
Costs and Benefits of Soil and Water Conservation (SWC) Technologies in North-Western Ethiopia



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Costs and Benefits of Soil and Water Conservation (SWC) Technologies in North-Western Ethiopia

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Abstract

To this day, the agricultural sector is pivotal to the Ethiopian economy. Smallholders constitute the foundation of Ethiopian agriculture. The Ethiopian subsistence agriculture is almost entirely rain-fed and with generally low yields. Soil erosion by water is a major threat to food security, environmental sustainability and prospects for rural development in the country. The desired impact of soil and water conservation measures is to eliminate or at least to reduce the effects of land degradation. The profitability of soil and water conservation (SWC) measures is an essential precondition for their adoption. Other factors are pushed to the back as long as a technology is not profitable. The objective of this research was to determine the economic efficiency of three different types of SWC technologies (soil bund, stone bund and *Fanya Juu*) in the watersheds of Debre Mewi and Anjenie in the Amhara regional state in North-Western Ethiopia. A farm household survey was carried out among 60 farmers in both watersheds. Universal Soil Loss Equation (USLE) was used to assess erosion risk on farmers' fields. A Cost-Benefit Analysis (CBA) was carried out to determine profitability of the measures. Field observations and measurements as well as farmers' estimates indicate that the actual implementation of SWC line interventions in Debre Mewi and Anjenie watersheds differs from official design recommendations. Erosion estimates of farmers' fields suggest that adapted SWC structures were successful in reducing soil erosion. Apart from reducing the cultivable area, SWC measures require high initial labor investments. Under the current production system in Debre Mewi and Anjenie SWC line interventions seem not or hardly profitable for farmers unless farmers further intensify their production. Further adaptations to agricultural practices and SWC design and implementation might help to improve profitability of SWC measures and farm household incomes.

Keywords: Cost-Benefit Analysis, CBA, Soil and Water Conservation, SWC, USLE.

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List of abbreviations and acronyms

AISCO	Agricultural Inputs Supply Corporation
AISE	Agricultural Inputs Supply Enterprise
ARARI	Amhara Regional Agricultural Research Institute
B/C ratio	Benefit/ Cost ratio
CBA	Cost Benefit Analysis
CSA	Central Statistical Agency
DA	Development Agent
DAP	Di-Ammonium-Phosphate
DEM	Digital Elevation Model
ESE	Ethiopian Seed Enterprise
IRR	Internal Rate of Return
MoARD	Ministry of Agriculture and Rural Development
NPV	Net Present Value
PA	Peasants' Association
PC	Producers' Cooperative
RUSLE	Revised Universal Soil Loss Equation
SC	Service Cooperative
SCRIP	Soil Conservation Research Program
SLM	Sustainable Land Management
SWC	Soil and Water Conservation
TLU	Tropical Livestock Unit
USLE	Universal Soil Loss Equation
WFP	World Food Program

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1. Background

1.1. Ethiopian agriculture

The Ethiopian topography is characterized by a central highland plateau that is divided into a northwestern and southeastern part by the Great Rift Valley. The mountainous highlands are incised by deep gorges and river valleys. Climatic conditions vary widely within in Ethiopia because of its location in the tropics combined with huge variation in topography (Ofcansky and Berry, 1993). Throughout history these favorable conditions have attracted humans to the Ethiopian highlands to settle and farm there. The highlands, which can be defined as all areas above 1000 m.a.s.l up to the highest peak Ras Dashen at 4550, normally exhibit sufficient rainfalls and suitable temperatures that make rain-fed agriculture possible. Nonetheless, low temperatures make cultivation above 3800 m difficult. On the western side of the highlands, areas below 800 m are too dry for cultivation while on the eastern side the limit lies at 1200 m (Hurni et al., 2010).

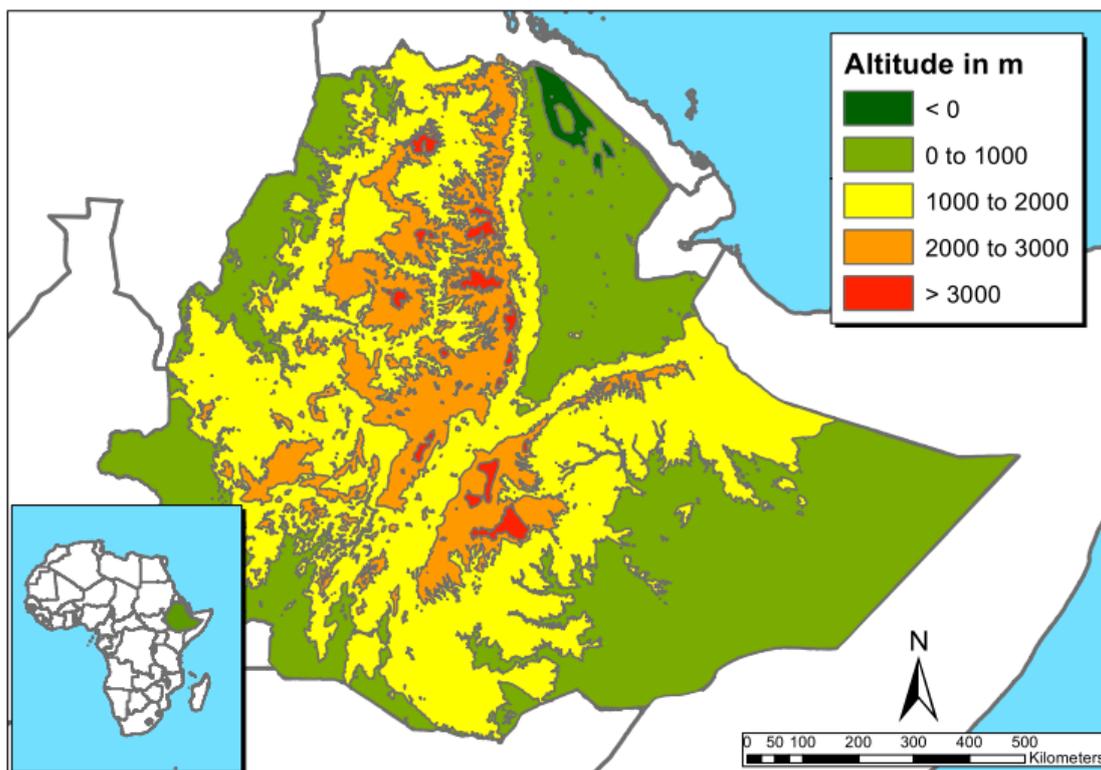


Figure 1 Location of Ethiopia on the horn of Africa and altitudinal belts in Ethiopia.

Source: Own compilation with map material from maplibrary.org

To this day, the agricultural sector is pivotal to the Ethiopian economy. Agriculture contributes about 40 % of the total GDP and gives employment to about 80 to 85 % of the population. Smallholders constitute the foundation of agriculture by cultivating 95 % of the cropped area and producing 90 to 95 % of all cereals, pulses and oil seeds. The Ethiopian subsistence agriculture is almost entirely rain-fed and with generally low yields (Mengistu, 2006; CIA, 2011).

The high importance of agriculture to the Ethiopian economy and social life makes agricultural development one of the key issues on the global development agenda. A July 2011 estimate puts the

Ethiopian population at almost 91 million with an annual growth rate of about 3.2 % (CIA, 2011). Consequently there are extreme land shortages in the Ethiopian highlands, where most of the agricultural production takes place. Since the 1960s per capita land area has fallen from 0.5 ha to only 0.2 ha in 2008. On top of that there is a high variability in agricultural production due to low productivity, recurrent droughts and variable rainfall (World Bank 2005 cited in Spielman et al., 2011).

In the past millennia little has been done by peasants and society to conserve natural resources. This was hardly necessary considering the low population and the relative abundance of land. In the 20th century, however, Ethiopia experienced an exponential population growth accompanied by massive deforestation and land degradation in the highlands (Hurni et al., 2010). Sonneveld (2002) concludes that “a further growth of food production in Ethiopia under current technology levels would only be possible by increasing the cultivated area. However, a land balance between presently cultivated and potentially suitable land for rain fed crop cultivation makes clear that the possibilities for area expansion are limited”. Consequently production increases will have to come from intensification of the arable areas. “This”, Sonneveld continues, “will be very difficult to implement unless water erosion and soil degradation are brought under control. Hence, a call for soil conservation in Ethiopia is justified” (Sonneveld, 2002).

1.2. Agricultural policies

During the imperial reign agricultural development was much hampered by a variety of factors, including tenancy and land reform problems, the government’s neglect of the agricultural sector, low productivity and a lack of technological development. Despite growing public demand for land reforms in the 1960s, a quasi-feudal land tenure system was maintained under Emperor Haile Selassie I (r. 1930 – 1974). Most of the land was owned by the aristocracy and the church. The majority of farmers were only tenants who had to hand over up to 50 % of their harvests to their landlords (Ofcansky and Berry, 1993).

In 1973/74 the region of Wollo was struck by a devastating famine which left 20,000 people dead. Following the famine and the imperial government’s inadequate response to it, the Ethiopian monarchy was toppled in 1974. Power was eventually seized by a military government popularly known as *Derg* (Amharic for ‘committee’). In the land reform, which was implemented by the *Derg* in 1975, all rural land was nationalized, tenancy abolished, the hiring of wage labor on private farms forbidden, all commercial farms put under state control and each peasant family was granted so-called ‘possessing rights’ to a plot of land not to exceed 10 hectares (Ofcansky and Berry, 1993). From 1975 onwards all farmers were forced to join Peasant Associations (PA) (in Ethiopia PAs are referred to by the Amharic word for neighborhood, *kebele*). The main task of the PAs was to carry out the land reforms by distributing the nationalized land. Starting from 1976 Service Cooperatives (SC) were established to promote cooperation of PAs in relation to pre- and post-harvest activities. Producers’ Cooperatives (PC), which were established at the same time, remained insignificant in terms of the number of farmers organized in them and the land that they cultivated. Shortly after their inception the PAs and SCs degenerated into ‘organs of transmission’ for government policies (Ludi, 2004).

The focus of agricultural development under the *Derg* regime lay on the large scale state farms and the PCs. In 1987/88 state farmland only accounted for 3.3 % of the total cultivated area and 6 % of

the total agricultural output. Yet, between 1982 and 1990 state farms received 43 % of the government's agricultural investments (Ofcansky and Berry, 1993). According to Ludi (2004) "smallholders were supported only to the extent that they produced surpluses, which could be taxed" (Ludi, 2004, p. 339).

After the fall of the *Derg* regime in 1991 and the first democratic elections in 1994, the current Ethiopian government has made several macro-economic reforms and implemented new agricultural extension policies. However, all agricultural land remained in the hands of the state but could now be inherited and even leased (Ludi, 2004). The new policies were usually centered on the promotion of improved seeds, fertilizer and credit by state-run companies (Spielman et al., 2011). In addition to that, previously existing quota systems were removed, the fixing of prices by the government ceased and wage labor on farms was permitted again. Moreover, the government made additional resources and personnel available to support the previously neglected smallholder sector (Ludi, 2004).

As hitherto the state-run agricultural extension in Ethiopia remains hierarchical in nature. It consists of regional Bureaus of Agriculture and Rural Development (BoARDS) under the supervision of the federal Ministry of Agriculture and Rural Development (MoARD). The BoARDS are in turn comprised of *woreda* (district) offices and extension agents (known in Ethiopia as 'development agents' or DAs) working at *kebele* (PA) level. The regional extension programs have increased the number of extension staff by a factor of more than three from 15,000 in 1999 to 47,500 in 2008. All of the organizations mentioned work with the still existing Service Cooperatives and regional credit and savings institutions in supplying inputs and facilitating the access to credit. The new agricultural policies of the past two decades have led to an increase in agricultural productivity but it has been suggested, that the strictly state-controlled provision of agricultural inputs and extension services have "outlived their usefulness" (Spielman et al., 2011, p. 29).

1.3. Land degradation and SWC in Ethiopia

Especially in recent decades, an ever more increasing population pressure has worsened the strain on natural resources in Ethiopia. Today, population densities and herd sizes are the highest in all of Africa. Farmers are forced to even cultivate marginal lands on steep slopes that are highly susceptible to soil erosion (Hurni, 1993; Taddese, 2001; Sonneveld, 2002). Nowadays, soil erosion by water has become a major threat to food security, environmental sustainability and prospects for rural development in the country (Bewket and Teferi, 2009; Teshome, 2010). According to Tamene and Vlek (2008) about 1.5 million tons of topsoil are lost from the Ethiopian highlands each year due to erosion. Preventing this loss has the potential to add about 1.5 million tons of grain to the country's harvest (Tamene and Vlek, 2008).

Throughout the 1970s and 80s the *Derg* used the PAs to implement their country-wide large-scale resource conservation projects, launched in reaction to the 1973/74 famine. These activities were financed with support from various international donor organizations like the World Food Program (WFP) and focused on soil conservation projects on arable land as well as afforestation and the enclosure of highly degraded areas (Ludi, 2004). However, the results remain doubtful. After the end of these programs a large proportion of the constructed conservation structures were either partially or even totally destroyed and abandoned by farmers (Taddese, 2001; Ludi, 2004; Bewket, 2007). According to USAID (2000 cited in Ludi, 2004) by 1990 only 30 % of the soil bunds, 25 % of the stone bunds, 60 % of the hillside terraces, 22 % of the original area of tree plantations, and 7 % of the closed areas implemented under the *Derg* rule remained intact. Many researchers argue that the main reasons for the failure of the projects lie in:

- the top-down approach in the planning and implementation process,
- limiting the input of farmers to labor contributions through food-for-work schemes or coercion,
- a lack of adaption of SWC measures to site-specific conditions and
- a lack of integration of previously existing indigenous SWC technologies.

(See Ludi (2004) and Bewket (2007) for summaries of studies on this subject.)

In the 1990s the present government of Ethiopia changed its approach towards resource conservation activities. SWC structures on cultivated land were built as part of agricultural extension packages. The relation between technical experts, governmental development workers and farmers remained delivery-oriented. Farmers were still not involved in the planning processes and were still forced to implement measures designed for them by technical experts, i.e. outsiders (Bewket, 2003).

In 2005 the Ethiopian Ministry of Agriculture and Rural Development (MoARD) in collaboration with several international development organizations for the first time published a guideline for 'Community Based Participatory Watershed Development', commonly known as the 'Watershed Development Guideline' (MoARD, 2005). Besides summarizing technical details of SWC measures, the guideline lays special emphasis on the integration of land users in the design and implementation process of SWC.

1.4. Problem statement

A common feature of land degradation in Ethiopia is the connection between rapid population growth, declining soil fertility and low crop yields (Taddese, 2001). Agriculture is of paramount importance for the Ethiopian society and economy. Nowadays, agriculture in the highlands is especially badly affected by soil erosion by water. According to Hurni (1993) the average annual rate of soil loss on cropland in the Ethiopian highlands is as high as 42 t*ha^{-1} . Soil erosion reduces the productivity of the soil "thereby making production unprofitable as soil quality declines below a certain threshold" (Shiferaw and Holden, 2001, p. 341). Besides these on-site effects, erosion also leads to off-site effects like the siltation of reservoirs and waterways (Lal, 2001).

Kappel (1996, p. 9), claims that in the 1990s "a growing number of scientists in the field of soil conservation agree that profitability has often been neglected in the design and propagation of

conservation technologies in the past. Ecological effectiveness and technical simplicity were guiding principles followed over many years". Since then several analyses of the financial efficiency of SWC in the Ethiopian highlands have been carried out. For example, by Shiferaw and Holden (2001) and Ludi (2004). Both of these studies were based on data collected by the Soil Conservation Research program (SCRIP) in three different locations across the Ethiopian highlands in the 1980s and 90s. Shiferaw and Holden (2001, p. 355) concluded that "private economic gains to small farmers from undertaking proposed mechanical and biological conservation investments are minimal" and that only grass strips seemed, under certain conditions, to be promising investments. Similarly, Ludi (2004) concluded that profitability of SWC structures is highly situation specific and depends on several factors:

- Ecological characteristics: topography, climate and soil characteristics
- Characteristics of the farming system: e.g. technology, crop types
- Economic characteristics: e.g. high transaction costs forcing farmers to remain in subsistence mode of production
- Institutional characteristics: e.g. land tenure insecurity, religious regulations.

2. Concepts and Theories

2.1. Land Degradation

The UN Convention to Combat Desertification defines 'land' as the "terrestrial bio productive system"(FAO, 2005). It does not just include the soil but also other natural resources like climate, water, land forms and vegetation (Stocking and Murnaghan, 2001).

Land degradation is a broad term that encompasses a variety of processes that lower the productive capacity of land. Since no single measure to assess productive capacity exists, indicators of land degradation have to be used. These indicators may show that land degradation has taken place; they are, however, not always the degradation itself (Stocking and Murnaghan, 2001). Vegetation degradation, water and wind erosion, salinization, soil compaction and crusting, and soil nutrient depletion are usually considered as the most common degradation processes (FAO, 2005).

The idea of productive capacity is to be seen in relation to the land user. For example: the conversion of forestland to cropland may cause biological degradation as well as economic degradation for forest users but at the same time be accompanied by increased economic benefits of food production (FAO, 2005). Blaikie and Brookfield (1987) are even more explicit when they define land degradation as a purely social problem. The authors argue that environmental processes, like leaching and erosion, take place in the presence as well as the absence of human intervention. "But for these processes to be described as 'degradation' implies social criteria which relate land to its actual or possible uses" (Blaikie and Brookfield (eds.), 1987, p. 1). This statement is in line with Mahmud et al. (2007, p. 3), who conclude that "land degradation is a complex phenomenon influenced by natural and socio-economic factors".

In a short literature review Haile et al. (2006) assert that there is no consensus on the explanation of the root causes of land degradation. However, high population pressure is seen by many as a main - yet not exclusive - cause of land degradation. On the contrary, some studies even suggest that areas with high population pressure are centers of innovation and land care practices (Tiffen et al. 1994 in Haile et al., 2006).

