_{30}) of 807 mm and 360 Joules m^{-1} h^{-1} respectively) occurred in 1987. The values of erosivity (EI_{30}) for each rain period range from 0.6 to 60.1 Joules $m^{-1}h^{-1}$ and the KE > 25 (Hudson, 1981) values, from 21.9 to 1072.7 Joules m_{-2}. The highest EI_{30} value of 60.1 Joules $m^{-1}h^{-1}$ resulted from a 59.5 mm rainfall that was spread over the period 27 to 30 July 1986.

Table 5 shows the number of rainfall periods in each group of erosivity (EI_{30}) and rainfall amount. Over half of the rain periods that occurred in either 1986 or 1987 had rainfall amounts below 30 mm and half of the periods in each year had erosivity values of less than 10 Joules $m^{-1}h^{-1}$. There were four rainfall periods with rainfall amounts of above 60mm in the year 1987, but no rainfall event of such amount occurred in 1986. However, the discussions in section 4.2.6. will show that the periods of heavier rainfall amounts and higher erosivities did not necessarily result in higher runoff and soil losses from the experimental plots.

Table 5: Number of rainfall periods in groups of erosivity (EI_{30}) and rainfall amount

grouping		number of rainfall periods 1986	number of rainfall periods 1987
rainfall amount (mm)	<20	11	9
	20.1 - 30	12	5
	30.1 - 40	8	2
	40.1 - 50	4	1
	50.1 - 60	6	3
	> 60	0	4
Total	-	41	24
EI_{30} ($J.m^{-1} h^{-1}$)	<10	21	12
	10-20	13	7
	20.1-30	5	0
	30.1-40	0	2
	>40	2	3
Total	-	41	24

4.1.2 Annual Runoff and Soil Loss Results - 1986

Further descriptions of the 1986 results shown in Figure 11 are given as follows.

Runoff was highest from the Graded Bund (38.9mm) and lowest from the Level Fanya juu (4.4mm). The annual runoff from the Graded Bund was more than one and half times greater than from the control plot. Three soil conservation measures-Level Fanya juu, Grass Strip and Level Bund-reduced the annual runoff by 81%, 75% and 57% respectively, as compared to the control plot. The percentage of the annual rainfall that became runoff was very low on all plots ranging from 0.3 to 3.0.

The Graded Bund had distinctively higher annual soil loss (5.15 tons/ha) than the other five measures. The control plot (traditional plot) had an annual soil loss of 2.02 tons/ha which is less than half of the annual soil loss of the Graded Bund. There was no marked difference in annual soil loss between the Graded Fanya juu and the control plot. The three level soil conservation measures - Level Fayna juu, Grass Strip and Level Bund-had distinctively lower annual soil losses (compared to those of the other three measures) amounting to 0.49, 0.84 and 1.04 tons/ha, respectively. These are between 2 and 4 times less than the annual soil loss from the control plot.

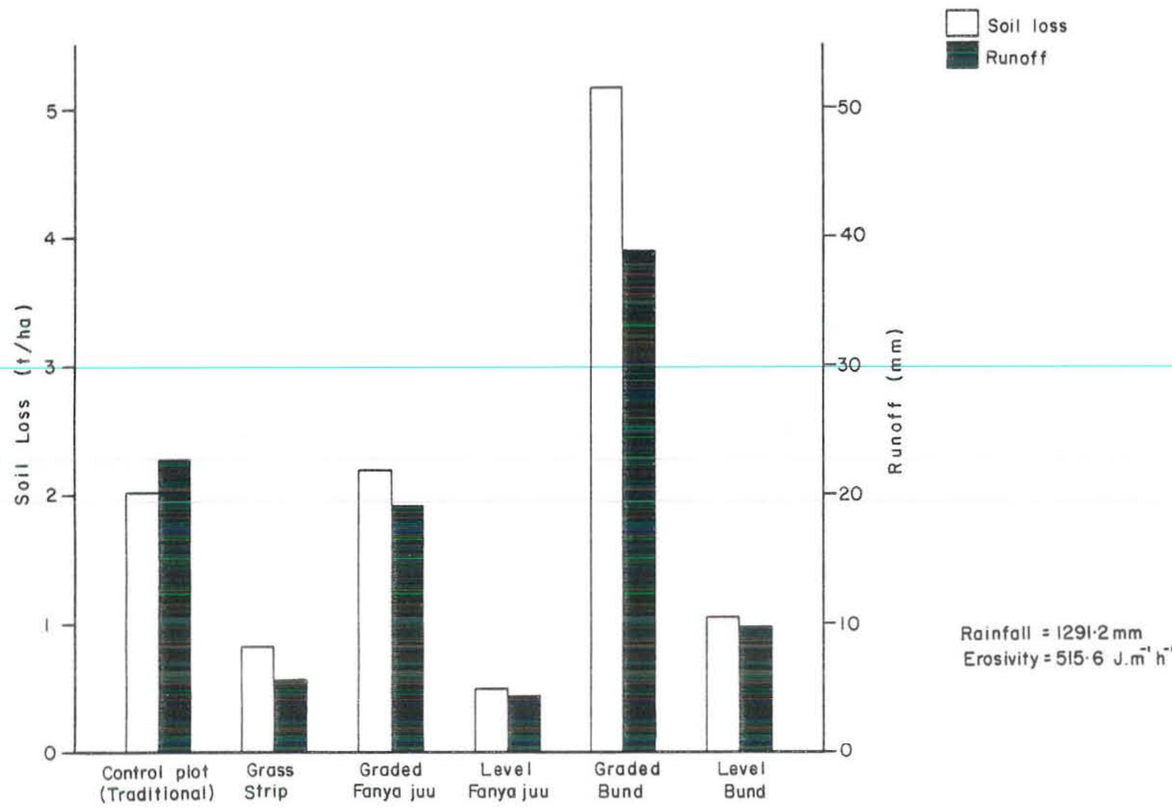


Figure 11: Annual runoff and soil loss from the six experimental plots in 1986.

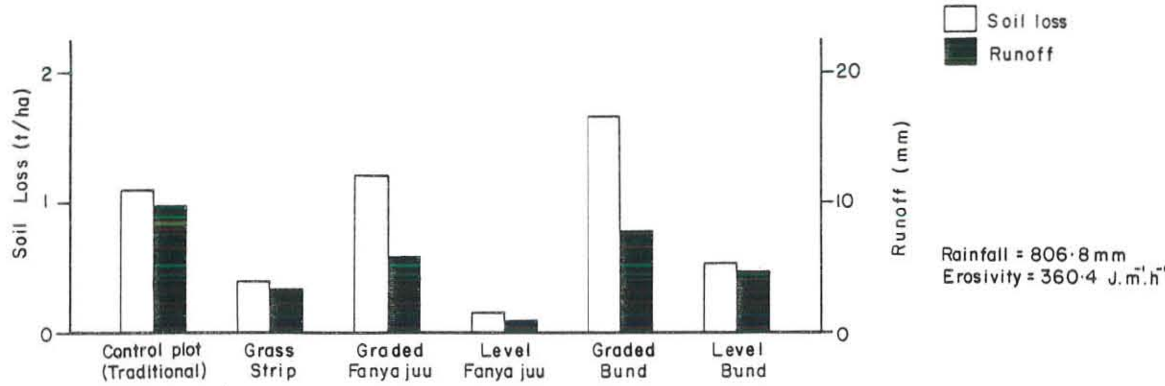


Figure 12: Annual runoff and soil loss from the six experimental plots in 1987.

4.1.3 Annual Runoff and Soil Loss Results - 1987

Figure 12 shows the annual runoff and soil loss results for the year 1987. Compared to 1986, the annual runoff of 1987 of all experimental plots was much lower. In this connection, it should be pointed out that the annual rainfall and erosivity in 1987 were also considerably lower than in 1986 (see section 4.1.1) The control plot showed higher annual runoff (9.7mm) than all other measures. But the difference in annual runoff between the control plot and the Graded Bund was not as high as it was in 1986. Compared to 1986, the annual runoff of the Graded Bund decreased by 80% in 1987 while that of the control plot decreased by 58%. The Level Fanya juu, the Grass Strip and the Level Bund showed distinctively lower annual runoff values than the other measures as it was in 1986.

The annual soil loss results of all experimental plots were also much lower than in 1986(cf. Appendix V). The Graded Bund showed higher annual soil loss (1.66 tons/ha) than the other five experimental plots as it did in the previous year. But the difference in annual soil loss between the Graded Bund and the control plot that was observed in 1987 was not as striking as it was in 1986. The three level measures (Level Fanya juu, Grass Strip and Level Bund) which showed markedly lower annual soil losses in 1986 persisted in showing much lower soil loss results in 1987 as well. These three measures reduced the annual soil loss by 87%, 64% and 51%, respectively when compared to the control plot.

4.1.4. Seasonal Results

Figure 13 shows the runoff and soil loss results of the six experimental plots during the four rainy seasons of 1986 and 1987 in which the _Kremt_ of 1986 is seen dominating the picture (see also Appendix VI and VII). The _Kremt_ of 1986 accounted for over 80% of the annual runoff and soil loss of both the control plot and the Graded Bund. Over two third of the annual runoff and soil loss of the other four experimental plots was also produced during the _Kremt_ of 1986. There was a similar trend in 1987 when the _Kremt_ of the same year also accounted for a major share of the annual runoff and soil loss of each experimental plot.

Comparing the four seasons, the Grass Strip, the Level Fanya juu and the Level Bund consistently showed much lower runoff and soil loss results when compared to the control plot, the only exception being in _Belg_ of 1986 when one of the three measures (the Grass Strip showed slightly higher soil loss than the control plot. The performance of the Graded Fanya juu was less consistent, showing markedly lower soil loss in the _Belg_ of 1987, markedly higher soil loss in the _Kremt_ of 1987 and only marginal differences in soil loss in the other two seasons, in comparison with the control plot.

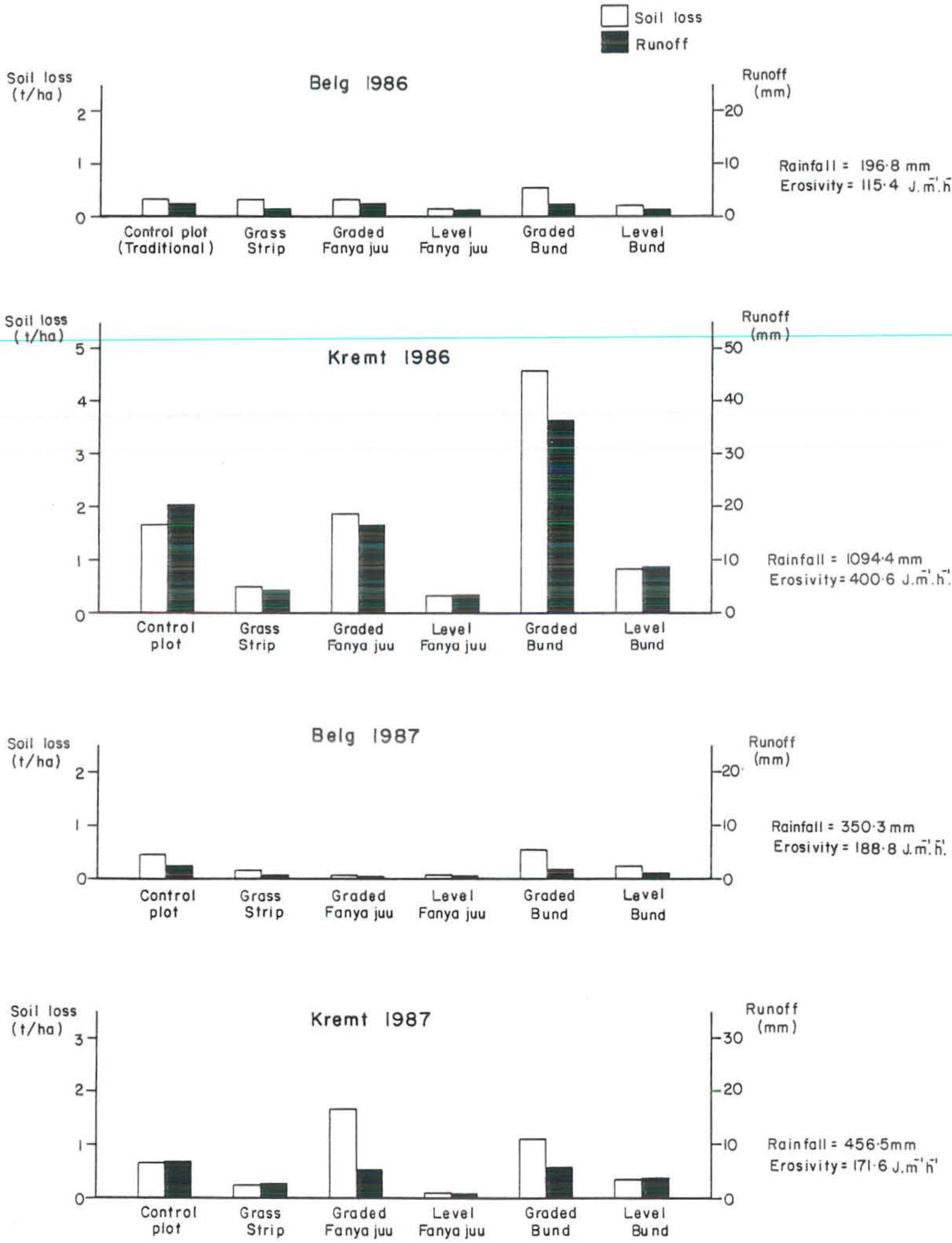


Figure 13: Seasonal runoff and soil losses – 1986 & 1987.

