EVALUATION OF THE ADAPTABILITY AND RESPONSE OF POTENTIAL INDEGENOUS TREES TO WATER HARVESTING IN THE REHABILITATION OF KURIFTU LAKE CATCHMENT

BY

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DECLARATION

I, Wondwossn G/Tsadik, hereby declare that this thesis is part of my own work and it has not been submitted to any other universities or colleges before.

_____   _____

       Wondwossen G/Tsadik   Date

I, main advisor of the student confirm that this thesis has been examined and got my approval.

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Abstract

Accelerated soil erosion and land degradation is peculiar to hill side lake catchments that are devoid of vegetation cover. When trees and shrubs on hill sides are removed the soil on the site will be exposed and it will easily be eroded by various agents of erosion since it loses its aggregation and stability. Subsequently up slopes will lose their productive potentiality and transported top soils to down slope cause problems of displacement and drying of lakes through time. With the prevalence of such phenomena hill sides will ultimately doom to irreversible conditions of site degradation. The study aimed at evaluating the potential of adaptability and performance of five tree species to rehabilitate the degraded hill side of Kuriftu Lake catchment and the role of artificial water harvesting structures, such as infiltration pits, in the process. The study shows that different tree species have significantly varying potentials to adapt and rehabilitate such degraded hill sides. In addition water harvesting structures significantly augment seedling establishment of some tree species on hill sides while other species could establish without them.

According to this study a significant decline in the height growth of *Acacia abyssinica* in steeper slope classes was redeemed by infiltration pits. Tree species like *Dodonaea angustifolia* showed no need for water harvesting structures especially in gentler slope classes. Comparable mean height growth indicates comparative hardiness. It was also found that planting of tree species like *Acacia seyal* to rehabilitate such hill sides should be restricted to gentler slopes and augmented by infiltration pits. Height growth of this species showed a significant decline on steep slopes that could not be redeemed through the use of pits. *Olea africana* performed better on gentle slopes with water harvesting pits. The results indicate that comparable performances of this species could be attained in steeper slope classes when seedlings are planted with infiltration pits. *Euclea schimperi* has been found to perform poorest among the species evaluated in this rehabilitation study.

Key words: Hardiness, infiltration pits, Kuriftu Lake catchment, land degradation, water harvesting.

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Abbreviations

AEZ- Agro Ecological Zone
ANOVA- Analysis of Variance
A.S.L- Above Sea Level
B.S.L- Below sea Level
DMRT- Duncan's Multiple Range Test
DZARC - Debre- Zeit Agricultural Research Center
FAO- Food and Agricultural Organization
MOA- Ministry of Agriculture
NRSC- Natural Resource Conservation Service
OTA- Office of Technology Assessment
UNEP- United Nations Environment Program
WWF- World Wildlife Fund

1. Introduction

1.1. General background

Many hillsides in the Ethiopian highlands have been excessively degraded to address smallholder farmers' demands of mainly firewood and food. These hillsides are commonly owned and their management and rehabilitation has been very complicated.

A study conducted in Northern Wello, Ethiopia however demonstrated that with sufficient seed source from the surrounding remnant vegetation in the soil seed bank natural regeneration is a potential solution to rehabilitate degraded hillsides. Otherwise, if regeneration under natural condition cannot be effected, rehabilitation of such hillsides is carried out by planting using potential tree species that can withstand the prevailing condition of the site.

Among the major lakes of potential scenic value found in the Ada Liben woreda East Shoa zone, Oromia is Lake Kuriftu with an estimated total area of 4 hectare and with an elevation of 1883m a.s.l. It is located at $8^0 46'28''$N and $39^0 00'38''$E. The total annual rainfall in the area where the lake is located for the year 2002 is 745.6 mm (station record), which would be adequate for normal tree growth and establishment.

Apart from some minor uses for recreation and water supply, the potentials of the lake are not fully utilized in an environmentally friendly approach. Presently it is very difficult to find naturally growing trees on the hillsides of the lake due to severe soil degradation process that resulted from encroachment and cultivation of the site for years.

As to the role of role of repeated cultivation in reducing regeneration potential of a site Demel (1996) states that if the soil is disturbed and brought under continuous cultivation, these activities effectively prevent the recovery of woody vegetation and create favorable condition for the accumulation of herbaceous species which will later on be replaced by weeds. Although it has been pointed out that the annual rainfall in the study area is sufficient to maintain tree growth, according to FAO (1987) on top of sufficient rainfall, soil moisture and depth ought to be maintained to grow trees in the tropics to make up for the shallow soil depth and poor moisture storage.

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The soil in the study area is mainly Andosol, which according to Mesfin (1998) is characterized as fine textured and among the most productive soils of Ethiopia given adequate supply of water. In spite of this, Driessen & Dual (1991) strongly indicated that even though Andosols are relatively productive and resistant to water erosion due to their permeability, up-on deforestation and air drying they are highly liable to wind and water erosion. There should be a mechanism to assist water infiltration and moisture status for these soils and thereby contribute to tree growth and establishment especially on degraded hill sides like the study area. This calls for the use of water harvesting techniques along different slope classes of the study area to assess the adaptability of potential tree species. According to FAO (1991) water harvesting is the collection of run off for productive purposes instead of it being left to cause erosion. In semi arid and drought prone areas it is a directly productive form of soil and water conservation.

Apart from the impact of continuous cultivation that reduces the regeneration potential of trees by abandoning seeds of climax species, the study area experiences the negative impact of the relation that exists between slope and soil depth. Slope is the angle formed by the surface of the soil with the horizontal. According to (Toumey, 1974), slope controls runoff and drainage and hence this will have effect on the water content of the soil. Soil depth and moisture status vary almost directly with the gradient when other conditions are held similar. These makes the classification of the study area in to different slope classes and study the role of water harvesting structures to moisture retaining and early seedling establishment important.

Adequate information on the type of tree species adaptable to the hillside particularly with respect to moisture stress and poor soil depth is not available. Knowledge of integrating water harvesting with tree planting on hillsides is not well full-fledged though not new to the area. Therefore the existing hillside soil erosion and land degradation problems call for the research task of identifying adaptable potential tree species through water harvesting under the prevailing conditions of the study area.

1.2. Objectives:-

: Evaluate the adaptability potential of indigenous tree species for the rehabilitation of the degraded hillside.

: Evaluate the role of water harvesting structures for adaptability of seedlings on degraded hillsides.

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2. Literature Review

2.1. Intimacy and Impact of Man on Forests

Humans have a long time history of dependency on forest and forest products. Forests provide timber as well as non timber forest products that have direct utility in the day to day lives of people. In addition forests provide indirect use of preventing soil erosion by runoff through their canopies (excepting canopy drips) and root system and they are also involved in modifying the microclimate of an area. Generally speaking forests are sources of basic necessities of life, natural homes for biodiversity, collectors and storerooms of water, ecosystems of complex food webs of life and shelters for diverse forms of life on earth.

Forests offered the first bipedal ancestors of *Homo sapiens* on wooded grasslands of East Africa with food in the form of plants and animals, and water. After the discovery of fire, wood was used for burning, and later on for making tools. As life evolved, humans started clearing land for agriculture and opted for more and more settled way of life (WWF, 2006).

The major change in human history that affected the environment was the beginning of domesticated plants and animals. These events, independent in various places in the world resulted in agriculture, an increase in predictable food supplies and a rise in the human population. With the advent of agriculture humans transformed ecosystems and dominated them to the extent that they created new ones by substituting domesticated plants and animals in the areas once occupied by wild organisms. A consequence of agriculture was the domination of ecosystems by humans. Domestication provided a dependable and predictable food supply unlike what hunters and gatherers faced most of the time. Dependence upon domesticated plants led to land clearance to increase the area dedicated to food production.

This advance in human history marked the beginning of deforestation which is the primary visible impact imposed by man on forests. This brought with it the start of one of one of the major processes of deforestation: forest clearing for food production. Patterns of shifting cultivation were developed that depended on the reinvasion of the forest to restore the fertility of the land (Kimmins, 1987). Shifting cultivation has little effect on the forest provided that the fallow periods are long enough and size of population is small. However with increasing population and more demand for agricultural products, more land will be cleared

and the fallow periods get shorter. Extensive deforestation brings with it loss of soil fertility, higher surface runoff and soil erosion, increase in water pollution and flooding, increase in green house effect and loss of plant and animal species (http://library.thinkquest.org/26993/consequences.htm).

These days the ecosystem that gave us life is under severe threat. Early humans were hunter - gatherers, and later farmers, and because the population was small, the impact on the environment was minimal. But in the past couple of thousand years, the growing demands of an ever - increasing human population has halved the Earth's original forest cover. Forests are the Earth's largest and most productive ecosystem, and trees their most visible and important constituent. Humankind's past is linked to the forest, and it is easy to see how its survival will map our future as well (WWF, 2006).

2.2. Soil Loss on Hillsides

Unwise utilization of soils results in the total loss in the productive potentiality of soil. Soils on hillsides that are devoid of vegetation cover are subject to accelerated soil erosion since the intensity of runoff increases with gradient. Erosion is the physical wearing away of the earth's surface by the agents of wind, ice, water, or movement in response to gravity. Surface soil material is removed in the process. The severity of erosion depends on a combination of many factors, including the amount and intensity of precipitation, the texture of the soil, the steepness of the slope, and the amount of ground cover. Erosion is often quantified in terms of tons of soil loss per acre per year. A ton of soil may be visualized as the thickness of a sheet of paper spread over an acre (Hillel, 1998).

There are two basic types of erosion namely Natural (also called geological) Erosion and Accelerated Erosion. Natural erosion occurs when soil is in its natural environment, surrounded by its natural vegetation. This type of erosion has been taking place over millions of years. While existing soil is gradually lost, new soils can be formed through the slow weathering of parent rock material, and from soil particles moved in by air and water. Under normal climate conditions, and with stable ground cover, soil losses from this type of soil erosion often can balance out, or even be less than the rate of soil production. On the other hand accelerated erosion is caused by the activities of human beings. By removing surface vegetation and plant residue cover, the soil becomes more vulnerable to removal by wind or water. Agricultural production can contribute to accelerated erosion, as can forest harvesting, surface mining, housing and construction, and urban highway construction, all of which eliminate stable plant cover (Zachar, 1982).

Whenever vegetation is removed, as when forests are cleared for agriculture, and the ground is exposed to rainfall, soil erosion by water and wind may increase. On sloping land it far exceeds the rate under natural conditions. Accelerated erosion, widespread throughout the tropics, is one of the most serious environmental and socioeconomic problems affecting rural people (Chamberlain, 1990).

The most prominent cause of soil loss on hillsides is water erosion. Raindrops can contribute to soil erosion when they strike bare soil. With an impact of up to 30 miles per hour, rain can blast apart good soil structural units and splash the soil into the air. If the ground is on a slope, the flying soil is easily picked up by water flowing overland and can be carried far away. Water erosion could take the form of sheet erosion, rill erosion and gulley erosion. Sheet erosion is the primary removal of the soil in thin layers from a sloping land, while rill erosion and gulley erosion are subsequent forms that cause removal of soil with water from land with poor surface drainage and advanced removal of soil with heavy loads of water out of fields respectively (wild,1993). Though soil erosion is a phenomenon that can never be stopped there are various measures that could be applied to minimize its consequences.

2.2.1 Agents of Forest Decline and Soil Erosion on Hillsides

The loss of protective vegetation through deforestation, over-grazing, plowing, and fire makes soil vulnerable to being swept away by wind and water. In addition, over-cultivation and compaction cause the soil to lose its structure and cohesion and it becomes more easily eroded. Erosion will remove the topsoil first. Once this nutrient-rich layer of soil is gone, few plants will grow in the soil again. The presence of vegetation prevents or reduces the likelihood of soil erosion. Plant roots form a network in the O- and A-horizons that bind soil particles together. Where vegetation is sparse or absent, such as in arid or cleared areas, this binding agent is absent. Wind or running water easily erodes soils under these conditions. Additionally, the canopy of leaves provided by vegetation lessens the erosive force of rain impacting on soil. Plants also reduce wind velocity near the ground surface, thereby lessening the ability of winds to erode and transport soil particles.