2.2. Soil Degradation

Soil degradation is as a major aspect of land degradation (Stocking and Murnaghan, 2001). It refers to biophysical processes that lead to a decline in soil quality. Soil degradation processes can be distinguished as being physical, chemical and/or biological. The speed and extent of these processes is in turn influenced by different factors, such as soils, relief, climate and farming systems (Haile et al., 2006). In addition to these bio-physical factors, soil degradation is aggravated by socio-economic and political factors (Lal, 2001).

Haile et al. (2006) state that agricultural use sooner or later degrades soil and reduces its fertility if not accompanied by suitable soil conservation measures. According to Lal (2001, p. 251) "soil degradation is accentuated by poverty and can cause more serious problems on soils managed for subsistence agriculture with no external input than on those managed for agriculture with science-based input".

2.3. Soil Erosion

Soil erosion is generally considered as the most common form of land degradation and an associated decline of agricultural productivity (Stocking and Murnaghan, 2001). "Soil erosion is a particular physical process that causes land and soil degradation [...]. [It] refers to the wearing away of the land surface by water and/or wind as well as to the reduction in soil productivity due to physical loss of topsoil, reduction in rooting depth, removal of plant nutrients, and loss of water" (Mahmud, 2007, p. 3).

Soil erosion occurs at all times as a result of the interaction of climate (weathering, precipitation), vegetation (nutrient uptake, protective cover), parent material and topography. This type of 'geological' or 'natural' soil erosion can further be influenced by land users. In that case one refers to 'accelerated (or human induced) soil erosion' (Haile et al., 2006).

Physically speaking soil erosion is a three stage process: First, soil particles are detached by either wind or water. Second, they are transported and third, the detached soil particles are deposited. In certain cases a general decline in soil quality can precede soil erosion, especially when the structural units of the soil are weakened, e. g. through tillage. In other cases erosion may induce the decline in soil quality and eventually cause soil and land degradation (Lal, 2001). Mahmud (2007) argues that one has to be careful not to attribute decline in soil quality and soil fertility solely to soil erosion as some researchers have pointed out that removing crop residues, volatilization and de-nitrification as well as leaching of nutrients also play a significant role in reducing soil fertility in Africa.

Soil erosion has severe economic effects through reduction in farm income and other losses which have a negative impact on agricultural production. These productivity effects can be both on- and off-site. "The on-site productivity loss due to soil erosion is attributed to three interacting effects: short-term productivity effects, long-term productivity effects and reduction in soil quality. The most severe effect is due to loss of topsoil depth in soils with a root-restrictive layer". The negative impacts on the environment are due to the pollution of natural waters (Lal, 2001, p. 530).

2.4. Soil and Water Conservation

The desired impact of soil and water conservation measures is to eliminate or at least to reduce the effects of land degradation. By applying SWC measures an attempt is made to conserve or restore the multiple functions of the land and water resources concerned (de Graaff, 1996). Since soil and water constitute the physical basis of agricultural production this usually means that SWC measures are aimed at increasing agricultural production and decreasing soil loss. A successful SWC technology is typically not just technically feasible but also adapted to the local environment, ecologically sound, economically viable and socially accepted (Herweg and Ludi, 1999).

Conversely, the above statement is in line with the conclusions of Berry et al. (2003). Based on case studies in seven countries, the authors empirically determined three common features of unsustainable programs to reduce the effects of land degradation. First, these programs frequently adopted a top-down approach and were not adapted to local conditions. Second, they were limited to short-term solutions not taking into account the root causes of land degradation. Third, the

programs focused mainly on surface erosion control and ignored other, equally important, aspects of degradation.

2.4.1. Classification of SWC

At present, there is no globally approved or endorsed system to describe soil and water conservation technologies. Terminology related to SWC is not conventionalized and a wide variety of systems exist to classify existing SWC technologies (appearance: e.g. terraces, bunds, ditches; material: e.g. stonewalls, earth bunds, grass strips; land management: e.g. enclosure; function and impact: e.g. cut-off drain) (Haile et al., 2006). To simplify matters Haile et al. (2006) propose a categorization based on the principle of functioning, which groups SWC measures into the following four categories:

- Vegetative and agronomic SWC
- Structural SWC in (sub-) humid areas
- Structural water conservation in arid areas
- Wind erosion control

The focus of this thesis will be on structural SWC in (sub-) humid areas. For the functional principle of these measures see Figure 2.

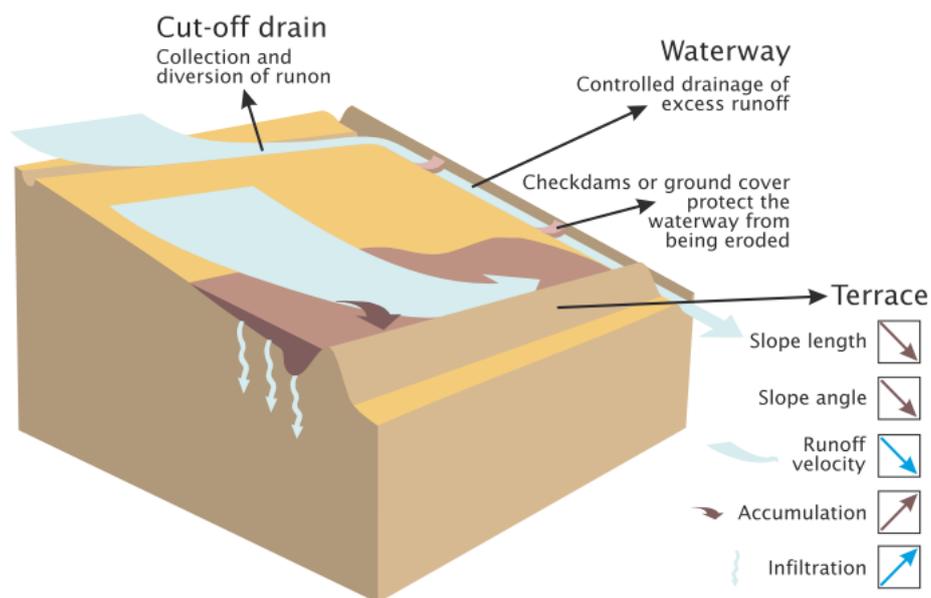


Figure 2 Functional principle of structural (mechanical) SWC in (sub-) humid areas.

Source: Haile et al. (2006)

The principal task of structural or mechanical SWC in humid and sub-humid areas is to protect uncovered cultivated parts of agricultural fields from surplus overland flow, the so-called run-on. At the beginning of a rainy season this can be accomplished by cut-off drains that divert the run-on. Structural measures like ditches, terraces and bunds help to interrupt or reduce the slope length thereby diminishing the velocity of water leaving the field, the so-called run-off. Progressively, topsoil will accumulate behind these structures, which reduces the slope angle and run-off velocity while at the same time increasing water infiltration on the field (Haile et al., 2006). The design of structural (mechanical) SWC depends, among other things, on the climate of the area they are to be applied in.

In high rainfall areas run-off reduction may result in waterlogging while in semi-arid areas it may increase yields. The most commonly implemented mechanical SWC structures in Ethiopia are stone and soil bunds as well as *Fanya Juu*-type terraces (Herweg and Ludi, 1999).

Stone bund

“Stone bunds are usually constructed where suitable stones are available on or near the field. They are preferred in sub-humid environments because the drainage of excess water is better than on soil bunds” (Haile et al., 2006, p. 115). Stone bunds have some additional advantages over the different types of soil bunds and *Fanya Juu*. If they are well maintained, stone terraces are stable and durable while pure soil bunds can be easily eroded by wind and water, especially during heavy rainfall. Moreover, excess water can pass more easily through (semi-permeable) stone terraces than through compacted soil bunds (Haile et al., 2006).

Soil bunds and *Fanya Juu*

Soil bunds and *Fanya Juu* (Swahili for ‘throw uphill’) terraces follow very similar design principles. They are embankment along a field’s contour. In case of soil bunds a trench is dug and the excavated soil material is thrown downhill, while for *Fanya Juu* it is thrown uphill. With ongoing erosion a terrace forms behind these barriers and prevents the soil material from moving further downhill (Herweg and Ludi, 1999). See Figure 3.

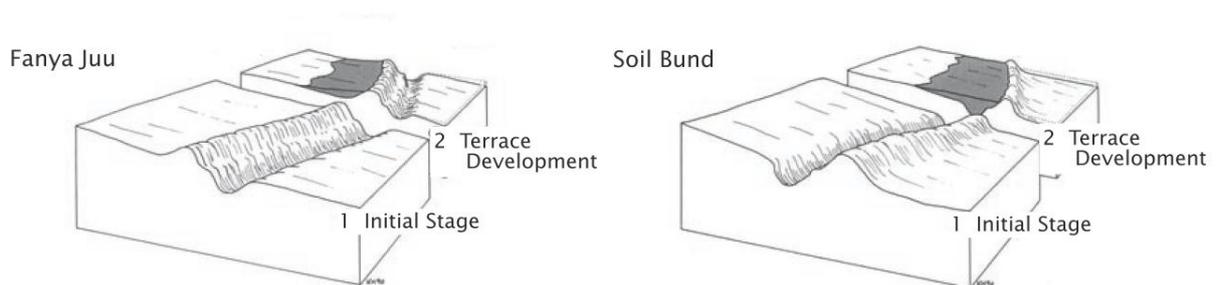


Figure 3 Different type of SWC terraces, left: *Fanya Juu*, right: soil bund.

Source: Haile et al. (2006)

Despite their apparent similarity there are certain differences between *Fanya Juu* and soil bunds with regard to labor requirements and how these structures deal with the accumulation of fertile soil. Soil bunds require less labor input for construction and maintenance than *Fanya Juu* because the excavated soil is thrown down- not uphill. However, the accumulated soil in the ditch behind the soil bund may cause waterlogging or be washed away. Moreover, the accumulated soil will be used in subsequent years to raise the bunds instead of being used for crop production. The bunds of *Fanya Juu* terraces, on the other hand, are mainly built from subsoil material. Drainage behind the bund is therefore much less affected than in case of normal soil bunds (Herweg and Ludi, 1999). See Figure 4.

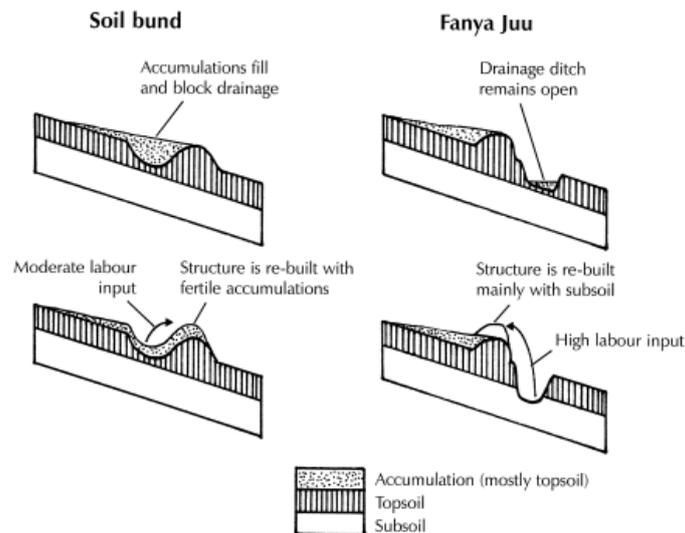


Figure 4 Differences in terrace development with soil bunds and *Fanya Juu*.

Source: Herweg and Ludi (1999)

2.5. Economics of Land Degradation

2.5.1. Evaluation

One definition of evaluation as used by a UN committee is “a process for determining systematically and objectively the relevance, efficiency, effectiveness and impact of activities in the light of their objectives” (de Graaff, 1996, p. 7). Consequently, the first step in evaluation is to decide on a perspective. Individuals, i.e. private enterprises and/or farm households have different objectives with regard to land degradation than e.g. the national government. In case of a financial analysis costs and benefits are considered from the point of view of the individual. They reflect private-economic interest. An economic analysis on the other hand reflects national-economic considerations, costs and benefits are thus considered from the standpoint of society as a whole (de Graaff and Kessler, 2010).

Another important preliminary step in determining the costs of land degradation and the costs and benefits to combat it, is to identify and quantify indicators for degradation. Only after this has been done one can start to evaluate which measures are most appropriate in a given environment for a given set of objectives. Land degradation assessment alone does not have much practical value and evaluation of measures to combat degradation relies on input from degradation assessment (Stocking and Murnaghan, 2001).

2.5.2. Costs of Land Degradation

Land degradation represents a loss of natural capital. Natural capital can be defined as the value that land, water, plant and animal resources have to society. This value includes (Berry, 2003):

- The direct contribution to primary production of agricultural activities. Reduced yields, changes in land use or crops, abandonment of fields, altered livestock mixes and patterns of grazing can be used as an indicator for the loss of this aspect of natural capital.
- The quality of environmental services indicated by processes such as changes in stream flow, silting of dams, reliability of irrigation water flow, decline in quality of drinking water.
- Biodiversity, both natural (flora and fauna) and agricultural (genetic diversity of crops and domestic livestock) (Berry, 2003).

The distinction between on- and off-site effects is generally considered as an important concept for the determination of the costs of land degradation (Berry, 2003). Generally, on-site effects lower the productive capacity of the land, resulting in lower yields and/or the need for higher inputs to maintain productivity. The costs of these effects are thus borne by the land users themselves. In contrast, the costs of off-site effects have to be carried by others (Stocking and Murnaghan, 2001). “The most common off-site effects include sedimentation in reservoirs and waterways, decline in water quality and contamination of drinking water, gully erosion and deposition of eroded materials on farmland” (Stocking and Murnaghan, 2001, p. 14).

In case of soil erosion, on-site effects occur on the field on which the erosion process takes place, i.e. where the soil particles are detached. Off-site effects of soil erosion, on the other hand, only occur when the erosion process has (physical) consequences in downstream areas (Posthumus, 2005).

2.6. Soil loss prediction models

The Universal Soil Loss Equation (USLE) is the most widely used soil loss prediction model (de Graaff and Kessler, 2010). The factor values of the USLE are empirically determined and need to be adapted to the local environment in which the equation is to be applied (Blaikie and Brookfield (eds.), 1987). For this research the most recent update of the USLE, the Revised Universal Soil Loss Equation (USLE) was used. The basic structure of the USLE is as follows (Renard et al., 1997; Ouyang, 2002):

$$A = R * K * LS * C * P$$

Where:

A	=	estimated average annual soil loss in tons*ha ⁻¹ *year ⁻¹
R	=	rainfall-runoff erosivity factor
K	=	soil erodibility factor
L	=	slope length factor
S	=	slope steepness factor
C	=	crop management factor
P	=	support practice factor

The USLE represents the empirically determined relationship between the four most important factors of rill and interrill erosion. The climatic erosivity with the R factor, the soil erodibility by K, topography by LS and land use and management by C and P (Renard et al., 1994). The following descriptions of the factors are adapted from Renard and Ferreira (1993) and Renard et al. (1997).

R Factor

The rainfall-runoff erosivity factor, or *R* factor, represents the erosive energy of the rainfall under given climatic conditions. It “represents the driving force of sheet and rill erosion” (Renard and Ferreira, 1993, p. 458). Among the factors relevant to the USLE the *R* factor is the most straightforward and exact to compute. It is based on the amount of rainfall and intensity. These data can be obtained from long-term meteorological data.

K Factor

The Soil Erodibility factor, or *K* factor, is defined as the rate of soil loss per rainfall erosion index unit. *K* is an indicator of the inherent soil erodibility under standard conditions of the USLE unit plot maintained in continuous fallow.

L and S Factors

The slope- length and steepness factors, or *LS* factor, accounts for the effect of topography on soil erosion in the USLE. Soil loss increases as slope length (accounted for by the slope length factor, *L*) and slope steepness (represented by the slope steepness factor, *S*) increase. However, soil loss increases faster with slope steepness than with slope length.

C Factor

The *C* factor, crop or cover management factor, reflects the effect of cropping and management practices on soil erosion rates. The *C* factor includes the average annual soil loss ratio (SLR). SLR is the ratio of soil loss experienced under given conditions to the soil loss experienced under clean-tilled continuous fallow conditions.

P Factor

The *P* factor represents the impact of conservation practices on the soil erosion rate. The factor gives an indication of how conservation practices will affect the average annual soil loss.

3. Objectives and Research Question

3.1. Objectives

The objectives of this research are to:

- Investigate the on-site costs of soil degradation and
- Investigate the profitability of three different types of soil and water conservation (SWC) measures (stone bunds, soil bunds and *Fanya Juu*) in the watersheds of Debre Mewi and Anjeni in Amhara regional state of Ethiopia.

3.2. Main research question

The concepts formulated in paragraph 2 are applied to reach the objective as formulated in paragraph 3.1.. The main research question corresponding to the objectives is:

RQ *What are the costs of soil degradation and erosion and the economic efficiency of SWC investments in the watershed of Anjeni and Debre Mewi in the Amhara region of Ethiopia?*

This research question has to be seen in the light of the framework of Akalu Teshome Firew's research on 'Impacts of Institutional and Socio-Economic Factors on Sustainable Land Management Investments in North Western Ethiopia'. Knowing the costs and benefits of certain SWC investments will contribute to answer the question what their role is in poverty alleviation. The latter is however, not within the scope of this M.Sc. research.

3.3. Sub-questions

To answer the main research question as formulated in paragraph 3.2 two sub-research questions have to be answered.

SQ 1. *What are the costs of soil degradation for farmers in the watersheds of Anjeni and Debre Mewi?*

SQ 2. *What are the costs and benefits for farmers in the watersheds of Anjeni and Debre Mewi of investing in SWC line interventions?*

4. Material and Methods

In order to answer the two sub-questions as formulated in paragraph 3.3 the following methodologies were applied.