4.1.5 Monthly Results

Figure 14a and Figure 14b show the monthly totals of runoff and soil loss (including rainfall and erosivity) from the six experimental plots for 1986 and 1987 (see also Appendices VIII & IX) All experimental plots had their peak runoff and soil loss in August in both years. In 1986, the 16 rainfall events of August having total erosivity(EI_{30}) value of 170.8 Jouls $m_{-1}h_{-1}$ (33% of the annual total) accounted for 45 to 64% of the annual runoff and 39 to 70% of the annual soil loss, when all plots are considered. Similarly , in 1987 the seven rainfall events of August having a total EI_{30} value of 89.6 Joules $m_{-1}h_{-1}$ (25% of the annual total) accounted for 61 to 81% of the annual runoff and 46 to 90% of the annual soil loss when all plots are considered.

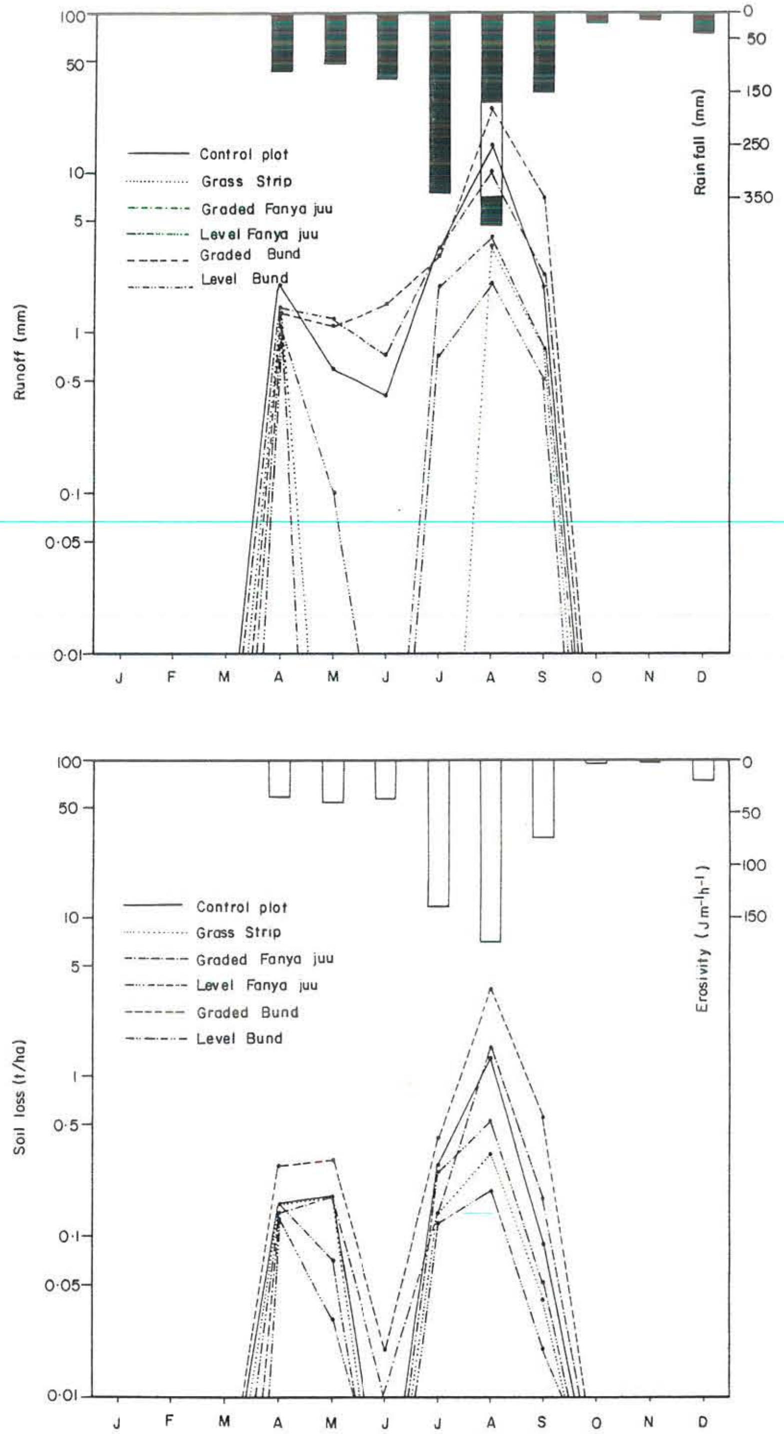


Figure 14a : Monthly runoff and soil loss from the six experimental plots in 1986.

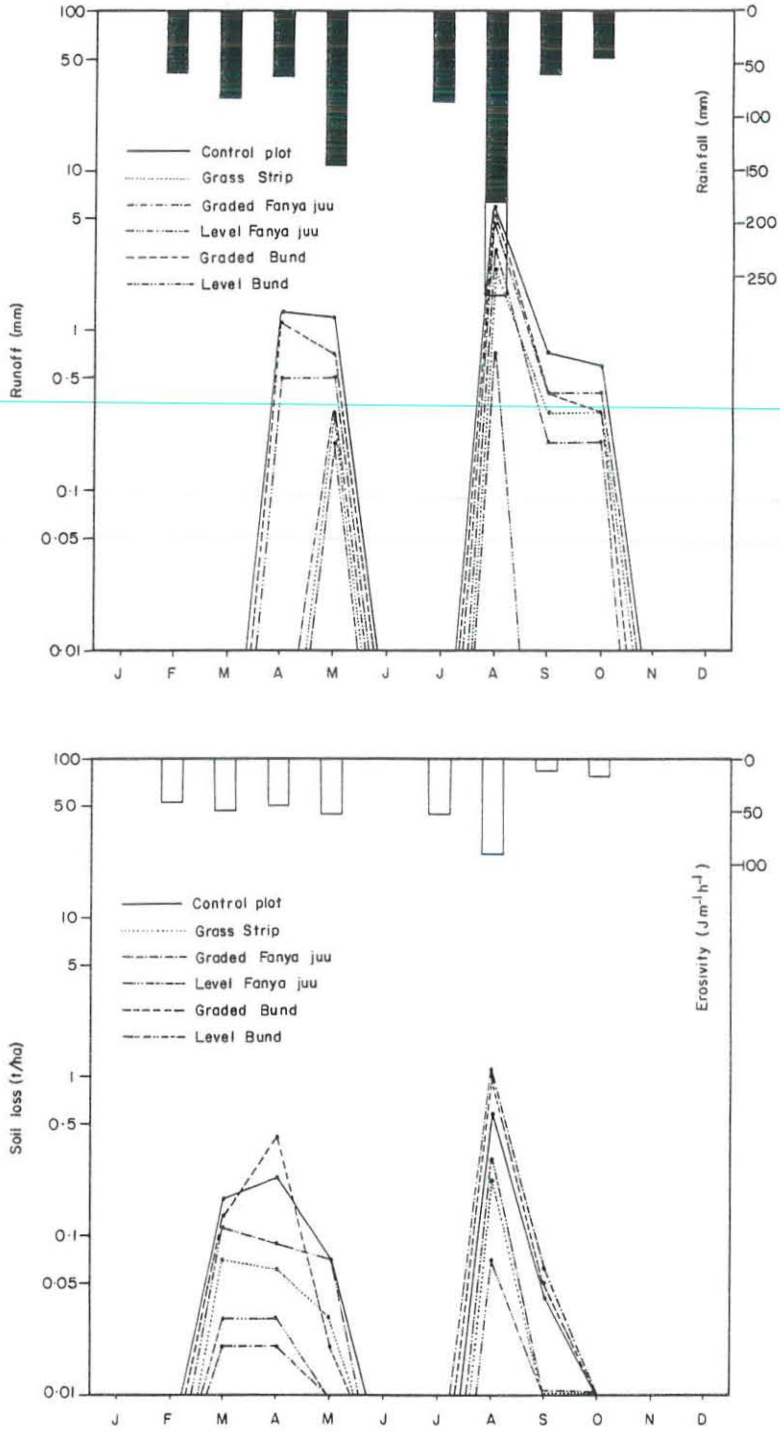


Figure 14b: Monthly runoff and soil loss for the six experimental plots in 1987.

4.2. Discussions

4.2.1 Variation of Runoff and Soil Losses

The results presented in section 4.1 (Figures 11,12,13 and 14) indicate that there were considerable monthly, seasonal and year to year variations in soil loss and runoff between experimental plots. The oneway analysis of variance (ANOVA) was therefore used to find out whether the observed variations are statistically significant or not. The method was first applied on all the data of runoff and soil loss that was collected in the whole study period and then performed on the data collected during the individual years to check the consistency of the results. Tables 6 to 11 give the results of the computation.

Table 6: 1986-87 runoff ANOVA

Source of variation	Degree of Freedom(DF)	Sum of squares(SS)	Mean of squares(MS)	F-ratio (F)	Probability (PR)
Between experimental plot	5	28.24	5.65	14.94	0.0001
Residual	258	97.51	0.38		
Total	263	125.75	-	-	-

Table 7:1986-87 Soil loss ANOVA

Source of Variation	DF	SS	MS	F	PR
Between experimental plots	5	0.386	0.077	10.06	0.0001
Residual	384	2.942	0.008		
Total	389	3.338			

Table 8. 1986 runoff ANOVA

Source of Variation	DF	SS	MS	F	PR
Between Experimental plots	5	30.81	6.16	13.50	0.001
Residual	162	73.95	0.46		
Total	167	104.76			

Table 9. 1986 Soil loss ANOVA

Source of Variation	DF	SS	MS	F	PR
Between Experimental plots	5	0.353	0.071	7.97	0.0001
Residual	240	2.125	0.009		
Total	245	2.478			

Table 10: 1987 runoff AVOVA

Source of Variation	DF	SS	MS	F	PR
Between Experimental Plots	5	3.19	0.64	4.24	0.0016
Residual	90	13.51	0.15		
Total	95	16.70			

Table 11. 1987 Soil loss ANOVA

Source of Variation	DF	SS	MS	F	PR
Between Experimental plots	5	0.068	0.014	2.45	0.0368
Residual	138	0.768	0.006		
Total	143	0.836			

From the F-ratios given in the six tables, it is seen that there is significant difference in runoff and soil loss between experimental plots. The considerable variation suggested by the data presented in Figures 11 to 14 (section 4.1) are therefore verified by the analysis of variance.

There are also some statistical techniques that can be employed to test whether observed differences between the means of pairs of treatments are significant or not. However, these are valid for a set of means that are characterized by large differences (Hicks, 1973). In the present study calculated annual means of runoff and soil loss could not satisfy this requirement. Therefore, in the subsequent discussions, differences between the treatments are explained by considering the actually observed values.