Wind and water are the main agents of soil erosion. The amount of soil they can carry away is influenced by two related factors; speed - the faster either moves, the more soil it can erode away, and plant cover - plants protect the soil and in their absence wind and water can do much more damage. The occurrence and rates of soil erosion depend primarily on amount and type of vegetation, slope, amount of rainfall, soil type, and any human activities (White, 2000).

The likelihood of soil erosion is directly related to the slope of the land. In flat or gently sloping areas, water infiltrates into pore space in the soil before beginning to run off at the surface. For short duration rainfall events, there may be little or no runoff, and therefore little or no soil erosion. In addition, the velocity of surface water movement is slower on gentle slopes, so that running water has less ability to erode and transport soil particles.

On the other hand White (2000) relates that on steeper slopes water begins to run off at the surface before all of the pore spaces are full. Running water also has a greater velocity on steeper slopes and therefore a greater ability to remove and transport particles. Both slope gradient and length will have an effect on the amount of erosion. Naturally, the steeper the slope of a field, the greater the amount of soil loss will be from erosion by water. Soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff. Consolidation of small fields into larger ones often results in longer slope lengths with increased erosion potential, due to increased velocity of water which permits a greater degree of scouring.

2.3. Topographic Description of Ethiopia

Ethiopia has extremely varied topography. The complex geological history that began long ago and continues, accentuates the unevenness of the surface; a highland complex of mountains and bisected plateau characterizes the landscape. According to some estimates about 50 percent of African mountains, about 371,432 square kilometers above 2,000 meters, are in Ethiopia. Altitudes range from 126 meters b.s.l in the Dalol (Afar) Depression on the northern border, to the highest mountain, Ras Dejen in the Semen Mountains north of Lake Tana rising to 4,620 meters. The plateau in the northern half of the country is bisected by the East African Rift Valley, which runs more than 600 kilometers north–northeast of the Kenyan border to the Koka Dam on the Awash River south of Addis Ababa. The rift then descends to the northeast and its lateral escarpments begin to diverge from each other crossing the Afar depression toward the Red Sea coast (Mengistu, 2003).

Although the whole of Ethiopia lies within the tropical altitudes, the climate is cool in the highlands and warm in the lowlands. The annual range of temperature is relatively small because of the proximity of the equator. Rainfall variability generally increases as rainfall total decreases, and thus is generally greatest in the lower rainfall areas of the north and northeast highlands. The rainfall is mostly uni-modal. The climate is mostly determined by the altitude, which dominates all aspects of land use because of its influence on temperature (Bishaw, 2001).

The lowlands, the major grazing land of Ethiopia, form a wide apron surrounding the highland massif and part of the Great Rift Valley. This arid, hot zone, with up to 90 growing days per year, is suited mainly to extensive grazing. It includes the lowest elevation in the country at 126 meters below sea level. The lowlands make up nearly 61 - 65 percent of the land-mass, and are the major nomadic pastoralist and agro-pastoralist areas. The topographic diversity of the country has resulted in the formation of a multitude of agro-ecological zones and sub zones with varied farming systems (Mengistu, 2003).

2.3.1 Soil Loss and Land Degradation in Ethiopia

The dry land areas in Ethiopia extend from the Afar depression which is located at 120m below sea level to the elevation of 2700m a.s.l. Ethiopian land which falls within the UNEP's definition of desertification is estimated to cover 71.5% of the country's total land area. Overgrazing, deforestation, poor farming practices and using dung for fuel are the major causes of land degradation in Ethiopia. The recorded annual soil erosion (surface soil movement) in Ethiopia ranges from low of16 tons/ha/yr to high of 300 tons/ha/yr depending mainly on the slope, land cover, and rainfall intensities. The total estimated annual soil loss (surface soil movement) from the cultivated, range and pasture lands (780,000 km2) in Ethiopia is estimated to range from low of 1.3 to an average of 7.8 billion metric tons per year (Hawando, 2000).

 The wide spread practices of burning dung, burning crop residues for fuel and for seed bed preparation under state farm conditions, burning of forests and range lands, deforestation for cultivation, fuel wood and construction materials, as well as poor farming practices particularly in the areas practicing cereal mono-culture farming system and cultivation of steep slopes, increase the susceptibility of the land resources to erosion in dry sub humid and semi-arid areas.

The alarming rate of desertification can be explained by the combined effects of several factors related to population pressure, such as deforestation, overgrazing, expansion of cropland, unsustainable use of the natural resources and unbalanced crop and livestock production. As the rural population in Ethiopia largely depends on agricultural production, land degradation is a serious threat to the livelihood and food security of millions of people. Other undesirable consequences are the undermining of sustainable socio-economic development and loss of biodiversity (Katrien, 2007).

Soil degradation in Ethiopia can be seen as a direct result of past agricultural practices in the highlands. The dissected terrain, the extensive areas with slopes above 16% and the high intensity of rain fall led to accelerated soil erosion once deforestation occurs. In addition some of the farming practices in the highlands encourage erosion. These include cultivation of cereal crops such as tef (*Ergrotis tef)* and wheat (*Triticum sativum*), which require the preparation of a finely tilled seed bed, the single cropping of fields and down slope final plowing to facilitate drainage. Furthermore the socio political influences, especially insecurity of land and tree tenure have discouraged the farmers from investing in soil conservation practices. Soil degradation is thus the most immediate environmental problem facing Ethiopia (Bishaw, 2001).

To a larger extent farming in Ethiopia is highly subsistent. The lag in agricultural productivity advancement behind population growth has caused intense land use conflicts, particularly between the agricultural and the forestry sectors in Ethiopia. To compensate for the low agricultural productivity, deforestation for arable land expansion has been the principal land use change employed in Ethiopia for centuries. Rate of deforestation in Ethiopia, which amounts to 163,000 - 200,000 ha yr-1, is one of the highest in tropical Africa (Reusing, 1998; Lemenih, 2004).

2.3.2. Consequences of Deforestation

The protective value of trees on hill sides outweighs their economic value especially for those trees on steeper slopes. The rapid increase in human and livestock populations in Ethiopia has resulted in major changes in land use systems mainly through deforestation. Conversion of native forests to farmland and grazing has been commonly practiced in the highlands for several decades. Such activities have caused widespread soil nutrient losses. Consequently, many agricultural soils have reached the point of no return, for example in the mountainous areas of the northern and central highlands. Loss of soil fertility is manifested not only through deforestation, soil erosion and forest conversion, but also through the use as household fuels and animal feeds of animal dung and crop residues that would otherwise have been left on the site to replenish soil nutrient levels (yimer, 2007).

A change in land use, mainly through conversion of native vegetation to cropland and/or grazing, may influence many natural phenomena and ecological processes, leading to a significant change in soil physical, chemical and biological properties (Turner, 1989; yemer2007).Deforestation has innumerable consequences that include alteration of local and global climate through the disruption of the carbon cycle and the water cycle. Forests act as a major carbon store because carbon

dioxide (CO_2) is taken up from the atmosphere and used to produce the carbohydrates, fats, and proteins that make up the tree. When forests are cleared, and the trees are either burnt or rot, this carbon is released as CO_2. This leads to an increase in the atmospheric CO_2 concentration. CO_2 is the major contributor to the greenhouse effect. It is estimated that deforestation contributes one-third of all CO_2 releases caused by people. On the other hand trees draw ground water up through their roots and release it into the atmosphere (transpiration) plying an important role in the hydrological cycle. Removal of trees will disrupt the cycle and this in turn leads to drier climate conditions (Collins, 2001).

Deforestation has other negative effects on the soil also. With all the lushness and productivity that exist in tropical forests, it can be surprising to learn that tropical soils are actually very thin and poor in nutrients. The underlying "parent" rock weathers rapidly in the tropics' high temperatures and heavy rains, and over time, most of the minerals have washed from the soil. Nearly all the nutrient content of a tropical forest is in the living plants and the decomposing litter on the forest floor. When an area is completely deforested for farming, the farmer typically burns the trees and vegetation to create a fertilizing layer of ash. After this slash-and-burn deforestation, the nutrient reservoir is lost, flooding and erosion rates are high, and soils often become unable to support crops in just a few years. If the area is then turned into cattle pasture, the ground may become compacted as well, slowing down or preventing forest recovery (Lindsey, 2007). This phenomenon contributes to land degradation.

According to OTA (1983), degradation of tropical land is a physical, chemical, and biological process set in motion by activities that reduce the land's inherent productivity. This process includes accelerated erosion and leaching, decreased soil fertility, diminished natural plant regeneration, disturbed hydrological cycle, water logging, flooding, or increased drought risk, as well as the establishment of weedy plants that displace more desirable plant species. Evidence that the degradation process is advancing includes, for example, a reduction in the water-holding ability of the soil, a decrease in the amount of soil nutrients available to plants, and a reduction of the soil's ability to hold nutrients, or soil compaction or surface hardening. This definition implies a strong interrelationship between inappropriate land-use practices and land degradation. In some places degradation is manifest (e. g. erosion and desertification), whereas in others it is inferred (e.g., declining crop yields).

2.4. Fundamental Ideas about Soil

Soil as an entity is defined in many different ways. The explanations given to it widely differ from discipline to discipline. Soils range in depth form just a few inches to tens of meters and in many instances they have been transported many kilometers from the site of their initial formation and then deposited over materials such as bedrock which is much different than the original source of the soil materials. The effects of five soil forming factors alter the soil material: climate, time, relief, organisms, and parent material. These factors act together to differentiate individual bodies of soil. This is accomplished through four basic processes acting on the parent material to alter its properties and differentiate one soil from another. These are (A) Translocations, (b) Transformations, (c) Additions, and (d) Losses. It is the interaction of these soil forming factors in various combinations that gives us the great variety of soils we see today. The effects of these soil forming factors (weathering) results in the formation of layers with in the soil from the surface down to varying depths depending on the intensity of the weathering .These layers are called horizons. The combination of these layers in a sequence from the surface of the soil down represents a soil profile (NRCS, 2006).

The layers in a soil profile which are identified by letters A, E, B, C, O, and R. called horizons. Horizons within a soil survey vary in thickness and have somewhat irregular boundaries, but all of the boundaries generally parallel the earth's surface. Since the weathering of the soil profile starts at the earth's surface and works its way downward, the uppermost layers have been changed the most, while the deepest layers are most similar to the original parent material. Exceptions to this vertical aging process occur when transport mechanisms move the soil material and deposit it on the surface of previously formed soil profiles. Soil horizons are sometimes very easily identified and at other times are very gradual and faint. As to its composition soil possesses mineral matter, organic matter, air and water. The organic matter of soils is made up of undecomposed and partially decomposed residues of plants and animals and the tissue of living and dead microorganisms. Organic matter contains appreciable quantities of nitrogen, phosphorus and sulfur which become available to higher plants as decomposition occurs. Furthermore, the decomposition of organic matter helps to produce substances that make all of the plant nutrients more available. From a physical point of view, organic matter improves the aeration of soils, increases the water-holding capacity of the soil, and contributes to aggregate stability by supplying food for microorganisms whose function it is to produce chemicals which hold the soil particles together (NRCS, 2006).

A soil that is degraded is either poor or lacks one or more of the above mentioned constituents. The loss in these premium qualities of soil will therefore make the use of soil and water conservation activities very important to cope up with the ever increasing trends of land degradation and loss of productive land especially on hillsides.

2.4.1 The Need for Soil and Water Conservation

Soil erosion happens when particles of soil come loose and are carried away by water or the wind. When it rains so much that the water cannot seep into the soil fast enough, the extra water flows down the slope, carrying soil particles with it. Erosion problem is likely to be more severe on certain types of soils, on steep slopes, where there is intense rainfall, and where the vegetation is removed. Soil conservation aims at reducing the amount of soil erosion and maintaining soil fertility. It relies on increasing the amount of water seeping into the soil, reducing the speed and amount of water running off, and keeping enough vegetation to protect the soil surface and to bind the soil together.