- SQ 1.** A sample of 30 farmers from each watershed was taken and a farm household survey conducted. The farmers were interviewed on their resource use, agricultural output and SWC activities. Group discussions and informal interviews were conducted to gather information about soil degradation and erosion in the watersheds. The USLE was used to determine potential soil loss on farmers' fields.
- SQ 2.** Agricultural outputs obtained under conditions with conservation were compared to those obtained without conservation measures to arrive at values for the net benefits of SWC measures. These net benefits were weighed against the SWC investment and maintenance costs. The necessary economic data were taken from the results of a farm household survey among 30 farmers in each of the two watersheds.

4.1. Study area

The research area consisted of the watersheds of Anjeni and Debre Mewi in the West Gojam Zone in the Amhara Regional State in north-west Ethiopia. The two sites represent typical watersheds in the *Weyna Dega* ecological belt in the Ethiopian highlands. Another reason, is the availability of long-term data on soil erosion as well as long time experience with SWC development activities (Teshome, 2010). See Figure 5 for location of the study sites.

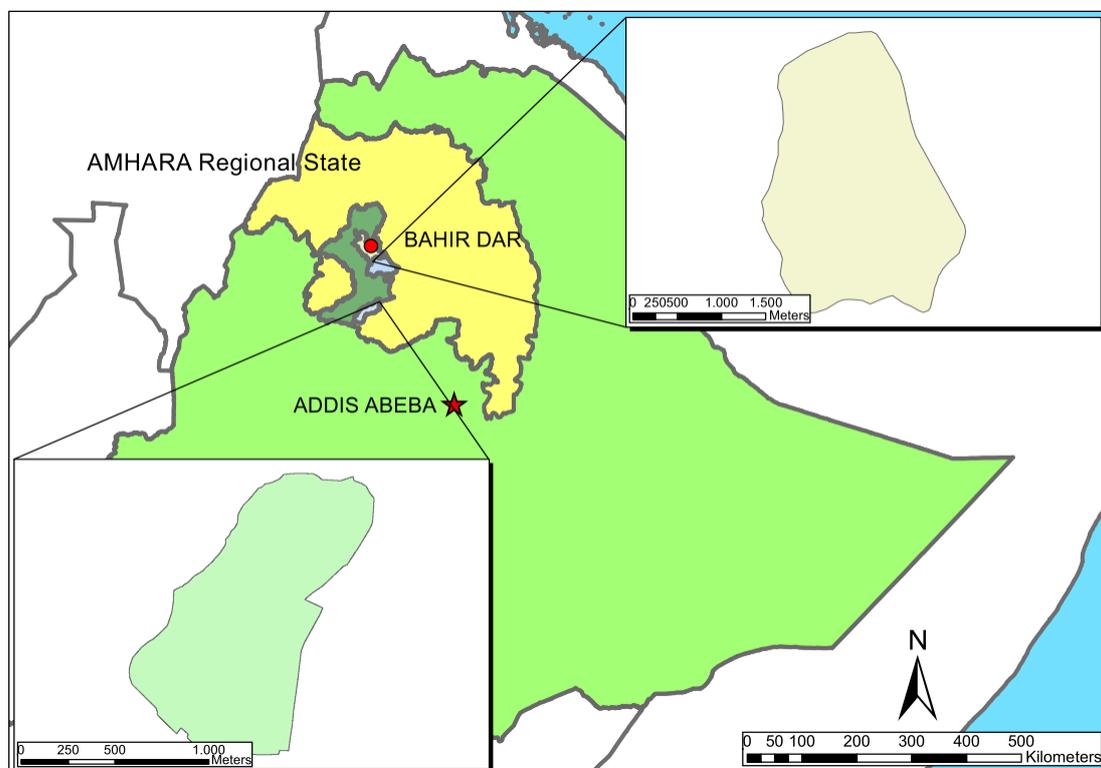


Figure 5 The two research watersheds Debre Mewi (top right) and Anjeni (bottom left).
Source: Own compilation with map material from maplibrary.org

Traditionally, major agricultural zones in Ethiopia have been distinguished on altitudinal basis: *Kolla* (below 1800 m.a.s.l), *Weyna Dega* (1800-2400 m.a.s.l), *Dega* (higher than 2400 m.a.s.l) and *Wurch* (higher than 3800 m.a.s.l.). Most of the agricultural production in Ethiopia takes place in the *Weyna Dega* belt. Although the altitudes in this classification vary widely within Ethiopia, Ethiopian land users would agree to certain characteristics of these zones. Sufficient rainfall allows all major rain fed crops, including tef (*Eragrostis tef*) and maize (*Zea mays*), to be grown and for at least one cropping season a year. The lower parts of *Weyna Dega* are also suitable for cash crops like coffee, tea and different spices (Haile et al., 2006). Based on their altitude, cropping pattern and climatic data, Debre Mewi can be classified as lying clearly in the *Weyna Dega* belt while Anjeni watershed is on the transition between *Weyna Dega* and *Dega*.

4.1.1. Debre Mewi watershed

Bio-physical setting

Debre Mewi watershed lies about 30 km south-east of the regional capital Bahir Dar between 11°21'56" and 11°20'10" northern latitude and between 37°24'41" and 37°26'1" eastern longitude. It is situated in altitude of about 2,300 m.a.s.l.. Administratively it belongs to the Amhara Regional State, West Gojam Zone and is located partly in Bahir Dar Zuria District and partly in Adet District (see Figure 5). Debre Mewi receives an annual average rainfall of about 1260 mm, 60 to 80 % of which fall in the rainy season between mid-June and mid-September. See Figure 6.

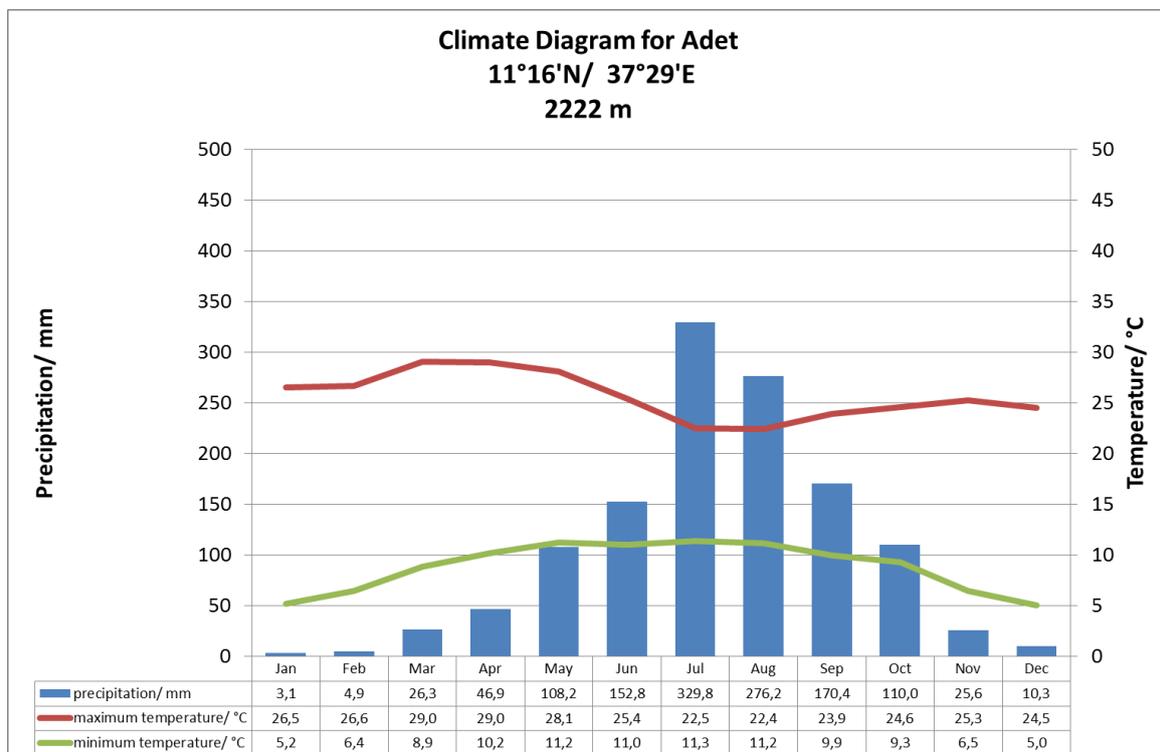


Figure 6 Climate diagram for Adet (10km south-east of Debre Mewi).

Source: Own compilation with data from Adet Agricultural Research Center

The topography of Debre Mewi watershed is characterized by moderate slopes between two and 15 % (Figure 7). Next to the rivers in the watershed, steeper slopes of more than 50 % inclination exist. In these areas land use (Figure 8) is dominated by public and private grazing land

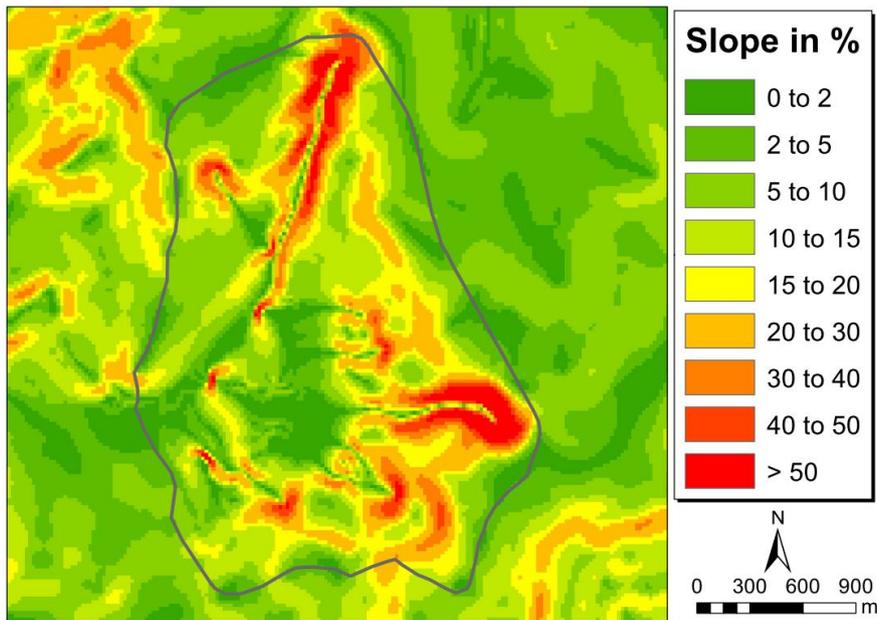


Figure 7 Slope classes in Debre Mewi watershed.
 Source: Own compilation with data from Getahun (2009)

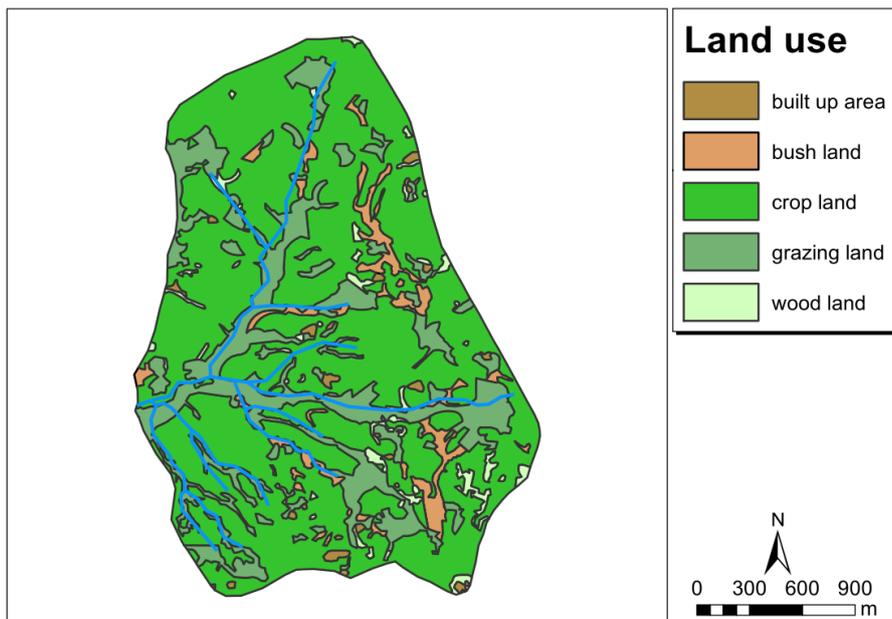


Figure 8 Land use in Debre Mewi watershed.
 Source: Own compilation with data from Getahun (2009)

The soils of Debre Mewi watershed are dominated by Vertic Nitosols, Nitosols and Vertisols (Zegeye, 2009). Only a limited amount of empirical data on soil losses is available for Debre Mewi watershed. Soil erosion experiments conducted in Debre Mewi by the Adet Agricultural Research Center observed soil erosion rates from 23.8 t to 46.9 t*ha⁻¹ on fields treated with SWC measures. Soil loss on untreated field was observed to be 71.4 t*ha⁻¹. See Table 1.

Table 1 Observed soil loss from experimental plots in Debre Mewi watershed in 2010.

Plot	Slope (%)	Crop	Annual soil loss (t*ha ⁻¹)
SWC	10	Tef	23.8
SWC	10	Tef	26.2
SWC	10	Tef	27.7
SWC	10	Tef	43.0
SWC	10	Tef	46.9
no SWC	10	Tef	71.4

Source: Adet Agricultural Research Center

In 2008 Zegeye et al. (2010) estimated soil erosion through rill erosion on agricultural fields by measuring the depth and width of the rills. Depending on the crop cultivated on the fields and their position in the watershed (upslope, midslope or downslope) soil losses ranged from 7.6 t to 34 t. Absolute values for of slope inclination of the plots were not given in the research paper. See Table 2.

Table 2 Estimated soil loss from agricultural fields with different slope positions (left) and different cultivated crops (right) in Debre Mewi in 2008.

Slope position	Annual soil loss (t*ha ⁻¹)	Crop	Annual soil Loss (t*ha ⁻¹)
Upslope	8.0	Maize	14.0
Midslope	23.0	Wheat	7.6
Downslope	34.0	Millet	7.7
		Tef	34.0

Source: Zegeye et al. (2010)

Socio-economic setting

Debre Mewi watershed lies next to one of the two main roads leading from the capital Addis Abeba to Bahir Dar. Farmers from Debre Mewi have relatively easy access to the regional capital Bahir Dar in the north (about 45 minutes by bus) and the next big town Adet, in the south (about 20 minutes by bus). Traders from Bahir Dar buy agricultural outputs on the local market. The total number of households in Debre Mewi is estimated to be 276 with a total of 1092 inhabitants (Zegeye et al., 2010). The farming system of Debre Mewi is characterized by small-scale subsistence crop-livestock mixed production. Major crops grown in the watershed are tef (*Eragrostis tef*), maize (*Zea mays*) and barley (*Hordeum vulgare*). These major cereals are followed in production area by finger millet (*Eleusine coracana*) and wheat (*Triticum spp*). Faba bean (*Vicia faba*), potato (*Solanum tuberosum*), noug (*Guizotia abyssinica*, also known as niger seed) and gomen (*Brassica carinata*) are cultivated on an even lesser area. Grass pea (*Lathyrus sativus*) is cultivated by exploiting the residual moisture available after cultivation of barley.

4.1.2. Anjeni watershed

Bio-physical setting

Anjeni watershed lies about 230 km north-west of the Ethiopian capital Addis Abeba and 100 km south of Bahir Dar. Anjeni is located at 10.68°N and 37.53°E at an altitude of approximately 2,450 m.a.s.l.. Anjeni is part of the Amhara Regional State, West Gojam Zone and Dembecha District (see Figure 5). Anjeni receives an annual average of around 1790 mm of precipitation. See Figure 9.

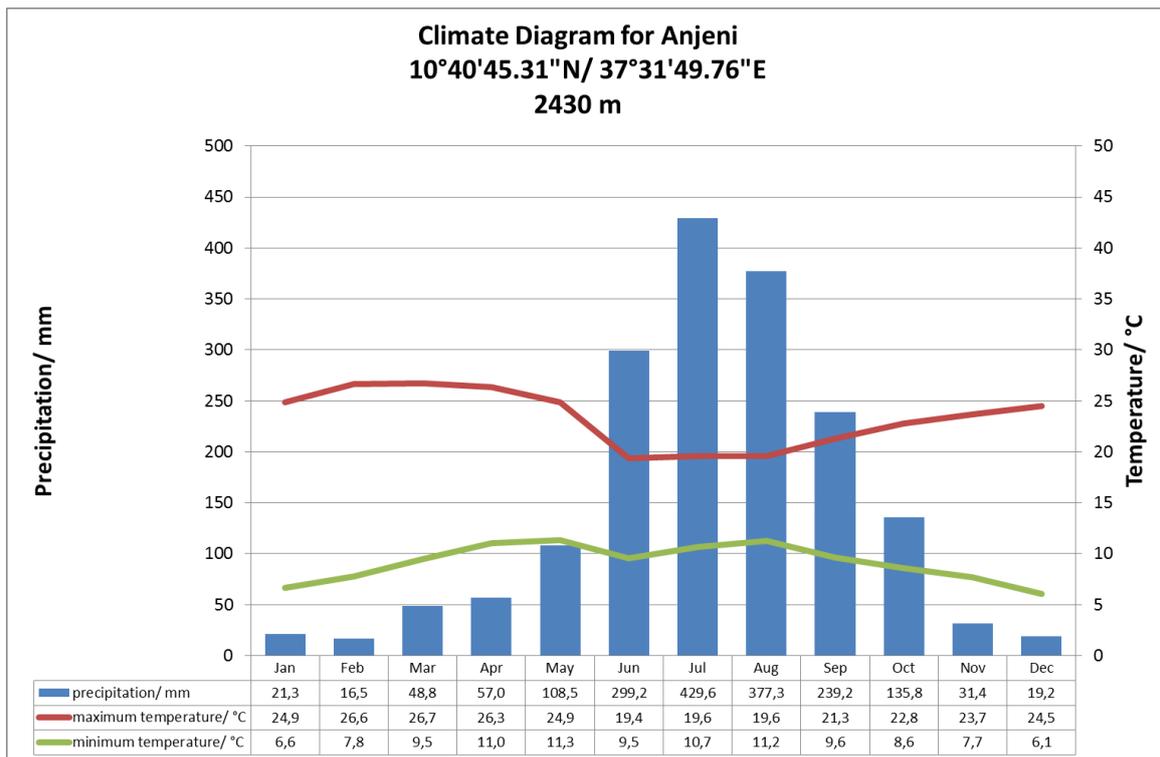


Figure 9 Climate diagram for Anjeni.