It was shown in sections 4.1.2. and 4.1.3. that the Graded Bund (EP-5) exceeded the control plot (EP-1) in annual soil loss in 1986 and 1987. The main explanation for this lies in the specific constructional design of the Graded Bund itself. The Graded Bund is designed in such a way that it has a samll spillway (15cm wide and 10cm deep) which represents the waterway used for draining runoff from cultivated land in high rainfall areas when graded structures are applied for soil conservation (see also Figure 5). Many

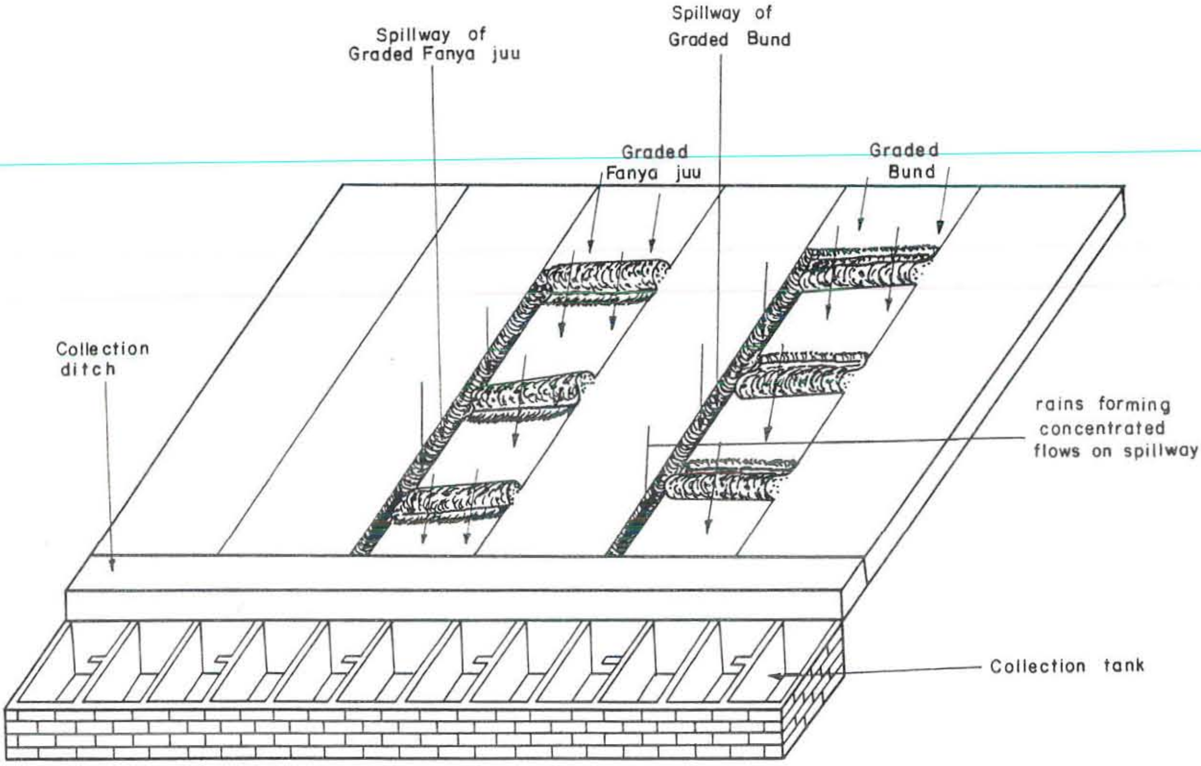


Figure 15 : Concentrated flows on spillways of the graded structures. Many rainfall events formed concentrated flows on the spillways of the two graded structures (the Graded Bund and the Graded Fanya juu), a situation which made the Graded Bund show much more annual soil loss than the control plot in 1986 and 1987.

rainfall events monitored in the two years therefore formed concentrated flows on the spillway of the Graded Bund thereby removing soil from it. The soil which was removed from the spillway by runoff created on it entered the collection tank of the graded bund. The situation is shown in Figure 15.

Visual evidence also showed that during many of the rainfall events that occurred in both 1986 and 1987, runoff was formed on the spillways before it happened on the whole parts of the graded structures and on the other experimental plots. This, therefore, was the situation which resulted in the Graded Bund showing greater soil loss than the control plot during the study period.

Compared to the control plot, the Graded Fanya juu (EP-3) showed slightly higher annual soil loss but lower annual runoff in both 1986 and 1987 indicating that there was more sediment concentration in the runoff of the Graded Fanya juu than in that of the control plot.

This and visual observations show soil was removed by runoff from the spillway of the Graded Fanya juu and taken into the collection tank of the same plot. But all the runoff from the spillway did not enter the collection tank. This is because of the presence of the Fanya juu ditch very near to the collection ditch. The actual field position of the spillway and the ditch of the Graded Fanya juu which is the nearest to the collection ditch is depicted in Figure 16.

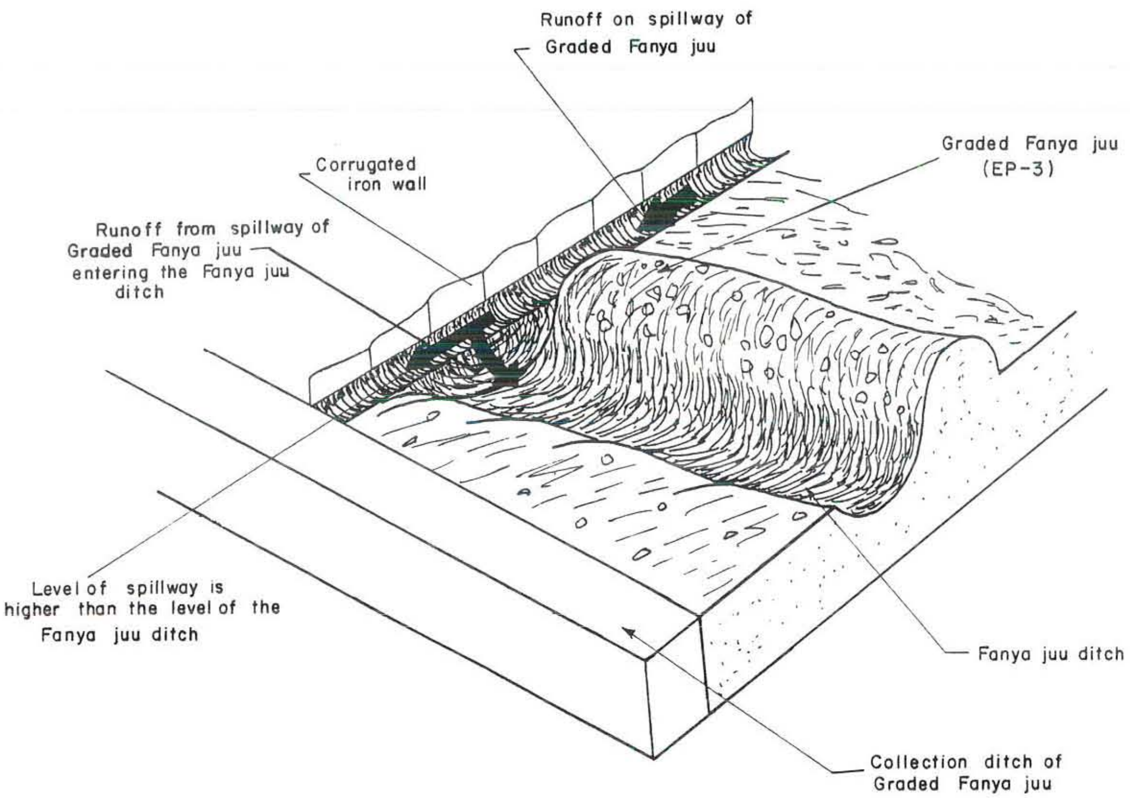


Figure 16: Position of the spillway and the Fanya juu ditch. Some runoff from the spillway of the Graded Fanya juu found its way into the ditch of the Fanya juu near the collection ditch and remained there.

Figure 16 shows that some runoff from the spillway of the Graded Fanya juu found its way into the ditch of the Fanya juu which is nearest to the collection ditch reducing thereby the amount of runoff and soil loss that could have entered the collection tank. This means the soil loss and runoff of this plot measured in 1986 and 1987 is much lower than it should have been. In the field, the writer has many times tried to lead all runoff of the spillway into the collection ditch by doing maintenance at the point where the Fanya juu ditch meets the spillway. But the situation could not be completely controlled because the level of the spillway is higher than the Fanya juu ditch (Figure 16).

It is because of this situation that the Graded Fanya juu showed less annual runoff than the control plot (in both 1986 and 1987) inspite of the former having a spillway that could add much to its annual runoff. But more sediment concentration in the runoff of the Graded Fanya juu due to soil removed from the spillway has made it show higher annual soil loss than the control plot.

The situation depicted in Figure 16 also provides the explanation why the Graded Fanya juu did not show as high annual soil loss as the Graded Bund although both have spillways of the same length and width. It is to be noted (Figures 4, 5 and 15) that the ditch of the Graded Bund is situated upslope or above the bund and not down slope or below the bund as is the case with the Graded Fanya juu. This means that all runoff from the spillway of the Graded Bund can enter the collection tank as a result of which it showed higher annual runoff and soil loss than the Graded Fanya juu.

The Grass Strip and the Level Bund had similar annual soil loss results in both years while the Level Fanya juu had annual soil loss results which are much lesser than those of the Grass Strip and the Level Bund. This happened partly because of the microtopographic situation, Figure 17 shows the field position of the collection ditch of the Level Fanya juu in relation to the nearest Fanya juu ditch and the part of the plot adjoining the collection ditch.

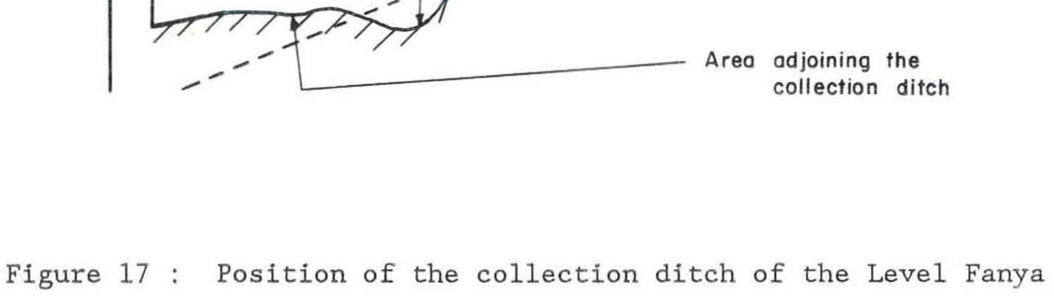


Figure 17 : Position of the collection ditch of the Level Fanya juu. The level of the collection ditch of the Level Fanya juu is slightly higher than the adjoining part of the plot.

Figure 17 shows that the collection ditch of the Level Fanya juu is higher than the adjoining part of the experimental plot. In the case of the Grass Strip and the Level Bund however, the reverse position exists. This means that the areas adjoining the two structures readily drain into their respective collection ditches as opposed to that of the Level Fanya juu which tends to ramain in the nearest Fanya juu ditch. Moreover, sediment loaded water collected in the Fanya juu ditch can only drain into the collection ditch if its level is raised above the level of the adjoining area, a condition which hardly existed during the two-year study period. This is one situation that made the Level Fanya juu show much lower annual soil loss results than the Grass Strip and the Level Bund.

4.2.2 Comparison of the 1986 and 1987 results

Compared to 1986, the annual soil loss and runoff results of all six experimental plots were much lower in 1987 (Figures 11,12 and Appendix V). This is mainly due to the rainfall distribution in the two years. The rainfall amount (during which samples were taken) of 1986 was one and half times greater than that of 1987. Because of this the total number of rainfall events monitored in 1986 and 1987 were 41 and 24, respectively which means that rainfall occurred more frequently in 1986 than in 1987. Since annual results are cumulative results of individual rainfall events, it is quite normal that the results of all plots were higher in 1986 than in 1987. This is also consistent with the general principle of soil erosion which holds that more erosion generally goes with more rainfall. On the other hand, it will be seen (Table 20, section 4.2.8) that the correlation of rainfall amount versus runoff and soil loss of each experimental plot is very low, indeed. This as well is consistent with the principle of soil erosion which asserts that the same quantity of rainfall coming at different soil moisture and crop cover conditions can result in different runoff and soil loss amounts.

4.2.3 Runoff and Soil Loss Relations

Figure 18 shows the correlation between runoff and soil loss in each experimental plot (EP) on the basis of the two-year data. The very low correlation ($r = 0.04$) on the Grass Strip implies that greater runoff did not result in greater soil loss on that plot. This indicates that the Grass Strip was trapping sediment without reducing the runoff, a function which it is normally expected to perform as a soil conservation measure. Another possible reason why the correlation is so low in the Grass Strip is the fact that a greater part of the annual soil loss of that conservation measure was produced by raindrop splash. This also applies to the annual soil loss of the Level Fanya juu. In 1986, 55% of the annual soil loss of the Grass Strip and 39% of the soil loss of the Level Fanya juu was due to erosion by splashing from the part of the plots near to the collection ditches and from the nearby structures.