Soil conservation efforts should be able to control erosion sufficiently, maintain the organic matter of the soil, soil physical properties and the appropriate level of nutrients in the soil. Equally important soil conservation is related with water conservation also. Water conservation efforts focus on stopping the water from becoming concentrated in the first place (by ensuring a protective cover of vegetation on the soil surface), slowing down the flow of running water (for example, with pits and dams), and spreading the water out over a large area for example, with contour ditches(Untitled doc). Soil and water conservation activities could be carried either with mechanical methods, biological methods or with the combination of both. With respect to the biological methods of soil and water conservation grasses and multipurpose tree species play an important role.

In this regard (Nair, 1984) emphasizes that trees play a crucial role in augmenting the overall capacity of the land to produce by modifying the physical property of the soil. The removal of the vegetative cover from the soil results in increases in bulk density decreases in porosity and reduction in infiltration rate. In line with this analogy, researches have demonstrated influence of trees in reversing this problem. Under *Prosopis cineraria* plantation in Semi-arid areas in India, silt and clay content of soil have increased up to a depth of 120 cm as compared to the surrounding open fields which are devoid of trees (Gebrehiwot, 2004).

These changes in soil physical properties resulted in the maintenance of soil moisture beneath the trees (Shankarnarayan et al., 1987; Gebrehiwot,2004) The

effect of a conservation measure in reducing soil loss generally varies with soil type, topography, climate and intensity of the measure, e.g., the distance between terraces or density of vegetation cover (Esser et al 2002).

Role of trees in protecting soils of dry lands against rainfall is also of paramount importance. Risks of soil erosion can be reduced by the combined cumulative effects of tree canopies, ground cover of annual crops or pasture grasses, legumes and shrubs, and a surface litter on rainfall erosive (Wiersum, 1984; Gebrehiwot, 2004). When the protective vegetation cover is removed, the structurally unstable soils are exposed to the beating action of rains. Tree crowns lessen solar radiation on the soil, reduce soil temperature, and thereby reduce moisture loss through evaporation from the surface soil where most annual food crops draw their moisture and nutrient uptakes. Most of the data in assertion to this come from tropical forests (Wilkinson and Ania, 1976; Gebrehiwot, 2004). Generally, trees have multiples of positive influences on the soil and water conservation tasks through their effect on soil physical properties, chemical properties, the hydrological balance and microclimate.

2.4.2. Water harvesting General Overview

The term water harvesting was probably used first by Geddes of the University of Sydney. He defined it as the collection and storage of any form of water either runoff or creek flow for irrigation use. These days water harvesting has become a general term for collecting and storing runoff water or creek flow, resulting from rain in soil profile and reservoirs both over surface /under surface. Previously it was used for arid and semi arid areas, but recently its use has been extended to sub humid and humid regions too (Sivanappan, 2004). In the semi-arid drought-prone areas where it is already practiced, water harvesting is a directly productive form of soil and water conservation. Both yields and reliability of production can be significantly improved with this method .Water harvesting can be considered as a rudimentary form of irrigation. The difference is that with water harvesting the farmer (or more usually, the agro-pastoralist) has no control over timing. Runoff can only be harvested when it rains (FAO, 1991). Water harvesting like many techniques in use today is not new. It is practiced as early as 4500 B.C. by the people of Ur and also latest by the Nabateans and other people of the Middle East. While the early water harvesting techniques used natural materials, 20th century technology has made it possible to use artificial means for increasing runoff from precipitation (Sivanappan, 2004).There are various ways of classifying water harvesting schemes adopted by different authors which some of them disagree in

terminologies but the general idea behind water harvesting is to use the run off created from a given catchment area on a cultivated area.

Water harvesting techniques could be of either rain water harvesting or flood water harvesting. The former refers to the collection of runoff and its use for the irrigation of crops, pastures and trees while the latter uses the floodwater of ephemeral streams and rivers. In arid and semi-arid regions, where rainfall is not sufficient to sustain a good seedling / tree growth, water harvesting for afforestation is applied. Parameters of most importance while selecting a water harvesting technique for afforestation are: (1) rainfall distribution and rainfall intensity, (2) topographical condition, (3) runoff / infiltration characteristics of the location, (4) water storage capacity of soils, cisterns and reservoirs, (5) the type of fruit, nut, or forest tree, (5) available technologies and socio-economic conditions and preferences of the cultivator (Prinz,2001). Among the various water harvesting systems the most prominent ones are: (1) Negarim micro catchments, "Negarim" is derived from the Hebrew word for runoff - "Neger", (2) Semi circular bunds, (3) V shaped, (4)trapezoidal bunds and contour bunds for trees. Each technique has its own design variations, technical details, suitability and limitations. Schematic representation of some of the systems is given below.
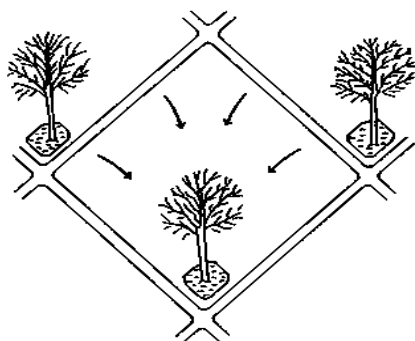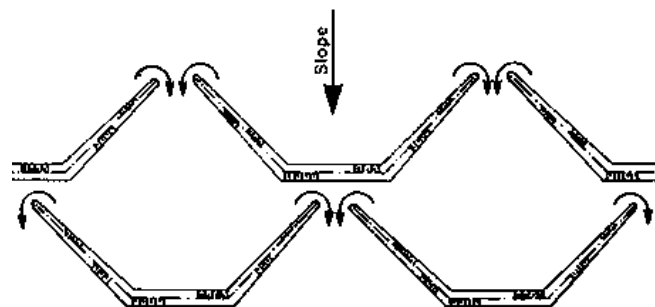
Negarim micro catchment   **Trapezoid**
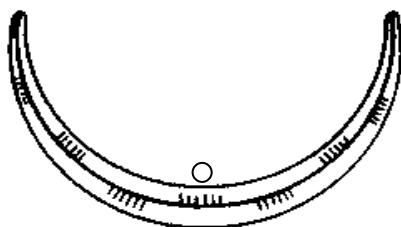
Semi circular   **v shaped**

Figure1: Major types of water harvesting structures.

Source: Water Harvesting.AGL/MISC/17/91   13

2.4.3. Contour Bunds for Trees

Contour bunds for trees are a simplified form of micro catchments. Construction can be mechanized and the technique is therefore suitable for implementation on a larger scale. As its name indicates, the bunds follow the contour, at close spacing, and by provision of small earth ties the system is divided into individual micr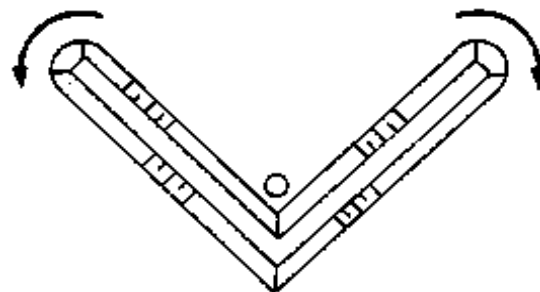o catchments. Micro catchments are simply ditches that concentrate surface runoff around the plant, thus reducing runoff and increasing infiltration to the plant roots. This system is more economical, particularly for large scale implementation on even land since less earth has to be moved. A second advantage of contour bunds is their suitability to the cultivation of crops or fodder between the bunds. As with other forms of micro catchment water harvesting techniques, the yield of runoff is high, and when designed correctly, there is no loss of runoff out of the system (FAO, 1991).

This system consists of small trash, earth or stone embankments, constructed along the contour lines. The embankments strap the water flow behind the bunds allowing deeper infiltration into the soil. The height of the bund determines the net storage of the structure. The water is stored in the soil profile and above ground to the elevation of the bund or overflow structure (Rebeka, 2006).

Contour bunds for trees are applicable to arid and semi arid areas where rain fall is between 200-700 mm. The topography has to be even without gullies or rills. Contour bunds are not suitable for uneven or eroded land as overtopping of excess water with subsequent breakage may occur at low spots. Bunds are formed with soil excavated from an adjacent parallel furrow on their upslope side. Small earth ties perpendicular to the bund on the upslope side subdivide the system into micro catchments. The cross-ties extend upslope from the main bund at an angle of 90° to the main bund; at least 30 cm should be left between the cross-tie and the infiltration pit to allow sufficient space for planting the seedling. Infiltration pits are excavated in the junction between ties and bunds. Excavated soil from the infiltration pit is used to form the ties. The pit is excavated in the junction of the bund and the cross-tie. A pit size of 80 cm x 80 cm and 40 cm deep is usually dug in the furrow above the bund and water collected in the furrow will then drain into the pit and supply the adjacent seedling. Diversion ditch protects the system where necessary. The system is more flexible, because the micro catchment size can be easily altered by adding or removing cross-ties within the fixed spacing of the bunds (FAO, 1991).

3. Materials and Method

3.1. Description of the Study Area

Kuriftu Lake catchment is located in the outskirts of the town of Debre zeit (Bishofftu) some 45km South East of Addis Ababa which is the capital of Ethiopia. It is found at an altitude of 1883mt a.s.l with total annual rainfall and average monthly temperature of 745.6 mm and 18.3 ^{0}c respectively for the year 2002(station record). As to its position the lake located at $8^046'28''N$ and $39^000'38''E$. Lake Kurifftu is among the major lakes of potential scenic value found in the Ada Liben woreda East Shoa zone, Oromia regional state, with an estimated total area of 4 hectare and maximum depth of 6 meter. Unlike many other bigger lakes like Hora and Bishoftu in the proximity of the town of Debre zeit, Lake Kuriftu is not a crater lake with underground water source but the result of accumulation of different seasonal streams that drain out in a very huge depression that gave the lake its shape. It was formed as a result of diverting and damming the tributary of the perennial Mojo River which is Belbela River for irrigation activity in the area. The lake gains water primarily from the Belbela River, with a small contribution from precipitation. Groundwater inflow plays a minor role in the water balance of this lake as the static water level in the area is well below the lake and the occurrence of loss of water through seepage is not well known (Seifu Kebede et al., 2001). During summer small scale irrigation associations pumped out the water from the lake to cultivate vegetables in the nearby flat and fertile lands. This has brought a substantial decline in the water level of the lake and the quality of small fish habitat. However in the year 2007, a resort hotel was built on one portion of the catchment that banned the use of motor pumps for irrigation and the lake receives relatively reduced interference from the nearby population these days.