Source: Own compilation with data from SCRP database

Anjeni watershed exhibits slightly steeper slopes than Debre Mewi watershed (Figure 10). Nevertheless, 50% of the Anjeni catchment is not steeper than 15% (Ludi, 2004). Land use in the watershed is dominated by crop land on the more moderate slopes. Grazing land, bush land and woodlot are found on the steeper slopes. See Figure 11.

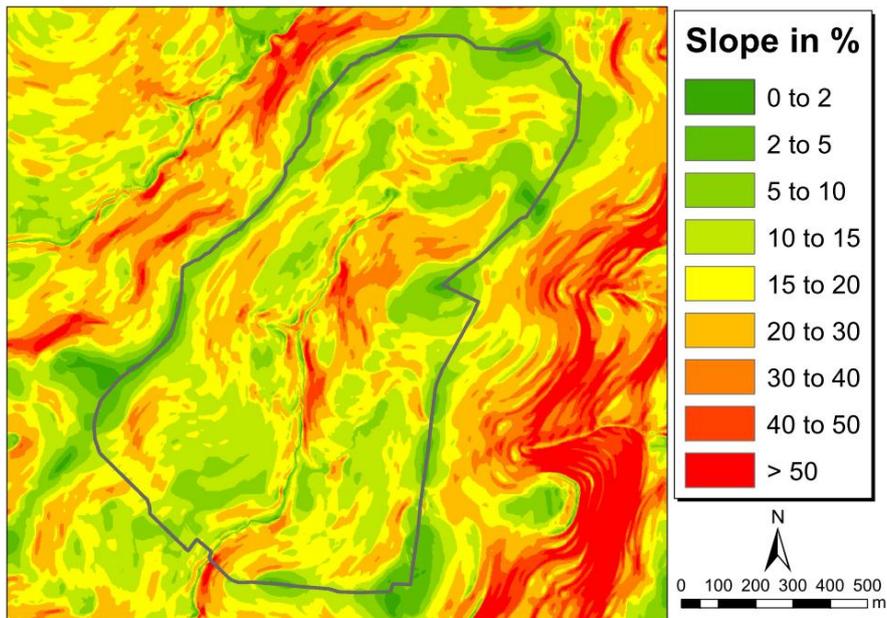


Figure 10 Slope classes in Anjeni watershed.
 Source: Own compilation with data from SCRP database

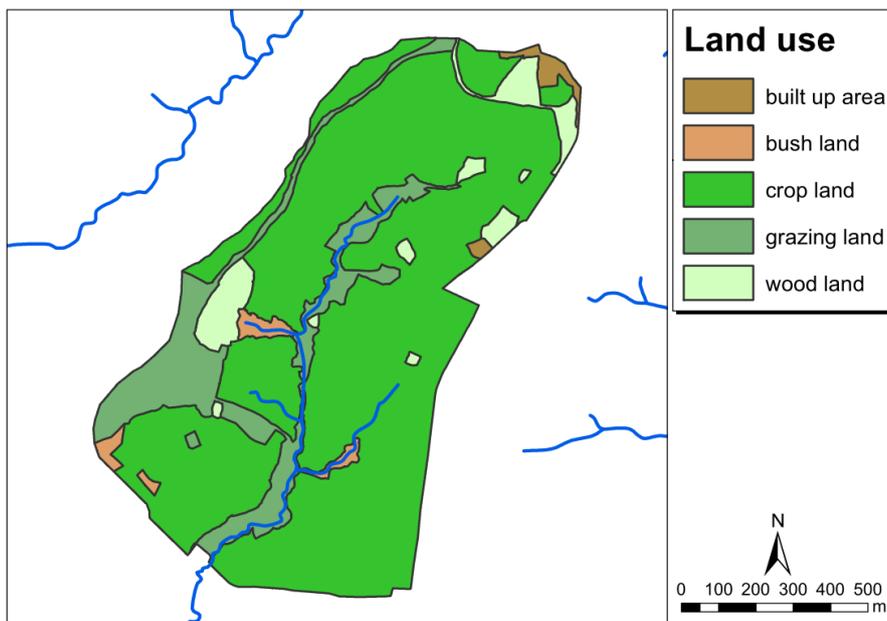


Figure 11 Land use in Anjeni watershed.
 Source: Own compilation with data from SCRP database

The soils in Anjeni are dominated by Alisols, Nitisols, Regosols and Leptosols. All soils in Anjeni have a high clay content. They are generally acidic and low in organic carbon content. Moreover they have low to medium total nitrogen and plant available phosphorus content. These facts indicate overexploitation of soils and leaching processes (Ludi, 2004; Haile et al., 2006). Soil erosion measurements in an experimental set up have been conducted in Anjeni watershed since 1983. Soil losses in the period from 1983 to 1999 have been observed to be ranging from 17 t ha⁻¹ up to as high as 176 t*ha⁻¹. See Table 3.

Table 3 Observed soil losses on experimental plots in Anjeni watershed from 1983 to 1999.

Slope (%)	Annual soil loss (t*ha ⁻¹)		
	Average	Range	Standard Deviation
12	90.0	17 - 176	69
28	110.0	59 - 167	29

Source: Herweg and Ludi (1999)

Socio-economic setting

Anjeni watershed lies about 17 km away from the town Dembecha, which in turn is situated along the main highway leading from Addis Abeba to Bahir Dar. Bus connections between Anjeni and Bahir Dar are irregular. Walking from the watershed to Dembecha takes approximately three hours. Therefore, farmers in the watershed rely on selling their outputs on the local market and on home-consumption. Like in Debre Mewi, the farming system of Anjeni is characterized by small-scale subsistence crop-livestock mixed production. Major crops grown in the watershed are barley (*Hordeum vulgare*), tef (*Eragrostis tef*), maize (*Zea mays*) and wheat (*Triticum* spp.) followed by faba bean (*Vicia faba*) and potato (*Solanum tuberosum*). Noug (*Guizotia abyssinica*), field pea (*Vigna unguiculata*, also known as cowpea), lupine (*Lupinus* spp.) and linseed (*Linum usitatissimum*) are of minor importance in terms of the cultivated area.

4.2. Cost-Benefit analysis

For this research a financial Cost-benefit analysis (CBA) was carried out to determine the economic efficiency of soil bunds, *Fanya Juu* terraces and stone bunds. CBA is a monetary evaluation method centered on the quantification and measurement of the costs and benefits of an intervention with long-term effects. It is based on applied welfare economics (Posthumus, 2005). CBA consists of an impact analysis and a subsequent valuation of the impacts. The eventual aim of a CBA is to compare the present value of the stream of benefits (positive effects) and the present value of all investments and recurrent costs (negative effects) (de Graaff and Kessler, 2010). A CBA can be carried out either for individual enterprises (financial CBA) or society as a whole (economic and social CBA). Unlike an economic CBA, a social CBA also takes into account equity of income distribution as an objective (de Graaff and Kessler, 2010).

4.2.1. Main steps of a CBA

A CBA process consists of the following analytical steps (de Graaff, 1996; Posthumus, 2005):

1. Determination of evaluation criteria.
2. Identification of effects (costs and benefits).
3. Quantification in physical terms of the effects.
4. Valuation of effects
5. Determination of time horizon.
6. Weighing of the costs and benefits in time (discounting).
7. Sensitivity analysis

Evaluation criteria

The costs of establishing and maintaining SWC measures should be compensated by the discounted stream of additional benefits due to the reduced land productivity losses, over the expected lifetime of the measures (de Graaff, 1996). While a variety of economic evaluation criteria is available, the most commonly used ones are the Benefit/Cost ration (B/C ratio), the Net Present Value (NPV) and the Internal Rate of Return (IRR). For financial CBA the criteria of choice usually are NPV and IRR (de Graaff, 1996; Posthumus, 2005). For this research NPV and IRR are used as evaluation criteria.

Net Present Value (NPV)

The NPV is computed by subtracting the present value of all costs (C) from the present value of the stream of benefits (B) during the lifetime (T) of a project. It can be calculated as:

$$NPV = \sum_{t=0}^T \frac{B_t - C_t}{(1+r)^t}$$

The subscript t refers to a particular time period and r to the discount rate per time period. Only a positive NPV favors the 'with' situation (implementation of intervention) to the 'without' case (no intervention and ongoing degradation) (Posthumus, 2005). In case of mutually exclusive options of interventions the one with the highest NPV is to be preferred (de Graaff, 1996).

Internal Rate of Return (IRR)

The IRR is defined as a particular discount rate (r) at which the NPV of an intervention is zero. The corresponding NPV is also known as the break-even point. The IRR is determined in an iterative process (Posthumus, 2005).

$$\sum_{t=0}^T \frac{B_t - C_t}{(1+r)^t} = 0$$

An investment is favorable if the IRR is greater than the alternative or opportunity cost interest rate accessible to the stakeholder (Posthumus, 2005, p. 101). IRR is a recommend evaluation criterion when discount rates are uncertain or disputed. IRR is not always an appropriate evaluation criterion

for the comparison between different interventions. The IRR of one alternative might be higher while its absolute profit, NPV, is lower (de Graaff, 1996).

Identification of effects (costs and benefits)

Costs are defined as “the value of resources, which are used (several times: oxen; fixed costs) or used up (at once: fertilizer; variable costs) for a certain activity (production, services)” (de Graaff and Kessler, 2010). In order to execute a financial CBA for stone bunds, soil bunds and *Fanya Juu* the variable costs for agricultural production on treated and untreated fields as well as the benefits of production were determined through a farm household survey. Moreover, the investment and maintenance cost of the different types of SWC were established through a household survey, field measurements and literature research.

Agricultural production

Variable costs

Labor costs

- Land preparation, ploughing
- Sowing
- Application of inorganic fertilizer, manure and/or compost
- Weeding
- Spraying
- Harvesting
- Threshing and transport

Benefits

- Crop yield: grains or tubers
- Crop by-products: straw

Material costs

- Local or improved seeds
- Inorganic fertilizer: DAP (Di-Ammonium-Phosphate) and urea
- Organic fertilizer: manure and/ or compost (not included in the CBA)
- Pesticides: herbicides and/or insecticides

SWC benefits and investment and maintenance costs

Investment and maintenance costs for the construction of SWC consist mainly of labor. Nevertheless certain tools are necessary for layout and design as well as construction and maintenance (MoARD, 2005). It was assumed that maintenance costs of SWC were equal to 5 % of establishment costs. Benefits of an SWC measure come about through the stabilization and/or an increase of yields through implementing the respective measure.

Input costs

Layout

- Line level (provided by agricultural extension, not included in CBA)
- Two range poles (not included in CBA)
- 10 meters of string (not included in CBA)

Benefits

- Yield stabilization/increase

Work

- Shovel
- Hand hoe

Quantification in physical terms of the effects

The desired impact of the construction of SWC is to stop the progressive decline in agricultural productivity due to soil degradation and -erosion and at the same time to increase productivity on the treated fields. In order to quantify the effects of SWC measures a household survey was conducted. Farmers were interviewed on their resource use for agricultural production and their agricultural outputs (chapter 4.3). Bio-physical measurements at field level were used to make a conversion of local units to the metric system possible (chapter 4.4). USLE was used to estimate current erosion rates in the two watersheds and the effectiveness of locally existing conservation measures (chapter 4.5).

Valuation of effects

All effects considered in the CBA were valued at market prices obtained through interviews with SC officials and during group interviews with farmers. Agricultural by-products for which there is currently no market price were not considered in the CBA. Similarly, organic fertilizers, i.e. manure and compost, were not valued in the CBA since there is currently no market price them in either of the watersheds.

Determination of time horizon

According to Ludi (2004, p. 107) “planning horizons of small-scale subsistence farmers in the Ethiopian Highlands are usually rather short given the insecure environment in which they operate”. For this research the time horizon chosen for the CBA was 20 years.

Weighing of the costs and benefits in time (discounting)

Costs and benefits of an investment in SWC occur over the investment’s lifetime. In the application of a CBA, future costs and benefits are discounted to their present value. The choice of the discount rate should be based on the social time preference (that of the decision maker or stakeholder) and opportunity costs of capital. The latter is based on the foregone production that results when capital is invested in one project rather than another (Posthumus, 2005). For this research a discount rate of 12.5 % was chosen, which is equivalent to the interest rate for credit farmers can receive locally from agricultural service cooperatives.

Sensitivity analysis

Sensitivity analyses were carried out for different input factors to the CBA. First of all, the influence of different opportunity costs of labor on NPV and IRR was determined. Secondly, the influence of different assumptions on yield declines in case of the absence of SWC was evaluated.

4.2.2. CBA approaches in this research

In this research two methodologically different approaches to a financial CBA were applied:

Approach I: In the first approach it was assumed that SWC structures are constructed in year 0. It was further assumed that in year 1 in- and output levels change from currently

observed 'without' conditions to those currently observed under 'with' conditions. However, it was also assumed that yields obtained on fields with SWC are reduced by 25 % in the first year due to soil disturbances. In year 2 they reach the level currently observed under 'with' conditions. Yields under 'without' conditions, on the other hand, are reduced by 1 % annually due to ongoing soil erosion (the choice of these values are explained in chapter 5.7).

Approach II: In the second approach average in- and outputs currently obtained under conditions without SWC measures were taken as a starting point. It was also assumed that the measures are constructed in year 0. All in- and outputs on field with SWC structures were reduced by the area occupied by the structures (depending on the width of the bunds and the distance between the bunds, see Table 29). Additionally, yields obtained under 'with' conditions were assumed to decline in the first two years due to soil disturbances (50 % in year one and 25 % in year two). In the third year yields under 'with' conditions were assumed to increase by 10 % due to increased water storage behind the bunds, top soil accumulation and higher fertilizer use efficiency. Yields under without conditions were assumed to decline by 1 % annually due to ongoing erosion (chapter 5.7 elaborates on the relation between erosion and productivity as well as the choice for the above mentioned yield declines and increases).

4.3. Farm household surveys

The objective of the formal farm household survey conducted for this research was to obtain data on the implementation of SWC technologies as well as costs and benefits for the financial CBA of SWC technologies (see Appendix I.). Akalu Teshome Firew's formal survey was used as a starting point for this survey. A sub-sample of the previously interviewed households was taken. In each of the two watersheds (Debre Mewi and Anjeni) 30 farmers were interviewed.

4.4. Measurements at field level

During field work the characteristics of 14 agricultural fields were measured in each of the watersheds. A hand-held GPS device with a barometric altimeter (Garmin GPS eTrex Vista HCx) was used to measure the size of the fields. The device also recorded altitudes along the plots' contours. These altitude measurements were in turn used to calculate the slope of the fields. In case SWC was implemented on the plot, the length of bunds was measured with the GPS device as well. Additionally, the width and height of the bunds were measured with a simple measuring tape. Soil depth of agricultural plots was not measured in this research. Instead, farmers indicated the depth of the soils on their field on a measuring tape.

Farmers in different parts of Ethiopia use different characteristics to classify soils. They tend to use top soil color, soil depth, soil texture, water infiltration and percolation, capacity to retain heat and response to fertilizer and manure application. Generally, however, farmers use colors to describe soils (Haile et al., 2006). During the household survey and field visits soil types were determined according to color in consultation with local farmers and DAs. Kaltenrieder (2007) lists typical Ethiopian soils associated with the topsoil colors black, brown, red and yellow.

Black e.g. *Andosol, Vertisol*
 Brown e.g. *Cambisol, Phaeozem*
 Red e.g. *Lixisol, Nitosol*
 Yellow e.g. *Fluvisol, Xerosol*

4.4.1. Conversion from local units

Data obtained during the farm household surveys are almost exclusively in local units. In order to make these results comparable measurements were conducted to determine metric equivalents to local units.

Area measurements are normally given in *timad*. As already observed by Ludi (2004) the size of one *timad* (or *timmad*) depends on slope, stone cover and perceived productivity. It is the area that can be ploughed with one pair of oxen in one day. Locally, a *timad* is usually converted into 0.25 ha. However, calculations by Ludi (2004) revealed the average size of one *timad* in the three SCRP research sites Maybar, Andit Tit and Anjeni to be 0.342 ha, 0.290 ha and 0.394 ha, respectively. For this research the size of one *timad* is assumed at 0.34 ha which is the median of all parcel measurements in Debre Mewi and Anjeni. See Table 4.

Table 4 Average and median size of one *timad* in hectare

Watershed	Size of 1 <i>timad</i> (ha)			
	n	Average	Median	Standard Deviation
Debre Mewi	16	0.30	0.32	0.09
Anjeni	14	0.46	0.36	0.37
Total	30	0.38	0.34	0.28

Source: Calculations based on field measurements in October/November 2011

Agricultural outputs were given by the respondents in quintal, which is equivalent to 100 kg, and *shekim*. The latter describes the amount of grass or straw one person can carry. It varies with the type of straw and physical ability of the person carrying it. During the time of field work of this research only barley straw and dry grass were available, hence the metric equivalent of one *shekim* is only based on these two. In the following one *shekim* is assumed at 33 kg. See Table 5.