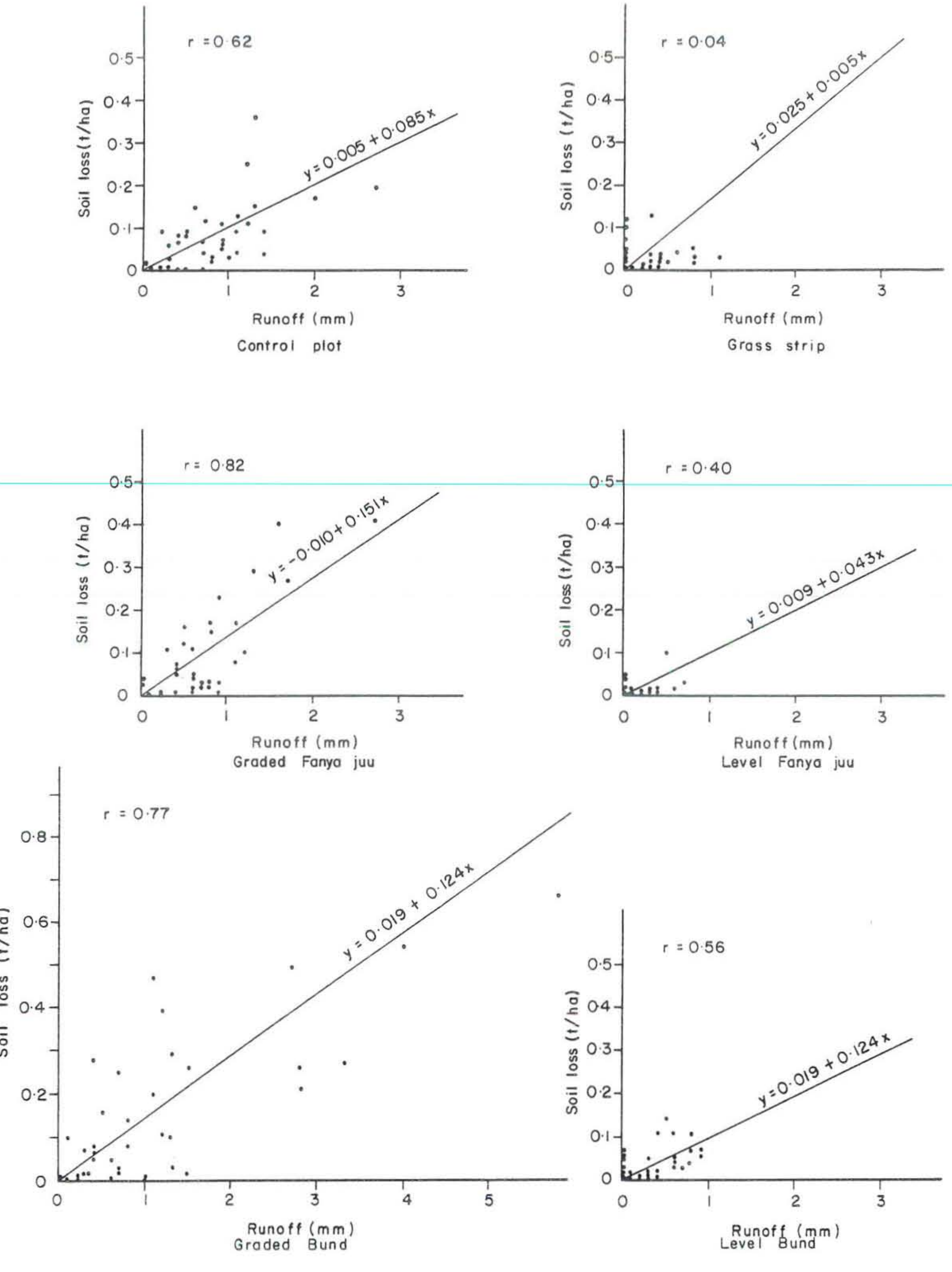


Figure 18 : Correlation between runoff and soil loss on the six experimental plots

The high correlation observed on the Graded Bund (r = 0.77) explains why the same structure showed particularly high soil loss results in the Kremt of 1986. The then frequently occuring Kremt rains (mainly those of August) were able to form concentrated flows on the spillway of the Graded Bund which made it show dominant seasonal runoff and soil loss results.

The correlation of r = 0.62 observed on the control plot is probably the most useful one of all six correlation values. It implies that soil erosion on steeper slopes can be controlled to a greater extent if the amount of runoff is reduced by means of soil conservation measures.

4.2.4 Low Runoff and Soil Loss Results

The annual soil loss results of the control plot shown in Figure 11 and 12 are much lower than the average soil loss rate for cultivated areas in the highlands of Ethiopia estimated by Hurni (1986a) and given in section 1.1 in this paper. They are even below the soil loss tolerance for the Maybar area which is estimated to be between 4 and 6 tons/ha/yr (Weigel, 1986a:24). Runoff as a percentage of annual rainfall amount was also very low in all experimental plots in both years. It varied between 0.3 and 3.0% in 1986 and between 0.1 and 1.2% in 1987 (Appendix V). Even the percentage of rain that run off the experimental plots during events of maximum runoff (Table 12) was very low as compared, for example, to the maximum runoff events on the four test plots at Abbo Ager Research Station in the period 1981-1982 (cf. SCRP, Progress Reports, Vol. 1-4:20).

Table 12: Maximum runoff events on the experimental plots

	Period From	Period to	EI_{30} ($J.m^{-1}h^{-1}$)	rainfall (mm)	runoff (% of rain)
control plot (EP-1)	16/8/87	17/8/87	2.3	14.7	6.1
Grass strip (EP-2)	16/8/87	17/8/87	2.3	14.7	3.4
Graded Fanya juu (EP-3)	31/8/87	1/9/87	9.1	18.5	6.5
Level Fanya juu (EP-4)	24/8/86	25/8/86	4.4	13.4	1.5
Graded Bund (EP-5)	31/8/87	1/9/86	9.1	18.5	17.8

Level Bund					
(EP-6)	16/8/87	17/8/87	2.3	14.7	4.1

The factors which were likely responsible for the low annual runoff and soil loss results are discussed as follows.

4.2.4.1 Soil Cover

The extent to which the soil surface is protected by crop or residue cover is an important factor which affects soil erosion (Wischmeier and Smith, 1978). Several other research works (reviewed in section 2.2 in this paper) have also indicated that residue cover significantly decreases soil losses. It was indicated in section 1.6 that in this study, crop growth (height) measurements have been done every week and that the effect of crop growth on soil loss during the four cropping seasons is examined using Pearson's Correlation Coefficient. The method was applied on the monthly data of crop growth (independent variable) and the monthly soil loss values (dependent variable) of the control plot. The results (Table 13) show that soil loss was negatively correlated with crop growth during all four seasons.

Table 13: Correlation between crop growth (height) and soil loss from the control plot in the four seasons of 1986 and 1987.

Year	Season	Crop	Correl.Coeff. (r)
1986	Belg	barley	- 0.66
	Kremt	horsebeans	- 0.61
1987	Belg	emmer wheat	- 0.50
	Kremt	horsebeans	- 0.84

The values shown in Table 13 have the obvious limitation of being the results of short period observation (a season). But that crop growth has played a major role in reducing the amount of soil loss in this study is clearly indicated. This finding also validates the suggestion (given in section 4.2.6) that crop growth was a major factor affecting soil losses from the experimental plots during individual rainfall events.

4.2.4.2 Dominance of Low - Erosivity Rains

Figure 19 shows the distribution of rainfall events at four erosivity groups in 1986 and 1987. Thirty four (83%) of the forty one rainfall events observed in 1986 had erosivity values below 20 Joules $m^{-1}h^{-1}$. Similarly, 19 rainfall events (79%) out of the total number of 24 events events observed in 1987 had erosivity values below 20 Joules $m^{-1}h^{-1}$. Moreover, if the threshold of separating erosive and non - erosive storms (rainfall

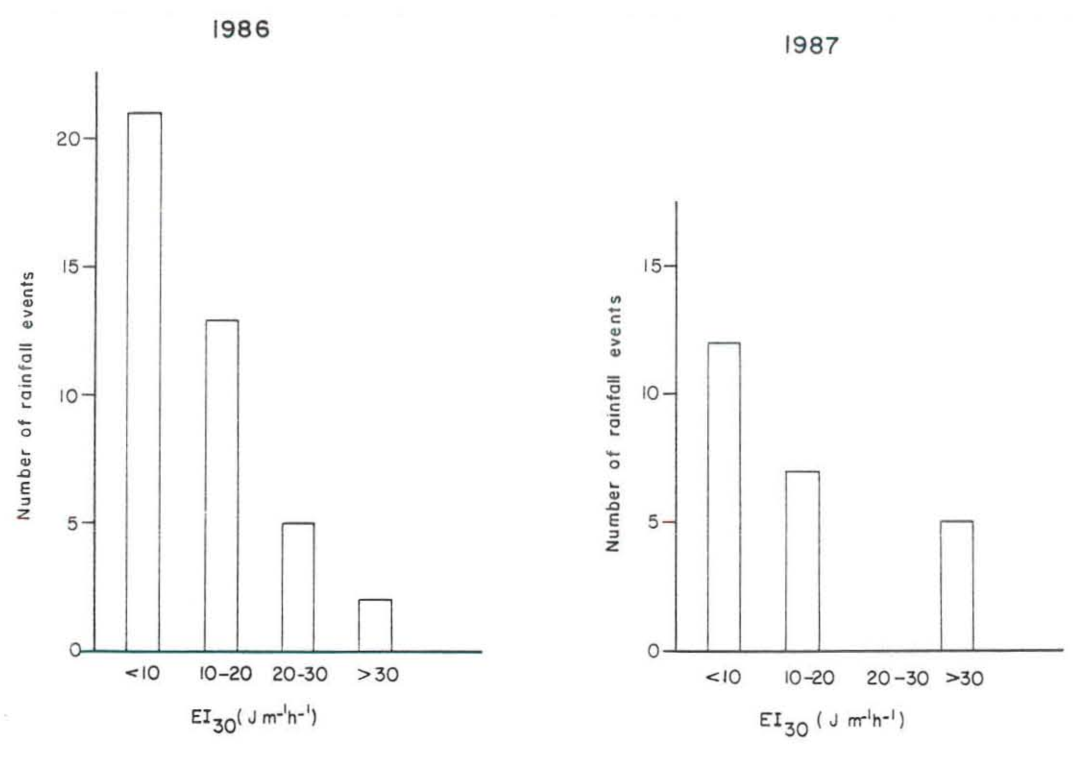


Fig. 19 : The distribution of rainfall events in four erosivity groups in 1986 and 1987.

intensity of 25mm/hr) suggested by Hudson (1981) is used, 76% of the total rainfall amount observed in 1986 and 71% of that observed in 1987 was non-erosive (Figure 20). The study period was therefore mainly characterized by low - erosivity rains.