Presently, the Medhanialem Orthodox church is enclosing the area where this study is conducted. Even though repeated attempts were underway to grow trees of exotic origin on the hills, the majority gave rise to very low survival percentages presumably due to poor moisture reserve for the growing period that continues beyond the rainy season. Seedlings planted on the site for prior observation in the last growing seasons showed a very poor survival rate, too. The site used to be cultivated over and over without rehabilitations.
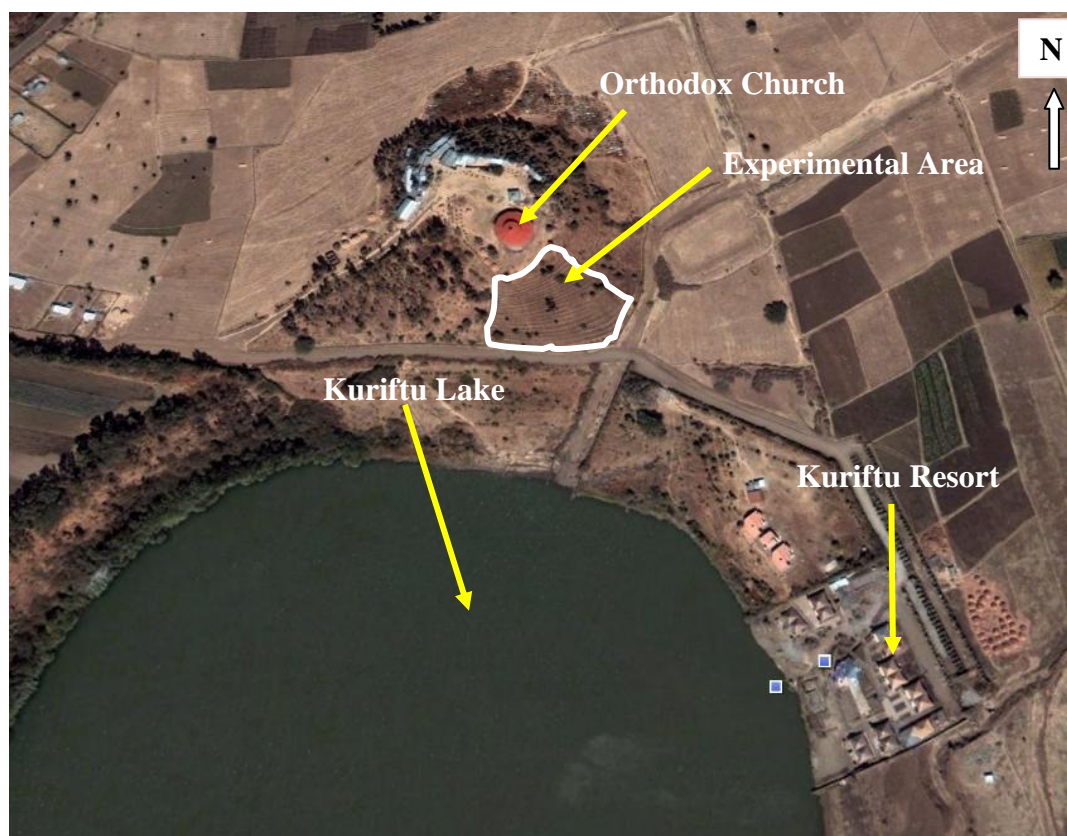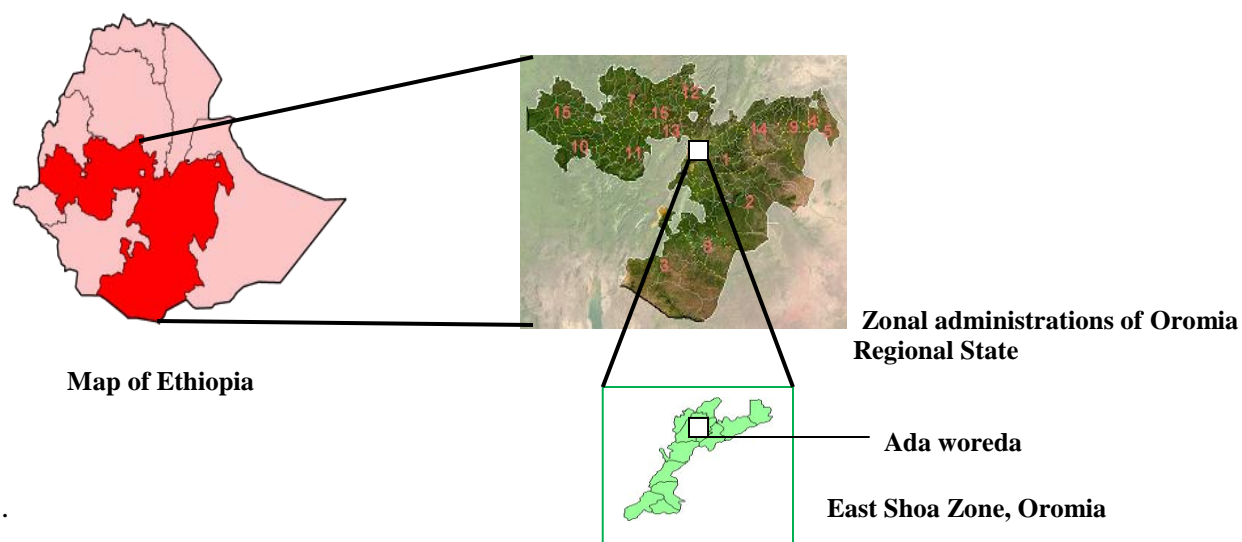
Figure 2: Location of the study area
Sources: http://www.maplibrary.org/stacks/Africa/
   : http://en.wikipedia.org/wiki/Wikipedia_help_desk.
   : Google Earth

The soil in the study area is basically Andosol. According to Fisseha .I (1992) the major soil types occupying the upper part of topographic position in Debre Zeit are Vertic Andosols which are highly liable to wind and water erosion. Though less is documented about the geology of the soil in the study area it is known that mostly Andosols occur in volcanic regions all over the world and the parent material from which the soils of the study area are developed could be volcanic ash or other volcanic ejecta. The study was conducted on the degraded hillside of the lake catchment within the boundary of the presently enclosed area by the Orthodox Church.

3.2. Description of the Tree Species Selected for Evaluation

It is known that there are a considerable number of species of indigenous origin whose environmental requirements may match with the study area. However, the following five indigenous tree species have been selected for assessment based on two environmental requirements i.e. total annual rain fall and temperature. Basically the natural growing zone of the species has been taken as a basic selection criterion. Careful attempts have been made to reconcile the environmental requirements of the species with the conditions of the testing site and all of them could qualify as multipurpose trees and shrubs with relatively high tolerances to environmental stress.

All the species can grow from the agro ecological ranges of dry Woyna Dega to Wet Woyna Dega zone according to the traditional (Ethiopian) agro ecological zone classification. Very strictly speaking the study area is in the Dry Woyna Dega agro ecological zone that is characterized by annual rainfall of less than 900mm and altitude range between 1500and 2300. This is SM_{2-5} i.e. Tepid to cool sub moist plains and plateau (MOA 1998). The following tree species were considered for evaluation of their adaptability on the hillside:

A/ Acacia abyssinica:

It is an indigenous tree species found on woodland or grasslands of the moist and Wet Kolla and Woyna Dega ACZ within the altitude ranges of 500-2000m. Flat-crowned tree 6–15 m high; bark rough and fissured, brown to nearly black Young trees establish ramifying root system before stem growth. The tree is noted apart from other acacias by its umbrella shaped canopy (Azene et al., 1993).

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Figure 3*: Acacia abyssinica* **in the field**

B/ Euclea schimperi:

This is a small indigenous tree/shrub that grows in dry wood land, bush land, riverine forests and marginal arid areas in Dry, Moist and Wet Kolla and Woyna Dega ACZ, with in the altitude ranges of 1500-2300m. The wood is very hard and can be used for firewood, farm tools, live fence, etc. The wood is hard and it coppices (Azene et al., 1993).

Figure4: *Euclea schimperi* **in the field**

C/ Olea africana:

This is an indigenous tree species that does best in good forest soils. However it is hardy and drought resistant once established, even in poor soils. It grows in Moist, and Wet Woyna Dega and lower Dega agro climatic zones. It can be used for charcoal, timber, bee forage, milk flavoring. The wood produces a fierce heat on burning and its poles are very durable in the ground (Azene etal., 1993).

Figure 5: *Olea africana* **in the field**

D / Dodonaea angustifolia:

This indigenous tree species grows in a variety of habitats from riverine forests to rocky soils or arid marginal areas in Dry and Moist Kolla and lower Woyna Dega AEZ from 1100-1800m. It can be used for windbreak, soil conservation, live fence and firewood. It is evergreen growing 3-8m ht. It is fast growing and usually useful as a tree to reclaim poor land from marshes to sand dunes (Azene et al., 1993).

Figure 6*: Dodonaea angustifolia* **in the field**

E/ Acacia seyal:

This indigenous tree species grows in Dry and moist Woyna Dega agro climatic zones within the altitude ranges of 1200-2100m.It can be used for fire wood, charcoal, bee forage, nitrogen fixation and soil conservation. It is medium to fast growing and withstands lopping and pollarding. In Western Ethiopia the tree is used as shade to coffee (Azene et al., 1993).

Figure7: *Acacia seyal* **in the field**

3.3. Experimental Design and Field Layout

The whole study area of the hillside was first classified in to two slope classes. As slope controls runoff and soil water infiltration and hence has impact on seedling establishment it was thus considered as the first factor (factor1) with the two different classes as its levels. The two slope classes identified for this research task were slope class I (0-17%) and slope class II (18-27%) and hence the first factor comprised two levels in it. Classification of the study area in to slope classes was done using the impulse hypsometer that operates through generation of IR radiation.

Species type was considered as the second factor (factor2). It is known that different tree species have variability in coping up with the prevailing condition of the site and stay survived. Accordingly the five different tree species listed in the species description part (section 3.2) were considered as levels for the second factor.

The last factor considered for the research was water harvesting structure. Different literature sources agree that provision of infiltration pits(Water harvesting structures) assists soil water infiltration on hillsides where runoff tends to persist and cause erosion and low seedling survival rate. Based on this fact the five different species for evaluation were treated under conditions where they were given with infiltration pits as well as without infiltration pits in different slope classes at the time of planting (figure 9). Therefore the last factor was considered to have two levels in it i.e. level zero which referred to a condition where seedlings are planted without infiltration pits adjacent and level one where seedlings were planted with infiltration pits adjacent to them.

Contour bunds for trees, which according to (FAO 1999) are the most simplified forms of micro catchments for better soil and moisture conservation were constructed following the contour over the whole study area. As the name indicates, the bunds follow the contour at close spacing, and by provision of small earth ties (cross ties) the system is divided in to individual micro catchments. To bring alignment of the bunds along the contour the Line level technique was used.
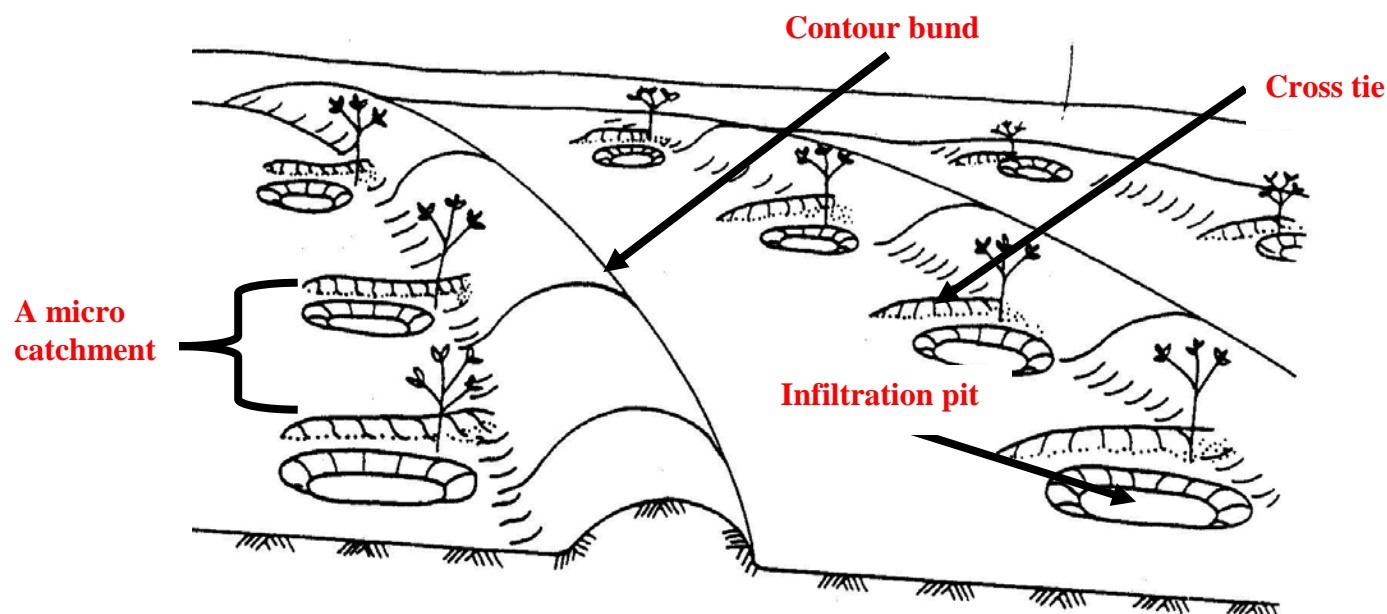
Figure 8: Alignment of contour bunds, cross ties and infiltration pits in the field.
Source: FAO, Water Harvesting.AGL/MISC/17/91