Table 5 Average and median weight of one *shekim* of barley straw and dry grass in kg

Crop	Weight of 1 <i>shekim</i> (kg)			
	n	Average	Median	Standard Deviation
Barley	3	29.3	26	12.4
Grass	5	35.8	36	13.1
Total	8	33.0	26	12.2

Source: Calculations based on field measurements in October/November 2011

4.5. Erosion assessment

The USLE was used to estimate soil erosion on 28 agricultural plots (14 in each watershed) and a hypothetical plot cultivated with crop rotations typical for the watershed. Values for the K, L and S factors were taken from Hurni (1985). Values for the R and C factors were taken from the latest adaption of the USLE to Ethiopian highland conditions by Kaltenrieder (2007). See Appendix III for values of all USLE factors.

Soil loss in $t \cdot ha^{-1}$ was subsequently converted into reduction of soil depth in mm by using average bulk densities of soils in the watersheds. For Anjeni an average bulk density of $1 g \cdot cm^{-3}$ was assumed (Ludi, 2004). The average bulk density of soils in Debre Mewi was assumed to be $1.21 g \cdot cm^{-3}$ (Zegeye et al., 2010).

5. Results and Discussion

In this section, first a general description of the sampled farm household will be given. Second, a general overview of agricultural practices in Debre Mewi and Anjeni watersheds will be presented. Third, the history of SWC technologies in Debre Mewi and Anjeni watersheds is discussed. Fourth, a summary of SWC design recommendations by the Ministry of Agriculture and Rural Development (MoARD) will be presented. Fifth, the local design of SWC practices in the two watersheds is evaluated and compared to the design recommendations by the MoARD. Sixth, soil loss on untreated fields and soil loss reduction through adapted SWC measures is estimated by applying the USLE on field level. Next, the relation between soil erosion and productivity is discussed. Lastly, the results of the financial CBA for the three different types of SWC will be presented.

5.1. Farm household characteristics

Farm households in Debre Mewi and Anjeni watersheds are characterized by a high level of subsistence production and small and fragmented landholdings. The average farm size is 1.9 ha in Debre Mewi and 1.7 ha in Anjeni watersheds. In both watersheds farmers possess from one up to 11 individual parcels that are scattered throughout the respective watersheds. The average size of a parcel is 0.42 ha (median = 0.34 ha) and 0.38 ha (median = 0.34 ha) in Debre Mewi and Anjeni, respectively. Farmers usually have one parcel that is part of their homestead and on which they exclusively grow crops for home consumption, such as maize, potatoes and vegetables. The main characteristic that defines differences in farm households is farm size. For this reason farm households in Debre Mewi and Anjeni watersheds that were considered in this research were categorized in three classes depending on their total farm size:

1. Farms with a size less than 1.4 ha
2. Farms with a size between 1.4 and 2.0 ha
3. Farms with a size of more than 2.0 ha

Table 6 provides an overview of selected farm household characteristics in the two watersheds.

Table 6 Selected farm household characteristics in Debre Mewi and Anjeni watersheds

Household characteristic	Debre Mewi			Anjeni		
	<1.4 ha	1.4 - 2.0 ha	>2.0 ha	<1.4 ha	1.4 -2.0 ha	>2.0 ha
Number of households	8	7	14	14	8	8
Family size	5.0	6.0	7.1	6.1	6.4	6.5
Age of household head	42.1	42.6	48.2	38.6	46.8	50.0
Farm size/ ha	1.1	1.6	2.6	1.3	1.7	2.4
Number of parcels	5.4	6.9	7.6	5.7	5.0	5.4
Rented or shared land/ ha	0.60	0.54	0.59	0.72	0.51	0.65
Cultivated land/ ha	1.00	1.40	1.96	1.31	1.66	2.05
Wood land/ ha	0.02	0.06	0.13	0.09	0.17	0.19
Grazing land/ ha	0.09	0.09	0.66	0.23	0.13	0.57
Number of oxen	1.8	1.4	2.3	2.1	2.0	2.0
Tropical Livestock Units	2.9	2.4	4.7	3.3	3.9	3.8
Off-farm income/ EtB	800	400	2242	2020	-	240
Crop income/ EtB	1807	2404	3181	1343	660	896
Livestock products income/ EtB	653	0	220	298	100	226
Livestock sales income/ EtB	2264	2172	4724	1425	1638	650
Gross cash income/ EtB	3696	4494	8543	2990	1516	1201
Gross cash income/ €	185	225	427	150	76	60
Value of subsistence crops/ EtB	3444	5702	6695	5028	5284	5940
Value of subsistence crops/ €	172	285	335	251	264	297

Source: Data from farm household survey 2011

As can be seen from Table 6, the number of livestock (measured in Tropical Livestock Units, TLU) in both watersheds are quite low. Oxen are the most important kind of livestock for smallholders in the Ethiopian highlands (Haile et al., 2006). Pairs of oxen are used as the only means of drawing the traditional Ethiopian plough sets (Amharic: *Maresha*) in Debre Mewi and Anjeni in particular and in the Ethiopian highlands in general. Owning a pair of oxen means that a farmer is independent from any kind of arrangement to share oxen with other farmers. Smallholders commonly distinguish between 'rich' and 'poor' farmers as those possessing two or more oxen and those possessing one or no oxen (Haile et al., 2006). However, most of the farmers own two or more oxen (22 of the sampled farmers in Debre Mewi and 28 of the sampled farmers in Anjeni). Six of the farmers in Debre Mewi own just one ox. In Anjeni watershed there are only two farmers with only one ox.

Apart from oxen, farmers in Debre Mewi own an average of 1.4 cows, 1.3 heifers and 0.93 calves. In the Anjeni the values are 1.1, 1.1 and 0.8, respectively. Other important livestock in the watersheds are donkeys and mules (between 0 and 4 individuals per household), sheep (on average 2 sheep per household in Debre Mewi and 2.5 in Anjeni) and poultry (average 2.3 in Debre Mewi and 3.1 in Anjeni).

In terms of household consumption of produced crops farmers both in Debre Mewi and Anjeni have an above average of household consumption in Amhara Regional State. The sampled farmers in Debre Mewi sell 51 % of their tef production but only 15 % of their barley production, 13 % of their

wheat production and 15 % of their maize production. On state level the values are: 42 %, 33 %, 36 % and 22 %, respectively (CSA, 2011).

5.2. Agricultural production in Debre Mewi and Anjeni

5.2.1. Provision of inputs

Currently there is no free market for hybrid seeds and fertilizers in Ethiopia. All mineral fertilizers are bought on the world market by the state-owned Agricultural Inputs Supply Enterprise (AISE). Similarly, most of the hybrid-seeds and other improved seed varieties are supplied by the state-run Ethiopian Seed Enterprise (ESE) and to some degree by private seed companies. All agricultural inputs are distributed to the SCs who in turn sell them to individual farmers (Spielman et al., 2011). The only types of mineral fertilizer currently available in the two research watersheds, and for that matter: in Ethiopia in general, are Di-Ammonium-Phosphate (DAP) and urea.

5.2.2. Cropping patterns

Dominant crops in Debre Mewi and Anjeni watershed are tef, barley, maize and wheat. In Debre Mewi watershed farmers also grow finger millet. In Debre Mewi finger millet flour is used as a substitute for the more costly tef flour which is traditionally used for making the Ethiopian staple food *Enjera*. Intercropping of cereals with pulse crops and oil seeds is common in both watersheds. In the recent 10 years maize cultivation has gained importance. Additionally, the area cultivated with potatoes is increasing. Farmers intercrop potatoes with maize or plant them separately.

Crop rotations are an integral part of Ethiopian farming systems. All farmers interviewed for this research professed to practicing crop rotation. To a certain degree previously practiced rotations have been affected by factors related to food insecurity and the need to increase staple cereals (MoARD, 2005). Previous systems in which cereals were rotated with pulse crops are gradually replaced by systems in which cereal crops are rotated with other cereal crops. During group interviews and farm household interviews, farmers pointed out that one reason for the shift in cropping pattern is due to higher occurrence of diseases in pulse crops. Typical crop rotations for Debre Mewi and Anjeni were compiled from group discussions with farmers and results of the farm household survey. See Table 7 and Table 8 for typical crop rotations in Debre Mewi and Anjeni, respectively.

Table 7 Typical crop rotations in Debre Mewi watershed (excl. cultivation with residual moisture and legume crops).

	Year 1	Year 2	Year 3	Year 4	Year 5
1.	Barley	Tef	Maize	Wheat	Tef or Finger Millet
2.	Maize	Tef	Maize	Barley	Tef or Finger Millet

Source: Own compilation from group interviews and farm household survey 2011

Maize in Debre Mewi is commonly intercropped with gomen, noug (a.k.a. niger seed), faba bean and/or potatoes (for Latin names see chapter 4.1.1 and 4.1.2). Cultivation of barley in the main

season is often followed by growing grass pea on the same plot. Grass pea is a nitrogen-fixing crop that is very resistant to water stress. It can exploit the residual moisture left in the soil after barley has been harvested and still produce reliable yields. Grass peas and their by-products can be used for human consumption and as animal feed. However due to anti-nutritive substances over-consumption of grass pea, which often occurred during past famines, can be toxic (Campbell, 1997).

Table 8 Typical crop rotations in Anjeni watershed (excl. cultivation with residual moisture and legume crops).

	Year 1	Year 2	Year 3	Year 4
1.	Barley	Maize	Tef	Barley or Noug
2.	Tef	Barley	Tef	Barley
3.	Noug	Tef	Barley	Maize
4.	Maize	Barley	Tef or Wheat	Barley

Source: Own compilation from group interviews and farm household survey 2011

In Anjeni watershed the cultivation of barley on plots with SWC (henceforth referred to as barley I) is followed by a second sowing of barley in October/ November (henceforth referred to as barley II). The yield levels of barley grown with the residual moisture are generally lower than those of barley I. During the household survey for this research some of the interviewed farmers explicitly stated that they do not expect any yield higher than the seed input. The cultivation on residual moisture is rather seen as a way of storing the seeds on the field. Farmers in both watersheds commonly intercrop maize with gomen, noug (a.k.a. niger seed), faba bean and/or potatoes.

In the past, fallowing was practiced in Ethiopia as a means of restoring soil fertility. However, due to ever increasing population and decreasing land holdings of smallholders the practice is decreasing (Hurni et al., 2010). In the production season 2010/11 only one farmer in Anjeni fallowed a single plot whereas in Debre Mewi none of the interviewed farmers introduced a fallow period in their crop rotation.

In the CBA the following crop rotations were assumed to have been practiced:

Debre Mewi: Barley I - Grass pea - Tef - Maize - Wheat - Finger Millet

Anjeni: Barley I - Barley II - Tef - Maize - Wheat

Cropping pattern with regard to SWC

During the household survey and group interviews no evidence was found that farmers change their cropping patterns depending on whether or not the plot was treated with SWC measures. The only difference that was found concerns the cultivation of barley II on plots with SWC measures in Anjeni. Farmers only grow barley II on plots that are not treated with SWC if they perceive the plot as fertile and it is part of their homestead. Table 9 gives an overview of the number of plots covered in the

survey depending on the type or crop that they were cultivated with and depending on the type of SWC measure they were treated with.

Table 9 Number of plots grown with different crops in main season (excluding cultivation with residual moisture) depending on type of SWC line intervention.

SWC		Tef		Wheat		Barley I		Maize		Faba Bean		Field Pea		Finger Millet		Potato		Noug		Linseed	
		n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Debre Mewi	No SWC	23	25	10	11	18	20	28	30	3	3	-	-	7	8	2	2	1	1	-	-
	stone bund	3	33	1	11	-	-	2	22	1	11	-	-	2	22	-	-	-	-	-	-
	soil bund	9	35	2	8	5	19	8	31	-	-	-	-	2	8	-	-	-	-	-	-
Anjeni	No SWC	5	22	4	17	5	22	7	30	1	4	1	4	-	-	-	-	-	-	-	-
	stone bund	4	31	3	23	3	23	1	8	1	8			-	-	1	8	-	-	-	-
	soil bund	3	27	3	27	1	9	2	18	1	9	1	9	-	-	-	-	-	-	-	-
	<i>Fanya Juu</i>	30	23	23	18	32	25	25	20	8	6	-	-	-	-	5	4	3	2	2	2

Source: Data from farm household survey 2011

5.2.3. Fertility management

Mineral fertilizers

The use of mineral fertilizers is widespread both in Anjeni and in Debre Mewi watershed. Like in the rest of Ethiopia only two types of fertilizers are available in the two watersheds: Di-Ammonium-Phosphate (DAP) and urea (Spielman et al., 2011). Fertilizer use in Anjeni is generally lower than in Debre Mewi. Within the watersheds amounts of mineral fertilizers applied vary between crops and between individual farmers. Table 10 and Table 11 give an overview of amounts of DAP and urea applied in Debre Mewi depending on the crop. Table 12 and Table 13 show the amounts of DAP and urea applied in Anjeni.

Table 10 Amount of DAP applied for different crops in Debre Mewi watershed depending on SWC in kg*ha⁻¹

Crop	Amount of DAP (kg*ha ⁻¹)					
	No SWC		Stone bund		Soil bund	
	n	Average	n	Average	n	Average
tef	23	103	3	98	9	143
wheat	10	126	1	221	2	147
barley I	18	101	-	-	5	85
maize	28	69	2	0	8	77
finger millet	7	144	2	110	2	110
grass pea	8	0	-	-	2	0

Source: Data from farm household survey 2011

Table 11 Amount of urea applied for different crops in Debre Mewi watershed depending on SWC in kg*ha⁻¹

Crop	Amount of urea (kg*ha ⁻¹)					
	No SWC		Stone bund		Soil bund	
	n	Average	n	Average	n	Average
tef	23	52	3	37	9	66
wheat	10	85	1	0	2	98
barley I	18	52	-	-	5	34
maize	28	71	2	0	8	72
finger millet	7	32	2	0	2	0
grass pea	8	0	-	-	2	0

Source: Data from farm household survey 2011

Table 12 Amount of DAP applied for different crops in Anjeni watershed depending on SWC in kg*ha⁻¹

Crop	Amount of DAP (kg*ha ⁻¹)							
	No SWC		Stone bund		Soil bund		Fanya Juu	
	n	Average	n	Average	n	Average	n	Average
tef	5	22	3	80	3	135	30	80
wheat	4	79	3	82	3	147	23	126
barley I	5	103	1	93	1	147	32	70
maize	7	133	2	98	2	37	25	85
barley II	1	0	-	-	-	-	6	6

Source: Data from farm household survey 2011

Table 13 Amount of urea applied for different crops in Anjeni watershed depending on SWC in kg*ha⁻¹

Crop	Amount of urea (kg*ha ⁻¹)							
	No SWC		Stone bund		Soil bund		Fanya Juu	
	n	Average	n	Average	n	Average	n	Average
Tef	5	0	3	37	3	0	30	3
wheat	4	0	3	25	3	0	23	27
barley I	5	0	1	0	1	0	32	5
maize	7	147	2	98	2	37	25	55
barley II	1	0	-	-	-	-	6	0

Source: Data from farm household survey 2011

Organic fertilizers

In most areas of the Ethiopian highlands manure is used as fuel and as a source of income. Due to the practice of grazing on common grazing land, most livestock droppings are not available as manure for individual farmland. Moreover, mulching is not common because crop residues are often used as livestock fodder (MoARD, 2005).

Still, apart from mineral fertilizers the use of animal manure and compost is widespread in Debre Mewi in Anjeni. It is common in both watersheds to clean out animal stables in the morning after the livestock have been led to the common grazing areas. The manure from the stables is then distributed on a plot adjacent to the homestead. Sometimes farmers also apply manure and compost on plots that are not part of their homestead. In that case donkeys or mules are used to transport it there. The practice of composting is widely applied in Anjeni watershed while only few farmers prepare and apply compost in Debre Mewi.

Valuation of fertilizer inputs

Fertilizer prices were obtained from the offices of agricultural cooperatives in the respective watersheds. In the production season in 2010/11 100 kg of DAP were available at a price of 740 and 764 EtB in Debre Mewi and Anjeni, respectively. The price for 100 kg of urea lay at 660 EtB in Debre

Mewi and 650 EtB in Anjeni. Organic fertilizers were not included the CBA since there is currently no market for manure or compost in either of the watersheds.

Rise of fertilizer prices

From the production season 2010/11 to the production season 2011/12 fertilizer prices have increased in both watersheds. In Debre Mewi the price for 100 kg of DAP has risen from 740 EtB to 1200 EtB which is equivalent to an increase of around 62 %. In Anjeni the price for 100 kg has increased by about 67 % from 764 EtB to 1278 EtB. In the same time the price of urea in Debre Mewi increased from 660 to 900 EtB for a bag of 100 kg, which is equivalent to an increase of more than 36 %. In Anjeni the price growth was less pronounced. Here, the price for 100 kg of urea increased by only about 10 % from 651 to 718 EtB.

These price increases are probably attributable to several factors. First of all, Ethiopia has been experiencing high rates of consumer price inflation over the past years. The CIA (2011) estimated the inflation at 8.1 % in 2010 and 33.2 % in 2011. Secondly, no private market for fertilizer currently exists in Ethiopia. All fertilizers are bought on the world market by state-run companies and are not subsidized (Spielman et al., 2011). Therefore, price shocks that have been happening in recent years (FAO, 2010) are transmitted to the rural household level.

In light of the recent spike in fertilizer prices farmers were asked about their strategies to cope with the price increase. Table 14 shows the frequencies of replies to this question.