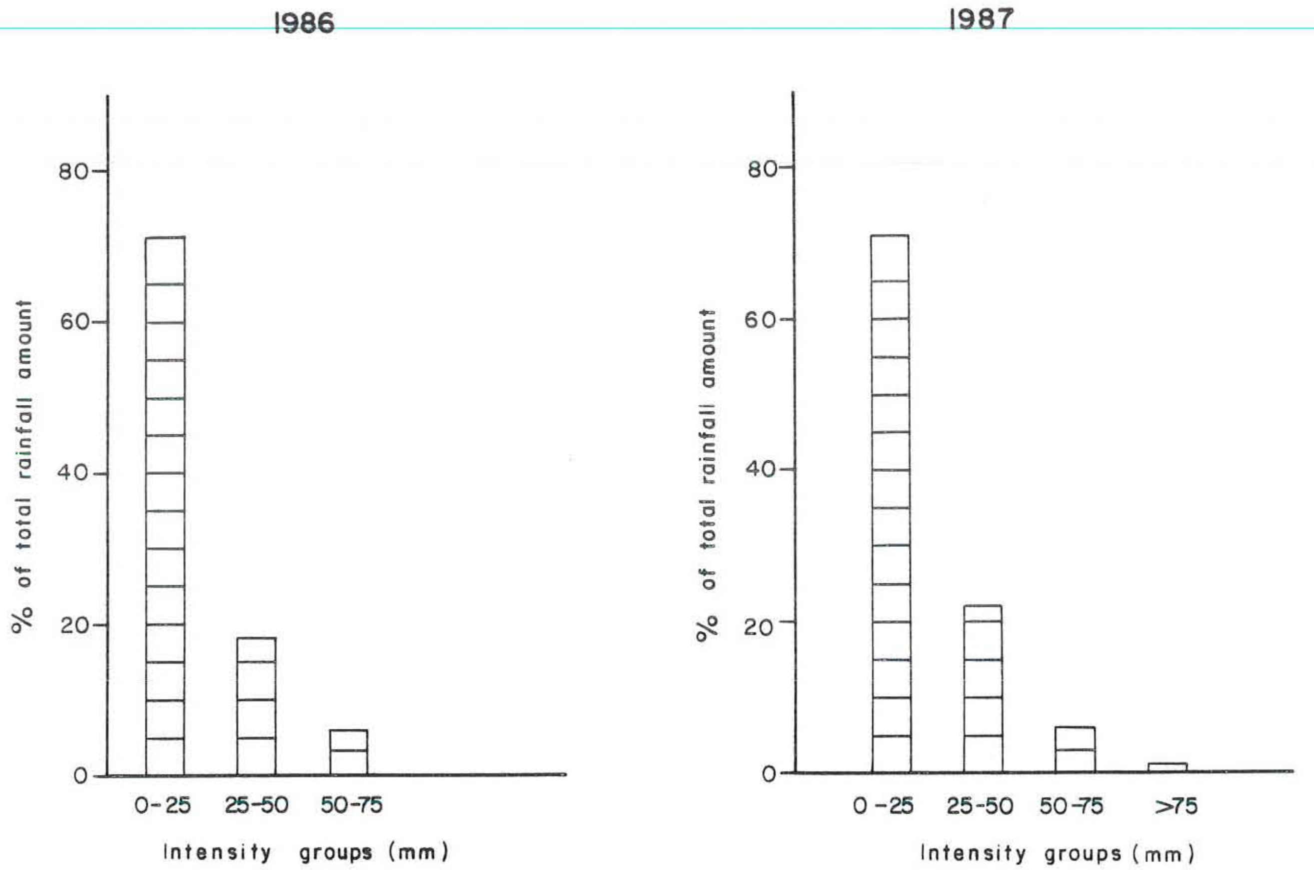


Figure 20 : The distribution of rainfall amount in four intensity groups in 1986 and 1987.

Since there is a close association between rainfall erosivity and the amount of runoff and eroded soil, it is very likely that the dominance of low erosivity rains combined with the other factors which will be discussed below have resulted in low annual runoff and soil losses from the control plot.

4.2.4.3. Surface stoniness

The high percentage of stone cover on the experimental plots (EPs) is also most likely one of the factors responsible for the low runoff and soil loss results. Table 14 shows the percentages of stone cover (determined using the method indicated in section 1.6) on each experimental plot. Evidently, there is a dense stones cover on all experimental plots.

Table 14 : Percentage of stone cover on experimental plots

experimenal plot	% of ground covered by stone
EP-1 (control plot)	78
EP-2 (Grass strip)	75
EP-3 (Graded Fanya juu)	53
EP-4 (Level Fanya juu)	58
EP-5 (Graded Bund)	75
EP-6 (Level Bund)	76

In this connection, De Ploey (1985:531) quoting several authors, states that stone cover decreases runoff yields on a slope by intercepting raindrops and dissipating their impact energy thereby increasing infiltration. In the present study as well, visual observation showed that the small depressions (formed due to the rough stone cover) on the plots were retaining rain water and promoting its infiltration into the soil. It is therefore very likely that the dense stone cover on the plots which encouraged abundant surface storage and high infiltration was one of the major factors for the low runoff and soil loss results.

As already indicated in section 4.2.2, the considerably low rainfall amount of Kremt 1987 was also another factor which resulted in low annual runoff and soil loss during that year.

4.2.5 The Dominance of Single Heavy Events in Soil Losses

It was stated in section 2.1 that several authors (Edwards, 1985; Sheng et al., 1981 and Hudson, 1981) have reported the dominance of a single or a few heavy storms in soil losses. The summary shown in Table 15 corroborates these findings. It is observed from the table that in this study as well a few heavier rainfall events have produced significant proportions of the annual soil losses of the experimental plots (EPs). In 1986, over 60% of the annual soil loss of the control plot was the result of nine rainfall events. Similarly in 1987 five rainfall events accounted for 73% of the annual soil loss of the control plot. Table 15 also shows that the nine rainfall events of 1986 and the five events of 1987 accounted for the largest proportion of the annual soil losses of the other five experimental plots.

Table 15 : Percentage of annual soil loss of each EP produced during two groups of rainfall periods in 1986 and 1987

	Group No.	No.of rainfall periods	rainfall amount (mm)	EI_{30} ($J.m^{-1}\ h^{-1}$)	% of annual soil loss accounted by each group					
					EP-1	EP-2	EP-3	EP-4	EP-5	EP-6
	I	9	330.3	205.9	64.3	55.0	70.3	63.4	71.3	62.5
1986	II	32	960.9	310.1	35.7	45.0	29.7	36.6	28.7	37.5
	Total	41	1291.2	516.0	100	100	100	100	100	100
	I	5	276.2	126.8	72.7	65.0	76.9	73.4	83.1	70.4
1987	II	19	530.6	233.6	27.3	35.0	23.1	26.6	16.9	29.6
	Total	24	806.8	360.4	100	100	100	100	100	100

4.2.6 Soil Losses During Individual Rainfall Events.

The first measurement of soil loss and runoff was done from a rainfall that occurred over the period of 1 to 4 April 1986, ten days after the experimental plots were seeded with barley. The period was characterized by a high rainfall amount (45.2mm) but low erosivity value (12.6 Joules $m^{-1}h^{-1}$). The soil loss from all experimental plots was very low (less than 0.05 tons/ha) during this period (see also appendix X). This is because of a combination of several factors. First, although much in quantity the rain was very low in erosivity. Secondly, the rains that preceded the event under consideration were not heavy enough to bring the moisture content of the sandy loamy soil (characterized by high surface stoniness) closer to saturation. Infiltration was therefore very high when the rains of this period occurred. Thirdly, the soil surface of the plots was to some extent protected from direct rain drop impacts (average height of the barley seedlings was 8.5 cm on 3 April, 1986). Under these conditions runoff from the plots was very low and so was soil loss.

Table 16 : Soil loss from the control plot (EP-1) during five successive rainfall events in April and May 1986.

rainfall period		rainfall amount	EI_{30}	control plot (EP-1)	
From	To	(mm)	$(J.m^{-1}h^{-1})$	soil loss (t/ha)	% of annual total
4/4/86	13/4/86	29.5	20.2	0.12	5.9
13/4/86	2/5/86	36.9	6.3	0.00	0
2/5/86	5/5/86	18.4	11.1	0.09	4.5
5/5/86	20/5/86	26.0	3.3	0.00	0
20/5/86	28/5/86	39.7	16.2	0.08	4.0

The average height of the barley crop had increased to 16cm when the rains of the period that extended from 4 to 13 April 1986 occurred (Table 16). In spite of the better vegetative protection and the considerably lower rainfall amount compared to the preceding period, the soil loss from the control plot in this period was three times greater than in the preceding one. This appears to be due to the heavy rain prior to this event which increased the moisture content of the sandy loamy soil thereby reducing its capacity for holding moisture. Therefore, lower rainfall amount having relatively higher erosivity value coming at a time of lowered infiltration produced more soil loss from the control plot as compared to the preceding period.

During the four rainfall periods that followed (Table 16) increased vegetative protection due to increased crop growth (the average height of the barley crop was 37 cm on 1 May 1986), low erosivity and high soil infiltration (due to longer times of sunny weather conditions appearing between periods of small showers) have resulted in either no soil loss at all or in very low soil loss values associated with the events of relatively higher erosivities.

The effect of increased crop growth on soil loss is more evident from Table 17 which shows the soil loss from the control plot during seven rainfall periods in June and July 1986. The crop grew to an average height of more than 75 cm at the end of May and to 90 cm at the beginning of July. The soil was therefore well protected from raindrop impacts by increased vegetative cover. This was very likely the major cause for the continuous absence of any soil loss from the control plot during the successive rainfall events shown in Table 17.

Table 17 : Soil loss from the control plot (EP-1) during six Successive Rainfall Events in June and July 1986.

Rain Period		Rainfall amount	EI_{30}	Control Plot (EP-1)	
From	To	(mm)	$(J.m^{-1}h^{-1})$	Soil Loss (t/ha)	% of annual total
28/5/86	24/6/86	57.5	8.9	0.00	0
24/6/86	29/6/86	37.6	7.5	0.00	0
29/6/86	30/6/86	36.6	22.3	0.00	0
30/6/86	2/7/86	17.9	2.5	0.00	0
2/7/86	3/7/86	26.7	9.1	0.00	0
3/7/86	10/7/86	49.6	14.3	0.07	3.5

The exception is the period extending from 3 July to 10, 1986 during which a very small amount of soil loss was recorded. Apparently, the comparatively less protection from raindrop impacts due to shrinkage of the drying crop (the crop was harvested on 12 July 1986) and the heavy rainfall amount with relatively higher erosivity that was observed during this period have resulted in a little amount of soil loss (3.5% of the annual total) from the control plot. The fact that some soil loss (0.12 tons/ha) was produced during the period extending from 4 to 13 April 1986 (Table 16) but nothing during the one (29 to 30 June 1986, Table 17) with about the same erosivity value indicate that erosion occurs particularly during the early stage of crop growth when the soil surface is not protected to a greater extent from the raindrop impacts.

The period in which there was a clear association of high rainfall amount (59.5mm) with a high erosivity index (60.1 Joules $m^{-1}h^{-1}$) was the one which extended from 27 to 30 July 1986 (Table 18). As already indicated in section 4.1.1, this was the period with the highest erosivity index observed in the study period. But the soil loss from the control plot during this period was very low (0.11/ha). The soil loss from the other experimental plots was also very low, the highest (measured from the Graded Bund) being 0.14 tons/ha. The protection of the stony soil surface from rain drop impacts provided by crop cover (average height of the horsebeans was 6.5 cm on 24 July 1986) and high soil infiltration seem to have resulted in a very low soil loss amount even during this period of considerably high rainfall amount and high erosivity.

There was a more direct relationship between rainfall quantity (or erosivity) and soil loss amount in Agusut 1986 but the soil loss values even during this month of highest monthly rainfall amount and erosivity (400mm and 170 $J.m^{-1}h^{-1}$, respectively) were very low (Table 18). It is evident that the dominance of low-erosivity rains is one of the factors which resulted in the low soil loss amounts observed in August. However, even the rainfall events with relatively higher erosivities did not produce significantly higher soil loss amounts. This shows that during this period too, crop cover (the horsebean crop reached an average height of 34cm on 8 August 1986) was the major factor in reducing soil losses from the control plot.

Table 18 : Soil loss from the control plot during seven rainfall events in late July and in August 1986

Rainfall Period		Rainfall amount (mm)	EI_{30} ($J.m^{-1}h^{-1}$)	Control Plot EP-1	
				Soil loss (t/ha)	% of annual total
From	To				
27/7/86	30/7/86	59.5	60.1	0.11	5.4
1/8/86	3/8/86	25.6	8.5	0.09	4.5
4/8/86	5/8/86	31.6	13.5	0.15	7.4
5/8/86	6/8/86	27.1	14.0	0.13	6.14
10/8/86	20/8/86	48.4	14.4	0.25	12.4
25/8/86	26/8/86	35.9	23.5	0.17	8.4
26/8/86	29/8/86	54.3	40.6	0.19	9.4

The rain period of 10 March to 11 April 1987 accounted for the highest percentage (33%) of the annual soil loss of the control plot (see Appendix X rainfall period No. 45). It was characterized by high erosivity index (53.1 $J.m^{-1}h^{-1}$). This is the period in which high rainfall amount and erosivity converged at a time of low vegetation cover (the plots were seeded with emmer wheat on 2 March 1987) to produce the highest percentage of soil loss accounted by a single rainfall event. But, in absolute terms, the amount of soil loss from the control plot even during this period of high erosivity was very low (0.36t/ha), indicating the influence of high soil infiltration on soil loss .