To serve the purpose of the experiment various modifications regarding the recommended bund spacing, bund height and size of infiltration pits were made. After the alignment of the contour bunds was settled with the help of line level and small wooden pegs, contour bunds were made by digging a furrow along the alignment following a somewhat curved path and heaping up the soil down slope. This was followed by compaction and stabilization of the structure by planting grass species and construction of infiltration pits of dimension 40cm*40cm*20cm in each micro catchment area. The soil dug out of the pits was used for the construction of cross ties that point to the contour bund at right angle (figure 8 and figure 9).The junction between the contour bunds and cross ties at the right angle was left open along the furrow so as to minimize the risk of seedling death due to excess water accumulation.
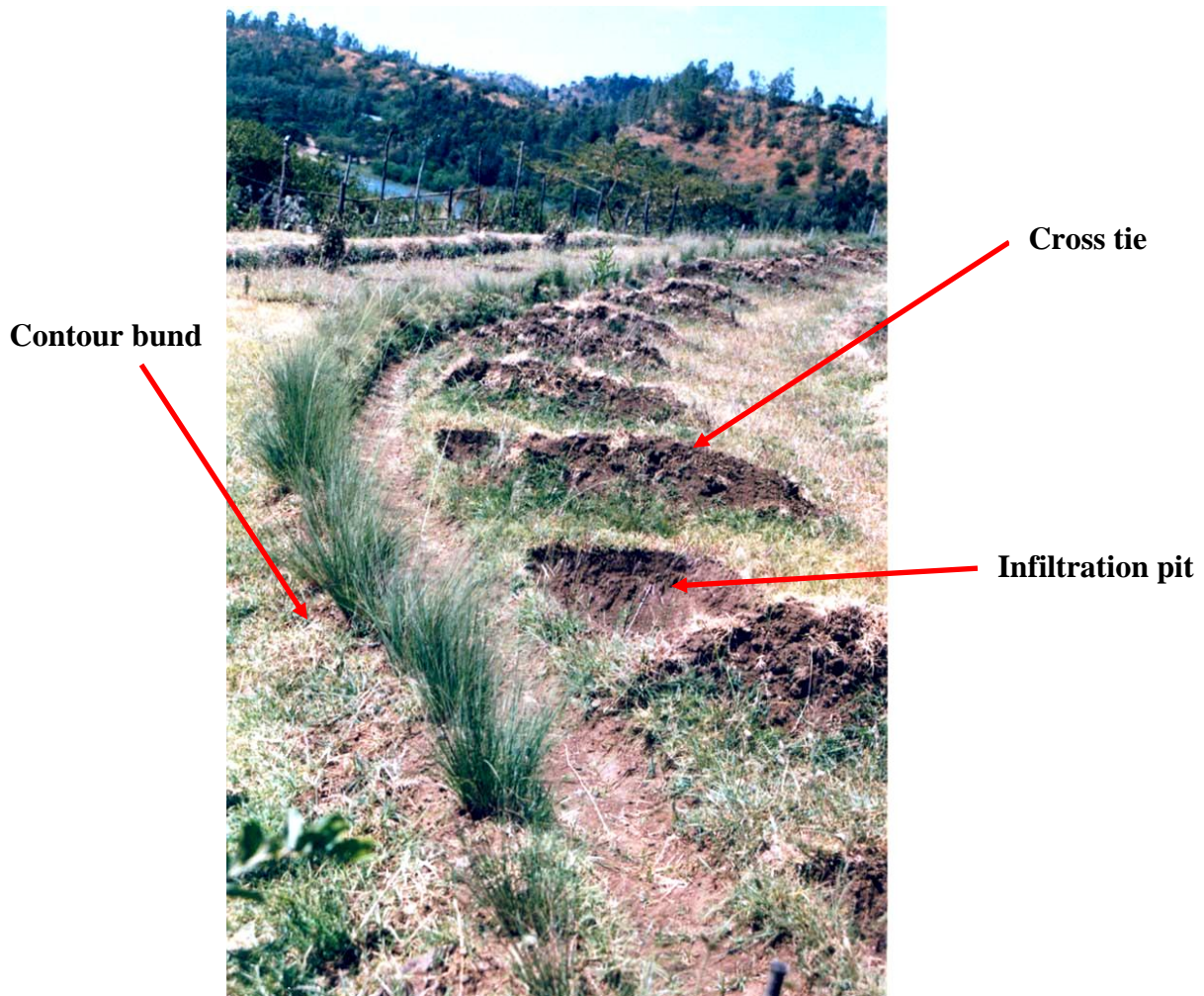
Figure 9: Alignment of bunds, infiltration pits and cross ties constructed in the field (1ˢᵗ year. June,2005)

On average a bund height of minimum 25cm for lower slope classes and 30 cm for higher slope classes was maintaind for all the bunds constructed through out the study area based on the recommendation given in most litratures for arid and semi arid areas.The spacing between the bunds was wider(3m) in lower slope classes(0-17%) and narrower(2.5m) in higher solpe classes(18-27%).In this regard the overall recommendation of bund spacing was followed with some modifications for the purpose of making the experimntal area more managable with in the given and available resource and to make it fit to the existing situation of the study area.However there was no overtopping of the bunds with excess runoff and subsequent damage on the earthwork structures encountered throughout the life span of the experiment as a result of adopting a modified bund spacing.The total length of earthwork construction is presented in appendix 1.

The whole study area was then divided in to three blocks. The most appropriate experimental design that handles the variations that arise from the three important factors mentioned earlier in this section is the Split-Split Plot design. Therefore split split plot design was used and the first factor which is slope (S_1 or S_2)was assigned to the main plot , water harvesting structure(H_0 or H_1) to sub plot factor and species type(A,B,C,D,E) to sub sub plot (split- split plot) factor. As a result there are 3 blocks (I-III) each with 2 main plot treatments (slope class I & slope class II) attached with 2 sub plot treatments (H_0 & H_1) and this combination was further attached to 5 treatments (figure 12) which are the five tree species for evaluation (A-E) in split-split plots. The assignment of treatments and levels was carried out through step wise randomization procedure(appendix 3) of the split split plot design .Assignments of factors and levels is also presented in fig.13.

Pure and viable seeds of the selected tree species were collected and their seedlings were raised in the nursery at DZARC using the standard procedures and substrate mixtures in June 2004which is the year ahead of the field work. To come up with an optimum seedling size (about 40cm) of the various tree species for planting 7-10 months were needed in the nursery.

Fifteen seedlings of each species were planted on individual plots of size about 50 sq. m across the slope with a spacing of 1.5 m in the space between the infiltration pit and the crosstie (figures 10 and 11). Planting was carried out after the first runoff had been harvested in June 2005.
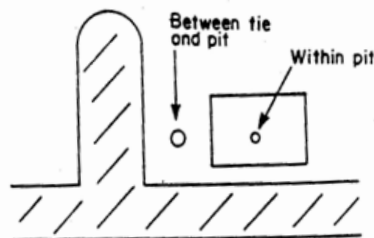
Figure10: Planting positions for seedlings
Source: FAO, Water Harvesting, 1991

Olea africana

Dodonaea angustifolia

Acacia seyal

Acacia abyssinica

Figure 11: Illustrations of planting positions in the experimental area

Figure 12: Field layout and randomization

Block I

Area for a single tree
(3*5)= 15 trees/plot

S2

D(0)	C(0)	A(0)	B(0)	E(0)

S1

A(1)	C(1)	E(1)	D(1)	B(1)

Species: A=*Acacia abyssinica*
B=*Euclea schimperi*
C=*Olea africana*
D=*Dodonaea angustifolia*
E=*Acacia seyal*

(0)= Seedlings without pit
(1)= Seedlings with pits

S1=Slope class I (0-17%)
S2=Slope class II (18-27%)

Main plot

Subplot

Sub- sub plot
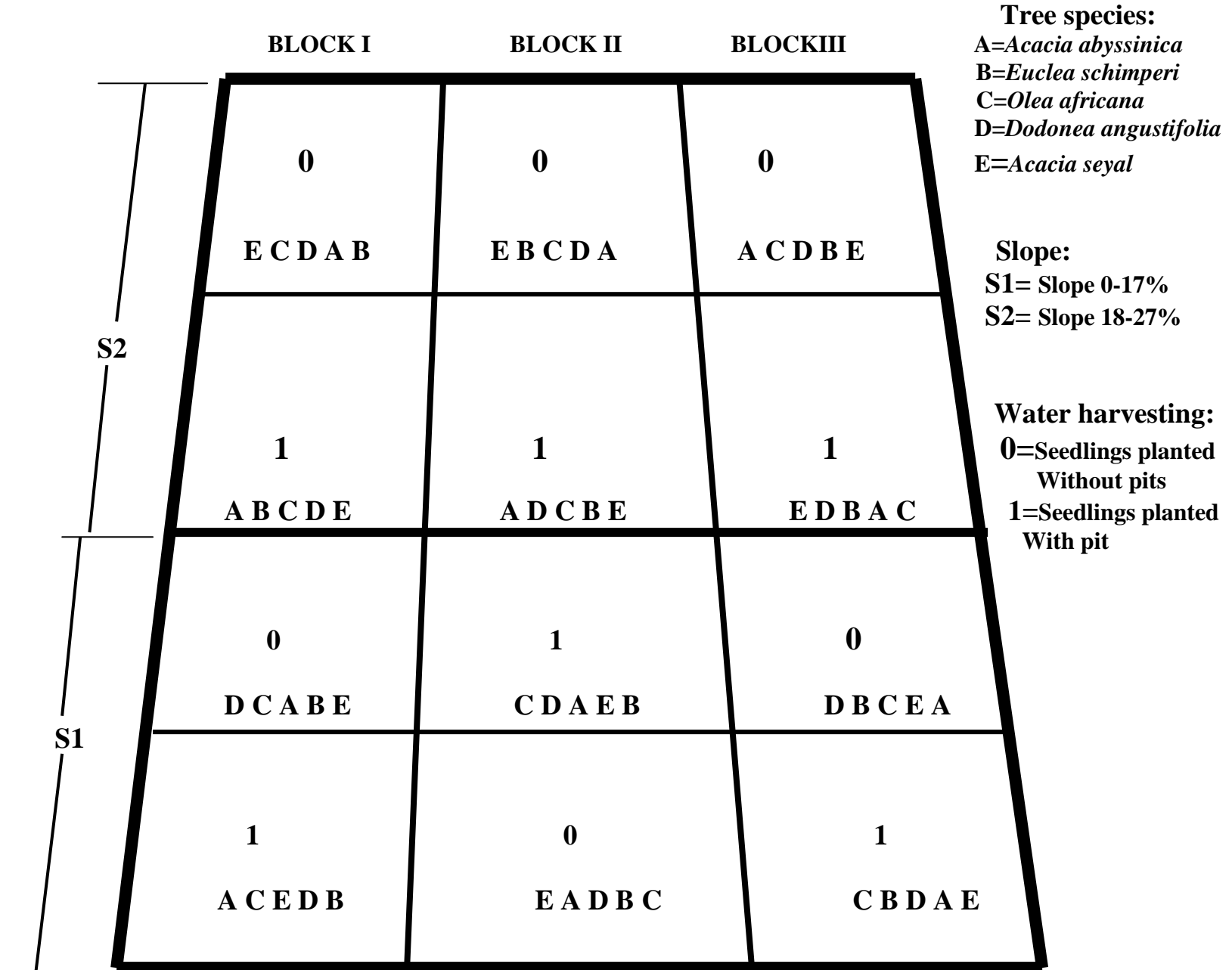
Figure 13: Assignment of treatments within a block in the field

3.4. Data collection and analysis

The major tree characteristics about which data was collected were tree height, collar diameter and survival. For this data collection formats were developed (appendix2&4).The raw field data was then summarized by mean values of 15 trees per plot per species for the variables height, diameter and survival count and then transferred to data summary sheet of split-split plot design prior to subsequent analysis using statistical software.

Data collected on survival, height and diameter of trees starting from the onset of the dry season were then subjected to the Mstat c statistical software for analysis to see if there is significant difference among treatment means at p=0.05. This was carried out by generating ANOVA table using the data for input variables under consideration from summary sheets (appendix 4). Survival percentage values were subjected to logarithmic transformation before parametric tests. This is because in order to apply ANOVA for test of significance among treatment means basic assumptions behind the use of ANOVA have to be fulfilled. Experimental data which comprise whole number such as survival percentage data often tend to follow Poisson distribution where the mean and the variance tend to be equal or proportional giving rise to an unsymmetrical distribution. Such data have to be transformed so that ANOVA becomes applicable. To identify treatment means that are significantly different among each other DMRT test for mean separation at p=0.05 was used.