Table 14 Farmers' strategies to cope with rising fertilizer prices in 2010/11

Strategies	Frequency (%)		
	Debre Mewi n=30	Anjeni n=30	
Decreasing the use of mineral fertilizer	yes	50.0	65.5
	no	50.0	34.5
Decreasing the land rented in	yes	30.0	48.3
	no	70.0	51.7
Shifting from cereal to pulse crop cultivation	yes	20.0	27.6
	no	80.0	72.4
Increasing the use of manure and compost	yes	33.3	96.6
	no	66.7	3.4
Increasing livestock activities	yes	13.3	17.2
	no	86.7	82.8
Other	yes	23.3	31.0
	no	76.7	69.0

Source: Data from farm household survey 2011

Increasing the amount of manure and fertilizer is not easy for all farmers on all plots. As mentioned in the previous paragraph it is common in both watersheds to clean out stables and apply the manure on a nearby plot. The other plots are usually scattered throughout the area. To apply manure or compost on these plots requires donkeys or mules to transport it there. In Anjeni the walking distance to plots that are not part of the homestead ranges from 6 to 120 minutes with an average of 25 minutes. In Debre Mewi the distances range from 7 minutes to one hour with an average of around 18 minutes distance. In Debre Mewi 24 % of the farmers possess neither mules nor donkeys, 41 % possess only one donkey and no mules, 28 % possess two donkeys and the remaining 7 % possess more than just two donkeys. In Anjeni the percentage of farmers owning neither donkeys nor mules is even higher (52 %), 38 % possess one donkey only and the remaining 10 % own more than two donkeys or mules.

Another commonly applied strategy is to decrease the amount of land rented in from other farmers. Thereby it becomes possible for farmers to focus on their own plots and make long-term investments in these plots such as the construction of SWC measures and the application of organic manure to improve soil structure and fertility.

The recent rise in fertilizer prices and farmers' strategies to react to the price rise are important in relation to the general situation of agriculture in Ethiopia. Yields and farm sizes in Ethiopia in general, and in the two watersheds in particular, are already very low. As remarked by Sonneveld (2002) further intensification of agriculture under current technology levels would require an expansion of cultivated land. Since this is not possible due to climatic and soil constraints, production increases must come from intensification of the already cultivated areas. However, under the current soil erosion and degradation processes that are taking place in the Ethiopian highlands, this will be difficult to implement (Sonneveld, 2002). This general trend on a national level also holds true for the situation in the two watersheds. With increasing fertilizer prices farmers reduce their use (50 % in Debre Mewi and 65 % in Anjeni) which will make it more difficult to increase yields and raise farm household incomes.

5.2.4. Labor inputs

Basically, three different labor arrangements exist in both watersheds. Most of the farm work is carried out by family members of the individual farm households. In times of high labor demand and limited time availability, *wonfel* and hired labor become more important. *Wonfel* is a reciprocal labor arrangement in which farmers, usually friends and/or relatives, work together to increase per capita labor efficiency (MoARD, 2005). *Wonfel* is most commonly used during times of harvest and threshing. Hired workers, on the other hand, are employed for labor-intensive weeding.

Labor requirement per area is defined as the total labor that is needed to produce a crop on a certain area. It was calculated by adding up all labor inputs, including *wonfel* and hired labor, beginning with land preparation up to threshing and transport of the harvested crop. Labor requirements vary with the cultivated crop. As can be seen from Table 15, labor requirements vary with the cultivated crop considered.

Table 15 Labor requirements per area for production of different crops in Debre Mewi and Anjeni watersheds.

Crop	Labor requirements (PD*ha ⁻¹)					
	Debre Mewi			Anjeni		
	n	Average	StDev	n	Average	StDev
tef	37	101	45	47	97	39
wheat	12	97	82	36	63	24
barley I	24	40	18	46	47	21
maize	38	111	49	37	115	89
faba bean	3	93	65	11	46	28
finger millet	12	166	80	-	-	-
field pea	-	-	-	2	41	0
potato	3	162	155	7	106	56
noug	1	82		3	50	9
grass pea	10	29	13	-	-	-
barley II	-	-	-	8	33	12

Source: Data from farm household survey 2011

Variations in labor requirements among crops are easily explainable by different management requirements for the different crops. For example, land that is to be cultivated with tef or finger millet needs to be ploughed up to seven times before sowing which is much higher than for all other crops. Moreover, most crops, like barley, are sown by broadcasting. Maize, on the other hand, is often sown in rows, which is more labor- and time intensive. Variations between farmers, on the other hand, are less obvious. Ludi (2004) observed the same circumstance and attributed it to the following two factors:

- The location of a plot: the further away a plot is from the homestead, the less labor is invested.
- The quality of a plot: the steeper, stonier or more heavily degraded the plot, the less labor is invested.

Valuation of labor inputs

Labor inputs to agricultural production were valued at the local wage rate for hired agricultural labor. Throughout the year there are variations in wage rate in both watersheds. The average wage rate during times of crop production in the year 2010 was around 15 EtB per day in both of the watersheds.

5.2.5. Agricultural outputs

Table 16 and Table 17 show average crop yields for major crops cultivated in Debre Mewi and Anjeni watersheds depending on what kind of SWC measure the plots were treated with.

Table 16 Crop yields in Debre Mewi watershed depending on SWC measure.

Crop	Crop yields (kg*ha ⁻¹)							
	No SWC		Stone bund		Soil bund		Total	
	n	Average	n	Average	n	Average	n	Average
tef	19	879	3	833	13	1101	35	958
wheat	9	1289	1	1176	3	931	13	1198
barley I	17	1403	-	-	6	983	23	1293
maize	24	1334	3	1667	11	1511	38	1412
finger millet	7	1492	2	1471	2	1176	11	1431
grass pea	19	879	-	-	2	846	21	876

Source: Data from farm household survey 2011

Table 17 Crop yields in Anjeni watershed depending on SWC measure.

Crop	Crop yields (kg*ha ⁻¹)									
	No SWC		Stone bund		Soil bund		<i>Fanyaa Juu</i>		Total	
	n	Average	n	Average	n	Average	n	Average	n	Average
tef	5	618	3	735	3	637	30	756	41	729
wheat	4	625	3	719	3	637	23	863	33	801
barley I	5	941	1	980	1	1765	32	924	39	949
maize	7	1919	2	588	2	956	25	1249	36	1326
barley II	1	147	-	-	-	-	6	719	7	637

Source: Data from farm household survey 2011

From the data presented in Table 16 and Table 17 no general conclusion can be drawn whether or not SWC measures increase crop yields. As has been presented in chapter 5.2.3, farmers apply different amounts of fertilizers. The amounts of organic and inorganic fertilizers applied influence crop yields and confound the results of the analysis.

Despite higher annual precipitation yield levels in Anjeni are lower than in Debre Mewi. There are several possible explanations for this difference:

- Fertilizer application rates differ between the two watersheds. Farmers in Debre Mewi generally apply more mineral fertilizer than farmers in Anjeni. This is probably due to the easier access to the market in Bahir Dar.
- Use of improved seed varieties is much lower in Anjeni than in Debre Mewi.
- Soil depth in Anjeni is lower than in Debre Mewi which could have negative effects on yields.

Valuation of agricultural outputs

In both watersheds farmers have the option of selling their agricultural outputs either to traders on the local markets that exist in both watersheds, or to the agricultural cooperatives. However, in comparison the amount sold to the cooperatives is much lower than the amount sold on local markets. The prices used for this research are for agricultural outputs of the production season 2010/11. It has to be noted that in Anjeni prices vary throughout the year. Shortly after harvest

prices are lower than during the rest of the year. Information on how much of the outputs in Anjeni are sold at which price were not available for this research. Hence, crop yields in Anjeni were valued at an average of the two price levels. The only marketable crop by-products in Debre Mewi watershed are tef straw (35 EtB*shekim⁻¹, roughly 1 EtB*kg⁻¹) and barley straw (15 EtB*shekim⁻¹, about 0.5 EtB*kg⁻¹). An overview of prices for different crops in Debre Mewi and Anjeni watersheds can be found in Table 41 in Appendix II.



Figure 12 Farmers at kebele office in Debre Mewi town.
Photo: Dirk Rolker, 2011



Figure 13 Private trader on local market in Debre Mewi town.
Photo: Dirk Rolker, 2011

5.3. SWC in Debre Mewi and Anjeni

During the household survey of this research information was gathered about a total of 143 agricultural plots in Debre Mewi watershed and 170 plots in Anjeni watershed. Table 18 gives an overview of the number of plots and with which SWC line interventions they were treated.

Table 18 Number of sampled plots treated with SWC in Debre Mewi and Anjeni watersheds.

SWC	Debre Mewi	Anjeni
no SWC	104	25
stone bund	8	10
soil bund	28	9
<i>Fanya Juu</i>	-	102
Total	140	146

Source: Data from farm household survey

The stone bunds in Debre Mewi were constructed in the last eight years, between 2003 and 2011. Soil bunds in Debre Mewi were constructed in the last twelve years, between 1999 and 2011. The earliest stone bunds in Anjeni were constructed in 1984 and the youngest in 2011. The age of the sampled *Fanya Juu* bunds varied between 27 years and one year.

It has to be noted, that the relation of plots treated with different kinds of SWC line interventions presented here does not represent the frequency of treated plots on a watershed level. In Debre Mewi the percentage of plots treated with introduced SWC in the whole watershed is much lower while in Anjeni there are almost no plots that are not treated with introduced SWC. The low number of sampled plots treated with stone bunds can be explained by the fact, that the number of plots treated with stone bunds is generally low in Debre Mewi watershed. Farmers in Debre Mewi pointed out that this is due to the limited availability of stones suitable for stone bund construction.

5.3.1. Debre Mewi watershed

Information on the history of SWC technologies in Debre Mewi watershed was gathered during the household surveys and during an interview which was held with the chairman of the farmers' research group in Debre Mewi. The major objective of the farmers' research and extension group is to evaluate on-farm research and disseminate research outputs through farmer-to-farmer extension. It is the chairman's task to facilitate the contact between farmers and researchers from the Adet Agricultural Research Center.



Figure 14 Interview with key informant.

Photo: Dirk Rolker, 2011

The practice of stone- and soil bund construction was first introduced in Debre Mewi watershed in 1996/97. According to the chairman these first attempts were based on campaign work and did neither aim nor succeed in raising awareness about the problem of soil erosion. People were forced to partake in these programs. As a consequence, some farmers refused to implement introduced SWC measures on their farms as a means of political resistance. The chairman further claimed that today all farmers see the different types of terraces as being beneficial for their production. However, they supposedly fail to construct them because of a lack of technical assistance from local DAs and a lack of cooperation between farmers of neighboring fields. Previous field observations in Debre Mewi showed that a lot of the bunds were not properly constructed and only poorly maintained (Zegeye et al., 2010).

The problem of lack of cooperation proved to be a recurrent theme during individual farmer interviews. Waterways have to be constructed along with soil bunds to drain excess water. Without

these waterways the risk of waterlogging behind the bunds increases (Haile et al., 2006). Farmers in Debre Mewi regularly complained that they could not reach agreements with their neighbors concerning the construction of these waterways along field boundaries and thus refrained from constructing the bunds in the first place. According to Teshome et al. (2012, p. 5) “social capital and specifically cooperation between adjacent farm owners is an important factor for the final adoption and dis-adoption [...] of SWC measures”.

Perception of SWC in Debre Mewi watershed

When asked to judge whether the impact of soil erosion on their crop yields is high, moderate or low all 30 farmers in Debre Mewi stated that it was ‘high’. To the subsequent question whether soil erosion could be effectively controlled only two farmers answered with ‘No’ while the other 28 affirmed that it could be controlled. Farmers were also questioned on the perceived benefits (Table 19) and problems (Table 20) associated with the implementation of introduced SWC technologies. All farmers stated that soil/ stone bunds had a high potential in minimizing soil and nutrient loss and a large number of the respondents (24 farmers, 80%) answered that it had a positive impact on yields. The most common problem of stone/ soil bunds concerned the high labor requirements for their establishment.

Table 19 Perceived benefits of introduced SWC technologies in Debre Mewi watershed (n=30)

Perceived benefits	Frequency (%)			
	None	Small	Medium	Large
Minimized soil/nutrient loss	0	0	0	100
Increased water retention	6.7	6.7	26.7	60
Improved soil fertility	3.3	3.3	13.3	80
Increased yields	6.7	3.3	20	70
Terraces as a feed source for livestock	6.7	13.3	20	60

Source: Data from farm household survey 2011

Table 20 Perceived problems associated with introduced SWC technologies in Debre Mewi watershed (n=30)

Perceived problems	Frequency (%)			
	None	Small	Medium	Large
Complication of oxen-ploughing	50	23.3	13.3	13.3
High labor requirement for establishment	20	6.7	0	73.3
Increased number of rodents/ pests	72.4	6.9	6.9	13.8
Increased weed infestation	100	0	0	0
Reduction in cultivable area	50	40	3.3	6.7

Source: Data from farm household survey 2011

Additionally, some farmers remarked that stone/ soil bunds not only minimize soil from being eroded but also prevent seeds and fertilizer from being washed away during heavy rainfall events. According to Ludi (2004), this argument is frequently made by DAs to convince farmers to construct SWC measures. She found support for this claim based on the evaluation of SCRP data from Anjeni. The fact that the highest yields within a field were recorded just behind bunds can be explained by

fertilizer not being washed away from this location or even accumulation of fertilizers from upslope parts of the field. During a group discussion a farmer added his personal experience during the previous growing season: He applied fertilizers which were completely washed away during a storm the next day as a result of which he got a very low yield on that plot. Other farmers concurred with this conclusion and stated that there are “no yields without fertilizers”.

5.3.2. Anjeni watershed

Anjeni watershed has a long history of introduced SWC technologies starting during the reign of the *Derg* regime. A research site was established in the watershed by the Swiss Soil Conservation Research Program (SCRIP) in March 1984. In 1985 the first SWC measures were constructed outside the watershed. During a campaign from February to April 1986 the watershed was finally treated with graded *Fanya Juu* bunds. Participation by the local community was ensured by the promise of building a clinic as an incentive (Ludi, 2004).

During group discussions farmers pointed out that two and half decades ago the problem of erosion was so severe that not enough crops could be produced for farmers to survive. This high food insecurity caused farmers to migrate to other areas. After the introduction of new SWC line interventions food-security could again be reached and seasonal migration was reduced. They further stated that Anjeni watershed now is a model for soil and water conservation activities for the Amhara region and the nation at large.

Before the fall of the *Derg* regime in 1991 the local administration punished farmers for ploughing under conservation structures. Unlike in most other areas of Ethiopia (see chapter 1.3) farmers in Anjeni did not destroy the conservation structures. As of November 2011 almost the entire watershed is treated with *Fanya Juu* bund, the oldest of which have almost developed into bench terraces. However, since the end of the *Derg* rule several adaptations have been made to the original layout of *Fanya Juu* in Anjeni. On steeper land farmers removed every second bund and on flatter land they removed two out of three bunds. Moreover, farmers reduced the width of the constructed bunds. Both of these adaptations were done to increase the area available for cropping and facilitate oxen ploughing (Ludi, 2004).

Perception of SWC in Anjeni watershed

Out of 30 interviewed farmers in Anjeni 25 (83%) responded that soil erosion had a high impact on their crop yields while three (10%) stated it was moderate and two that it was low (7%). All farmers are convinced that soil erosion can be effectively controlled. Asked about the benefits they receive from the implementation of introduced SWC all farmers responded that it minimized soil and nutrient losses and that there is a large benefit from grass grown on bunds which provides an extra source of livestock fodder (Table 21).

Table 21 Perceived benefits of introduced SWC technologies in Anjeni watershed (n=30)

Perceived benefits	Frequency (%)			
	None	Small	Medium	Large
Minimized soil/nutrient loss	0	0	0	100
Increased water retention	0	10	16.7	73.3
Improved soil fertility	0	3.3	16.7	80
Increased yield	0	3.3	10	86.7
Terraces are a feed source for livestock	0	0	0	100

Source: Data from farm household survey 2011

Like in Debre Mewi watershed the biggest problem associated with the introduced SWC measures concerns the high labor requirement for their construction. However, this is not as clearly stated as in Debre Mewi watershed. About half of the respondents, in particular those who constructed SWC measures more than five years ago, do not see any problem in high labor requirements while the other half sees it as large problem. This difference might be due to the fact that farmers now underestimate the necessary labor it took to construct the measures (Table 22).

Table 22 Perceived problems associated with introduced SWC technologies in Anjeni watershed (n=30)

Perceived problems	Frequency (%)			
	None	Small	Medium	Large
Complication of oxen-ploughing	72	24	3	0
High labor requirement for establishment	45	7	0	48
Increased number of rodents/ pests	62	17	7	14
Increased weed infestation	100	0	0	0
Reduction in cultivable area	76	17	7	0

Source: Data from farm household survey 2011

5.4. SWC design recommendations

5.4.1. Stone bunds

The Watershed Development Guidelines by the Ethiopian Ministry of Agriculture and Rural Development (MoARD) suggest not constructing stone bunds on slopes steeper than 35%. Moreover, the work norm of the guidelines estimate the necessary labor requirements for stone bunds at 250 PD*km⁻¹ (MoARD, 2005). Table 23 shows stone bund design recommendations and resulting labor requirements based on the Watershed Development Guidelines by the MoARD (2005).

Table 23 Stone bund design recommendations

Slope (%)	Height of bund (m)	Vertical interval (m)	Distance (m)	Labor for construction (PD*ha ⁻¹)	Area loss (%)
5	0.5	1	20	125	5.0
10	0.5	1.5	15	167	6.7
15	0.75	2.2	12	208	8.3
20	0.75	2.4	10	250	10.0
25	1	2.5	8	312.5	12.5
30	1	2.6	8	312.5	12.5
35	1	2.8	6	417	16.7
40	1	2.8	5	500	20.0
50	1.15	2.8	4	625	25.0

Source: adapted from Watershed Development Guideline by MoARD (2005)

5.4.2. Soil bunds

According to the Watershed Development Guidelines (MoARD, 2005, p. 69) the choice of the vertical interval (VI), the vertical distance between two bunds, should “follow a flexible and quality oriented approach”. Ludi (2004) states that the horizontal interval (HI) between bunds should be chosen by dividing the VI, in cm, by the slope angle, in %:

$$HI = \frac{VI * 100}{Slope}$$

For slopes above 15 % inclination the guidelines advise against soil bunds and recommend rather constructing stone-bunds or stone-faced soil bunds. According to work norm of the guideline 150 PDs are necessary to construct one km of soil bunds regardless of slope (MoARD, 2005). Table 24 shows the soil bund design recommendations and resulting labor requirements based on MoARD (2005).