Table 19 : Soil loss from the control plot (EP-1) during four successive periods in July and August 1987

rainfall period		rainfall amount (mm)	EI_{30} $(J.m^{-1}h^{-1})$	control plot (EP-1)	
from	to			soil loss (t/ha)	% of annual total
30/6/87	30/7/87	85.9	53.4	0.002	0.2
30/7/87	11/8/87	65.5	14.9	0.15	13.6
11/8/87	12/8/87	61.3	35.1	0.09	8.2
12/8/87	14/8/87	39.0	14.5	0.10	9.1

The rainfall period characterized by 85.9 mm of rainfall and by erosivity index of 53.4 Joules $m^{-1}h^{-1}$ (Table 19) was non- erosive although there was no crop cover on the plots during this period (the emmer wheat was harvested on 1 July 1987 and no rain occurred during that day). This was very likely because of two reasons. First, the usual practice of feeding the stubble of the harvested crop to cattle was not carried out during this time. Instead, the farmer left it on the plots as natural fertilizer. This new management practice provided residue cover for the soil, increased its organic matter and prevented soil compaction due to trampling by cattle (cattle were prevented from reaching the plots in order to protect the conservation structures.) All these encouraged infiltration of more water into the soil. Secondly, it was because of the total absence of rain in June (cf Appendix IX). This meant that the rains of July, many of which came between sunny weeks, dropped on the dry sandy loamy soil of the experimental plots, a condition which encouraged infiltration of more water into the soil.

There were relatively higher soil losses during the subsequent rainfall events shown in Table 19. Compared to the large rainfall amounts of these periods, however, the soil loss values were very low. Apparently the crop residue (stubble) left over from the harvested emmer wheat, the total absence of rain in June 1987, the sunny whether conditions coming between rain periods in July and early August 1987 (the plots were bare in early August), all of which promoted infiltration of water in to the soil, had reduced soil losses to insignificant quantities.

The attempt in the foregoing discussion was to show the interaction of rainfall, soil and land cover characteristics in controlling the amount of soil loss from the experimental plots. The discussion was based on soil losses from the control plot. The pattern of soil losses from the other plots was not however very much different from that of the control plot (cf. Appendix X).

Two findings stand out to be clear from the discussion. First, in most rainfall events, high rainfall amounts did not result in high soil losses; neither did most high-erosivity events. Secondly, during a greater part of the study period, soil loss from the experimental plots appears to have been controlled mainly by crop cover and soil moisture conditions and to a lesser extent by rainfall factors.

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Two findings stand out to be clear from the discussion. First, in most rainfall events, high rainfall amounts did not result in high soil losses; neither did most high-erosivity events. Secondly, during a greater part of the study period, soil loss from the experimental plots appears to have been controlled mainly by crop cover and soil moisture conditions and to a lesser extent by rainfall factors.

4.2.8 Correlation of rainfall amount, energy, I_{30} and erosivity Versus Runoff and Soil Loss : 1986 - 1987.

Table 20 shows the correlation between four physical properties of the rain - rainfall amount, energy, I_{30}, erosivity - and the runoff and soil loss results of each experimental plot. As already indicated in section 1.6 both the Wischmeier and the KE>25 methods were used in the calculation of erosivity. The correlation values for both erosivity indices are therefore given in the table. The correlation was performed on all the data collected during 1986 and 1987.

Table 20 Correlation of rainfall amount, energy, I_{30} and erosivity versus runoff ans soil losses of the six experimental plots.

	EP-1 Control plot		EP-2 Grass Strip		EP-3 Graded Fanya juce		EP-4 Level Fanya juce		EP-5 Graded Bund		EP-6 Level Bund	
	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss	Run-off	Soil loss
Rainfall	0.40	0.44	0.18	0.33	0.23	0.20	0.20	0.35	0.22	0.22	0.31	0.40
Energy	0.42	0.49	0.04	0.38	0.29	0.26	0.23	0.38	0.27	0.28	0.41	0.46
I_{30}	0.38	0.41	0.10	0.41	0.44	0.36	0.51	0.45	0.48	0.46	0.41	0.52
EI_{30}	0.45	0.46	0.07	0.36	0.37	0.28	0.40	0.40	0.37	0.34	0.48	0.52
K.E>25	0.32	0.49	-0.08	0.45	0.22	0.18	0.25	0.43	0.27	0.33	0.28	0.52

The values of correcltion coefficient are all low. This strengthens the suggestions (given in the preceding section) that during the study period runoff and soil loss results depended much on crop cover and soil moisture conditions and less on rainfall amounts and erosivities.

4.2.9. Production Results

The yields of four crops which were harvested from the experimental plots during the four cropping seasons of 1986 and 1987 are presented in Table 21. They were calculated both without reducing and after reducing (in bracket) the area taken by the conservation measures.

If the yields calculated without reducing the area taken by the structures are considered, it is observed that the control plot showed higher yields than the other experimental plots during the four successive cropping seasons. This is most likely due to the fact that the control plot has more area under crops than the other experimental plots (the area taken by the conservation measures on the treated plots ranged from 14 to 20% of their total areas).

Table 21 Crop yields (t/ha) from the EPs during the four successive seasons of the study period (1986-1987)

		EP-1	EP-2	EP-3	EP-4	EP-5	EP-6
1st crop (barley) Belg-1986	Yield without reducing area taken by measures	1.5	1.1	1.0	1.1	1.0	0.7
	Yield after reducing area taken by measures	(1.5)	(1.4)	(1.2)	(1.5)	(1.1)	(0.9)
2nd crop (broad beans) Kremt-1986	Yield without reducing area taken by measures	2.4	1.5	2.1	1.5	2.2	1.7
	Yield after red ucing area taken by measures	(2.4)	(1.9)	(2.5)	(1.8)	(2.6)	(1.9)
3rd Crop (Emmer wheat Belg-1987	Yield without reducing area taken by measures	1.8	1.4	1.5	1.7	1.2	1.3
	Yield after reducing area taken by measures	(1.8)	(1.8)	(1.8)	(2.1)	(1.5)	(1.5)
4th Crop (Broad beans) Kremt-1987	Yield without reducing area taken by measures	1.5	1.3	1.2	1.1	1.2	1.1
	Yield after reducing area taken by measures	(1.5)	(1.6)	(1.4)	(1.4)	(1.4)	(1.3)

The coefficient of variation was used to see whether the yields of all plots (those calculated without reducing the area taken by the measure) were getting progressively similar or different during the course of the four cropping seasons. The results of the computation are given in table 2.

Table 22: Values of coefficient of variation (c.v) calculated from crop yields of the six experimental plots

Crop Number	Year and season	c.v(%)
1st crop (barley)	Belg - 1986	24.4
2nd crop (horse-beans)	Kremt - 1986	20.0
3rd crop (Emmer wheat)	Belg - 1987	16.7
4th crop (horse-beans)	Kremt - 1987	12.9

Table 22 shows that the values of coefficient of variation decreased progressively which implies that the superiority (in yields) of the control plot was progressively diminishing. This in turn means that the yields of the treated experimental plots were increasingly approaching that of the control plot in spite of their reduced cultivated land due to area taken by the conservation measures. This in turn indicates that production is slowly but progressively increasing due to soil conservation.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The runoff and soil loss results (presented in section 4.1 and discussed in section 4.2) are all below the tolerance level reflecting the strong influence of crop cover and surface stoniness on erosion losses during individual rainfall events. The results are also consistent with the dominantly low erosivity values observed during the study period. The low values of runoff as percent of rain (Appendix V) reflect the good water infiltration of the sandy loamy soil.

Although the observed runoff and soil losses are very low, considerable differences exist between the soil conservation measures. The Level Fanya juu, the Grass Strip and the Level Bund have shown distinctively lower annual runoff and soil losses as compared to the control (traditional) plot. This indicates that these measures are able to control soil erosion better than the traditional method of cultivation. The fact that the level soil conservation measures have proved to be more effective than the graded ones also indicates that the latter, which tend to encourage scouring of the waterway, are not appropriate soil conservation measures on the well drained, good infiltration, HAPLIC PHAEOZEM of the experimental plots.

The Grass Strip has proved to be an effective soil conservation measure under the rainfall conditions that existsed during the study period on the steep slope (28%) on which the soil conservation experiments are sited in spite of the view that it is an appropriate measure only for slopes of less than 15% (Hurni, 1986b).

Out of the total number of 65 rainfall events, 64 were monitored while the plots were under crop cover. In this study, therefore, crop cover was a major factor that reduced soil losses (under plot conditions) by protecting the soil from the erosive force of the falling rain drops thereby increasing infiltration and preventing runoff.

Therefore, under the rainfall conditions observed in 1986 and 1987, vegetative cover, together with the high surface stoniness have been sufficient to reduce the soil loss from the plots to values below the tolerance level.

Table 23 Annual Soil Loss Results from Test Plot-4 (1981-1987)

Year	Soil Loss (t/ha)
1981	5.0
1982	2.0
1983	15.0
1984	119
1985	25.4
1986	1.1
1987	11.2

Source: SCRP, 1981-1987.

However, soil loss data collected since 1981 from test plot 4(37% slope, 15mx2m, highly stony HAPLIC PHAEOZEM, located on a cultivated land 30 meters west of the experimental plots) indicate that extreme years will produce upto 100 times more erosion than during the study period (Table 21). This, therefore, suggest the need for physical (structural) conservation measures on cultivated steeper slopes of Maybar and the larger areas of the eastern escarpment of Wello and adjoining areas in Shewa.

5.2 Recommendations:

1. The discussions made in sections 4.2.4 and 4.2.6 have shown the role of crop cover in reducing soil erosion. Therefore, in the Maybar area and in the whole eastern escarpment of Wello and adjoining areas of Shewa the choice should be for agronomic soil conservation measures. Research in this respect is currently being carried out in Wello by Kassaye Goshu (in preparation).

2. But since soil loss rates which are well above the tolerance level can occur in these areas (Table 21) physical structures (Level Grass Strip, Level Bund and Level Fanya juu) should be applied as supportive measures. Even in such case, the stress should be on reducing inter-terrace erosion by means of agronomic measures.

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2. But since soil loss rates which are well above the tolerance level can occur in these areas (Table 21) physical structures (Level Grass Strip, Level Bund and Level Fanya juu) should be applied as supportive measures. Even in such case, the stress should be on reducing inter-terrace erosion by means of agronomic measures.

3. Whenever grass is available, the Grass Strip (an agronomic measure) should be used. It is proposed to check the Grass Strip only upto a slope gradient of 35%.

4. If grass is not available, then either the Level Bund or the Level Fanya juu can be adapted. However, the preference should be for the Level Fanya juu because it forms terraces much quicker than the Level Bund.

5. The level structures should be used on soils with good infiltration capacity. Therefore, they should not be used particulary on VERTISOLS and LITHOSOLS. Figure 21 shows the areas in Wello and adjoining areas of shewa, Gonder and Gojam to which the level structures are recommended as supportive to the agronomic measures. All of these areas have annual rainfall amounts between 900 and 1200 mm. Their altitudes lie between 1500 and 2700m asl and their slopes between 10 and 50%. The level physical measures should be used only for slopes between 15 and 50%. The slope gradients of greater than 10% but lesser than 15% are included in the map (Figure 21) because the average slope map of Ethiopia (LUDRP: 1984) from which data on slope is taken has slope categories of 0 to 10%, 10 to 25%, 25 to 35% ,35 to 50% and > 50%. The level structures can also be applied on the areas which belong to the Moist Weyna Dega Zone on soils with good infiltration (Hurni 1986b:25). They are therefore included in Figure 21.