4. Results

4.1. Height Growth

As it can be seen from the ANOVA table (Table 1) there exists significant difference among treatment means with respect to the variabl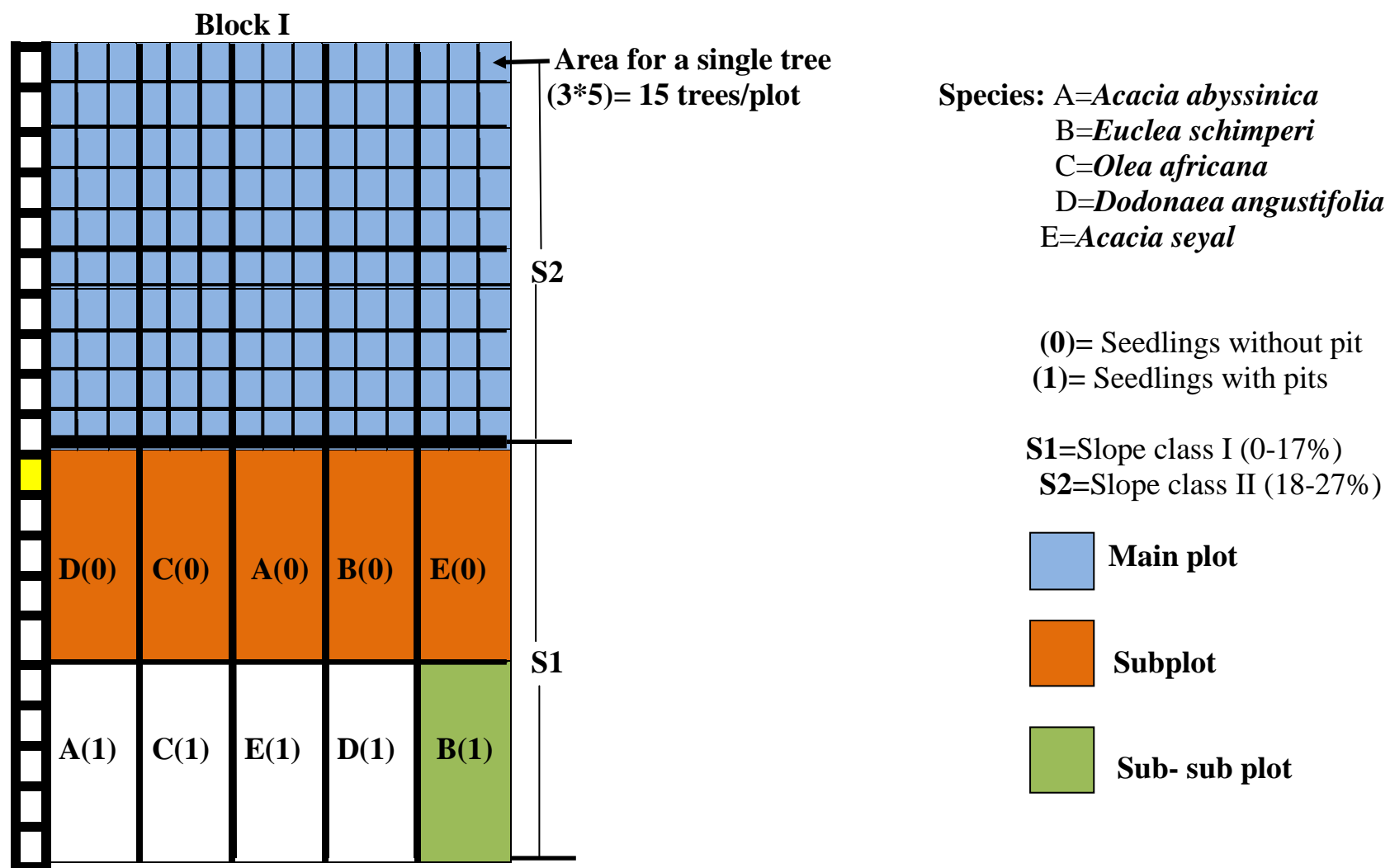e height at P= 0.05. This implies that under the prevailing conditions of the study area the five different tree species evaluated for their adaptability have shown significantly different performance by widely differing mean heights.

Once significance has been established the next step would be to find which of the means are the most significant ones or the best performing ones in terms of the variable under consideration which is height. This was done through DMRT. Accordingly *Acacia abyssinica* with mean height of 289.7cm was the found out to be the best performing tree species(Table 2) in terms of the variable height at P=0.05. The species attained this significantly higher performance in the lower

Table 1: Analysis of variance table for height

Factorial ANOVA for the factors:
      Replication (Variable 1: Block)
      Factor A (Variable 2: Slope)
      Factor B (Variable 3: Pit)
      Factor C (Variable 4: Species)

Source	Degrees of freedom	Sum of square	Mean square	F value	Prob.
Replication	2	715.68	357.84	0.34	
Factor A	1	8839.37	8839.37	8.46	0.0060
Factor B	1	6142.84	6142.84	5.88	0.0202
AB	1	259.16	259.16	0.24	
Factor C	4	318840.48	79710.12	76.33	0.0000
AC	4	4814.70	1203.67	1.15	0.3469
BC	4	1462.23	365.55	0.35	
ABC	4	894.28	223.57	0.21	
Error	38	39680.68	1044.22		
Total	59	381649.45			

Coefficient of Variation: 21.88%

slope class (0-17%) where it was supplied with water harvesting pits that were structures meant to facilitate run off infiltration and seedling establishment in the study area. An interesting aspect regarding the height performance of this tree species was that it gave rise to an equally comparable mean height of 241.2 cm in slope class II (18-27%) with infiltration pit and 236.8cm mean height in slope class I without infiltration pits signifying the role of infiltration pits.

The performance results of Acacia abyssinica in general indicated the fact that to attain significantly higher performance the species should more preferably be planted in lower slope classes where the soil is relatively better in moisture status and infiltration as compared to upper slope classes. On the other hand the results of the study disclosed that if this tree species is to be planted in higher slope classes and give better performance (figures15&16) the use of infiltration pits is an important precondition. This was clearly indicated in the mean separation by the significant decline in mean height to 215.6cm of the species when it was planted in slope class II without infiltration pits.

Table 2: Multiple mean height comparison of tree species evaluated.

Species	Slope class	Pit/No pit	Height(cm)
Acacia abyssinica	1	0	236.8 (AB)
		1	289.6 (A)
	2	0	215.6 (B)
		1	241.2 (AB)
Euclea schimperi	1	0	51.1 (FG)
		1	69.5 (EFG)
	2	0	42.8 (G)
		1	52.1 (FG)
Olea africana	1	0	103.9 (DEFG)
		1	115.5 (DE)
	2	0	83.9 (EFG)
		1	108.3 (DEF)
Dodonaea angustifolia	1	0	217.8 (B)
		1	226.8 (B)
	2	0	209.6 (BC)
		1	223.6 (B)
Acacia seyal	1	0	128.4 (DE)
		1	158.4 (CD)
	2	0	85.5 (EFG)
		1	92.6 (EFG)

LSD Value= 53.4
s_ = 18.66 at alpha 0.050
x
 # Different letters in the height column indicate that the means are significantly different.
Slope class I= 0-17%
Slope Class II.= 18-27%
(0)= Seedlings without pit
(1)= Seedlings with pits

The second best performing tree species found out from the study for the rehabilitation of the hill side was *Dodonaea angustifolia* with mean height of 226.8cm at p=0.05.Like *Acacia abyssinica* it attained this significant height performance(Table 2) in lower slope class when supplied with infiltration pits. However an equally comparable mean height of 217.9cm was also attained without infiltration pits in the same slope class suggesting that the use of infiltration pits is not crucial to its performance in lower slope classes.

Figure14: Mean height distribution of tree species evaluated on the study area
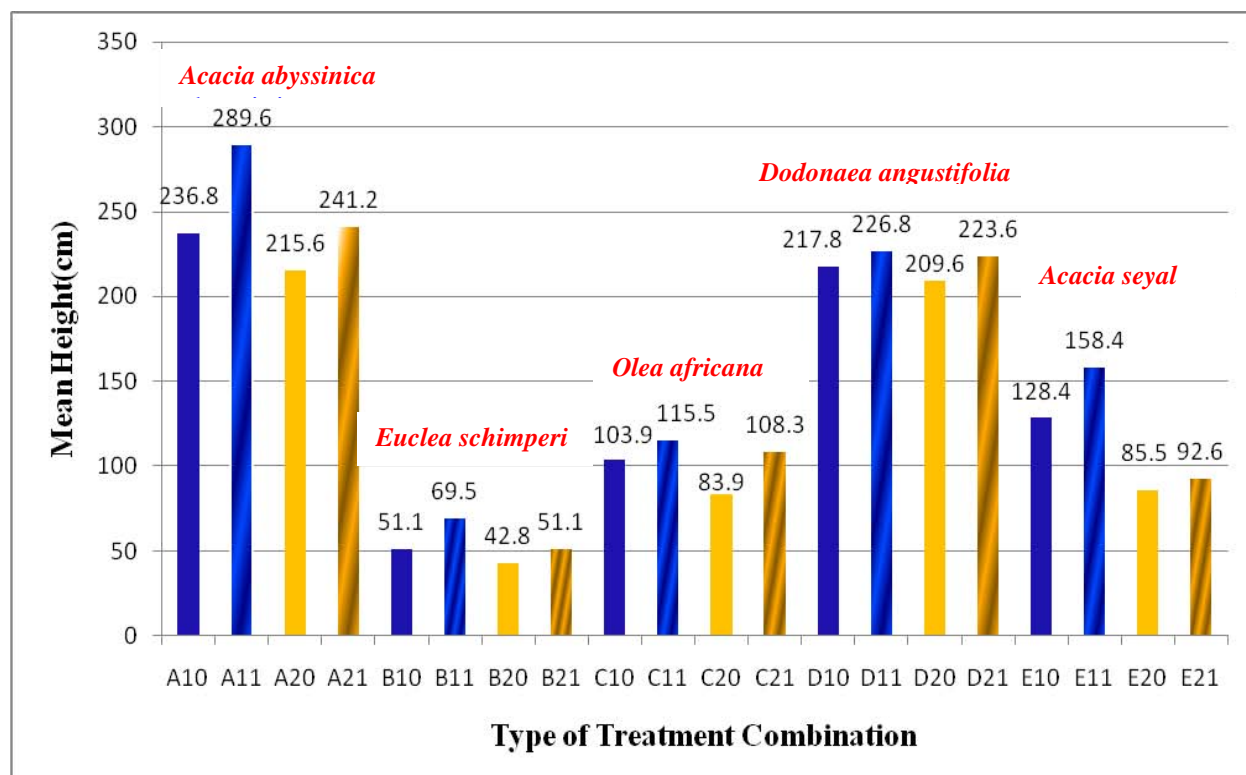
Legend:

Species: *A=Acacia abyssinica*
          B=Euclea schimperi
          C=Olea africana
          D= Dodonaea angustifolia
          E=Acacia seyal

   A10= *Acacia abyssinica planted in slope 1 without pit*

   A11= *Acacia abyssinica planted in slope 1 with pit, etc.*

   █ = *Planting in slope<17% without pit*

   █ =   *Planting in slope>17% without pit*

   █ = *Planting in slope<17% with pit*

   █ = *Planting in slope>17% with pit*

Figure 15: *Acacia abyssinica* **with pits in slope class II**

Figure 16: *Acacia abyssinica* **with pits in slope class I**

In slope class II its height did show a slight decline in the absence of infiltration pits while giving rise to an equally comparable mean height (223.6cm) with its performances in slope class I in the presence of infiltration pits, signifying the role of pits for its better performance in higher slopes (Figures 17&18).