Table 24 Soil bund design recommendations

Slope (%)	VI (m)	Distance (m)	Labor for construction (PD*ha ⁻¹)	Area loss (%)
3-8	1-1.5	50 - 12.5	30 – 120	2 – 8
8-15	1-2	25 – 6.67	60 - 225	4 – 15
15-20	1.5-2.5	16.67 – 7.5	90 - 200	6 – 13.3
15-30*	1.5-2.5	16.67 – 5	90 - 300	6 – 20

*only graded soil bunds

Source: adapted from Watershed Development Guidelines by MoARD (2005)

5.4.3. Fanya Juu

According to the watershed development guidelines *Fanya Juu* bunds should not be constructed on land with slope inclinations less than 3 % or more than 15 %. Labor requirements for *Fanya Juu* bunds are higher than those for conventional soil bunds. According to the guidelines, it takes 200 PDs to construct one km of bunds (MoARD, 2005). Herweg and Ludi (1999) observed that the *Fanya Juu* construction and maintenance is much more labor intensive because the excavated soil material has

to be thrown up- rather than downhill. See Table 25 for *Fanya Juu* design recommendations and resulting labor requirements based on MoARD (2005).

Table 25 *Fanya Juu* design recommendations

Slope (%)	VI (m)	Distance (m)	Labor for construction (PD*ha ⁻¹)	Area loss (%)
3-8	1-1.5	50 – 12.5	40 – 160	2 - 8
8-15	1-2	25 – 6.67	80 – 300	4 - 15

Source: adapted from Watershed Development Guideline by MoARD (2005)

5.4.4. Labor inputs to SWC

Labor requirements for the construction of SWC line interventions in the Ethiopian highlands have been estimated by various authors. A summary of these estimates can be found in Table 26

Table 26 Estimated labor requirements in PD*km⁻¹ for different types of SWC line interventions

SWC	Labor requirements (PD*km ⁻¹)		
	Shiferaw and Holden (1999)	Ludi (2004)	MoARD (2005)
stone bund	150	200	250
soil bund	70	100	150
<i>Fanya Juu</i>	250	100	200

Source: Own compilation from various sources

5.5. SWC implementation in Debre Mewi and Anjeni

Field observations and measurements as well as farmers' estimates indicate that the actual implementation of SWC interventions differs considerably from official design recommendations. As has already been mentioned in chapter 5.3.2, farmers in Anjeni altered the original layout as implemented within the scope of the SCRP. These alterations mainly concerned the removal of some of the bunds to facilitate oxen-ploughing and increase the area available for crop production. In Debre Mewi the differences between official recommendations and actual implementation also concern the distances between bunds and the resulting total length of bunds per area.

5.5.1. Result of farm household survey

Farmers' estimates on distances between SWC structures show a great variability. In the farm household survey, farmers were asked to indicate the slopes of their plots on chart representing different slope classes. These slope estimates, combined with estimates on the distances between bunds, did not show a pattern with regard to how distances between bunds are actually chosen with respect to the slope of a field. Instead, Table 27 gives an overview of minimum, maximum and median distances between bunds of SWC structures based on farmers' estimates.

Table 27 Distance between bunds of different SWC line interventions in Debre Mewi and Anjeni watersheds

SWC	Distance between bunds (m)							
	Debre Mewi				Anjeni			
	n	Min	Max	Median	n	Min	Max	Median
stone bund	7	15	50	20	7	15	30	20
soil bund	22	10	50	20	9	5	25	10
<i>Fanya Juu</i>	-	-	-		94	5	100	15

Source: Data from farm household survey 2011

Table 28 provides information on the average width of SWC bunds. Table 29 gives an overview of the area losses due to conservation structures. The figures for area loss were calculated by multiplying the average width of bunds with the total length of bunds on one hectare, which in turn results from the distance between the bunds.

Table 28 Width of bunds of different SWC line interventions in Debre Mewi and Anjeni watersheds

SWC	Width of bunds (cm)					
	Debre Mewi			Anjeni		
	n	Average	StDev	n	Average	StDev
stone bund	8	91	33	13	57	15
soil bund	28	72	29	9	83	50
<i>Fanya Juu</i>				101	74	35

Source: Data from farm household survey 2011

Table 29 Calculated area loss due to SWC structures in Debre Mewi and Anjeni watersheds

SWC	Area lost to SWC structures (%)	
	Debre Mewi	Anjeni
stone bund	3.6	4.2
soil bund	4.6	5.7
<i>Fanya Juu</i>		4.9

Source: Data from farm household survey 2011

For the financial CBA the median distances between bunds were used. The width of the bunds in the calculations was assumed at the averages presented in Table 28. Area losses in Approach II were assumed equal to the values presented in Table 29.

5.5.2. Result of field measurements

Measurements of fields with SWC line interventions in Debre Mewi and Anjeni watersheds showed a similar picture as the interview data with regard to the design of SWC structures. The spacing between bunds is wider than in the MoARD recommendations and the area occupied by the bunds is

thus less than it would be if the guidelines were followed. The average spacing between the observed soil and stone bunds in Debre Mewi watershed approaches 30 m. The minimum distance observed between two bunds was 10.5 m and the maximum distance 50 m. The distance between *Fanyaa Juu* bunds in Anjeni watershed ranged from only 7 m (which is probably a remnant of the original SCRIP design) up to 53 m. Table 30 and Table 31 give an overview of the design of observed SWC plots in Debre Mewi and Anjeni watersheds.

Table 30 Observed design of SWC line interventions in Debre Mewi watershed

ID	Slope (%)	SWC	Average width of bunds (cm)	Average distance between bunds (m)	Area occupied by bunds (%)
DM12	11	stone bund	110	38	4.7
DM14	19	stone bund	53	32	1.7
DM13	24	stone bund	130	15	10.1
DM10	6	soil bund	75	30	2.6
DM2	9	soil bund	66	28	2.5
DM3	15	soil bund	135	33	2.8

Source: Result of field measurements in October and November 2011

Table 31 Observed design of SWC line interventions in Anjeni watershed

ID	Slope (%)	SWC	Average width of bunds (cm)	Average distance between bunds (m)	Area occupied by bunds (%)
AJ1	9	<i>Fanya Juu</i>	130	21	7.1
AJ9	9	<i>Fanya Juu</i>	107	25	6.1
AJ2	10	<i>Fanya Juu</i>	123	26	3.9
AJ5	10	<i>Fanya Juu</i>	72	14	4.0
AJ6	11	<i>Fanya Juu</i>	103	18	4.4
AJ7	12	<i>Fanya Juu</i>	128	13	9.2
AJ11	14	<i>Fanya Juu</i>	102	20	5.8
AJ10	15	<i>Fanya Juu</i>	98	19	4.6

Source: Result of field measurements in October and November 2011]

5.5.3. Grass from SWC structures

SWC structures provide an extra benefit by producing grass on the bunds (Figure 15 and Figure 16). The Watershed Development Guidelines recommend growing grass on the conservation structures for stabilization (MoARD, 2005). Based on farmers' estimates 0.75 kg of grass is harvested from 1 m of soil bunds in Debre Mewi. In Anjeni about 1 kg of grass are harvested per each m of bund. Considering a distance of 20 m between soil bunds in Debre Mewi this would mean an additional 350 kg of grass are produced per each hectare that is treated with soil bunds. In Anjeni the estimated distances of 10 and 15 m, for soil bunds and *Fanya Juu* result in extra grass yields of 1046 and 666 kg per hectare, respectively. The values are lower than results of Kassie et al. (2008) who estimated extra grass production on *Fanya Juu* bunds in Anjeni to be as high as 1995 kg*ha⁻¹. Unlike in Debre Mewi watershed, fodder grass that is cultivated on the bunds is often not cut but animals are left to graze on the bunds directly, as shown in Figure 16.



Figure 15 Soil bund cultivated with grass in Debre Mewi watershed.

Photo: Dirk Rolker, 2011



Figure 16 Animals grazing on stabilized Fanya Juu in Anjeni watershed.

Photo: Dirk Rolker, 2011

During the time of the field work of this research there was a market for grass only in Debre Mewi but not in Anjeni. In Debre Mewi farmers received 10 EtB per *shekim* of grass. Taking into account the estimated weight of one *shekim* of 33 kg (see Table 5 in chapter 4.4.1) this leads to a price of around 0.30 EtB per kg of grass. Again, this value is comparable, though lower, to a price given by Kassie et al. (2008). Based on the average feed requirements and the price for an ox these authors estimated the price of one kg of grass to be 0.45 EtB.

5.5.4. Labor inputs to SWC

During the farm household survey farmers were asked to estimate the average length of SWC bunds on their field and the total labor input for their establishment on that field. In case SWC structures were constructed as part of a mass mobilization scheme farmers could not give estimates on the labor input. The average length of bunds was multiplied by the total number of bunds on the field. Subsequently, the total labor input was divided by the figure resulting from the previous calculation to come up with a figure on how much Person*Days (PD) are spent on the construction of one km of bunds. See Table 32 for the results.

Table 32 Labor requirements in PD*km⁻¹ for different types of SWC line interventions in Debre Mewi and Anjeni watersheds

SWC	Labor requirements (PD*km ⁻¹)					
	Debre Mewi			Anjeni		
	n	Average	StDev	n	Average	StDev
stone bund	8	201	152	13	54	59
soil bund	26	62	50	4	53	57
<i>Fanya Juu</i>	-	-	-	38	30	30

Source: Data from farm household survey 2011

Labor inputs estimated by the respondents of this research are considerably lower than all previously reported labor inputs to SWC in the Ethiopian highlands (see Table 26 in chapter 5.4.4), especially the values based on estimates by farmers from Anjeni are very low. This discrepancy can be explained by the fact that most of the SWC structures in Anjeni were constructed long ago. For example, 90 % of the labor estimates for *Fanya Juu* are for structures that were built five or more years ago and 42 % for structures that were built even 10 or more years ago.

In light of the fact that labor estimates by farmers are substantially lower than all previous estimates, standard figures by the Ethiopian Ministry of Agriculture and Rural Development as reported in the Watershed Development Guideline (MoARD, 2005) were used in the financial CBA of SWC measures. Finally, labor for the maintenance of SWC structures was estimated to be 5 % of the initial labor to construct the measures.

Valuation of labor inputs to SWC

SWC activities are usually carried out in the dry season when no, or only little, labor is needed for agricultural activities. Labor for the establishment constitutes the largest part of the investments in SWC measures. Its valuation is therefore critical in a CBA. According to Stocking and Abel (1989, cited in Posthumus, 2005) the valuation of labor inputs to SWC depends on the circumstances. When it is not at the expense of any other activity, the opportunity costs of labor for the construction of SWC could be valued at almost zero. Ludi (2004, p. 170), on the other hand, argues that “farmers do not necessarily consider this period as a slack season per se. In the Ethiopian Highlands, this is the time when other non-farm or off-farm activities are carried out”.

Given these arguments, opportunity costs of labor for SWC construction of 50 % of the market wage rate during the agricultural season were chosen. This is equivalent to 7.5 EtB*PD⁻¹. This valuation of labor inputs gives credit to both to the fact that SWC construction takes up time that could have been spent on other activities and to the fact that the same wages that can be earned during the agricultural season cannot be earned during the dry season. On the contrary, labor for maintenance of SWC structures was valued at 100 % of the market wage rate as it is usually carried out at the same time as seed bed preparation.

5.6. Erosion assessment at field level

At field level soil erosion was estimated by applying the Universal Soil Loss Equation (USLE). The considered fields belonged to individual farmers. In some cases the parcels were subdivided into smaller parcels which were cultivated with different crops. The erosion estimates are influenced by soil type, crop cover and slope length and –steepness. Contour-ploughing was assumed to have been practiced on all the considered fields.

The effectiveness of adapted SWC in reducing soil erosion is unknown. In the USLE estimates the only influence of SWC line interventions on soil loss that was taken into account is a decrease in slope length due to constructed bunds that trap the eroded soil material. For a summary of the USLE factors see Appendix III. Soil loss estimates on field level in Debre Mewi and Anjeni are shown in Table 33 and Table 34, respectively.

Table 33 Estimated soil loss (USLE) on agricultural plots in Debre Mewi watershed.

SWC	Soil type	Crop cover	Soil depth (cm)	Slope (%)	Soil loss (t*ha ⁻¹)	Soil loss (mm)	Soil life (years)
No SWC	red	maize	100	15	42	3	333
No SWC	red	maize	100	12	25	2	500
No SWC	red	grass	100	10	17	1	1,000
No SWC	red	barley, potato	100	9	25	2	500
No SWC	yellow	maize	100	15	41	3	333
No SWC	brown	tef	300	11	217	18	167
No SWC	black	barley	100	8	51	4	250
No SWC	black	finger millet	100	7	37	3	333
stone bund	yellow	maize	15	11	12	1	150
stone bund	yellow	faba bean	15	24	303	25	6
stone bund	yellow	maize, potato	15	19	24	2	75
soil bund	red	maize	100	9	30	2	500
soil bund	yellow	maize	100	15	21	2	500
soil bund	red	finger millet	200	6	30	3	667

Source: Own calculations based on field measurements in October and November 2011

Table 34 Estimated soil loss (USLE) on agricultural plots in Anjeni watershed.

SWC	Soil type	Crop cover	Soil depth (cm)	Slope (%)	Soil loss (t*ha ⁻¹)	Soil loss (mm)	Soil life (years)
No SWC	brown	barley	10	44	787	79	1
No SWC	brown	maize	50	15	28	3	167
No SWC	red	maize	100	12	32	3	333
No SWC	red	maize	100	7	8	1	1,000
No SWC	brown	maize	100	15	30	3	333
<i>Fanya Juu</i>	red	grass, barley	60	9	33	3	200
<i>Fanya Juu</i>	red	tef, maize, barley	100	10	85	9	111
<i>Fanya Juu</i>	brown	tef	25	10	71	7	36
<i>Fanya Juu</i>	red	tef	100	11	151	15	67
<i>Fanya Juu</i>	red	lupine	15	12	6	1	150
<i>Fanya Juu</i>	yellow	maize	45	9	10	1	450
<i>Fanya Juu</i>	brown	tef, potato	30	15	151	15	20
<i>Fanya Juu</i>	red	maize	10	14	15	1	100

Source: Own calculations based on field measurements in October and November 2011

It has to be noted that of the measured fields in Debre Mewi, the fields treated with stone bunds all have lower soil depths than other fields (Table 33). This could be an indication that marginal fields are treated preferentially. Similarly, the measured fields in Anjeni without SWC measures have relatively higher soil depths, than most of the soils treated with *Fanya Juu* (Table 34).

The estimates on the considered fields of individual farmers lead average soil loss values depending on the type of SWC as shown in Table 35.

Table 35 Average soil loss on farmers' field in Debre Mewi and Anjeni watersheds

SWC	Average soil loss (t*ha ⁻¹)	
	Debre Mewi	Anjeni
No SWC	57	177
soil bund	27	
stone bund	113	
<i>Fanya Juu</i>		65

The problem with these estimates is, however, that they are strongly influenced by the C-factor of the USLE. For example, all but one of the measured plots in Anjeni that were not treated with SWC, were planted with maize. Maize provides a much better crop cover than barley, tef or wheat. Consequently, soil loss on maize plots is lower than on plots cultivated with, for example, tef. The soil loss estimates for the plots treated with SWC, on the other hand, reflect the variability in crop cover in the watershed.

In order to come up with estimates on the efficiency of the locally implemented SWC practices a hypothetical situation was considered. The USLE was applied on a hypothetical field with a slope inclination of 10 % and a slope length of 100 m. Red and black soils, such as *Nitosols* and *Vertisols*,

are dominant in both watersheds. Hence a K-factor which represents an average of the K-factors for black and red soils as given by Hurni (Hurni, 1985) was chosen (0.2). The C-factor was chosen so as to represent a typical crop rotation as presented in chapter 5.2.2 (0.34) (Kaltenrieder, 2007). The effect of conservation measures on soil loss was included through a reduction in slope length. Strictly speaking this is not the only effect conservation structures have on soil loss. With time soil will accumulate behind the bunds and the slope angle will diminish. The reduced slope length and angle will also help to slow down runoff velocity and extend the time for water to infiltrate in the soil (Haile et al., 2006). Table 36 shows soil loss estimates for Debre Mewi and Anjeni watersheds based on the revised USLE.

Table 36 USLE soil loss estimates in Debre Mewi and Anjeni watersheds (slope: 10%, slope length without SWC: 100m)

SWC	Soil loss (t*ha ⁻¹)	
	Debre Mewi	Anjeni
No SWC	85	118
stone bund	38	53
soil bund	38	37
<i>Fanya Juu</i>		46

The calculated values presented in Table 36 seem reasonable in light of experimental data from Debre Mewi and Anjeni watersheds. As shown in Table 1. in section 4.1.1, soil erosion experiments on fields cultivated with tef and slopes of 10 % in Debre Mewi observed soil erosion rates from 23.8 t to 46.9 t*ha⁻¹ on fields treated with SWC measures. Soil loss on untreated field was observed to be 71.4 t*ha⁻¹. In Anjeni the average soil loss measured on a plot of 12 % is 90 t*ha⁻¹ and ranged from 17 to 176 t*ha⁻¹ (see Table 3 in section 4.1.2). The soil loss reduction achieved by SWC measures in Anjeni ranged between 57 % and 81 % which would mean a decrease to 38.7 and 17.1 t*ha⁻¹, respectively. It is therefore assumed, that the estimated values provide a realistic estimate of soil loss reduction by adapted SWC measures in Debre Mewi and Anjeni.