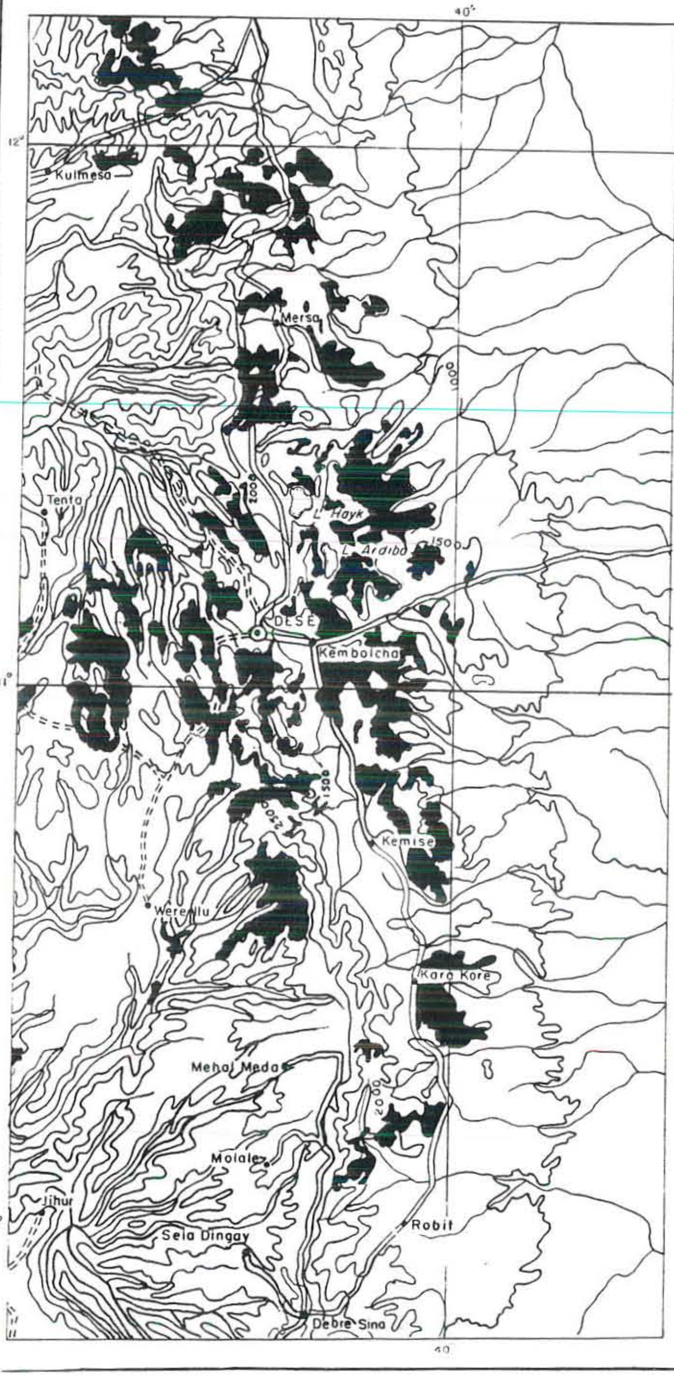
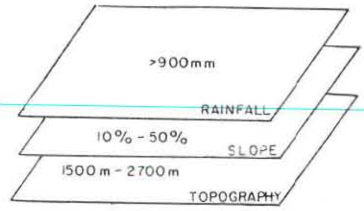


Fig. 21 EASTERN ESCARPMENT of WELLO AND ADJOININIG AREAS IN SHEWA

1:1,000,000



AREAS TO WHICH LEVEL CONSERVATION STRUCTURES ARE RECOMMENDED

TOPOGRAPHIC SITUATION

- All-Weather Road
- Dry-Weather Road
- Adm - Capital
- Other Towns
- River
- 2000 Contour

MAP SOURCES

Mean Annual Rainfall Map of Ethiopia, 1 2,000,000 Land Use Planning & Regulatory Dept; A.A, Ethiopia. 1982.

Slope Map of Ethiopia, 1:1,000,000 Land Use Planning & Regulatory Dept; A.A, Ethiopia.

Topography Map of Ethiopia, 1:1,000,000 Ethiopian Mapping Authority; Sheet, NC-37 & ND-37.

6. When making stone bunds, the stones should be picked from above the bund where accumulation takes place. It is also better (for bund stabilization) to pick the larger stones and leave the smaller ones behind.

7. The soil conservation experiment at Maybar should be continued to get more reliable data especially during years with more single heavy rainfall events.

8. The data collected during the study has already helped bring some improvements in the design of the experiment (covering of the waterway with plastic and removing structures which are nearest to the collection ditches). In addition to these, the collection ditches should have covers attached to the roof of the collection tanks. This is in order to remove the runoff contribution of the collection ditches which is found out to be significant (and therefore corrected) in this study.

9. Growth and crop cover percentage observation should be done everytime data is collected from the collection tanks. This will be more helpful in observing the relationship between soil loss and crop growth.

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Appendix I

Sample calculation of erosivity using the Wischmeier and Smith (1978) method.

period of Observation : From 2/5/86 (date) 09:30 (time)

to 5/5/86 (date) 09:00 (time)

Date	Starting time	Ending time	Duration (min)	N'	I'	Y'	E'
4/5/86	14:51	14:52	01	0.01	0.60	190.26	1.90
4/5/86	14:57	15:12	15	1.03	4 12	264.73	272.67
4/5/86	15:12	15:17	05	0.22	2.64	247.52	54.46
4/5/86	15:17	15:20	03	0.02	0.40	174.58	3.49
4/5/86	15:57	16:01	04	0.07	1.05	211.89	14.83
4/5/86	16:01	16:09	08	0.02	0.15	136.67	2.73
4/5/86	16:09	16:12	03	0.03	0.60	190.26	5.71
4/5/86	16:12	16:15	03	0.03	0.60	190.26	5.71
4/5/86	15:27	16:30	03	0.03	0.60	190.26	5.71
4/5/86	17:39	17:43	04	0.17	2.55	246.18	41.85
4/5/86	17:43	17:52	09	0.04	0.27	158.91	6.36
4/5/86	20:48	22:00	72	0.17	0 14	134.46	22.86
				a =	E =	I_{30} =	b=
				1.86	438.3	2.54	11.10

Explanations

N'	=	Amount of rainfall in the interval in cm
I'	=	Intensity of rain in the interval in cm/hr
Y'	=	Energy of one cm of rain in the interval
	=	$210 + 89 \log I'$ in Joules m^{-2}
E'	=	Energy of rain in the interval
	=	$N'Y'$ in Joules m^{-2}
I_{30}	=	Maximum 30 - minute intensity during the rainfall period in cm/hr
E	=	Energy of storm (for the whole period)
	=	$\{ E'$ in Joules m^{-2}
a	=	total amount of rainfall during the period
b	=	Erosivity (EI_{30}) in Joules m^{-1} h^{-1}

Source : after SCRP (data collected by the writer)

Appendix II

Sample calculations of erosivity using the KE > 25 method (Hudson, 1981).

Rainfall Period No	Date From	Date To	Intensity classes	Amount (mm)	Energy $J/m^2/mm$	Total (column4 x column5)
1	1/4/86	4/4/86	0 - 25	39.25	____	____
			25 - 50	4.7	27.5	129.3
			50 - 75	1.0	27.9	27.9
			> 75	0.0	0.0	0.0
						157.2 J/m^2
2	4/4/86	13/4/86	0 - 25	14.3	____	____
			25 - 50	15.2	26.2	398.2
			50 - 75	0.0	0.0	0.0
			> 75	0.0	0.0	0.0
						398.2 J/m^2

3	13/4/86	2/5/86	0 - 25	36.9	0.0	0.0
			25 - 50	0.0	0.0	0.0
			50 - 75	0.0	0.0	0.0
			> 75	0.0	0.0	0.0
						0 $J/m^2$2
4	2/5/86	5/5/86	0 - 25	4.2	___	___
			25 - 50	14.2	25.2	357.8
			50 - 75	0.0	0.0	0.0
			> 75	0.0	0.0	0.0
						357.8 J/m^2
5	5/5/86	20/5/86	0 - 25	26.0	___	___
			25 - 50	0.0	0.0	0.0
			50 - 75	0.0	0.0	0.0
			> 75	0.0	0.0	0.0
						0.0 J/m^2

Note : Data collected by the writer.

Calculation of runoff from the EP. (each 6m x 30m)

C = Water above sediment in Tank A in litres

= F.u

d = Total runoff in Tank A in litres

= c + i - 1

e = Total runoff i tank B (overlow and drained) in litres

= F.v.10.X

f = Total runoff in litres

= d + e

g = Runoff per surface area of plot in mm

= f/180

h = Runoff in percent of rain

= 10.g/a

Explanations

a = Rainfall amount of storm in cm

D = Diameter of collection tanks in cm

F = Basal surface of tanks in m^2

u = Average water height from sediment surface to water surface in tank A

X = Correction factor for slot divisor if Tank A had over flow

(1, if there is overflow, o, if not)

v = Average water height from bottom to water surface in tank B in mm

w = Wet weight of sediment sample taken (normally 500g but could be less also)

i = Total weight of wet sediment in tank A (including weight of wet sample)

j = Ovendry weight of sample (500g or less)

m = Ovendry weight of soil filtered from water in Tank A (Above sediment)

P = Ovendry weight of soil filtered from Tank B in gram.

Source : SCRP

Note : Each experimental plot has a pair of tanks which are termed here Tank A and Tank B.

Calculation of soil loss from the EPs (each 6m x 30m)

(For explanation of some symbols, see also appendix III)

i = Total of sediment in Tank A (wet, in kg)

j = Ovendry weight of sediment sample in gram

k = Percent (%) of soil in sediment sample

= 100j/w

l = Soil loss in Tank A in kg

= i.k/100

m = Ovendry weight of soil filtered from water in Tank A in gram per litre

n = Soil loss in runoff in Tank A in Kg

= m.c/1000

o = Total soil loss of Tank A in kg

= l + n

p = Ovendry weight of soil filtered from water in Tank B in gram per litre

q = Soil loss of Tank B in kg

= p.e/1000

r = Total soil loss of plot in kg

= o + q

s = Total soil loss of plot in tons per hectare ($t.ha^{-1}$)

= r/18

Source : SCRP

Appendix V

Summary of annual results

Year			EP-1 (control plot)	EP-2 (Grass Strip)	EP-3 (Graded Fanya juu)	EP-4 (Level Fanya juu)	EP-5 (Graded Bund)	EP-6 (Level Bund)
1986	Runoff	mm	22.8	5.6	19.0	4.4	38.9	9.8
		% of rain	1.8	0.4	1.5	0.3	3.0	0.8
	Soil loss (t/ha/yr)		2.02	0.84	2.19	0.49	5.15	1.04
1987	Runoff	mm	9.7	3.3	5.8	0.9	7.8	4.6
		% of rain	1.2	0.4	0.7	0.1	1.0	0.6
	Soil loss (t/ha/yr)		1.1	0.40	1.21	0.15	1.66	0.54

Appendix VII

Seasonal runoff and soil results - 1987.

	EP-1 (control plot)		EP-2 (Grass Strip)		EP-3 (Graded Fanya juu)		EP-4 (Level Fanya juu)		EP-5 (Graded Bund)		EP-6 (Level Bund)	
	Belg	Kremt	Belg	Kremt	Belg	Kremt	Belg	Kremt	Belg	Kremt	Belg	Kremt
Runoff mm	2.5	6.6	0.3	2.7	0.3	5.1	0.2	0.7	1.8	5.7	1.0	3.4
% of rain	1.3	3.9	0.2	1.6	0.2	3.0	0.1	0.4	1.0	3.3	0.5	2.0
Soil loss (t/ha)	0.47	0.64	0.16	0.25	0.05	1.15	0.07	0.08	0.56	1.10	0.22	0.33

Appendix VI

Seasonal runoff and soil loss results 1986

	EP-1 (control plot)		EP-2 (Grass Strip)		EP-3 (Graded Fanya juu)		EP-4 (Level Fanya juu)		EP-5 (Graded Bund		EP-6 (Level Bund)	
	Belg	Kremt	Belg	Kremt	Belg	Kremt	Belg	Kremt	Belg	Kremt	Belg	Kremt
Runoff mm	2.6	20.2	1.4	4.2	2.6	16.4	1.2	3.2	2.4	36.5	1.3	8.5
% of rain	1.3	1.9	0.7	0.4	1.3	1.5	0.6	0.3	1.2	3.3	0.7	0.8
Soil loss (t/ha)	0.34	1.68	0.33	0.50	0.32	1.87	0.16	0.33	0.58	4.57	0.21	0.83

Appendix VIII

Monthly runoff and soil loss results including monthly rainfall amount and erosivity - 1986.

Month	Rainfall (mm)	EI_{30}	EP-1 (Traditional) Runoff (mm)	EP-1 Soil-loss (t/ha)	EP-2 (Grass Strip) Runoff (mm)	EP-2 Soil-loss (t/ha)	EP-3 (Graded Fanya juu) Runoff (mm)	EP-3 Soil-loss (t/ha)	EP-4 Level Fanya juu Runoff (mm)	EP-4 Soil-loss (t/ha)	EP-5 Graded Bund Runoff (mm)	EP-5 Soil-loss (t/ha)	EP-6 Level Bund Runoff (mm)	EP-6 Soil-loss (t/ha)
A	111.6	33.9	2.0	0.16	1.4	0.16	1.4	0.14	1.1	0.13	1.3	0.28	1.3	0.14
M	95.1	37.5	0.6	0.18	0	0.17	1.2	0.18	0.1	0.03	1.1	0.30	0	0.07
J	120.7	37.0	0.4	0	0	0	0.7	0.01	0.0	0	1.5	0.02	0	0.00
J	339.5	139.6	3.3	0.28	0	0.14	3.3	0.14	0.7	0.12	3.1	0.41	1.9	0.25
A	400.3	170.8	14.6	1.31	3.4	0.33	10.1	1.55	2.0	0.19	25.1	3.59	5.8	0.53
S	149.6	73.8	1.9	0.09	0.8	0.04	2.3	0.17	0.5	0.02	6.8	0.55	0.8	0.05
O	19.0	2.0	0	0	0	0	0	0	0	0	0	0	0	0.00
N	15.3	1.3	0	0	0	0	0	0	0	0	0	0	0	0.00
D	40.1	19.7	0	0	0	0	0	0	0	0	0	0	0	0.00
Tot.	1291.2	515.6	22.8	2.02	5.6	0.84	19.0	2.19	4.4	0.49	38.9	5.15	9.8	1.04

Appendix IX

Monthly runoff and soil loss results
including monthly rainfall amount and erosivity - 1987.