Figure 17: *D. angustifolia* **with pit in slope class I.**

Figure 18: *D. angustifolia* **without pit in slope class II.**

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Figure19: Height growth differences of different tree species on the hillside

Acacia seyal with mean height of 158.4cm stood third (Table2) in terms of height performance on the hill side. It attained this height in lower slope class (Figure 20) when supplied with infiltration pits. With increasing slope a significant decline in the height performance of the species that could not even be redeemed through the use of pits was observed. This is explained by its equally comparable height performances (85.5cm and 92.6cm) in slope class II both in the absence as well as presence of infiltration pits.

Figure 20: *Acacia seyal* **with pit in slope class I**

On the other hand *Acacia seyal* and *Olea africana* showed equally comparable performances of 128.4cm and 115.5cm respectively in lower slope classes. However *Olea Africana* attained this height which is its highest performance when supplied with water harvesting pits while *Acacia seyal* was not. There was a decline in height performance of *Olea africana* and the use of water harvesting structure in higher slope classes was found out to improve its height performance. Among all the species compared *Euclea schimperi* performed least in terms of the variable height.

Figure 21: *Olea africana* **with Pits in the study area**

Figure22: Performance of *Euclea schimperi* **in the field**

4.2. Stem Diameter

The ANOVA for the variable diameter also showed that there exists significant difference (Table 3) among the species evaluated for the rehabilitation of the degraded hillside. With respect to the variable diameter *Acacia abyssinica* gave rise to significantly higher result of 5.2cm(Table 4) among the means compared at p=0.05.It showed this result in lower slope class when supplied with infiltration pits as in the case of its performance with respect to height. Very interestingly it showed an equally comparable mean diameter values of 4.4cm (the second highest mean diameter) in higher slope class (18-27%) with infiltration pits and 4.29cm mean diameter in lower slope class (0-17%) without infiltration pits. This explains the crucial role that infiltration pits play to at least attain an equally comparable diameter performance of the species with that of its performance in slope class I without pits. This was further explicitly indicated by the significant decline in mean diameter of the species to 3.7cm in higher slope class when it was planted without infiltration pits.

The performance of *Dodonaea angustifolia* stood second with respect to mean diameter. This species gave rise to the result when it was supplied with infiltration pits (Table 4) in both lower as well as higher slope classes.

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Table 3: Analysis of variance table for diameter
Factorial ANOVA for the factors:
  Replication (Variable 1: Block)
  Factor A (Variable 2: Slope)
  Factor B (Variable 3: Pit)
  Factor C (Variable 4: Species)

Source	Degrees of freedom	Sum of square	Mean square	F value	Prob.
Replication	2	1.19	0.59	0.82	
Factor A	1	6.45	6.45	8.96	0.0048
Factor B	1	7.01	7.01	9.74	0.0034
AB	1	0.20	0.20	0.28	
Factor C	4	82.67	20.66	28.70	0.0000
AC	4	1.96	0.49	0.68	
BC	4	0.46	0.11	0.16	
ABC	4	0.56	0.14	0.19	
Error	38	27.36	0.72		
Total	59	127.89			

Coefficient of Variation: 29.83%

This is clearly indicated in the mean separation by two equally comparable results of mean diameter values 4.6cm and 4.23cm for lower and higher slope classes respectively at p=0.05.Further on its mean diameter performance significantly declined from 4.6cm to 3.20cm in higher slope class when it was devoid of infiltration pits emphasizing the paramount role that pits play for its better performance.

Acacia seyal with mean diameter of 3.43cm scored the third significantly higher result at P=0.05. Like in the case of the variable height this species attained this performance in lower slope class when planted with infiltration pits. Almost like the case of its height *Acacia seyal* was accompanied by a significant decline in slope class II of its mean diameter when devoid of pits. Use of infiltration pits in slope class two improved its diameter performance only slightly. *Olea africana* followed acacia seyal in mean diameter performance and it gave rise to its highest mean diameter value of 3.06cm in lower slope class with infiltration pits. It could be disclosed from the mean separation that this species declines in its diameter performance in higher slopes and the use of pits in slope class II would at least

help to maintain an equally comparable performance (2.46cm) with that of its performance in slope class I.

Table 4: Multiple mean diameter comparison of tree species evaluated.

Species	Slope class	Pit/No pit	Diameter(cm)
Acacia abyssinica	1	0	4.29 (AB)
		1	5.2 (A)
	2	0	3.70 (ABC)
		1	4.4 (AB)
Euclea schimperi	1	0	1.06 (G)
		1	1.56 (FG)
	2	0	0.86 (G)
		1	1.26 (G)
Olea africana	1	0	2.46 (CDEFG)
		1	3.06 (BCDEF)
	2	0	1.93 (DEFG)
		1	2.46 (CDEFG)
Dodonaea angustifolia	1	0	3.73 (ABC)
		1	4.6 (AB)
	2	0	3.20 (BCDE)
		1	4.23 (AB)
Acacia seyal	1	0	2.30 (CDEFG)
		1	3.43 (BCD)
	2	0	1.46 (FG)
		1	1.63 (EFG)

LSD Value= 1.403
s_x = 0.4899 at alpha 0.050
 # Different letters in the diameter column indicate that the means are significantly different.
Slope class I= 0-17%
Slope Class II= 18-27%
(0)= Seedlings without pit
(1)= Seedlings with pits

As in the case of the variable height *Euclea schimperi* gave rise to the least performance among the species compared with respect to the variable diameter.

Figure23: Mean diameter distribution of tree species evaluated on the study area
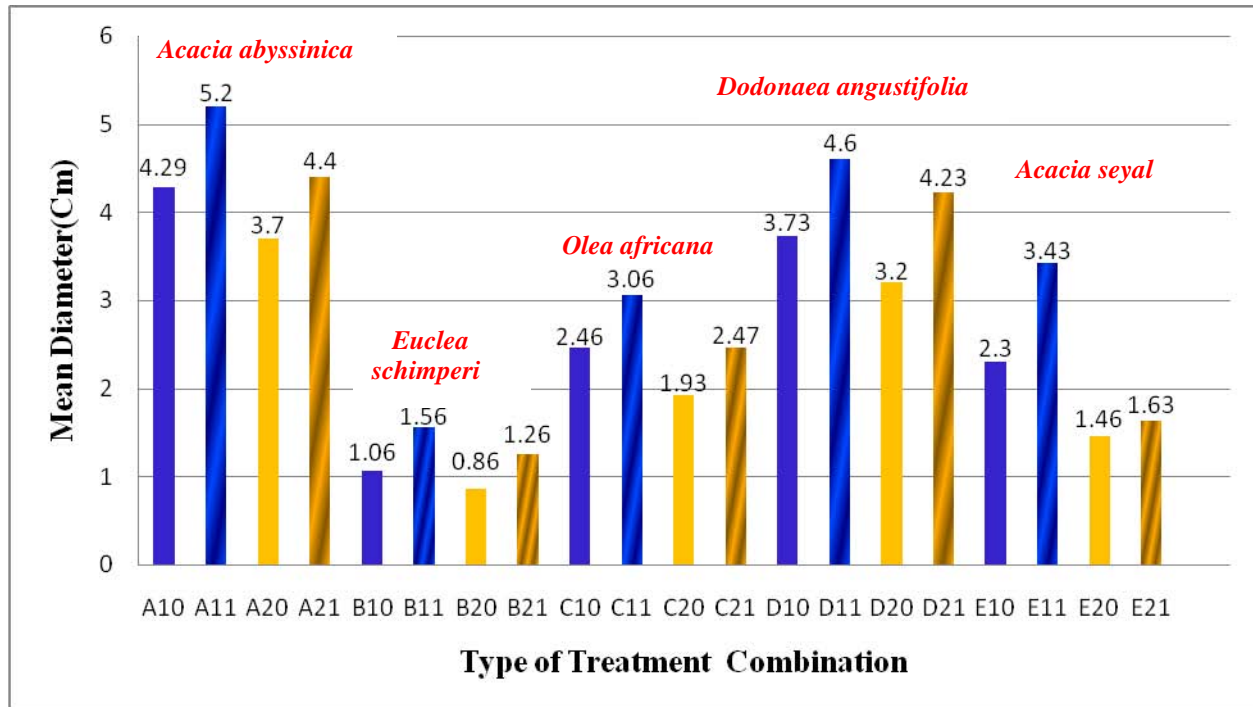
Legend:

Species: *A=Acacia abyssinica*
    B=Euclea schimperi
    C=Olea africana
    D= Dodonaea angustifolia
    E=Acacia seyal

A10= *Acacia abyssinica planted in slope 1 without pit*

A11= *Acacia abyssinica planted in slope 1 with pit, etc.*

= *Planting in slope<17% without pit*

= *Planting in slope>17% without pit*

= *Planting in slope<17% with pit*

= *Planting in slope>17% with pit*

4.3. Survival of Planted Trees

The survival potential of the five species evaluated on the hillsides of the study area was also found out to be significantly different as indicated in the ANOVA (table 5).

Table 5: Analysis of variance table for survival

Factorial ANOVA for the factors:

      Replication (Variable 1: Block)
      Factor A (Variable 2: Slope)
      Factor B (Variable 3: Pit)
      Factor C (Variable 4: Species)

Source	Degrees of freedom	Sum of square	Mean square	F value	Prob.
Replication	2	0.01	0.006	0.92	
Factor A	1	0.00	0.009	1.44	0.2361
Factor B	1	0.00	0.004	0.61	
AB	1	0.00	0.007	1.15	0.2890
Factor C	4	0.10	0.026	4.09	0.0074
AC	4	0.01	0.005	0.73	
BC	4	0.06	0.016	2.43	0.0635
ABC	4	0.07	0.018	2.81	0.0387
Error	38	0.24	0.006		
Total	59				

Coefficient of Variation: 4.20%

Unlike the height and diameter performances the analysis of survival data gave rise to highly interwoven and closely comparable mean values with very slight differences. As a result the stepwise sorting of the species based on their survival was not an easy task. However according to the results of DMRT(Table 6) *Dodonaea angustifolia* gave rise to significantly higher mean survival value of 1.987 at P=0.05 in lower slope class in the absence of infiltration pits. It also gave rise to equally comparable higher results in slope class II signifying that the use of pits is not that crucial for its survival in higher slope class. *Euclea schimperi* with mean survival value of 1.963 in lower slope class also stood equally comparable with *Dodonaea angustifolia.* On the other hand the survival of *Olea africana* was found out to be equally comparable with that of *Dodonaea angustifolia.* Olea africana showed this highly significant mean survival values regardless of its location in different slope classes and presence or absence of infiltration pits. Acacia seyal gave the next higher mean survival value (1.950) in slope class I. It

had equally comparable results in slope class II regardless of the presence or absence of pits as in the case of its situation with respect to the variable height.

As to *Euclea schimperi* it was equally comparable with *Dodonaea angustifolia* in lower slope class. Its higher slope class survival values were equally comparable with *Acacia seyal* too. *Acacia abyssinica* performed equally comparably with *Dodonaea angustifolia* in lower slope classes with pits though it showed the least survival value in higher slope classes among the species compared.

Table 6: Multiple mean comparisons of survival data for tree species evaluated.

Species	Slope class	Pit/No pit	Survival
Acacia abyssinica	1	0	1.763(C)
		1	1.930(AB)
	2	0	1.873(ABC)
		1	1.860(ABC)
Euclea schimperi	1	0	1.750(C)
		1	1.963(A)
	2	0	1.950(AB)
		1	1.940(AB)
Olea africana	1	0	1.967(A)
		1	1.973(A)
	2	0	1.967(A)
		1	1.953(A)
Dodonaea angustifolia	1	0	1.987(A)
		1	1.943(AB)
	2	0	1.953(A)
		1	1.963(A)
Acacia seyal	1	0	1.950(AB)
		1	1.800(BC)
	2	0	1.910(AB)
		1	1.907(AB)

LSD Value= 0.1280
s_ = 0.04472 at alpha 0.050
 x
 # Different letters in the survival column indicate that the means are significantly different.