Month	Rainfall (mm)	EI_{30}	EP-1 (control plot)		EP-2 (Grass Strip)		EP-3 (Geaded Fanya Juu)		EP-4 Level Fanya Juu)		EP-5 (Graded Bund)		EP-6 (Level Bund)	
			Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)	Runoff (mm)	Soil loss (t/ha)
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	58.0	41.3	0	0	0	0	0	0	0	0	0	0	0	0
M	83.4	49.5	0	0.17	0	0.07	0	0.02	0	0.03	0	0.13	0	0.11
A	61.3	45.4	1.3	0.23	0	0.06	0	0.02	0	0.03	1.1	0.42	0.5	0.09
M	145.8	52.57	1.2	0.07	0.3	0.03	0.3	0.01	0.2	0.01	0.7	0.02	0.5	0.02
J	-	-	-	-	-	-	-	-	-	-	-	-	-	-
J	85.9	53.4	0	0	0	0	0	0	0	0	0	0	0	0
A	266.5	89.6	5.9	0.58	2.4	0.22	4.7	1.09	0.7	0.07	5.3	1.03	3.2	0.30
S	59.0	11.6	0.7	0.04	0.3	0.01	0.4	0.06	0	0.01	0.4	0.05	0.2	0.01
O	45.1	17.0	0.6	0.01	0.3	0.01	0.4	0.01	0	0	0.3	0.01	0.2	0.01
N	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tot.	806.8	360.4	9.7	1.1	3.3	0.40	5.8	1.21	0.9	0.15	7.8	1.66	4.6	0.54

Appendix X

Runoff and soil loss from the EPs during individual rainfall events, 1986 and 1987
(rainfall events which did not produce any runoff on)
all EPs are not included in the list)

pd. No.	Date From	To	Rainfall amount (mm)	EI_{30}	EP-1 (control plot) Runoff (mm)	EP-1 Soil-loss (t/ha)	EP-2 (Grass Strip) Runoff (mm)	EP-2 Soil-loss (t/ha)	EP-3 (Graded Fanya Juu) Runoff (mm)	EP-3 Soil-loss (t/ha)	EP-4 Level Fanya Juu Runoff (mm)	EP-4 Soil-loss (t/ha)	EP-5 (Graded Bund) Runoff (mm)	EP-5 Soil-loss (t/ha)	EP-6 (Level Bund) Runoff (mm)	EP-6 Soil-loss (t/ha)
1	1/4/86	4/4/86	45.2	12.6	1.4	0.04	1.1	0.03	0.8	0.03	0.7	0.03	0.7	0.03	0.7	0.03
2	4/4/86	13/4/86	29.5	20.2	0.7	0.12	0.3	0.13	0.6	0.11	0.5	0.10	0.7	0.25	0.6	0.11
4	2/5/86	5/5/86	18.4	11.1	0.2	0.09	0	0.05	0.5	0.16	0.1	0.02	0.4	0.28	0	0.05
6	20/5/86	28/5/86	39.7	16.2	0.4	0.08	0	0.12	0.7	0.02	0	0.01	0.7	0.02	0	0.02
9	29/6/86	30/6/86	36.6	22.3	0.3	0.00	0	0.02	0.6	0.01	0	0.00	1.5	0.02	0	0.00
11	2/7/86	3/7/86	26.7	9.1	0.5	0.00	0	0.00	0.9	0.01	0	0.00	1.0	0.01	0.2	0.00
12	3/7/86	10/7/86	49.6	14.3	0.9	0.07	0	0.00	0.8	0.02	0	0.02	0.8	0.08	0.4	0.02
14	22/7/86	23/7/86	20.1	8.6	0.3	0.06	0	0.03	0.4	0.05	0	0.05	0.1	0.10	0	0.07
18	27/7/86	30/7/86	59.5	60.1	0.9	0.11	0	0.04	0.7	0.03	0.4	0.04	0.8	0.14	0.8	0.11
19	30/7/86	1/8/86	30.5	8.4	0.7	0.07	0	0.02	0.5	0.12	0.3	0.02	0.4	0.06	0.4	0.02
20	1/8/86	3/8/86	25.6	8.5	0.5	0.09	0	0.03	0	0.01	0	0.02	0.4	0.08	0.3	0.05
21	3/8/86	4/8/86	15.5	4.5	0.3	0.03	0	0.01	0	0.00	0	0.00	0.3	0.02	0.2	0.01
22	4/8/86	5/8/86	31.6	13.5	1.3	0.15	0.3	0.04	0.8	0.15	0.3	0.02	2.7	0.49	0.6	0.05
23	5/8/86	6/8/86	27.1	14.0	1.1	0.13	0.4	0.03	0.9	0.23	0.3	0.02	2.8	0.84	0.6	0.04
24	6/8/86	9/8/86	22.2	6.3	0.6	0.06	0	0.02	0.2	0.03	0	0.01	0.6	0.05	0.2	0.02
25	9/8/86	10/8/86	13.0	4.9	0.2	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0.00	0
26	10/8/86	20/8/86	48.4	14.4	1.2	0.25	0	0.07	0.8	0.17	0	0.05	1.2	0.39	0.4	0.11
27	20/8/86	22/8/86	32.0	10.7	1.1	0.04	0.3	0.02	0.6	0.04	0	0.01	1.3	0.10	0.4	0.02
28	22/8/86	23/8/86	21.1	4.8	0.7	0.01	0.2	0.00	0.4	0.01	0	0.00	0.6	0.01	0.4	0.01
29	23/8/86	24/8/86	18.3	6.9	0.9	0.05	0.2	0.01	0.6	0.05	0.1	0.00	1.2	0.11	0.3	0.02
30	24/8/86	25/8/86	13.4	4.4	0.8	0.02	0.2	0.01	0.6	0.02	0.2	0.00	1.3	0.03	0.3	0.01
31	25/8/86	26/8/86	35.9	23.5	2.0	0.17	0.6	0.04	1.7	0.27	0.4	0.02	4.0	0.54	0.8	0.07
32	26/8/86	29/8/86	54.3	40.6	2.7	0.19	0.8	0.03	2.7	0.41	0.6	0.02	5.8	0.66	0.9	0.06
33	29/8/86	30/8/86	29.0	11.3	1.1	0.04	0.4	0.01	0.9	0.03	0	0.00	2.8	0.21	0.5	0.05
34	30/8/86	31/8/86	12.9	2.5	0.2	0.00	0	0.00	0	0.00	0	0.00	0.1	0.00	0	0.00
35	31/8/86	1/9/86	18.5	9.1	1.0	0.03	0.4	0.02	1.2	0.10	0.3	0.01	3.3	0.27	0.4	0.02
36	1/9/86	3/9/86	19.3	10.9	0.8	0.03	0.4	0.01	1.1	0.08	0.2	0.01	2.8	0.26	0.4	0.02
38	6/9/86	18/9/86	57.6	24.9	0	0.02	0	0.01	0	0.01	0	0.01	0.7	0.02	0	0.01
45	10/3/87	11/4/87	82.4	53.1	1.3	0.36	0	0.10	0	0.04	0	0.05	1.1	0.47	0.5	0.14
48	9/5/87	12/5/87	12.8	4.0	0.3	0.00	0.1	0.00	0.1	0.00	0.1	0.00	0.2	0.00	0.2	0.00
49	12/5/87	21/5/87	51.8	16.6	0.4	0.07	0	0.03	0	0.01	0	0.01	0.3	0.02	0	0.01
50	21/5/87	22/5/87	10.1	2.7	0.4	0.00	0.2	0.00	0.2	0.00	0.1	0.00	0.1	0.00	0.3	0.00
51	22/5/87	29/5/87	31.4	11.5	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
52	29/5/87	30/5/87	14.1	4.2	0.1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
55	30/7/87	11/8/87	65.5	14.9	0.6	0.15	0	0.05	0	0.03	0	0.04	0.5	0.16	0	0.06
56	11/8/87	12/8/87	61.3	35.1	1.1	0.09	0.4	0.04	1.6	0.40	0.4	0.01	1.5	0.26	0.9	0.07
57	12/8/87	14/8/87	39.0	14.5	1.2	0.11	0.8	0.02	1.3	0.29	0	0.00	1.3	0.29	0.9	0.07
58	14/8/87	16/8/87	28.0	9.2	1.4	0.09	0.8	0.05	1.1	0.17	0.2	0.01	1.1	0.20	0.8	0.04
59	16/8/87	17/8/87	14.7	2.3	0.9	0.06	0.5	0.02	0.4	0.07	0.1	0.00	0.6	0.05	0.6	0.03
60	17/8/87	25/8/87	40.6	11.8	0.5	0.08	0	0.04	0.3	0.11	0	0.00	0.3	0.07	0	0.03
61	25/8/87	1/9/87	17.4	1.8	0.2	0.01	0	0.00	0	0.01	0	0.00	0	0.01	0	0.01
62	1/9/87	10/9/87	24.7	4.2	0.7	0.04	0.3	0.01	0.4	0.06	0	0.01	0.4	0.05	0.2	0.01
65	2/10/87	3/10/87	21.6	6.1	0.3	0.01	0.2	0.01	0.2	0.01	0	0.00	0.2	0.01	0.1	0.01
66	3/10/87	9/10/87	16.0	10.3	0.3	0.00	0.1	0.00	0.2	0.00	0	0.00	0.2	0.00	0.1	0.00

Appendix XI

Climatic data of Abbo Ager, Desse and Kembolcha.

Station		J	F	M	A	M	J	J	A	S	O	N	D
Abbo Ager	Max T°C	19.7	20.6	22.1	22.5	23.5	24.9	23.6	22.0	21.4	20.6	20.9	19.6
	Min T°C	9.4	10.9	12.0	12.5	13.2	14.0	13.4	13.2	12.9	10.9	9.8	9.6
	Rainfall (mm)	12.9	47.6	110.00	105.4	109.3	32.4	203.8	283.3	109.1	38.0	27.1	28.1
Desse	Max T°C	22.1	23.4	21.6	22.7	23.9	23.3	23.2	22.3	21.8	21.4	21.3	22.1
	Min T°C	4.0	6.5	5.9	7.9	7.8	8.6	10.4	9.9	8.5	5.7	2.7	3.0
	Rainfall (mm)	22.8	33.6	71.4	98.1	82.3	38.7	265.9	280.3	146.6	49.7	24.5	17.0
Kembolcha	Max T°C	23.8	24.8	26.2	25.9	28.3	30.0	29.0	26.0	25.4	23.4	23.8	23.3
	Min T°C	9.6	10.7	12.2	13.0	13.5	14.2	13.6	13.3	12.8	10.2	8.4	8.4
	Rainfall (mm)	26.9	41.5	92.9	80.2	72.2	48.4	243.4	247.2	108.5	38.1	23.1	15.6

Appendix XII

Soil depth(cm) of the six experimental plots

Control Plot	62
Grass Strip	65
Graded Fanya juu	63
Level Fanya juu	59
Graded Bund	59
Level Bund	50

Appendix XIII

Type of crop, seeding and harvesting dates on the experimental plots: 1986-87

	Season	Crop	Seeding date	harvesting date
1986	Belg	barley	22/3/86	12/7/86
	Kremt	horse-bean	13/7/86	22-24/11/86
1987	Belg	emmer-wheat	2/3/87	1/7/86
	Kremt	horse-bean	3/8/87	26/11/87

DECLARATION

I, the undersigned, declare that this thesis is my work and that all sources of material used for the thesis have been duly acknowledged.

Name Mulugeta Tesfay

Signature

Place Addis Abeba

Date of submission 6 July, 1988.