Slope class I= 0-17%
Slope Class II= 18-27%
(0)= Seedlings without pit
(1)= Seedlings with pits

Figure 24: Mean survival distribution of tree species evaluated on the study area
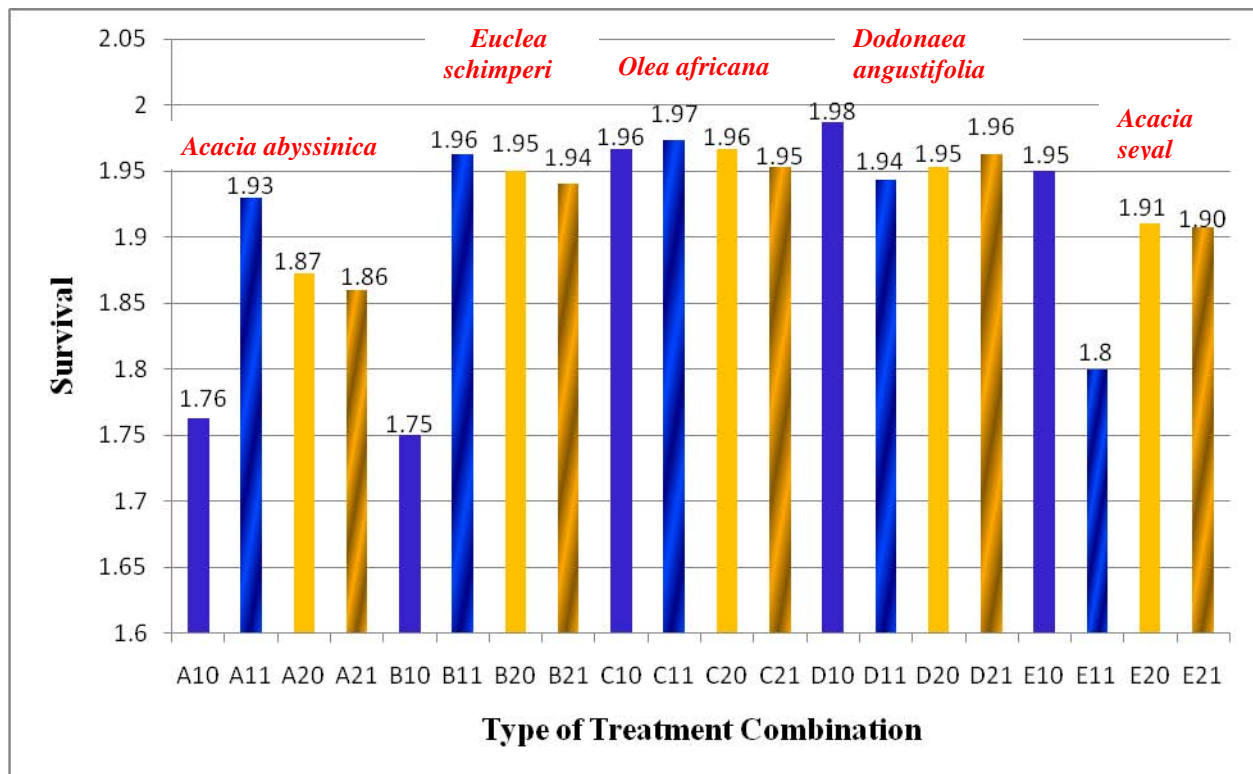
Legend:
Species: *A=Acacia abyssinica*
             B=Euclea schimperi
             C=Olea africana
             D= Dodonaea angustifolia
             E=Acacia seyal

  A10= *Acacia abyssinica planted in slope 1 without pit*

  A11= *Acacia abyssinica planted in slope 1 with pit, etc.*

 = *Planting in slope<17% without pit*

 =   *Planting in slope>17% without pit*

 = *Planting in slope<17% with pit*

 = *Planting in slope>17% with pit*

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5. Conclusion and Recommendation

5.1. Conclusion

The results of the study showed that there is significantly differing potential of adaptability (Figures14, 23&24) among the species evaluated on the hill side of the study area. It also provided a basis that different species have variability of performance in lower and higher slope classes and the decline in performance of some species in higher slope class could be redeemed though not significantly increased by the use of water harvesting structures that typically help to facilitate runoff infiltration and seedling establishment. The study has proven this typically for *Acacia abyssinica* mainly with respect to its height and diameter performance. The same conclusion holds to be true for *Dodonaea angustifolia* too. Another aspect that has been proven was a general trend of decline (Figure 14) in height and diameter performance of the species evaluated as one moved from lower slope classes to higher slope classes. This was more explicitly indicated in the case of *Acacia seyal* and *Acacia abyssinica.* This is an indication that to maintain seedling establishment and undertake successful rehabilitation of the hillside one should consider mechanisms of assisting run off infiltration.   On the other hand the study has also explicitly proven that planting of tree species like *Acacia seyal* ought to be restricted to lower slope classes more preferably with infiltration pits for their performance especially with respect to height significantly declines in higher slope classes and this could not be recovered through the use of infiltration pits.

 In this study prioritizing the best performing tree species for future rehabilitation tasks was tried on the basis of field data on three major variables namely diameter, height and survival count. It happened that the species that has a significantly higher height and diameter performance like *Acacia abyssinica* turned out to be the least surviving. On the other hand species like *Euclea schimperi* that had the least height and diameter performance gave rise to a highly significant survival data that are equally comparable with that of *Dodonaea angustifolia* which was proved as the best performing trees species in all aspects**.** Such complexities that are not following a somewhat definable trend across the three variables though expected make the task of evaluating the best tree species a bit perplexing. However even if a species has the highest survival it does not mean that it could be selected above others solely because it withstands the prevailing site condition of the area which is still in dynamism. On top of survival the ecological role that a species play counts a lot especially in the rehabilitation degraded hill sides.

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Accordingly from the results of the study it could be concluded that ***Dodonaea angustifolia*** could be planted without infiltration pits in lower slope class without its performance esp. with respect to height not significantly affected, explaining its relative stress tolerance while pits are more preferable for it in higher slope classes. ***Acacia abyssinica*** though it had the least survival its height and diameter performance is highly significant and thus it could be concluded that it is more preferable to plant the tree with infiltration pits for its better performance Regarding ***Olea africana*** it could be concluded from the results of the study that it is preferred to plant it with infiltration pits for better results and it is the third most preferred next to ***Acacia abyssinica*** for the rehabilitation task over ***Acacia seyal***. This is mainly because decline in the performance of ***Acacia seyal*** especially with respect to height cannot be recovered with the use of infiltration pits in higher slope classes as it was explicitly pointed out in the analysis results. Even though ***Euclea schimperi*** showed the highest survival value and hence hardy it is the least preferred for the rehabilitation of the study area due to its very low height and diameter performance.

5.2. Recommendation

Deforestation is a common phenomenon in the tropics. The consequences of deforestation turnout to be difficult to reverse in countries like Ethiopia, where population growth and land utilization patterns are exceptionally uncompromising. With an effort to make up for the loss huge tree planting campaigns on hill sides are held yearly at regional and national level at the onset of the rainy season on almost every corner of the country. Sadly enough the survival percentage after the onset of the dry season is very low. This is mainly attributed to the very less or almost no attention given to the seedlings after the very date of planting. Most of the seedlings happen to die because they have not been weeded. As they are planted on hill sides the runoff from upslope should be managed in such a way that it would neither waterlog the seedlings nor flood them away. On top of identifying the right and most adaptable tree species to plant, productive use of runoff created by slope variability through contour bunds for trees is a crucial precondition to facilitate seedling survival and establishment on hill sides.

Apart from selecting the species that better adapt to an area this study indicates that tree species also vary in their response to management practices to successfully establish across different slope classes. The performance of some species tend to be less influenced by their location as well as by the presence or absence of infiltration pits signifying their relative tolerance to moisture stress while for others the use of pits is very crucial. Therefore it is highly recommended that for

successful recovery and rehabilitation of degraded hillsides factors like slope and soil and water management activities should be taken in to account.

Basically the research disclosed an entry point for further related research within the limited budget available in relatively shorter time. The author also sincerely believes that in addition to measuring tree characteristics for comparison soil moisture data could be included to further elucidate the result. Yet the one fundamental recommendation from the results of the study is that for successful rehabilitation tasks on hill sides like Kuriftu Lake catchment and other similar areas one should take in to account which tree species to plant where and how. This is also one alternative way with which we can make up for the past failure histories of massive tree planting activities on the hillsides.

The research activity was undertaken in a fenced area with the hope that it would be implemented in other degraded hill sides in the proximity especially in collaboration with the rural community. Construction and maintenance of earthwork structures is a planned activity that demands the active participation of local people. In this regard to win the wholehearted willingness and participation of the local people in the extrapolation of the research it is also important that socio economic aspects should be clearly be dealt with the local community beforehand.

Lastly the research outcome could be exemplary to address the problem of hillside erosion by integrated approach. It could be regarded as a silvopastoral system where we have the different tree species as woody components and the grass that could be fed to cattle by cut- and- carry system as the non woody component. On top of their major direct uses trees have a positive effect by improving the physical, chemical and biological property of the soil through addition of nutrients and organic matter while the grass growing on site prevents soil erosion as well as helps to supplement cattle feed.

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7. Appendices

Appendix 1: Length of bunds (lateral and contour) on the hillside of Kuriftu Lake catchments

- ❖ **L stands for lateral bunds in meters**

L_1	L_2	L_3	L_4
63.3	60.0	47.70	41.50

No	*Block I*	*Block II*	*Block III*
1	31.50	32.50	20.60
2	30.70	31.50	32.80
3	29.60	30.70	31.70
4	28.95	29.50	30.60
5	28.00	28.60	29.33
6	27.20	27.60	28.60
7	26.54	26.70	27.60
8	25.45	25.90	26.90
9	24.70	25.20	26.10
10	24.00	24.20	25.20
11	23.50	23.30	24.40
12	22.90	22.80	23.60
13	22.20	22.40	22.80
14	21.80	21.60	22.00
15	21.20	21.00	21.50
16	20.30	20.30	20.80 ❖
17	19.70	19.60	20.10 ❖
18	19.00	19.10	19.10 ❖
19	18.30	18.50	18.50 ❖
20	17.70	17.80	18.00 ❖
21	17.20	17.20	17.40 ❖
Total	500.4	504.4	507.6 ❖

- ❖ Numbers 1-20 represent contour bunds across three blocks in meters.

Appendix 2: Field data collection form for the variables height, diameter and survival

BLOCK I   BLOCK II   BLOCK III

D(0)	B(0)	C(0)	E(0)	A(0)
C(1)	B(1)	D(1)	A(1)	E(1)

Appendix3: Treatment combination in the experimental area

Block I	S$_1$	+	S$_2$
	1A 1C 1E 1D 1B 0D 0C 0A 0B 0E	+	1A 1B 1C 1D 1E 0E 0C 0D 0A 0B
Block II	S$_2$	+	S$_1$
	0E 0B 0C 0D 0A 1A 1D 1C 1B 1E	+	1C 1D 1A 1E 1B 0E 0A 0D 0B 0C
Block III	S$_1$	+	S$_2$
	1C 1B 1D 1A 1E 0D 0B 0C 0E 0A	+	0A 0C 0D 0B 0E 1E 1D 1B 1A 1C

Blocks: I-III
Main plots: S$_1$, S$_2$
Sub plots: H$_0$, H$_1$
Sub sub plots: A, B, C, D and E where:

A=Acacia abyssinica
B=Euclea schimperi
C=Olea africana
D=Dodonaea angustifolia
E=Acacia seyal

Appendix4: Data summary sheet for Height, diameter and survival (Split-split plot design)

TREATMENTS			BLOCKS			TOTAL	MEAN
S(i)	P(i)	SP(i)	I	II	III		
1	0	A					
		B					
		C					
		D					
		E					
		S.P total					
	1	A					
		B					
		C					
		D					
		E					
		S.P total					
		M.Ptotal					
2	0	A					
		B					
		C					
		D					
		E					
		S.P total					
	1	A					
		B					
		C					
		D					
		E					
		S.P total					
		M.Ptotal					
		B. total					

- **Letters A-E=species**
- **(Si)=Slope classes**
- **(0), (1) =Seedlings without /with pits**
- **S.P total=Sub plot total**
- **M.P total= Main plot total**
- **B. total= Block total**