In conclusion, USLE erosion estimates show that soil erosion by water poses a threat by reducing top soil depth on farmers' fields in the watersheds of Debre Mewi and Anjeni. Although the effectiveness of locally adapted SWC in reducing soil erosion remains unknown, it can be assumed that they are effective by reducing the slope length and thereby reducing the velocity of run-off water.

5.7.Relation between erosion and productivity

According to Lal (2001, p. 531) "it is difficult to assess the loss of agronomic productivity due to soil erosion, because of the confounding effects of rainfall and other climatic factors during the growing season and that of management" For this research, no long term data on yields and soil loss were available for Debre Mewi watershed. This made it impossible to establish an empirical relation between crop yields and soil loss. For Anjeni watershed this relation has been established by Ludi (2004) based on 11 years of yield data she found that yields decreased by 0.23 % per cm of soil lost on plots not treated with SWC. Taking into account measured soil loss due to erosion and the

average bulk density of soils in the two watersheds (see section 4.1.1 and 4.1.2) this would mean that yields decrease by 0.14 % and 0.21 % annually in Debre Mewi and Anjeni, respectively.

Different authors have estimated productivity losses due to soil erosion in Ethiopia before Ludi. Bojö (1996) reports that according to these various sources, productivity losses range between 0.4 and 3 % annually or 1.3 to 3.9 % per cm of soil lost.

Crop yield increases due to SWC measures are equally difficult to attribute. An interdisciplinary study by Nyssen et al. (2007) evaluated stone bunds in a dry region of Northern Ethiopia. The bunds were constructed between three and 21 years prior to the research. The study found that on plots with stone bunds, cereal yields in general were 8 % higher and tef yields in particular and 11 %. These yield increases already take into account the area lost due to the conservation structures (Nyssen et al., 2007).

An evaluation of SCRP data by Herweg and Ludi (1999) found that crop yields rarely increased in the first three to five years after the construction of SWC measures. Nonetheless, crop yields and biomass from plots with soil and water conservation structures remained stable and exhibited only slight changes (decreases and increases) compared to control sites. Yield declines on conserved plots ranged between 50 and 4 %, while yield increases ranged between 4 and 15 %. The authors explain the stabilization of yields by the accumulation of top soil behind the bunds and the reduction of yields due to higher incidence of water logging on conserved plots.

In Debre Mewi watershed farmers were asked to estimate yield increases due to the construction of terraces. They estimated that tef yields on terraced plots increase by 50% from 200 to 300 kg*timad⁻¹ (588 to 882 kg*ha⁻¹) and maize yields by 100 % from 200 to 400 kg*timad⁻¹ (588 to 1176 kg*ha⁻¹). However, these high yield increase estimates are supported neither by yield estimates from the household survey (compare section 5.2.5) nor by the available literature on the subject.

De Graaff (1996) points out that after the construction of terraces yields decline in the first years after construction. Tenge et al. (unpublished, 2004 cited in Tenge et al., 2005) report an initial decline of maize yields on plots treated with bench terraces and *Fanya Juu* in the first two years after construction.

In conclusion, for the CBA conducted in this research an annual yield decline of 1 % was assumed in both approaches. This value represents an a relatively low estimate when compared to the values reported by Bojö (1996) and a value that is slightly higher than that reported by Ludi (2004). The yield increase after three years due to increased water retention, top soil accumulation and higher fertilizer use efficiency was estimated to be 10 % which is similar to yield increases reported by Nyssen, Poesen et al. (2007) and the average of minimum and maximum yield increases reported by Herweg and Ludi (1999). Initial yield declines in Approach I were assumed to be 25 % in the first year before yields reach the level currently obtained from plots with conservation measures. In Approach II it was assumed that yields decrease by 50 % in the first year and 25 % in the second year before a yield increase by 10 % in finally achieved in the third year.

5.8. Financial CBA

5.8.1. Gross margins

The first step towards the evaluation of the economic profitability of SWC measures was to determine labor and material inputs, crop revenues and the resulting gross margins of a typical crop rotation in Debre Mewi and Anjeni, respectively. The results can be found in Table 37 and Table 38.

Table 37 Overview of inputs, revenues and gross margins of crop production in Debre Mewi depending on SWC as estimated by farmers.

		SWC		
		No SWC	Stone bund	Soil bund
Labor inputs	(PD*ha ⁻¹)	101	134	94
Labor inputs	(EtB*ha ⁻¹)	1509	2007	1413
Material inputs	(EtB*ha ⁻¹)	1839	1330	1710
Crop revenues	(EtB*ha ⁻¹)	6262	5886	5854
Gross Margin	(EtB*ha ⁻¹)	2915	2549	2731

Table 38 Overview of inputs, revenues and gross margins of crop production in Debre Mewi depending on SWC as estimated by farmers.

		SWC			
		No SWC	Stone bund	Soil bund	<i>Fanya Juu</i>
Labor inputs	(PD*ha ⁻¹)	115	73	103	90
Labor inputs	(EtB*ha ⁻¹)	1730	1094	1544	1346
Material inputs	(EtB*ha ⁻¹)	1738	1825	1762	1955
Crop revenues	(EtB*ha ⁻¹)	5638	5043	5835	5846
Gross Margin	(EtB*ha ⁻¹)	2171	2125	2530	2544

As can be seen Table 37 material inputs on plots with SWC are lower than on plots without SWC. The cultivated area on plots with SWC is reduced by the bunds occupying the field. Hence fewer inputs are needed.

Furthermore, crop revenues on un-treated plots in Debre Mewi are 376 and 408 EtB per hectare higher than on plots treated with stone and soil bunds, respectively. The resulting gross margins are 366 and 184 EtB*ha⁻¹ higher. This could be due to the lower soil depth and lower inherent productivity of the treated plots. In Anjenie (Table 38) the picture is quite different. Only crop revenues and gross margins on plots treated with stone bunds are lower than plots un-conserved land (595 EtB*ha⁻¹ and 46 EtB*ha⁻¹, respectively). Crop revenues on plots conserved with soil bunds, on the other hand, are 197 and 208 EtB*ha⁻¹ higher. The resulting gross margins are 359 and 373 EtB*ha⁻¹ higher.

An explanation for this apparent difference probably lies also in the age of the measures. The oldest of the stone bunds in Debre Mewi were constructed 8 years ago and the oldest soil bunds 12 years ago. The maximum age of the surveyed stone bunds, soil bunds and *Fanya Juu*, on the other hand, was 27 years. Field observations in Anjeni have shown that most of the older *Fanya Juu* bunds have

stabilized into bench terraces. This results in a diminution of slope angles and increased topsoil depth behind the bunds which has a positive effect on yields. These yield increases apparently have the potential to off-set the yield reduction due to occupation of fertile land by the conservation structures. The stabilization of bunds into bench terraces cannot yet be observed on any of the conserved plots in Debre Mewi watershed. Instead, yields per area are now still lower due to the area lost to conservation structures.

5.8.2. CBA results

For this research two methodologically different approaches to a financial CBA were applied (see section 4.2.2). In both approaches, the design features of the SWC measures are based on the currently implemented conservation practices in the two watersheds. Hence, the construction and maintenance costs are also the same. The difference in the two approaches lies in the change of crop production on plots with conservation measures. In Approach I in- and output levels currently observed on fields without conservation change to those currently observed on fields with conservation. In Approach II, on the other hand, crop production on plots with conservation measures are assumed to increase by 10 % (see section 5.7) compared to that obtained under conditions without conservation. In this second approach input levels stay the same in both cases. In both cases, it was assumed that without conservation yields will decrease by 1 % annually.

Table 39 Overview of CBA results in Debre Mewi (yield decline: 1 %, discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹)

	SWC	
	Stone bund	Soil bund
Construction cost (EtB*ha ⁻¹)	938	563
Annual maintenance cost (EtB*ha ⁻¹)	94	56
Additional grass revenues (EtB*ha ⁻¹)	-	113
<i>Approach I</i>		
NPV (EtB*ha ⁻¹)	-2663	-205
IRR (%)	0	11
<i>Approach II</i>		
NPV (EtB*ha ⁻¹)	-281	822
IRR (%)	12	15
Yield increase to reach break-even point (%)	11	8

Table 40 Overview of CBA results in Anjeni.

	SWC		
	Stone bund	Soil bund	<i>Fanya Juu</i>
Construction cost (EtB*ha ⁻¹)	938	1125	1000
Annual maintenance cost (EtB*ha ⁻¹)	94	113	100
Additional grass revenues (EtB*ha ⁻¹)	-	320	213
<i>Approach I</i>			
NPV (EtB*ha ⁻¹)	-677	3547	3138
IRR (%)	9	32	30
<i>Approach II</i>			
NPV (EtB*ha ⁻¹)	-1301	-84	-304
IRR (%)	9	12	12
Yield increase to reach break-even point (%)	15	11	12

The results for Debre Mewi show that under currently observed in- and output levels the local adaptation of SWC measures seems not profitable. Stone bunds in Debre Mewi have a low NPV which could be due to the fact that they are constructed on marginal land with a low soil depth (see Table 33). If implemented on one hectare of farmland, stone bunds would reduce household incomes by 2663 EtB (as compared to plots without SWC) which is equivalent to around 43 % of the average gross cash income of households in Debre Mewi watershed (6229 EtB). Soil bunds, on the other hand, show only a slightly negative NPV and an IRR that is just slightly below the available credit rate in the watershed.

The second approach applied in this research shows that (under the assumption that yields obtained with SWC increase by 10 % and that yields obtained without SWC decrease by 1 % annually) stone bunds have a slightly negative NPV and are thus not profitable. However, stone bunds have an IRR that is very close to the discount rate. In order to reach profitability yields obtained under conditions with conservation would have to increase by 11 % (instead of the assumed 10 %). Under the second

approach soil bunds have a positive NPV and an IRR that is 2.5 percentage points above the discount rate. Soil bunds already reach profitability if yields increase by 8 %.

Stone bunds in Anjeni are unprofitable under both approaches and with negative NPVs and an IRR that was 3.5 percentage points below the discount rate. In the second approach a yield increase of 15 % is needed in order for stone bunds in Anjeni to become profitable.

For soil bunds and *Fanya Juu* in Anjeni the results of the CBA are strikingly different depending on the approach taken. Under the first approach both technologies reach a high NPV (3547 EtB*ha⁻¹ for soil bunds and 3138 EtB*ha⁻¹ for *Fanya Juu*) and IRRs that are far above the discount rate. Under the second approach, however, both soil bunds and *Fanya Juu*, are just short of becoming profitable. Yield increases of 11 and 12 %, respectively would be sufficient to make the technologies profitable.

5.8.3. Sensitivity analyses

Opportunity costs of labor

As has been argued in section 5.4.4 there are arguments for assuming different opportunity costs of labor for SWC construction. For this research, a sensitivity analysis was carried out to determine the influence of the opportunity costs of labor on the NPV of the considered SWC technologies in the two watersheds. The results for Debre Mewi and Anjeni can be found in Figure 17 and Figure 18, respectively.

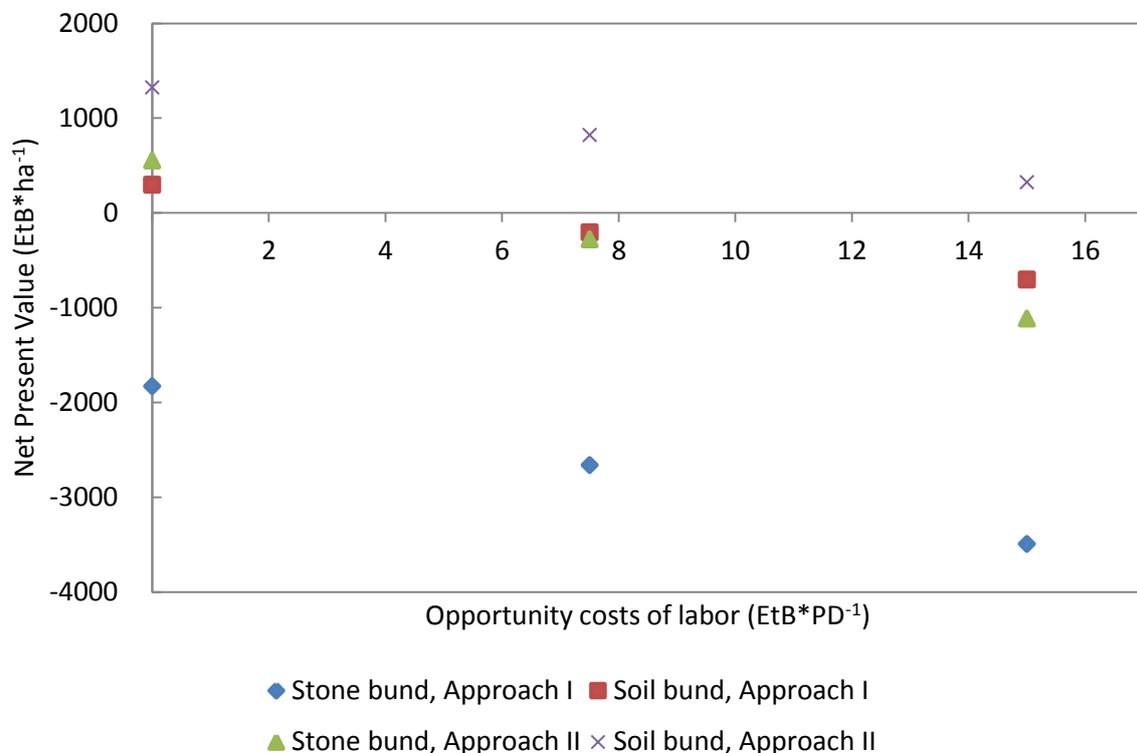


Figure 17 Sensitivity analysis of opportunity costs of labor for NPVs of SWC techniques in Debre Mewi watershed (yield decline: 1 %, discount rate: 12.5 %).

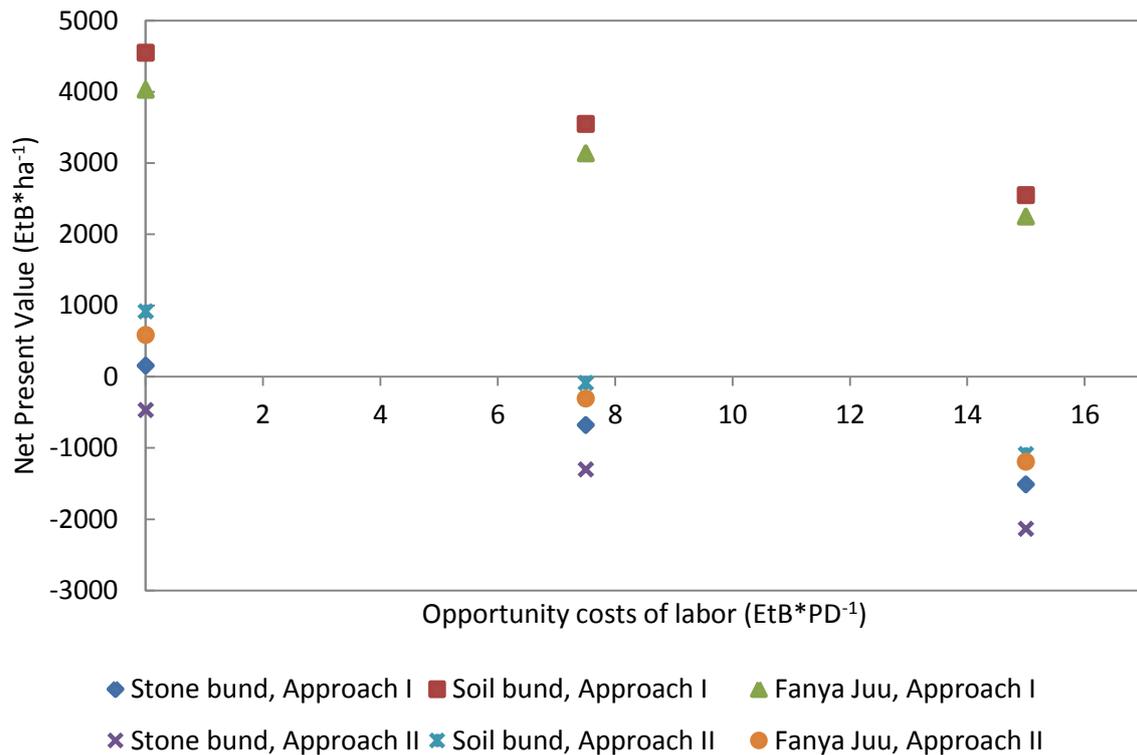


Figure 18 Sensitivity analysis of opportunity costs of labor for NPVs of SWC techniques in Anjeni watershed (yield decline: 1 %, discount rate: 12.5 %).

Ludi (2004) carried out various sensitivity analysis in her CBA of SWC measures in the Ethiopian highlands. She found that of the considered parameters labor cost proved to be the most important. Similarly, this study has found that opportunity costs of zero for the construction of SWC measures makes almost all of the considered technologies profitable. However, in order for stone bunds to become profitable in Approach II yields would have to increase by 11 and 15 % in Debre Mewi and Anjeni, respectively.

Increasing the opportunity costs of labor to the current market wage rate of 15 EtB*PD⁻¹ does not change the relative profitability of the measures. Soil bunds in Debre Mewi under Approach II remain profitable but the absolute NPV decreases by 500 EtB*ha⁻¹ from 822 EtB*ha⁻¹ to 322 EtB*ha⁻¹. Soil bunds and *Fanya Juu* in Approach I remain profitable with relatively high NPV of 2547 and 2249 EtB*ha⁻¹, respectively.

Yield decline

As has been elaborated in section 5.7 the relation between erosion and productivity is highly complex and uncertain. In a second sensitivity analysis different yield reductions due to ongoing erosion were assumed. Based on the relation between soil erosion and productivity found by Ludi (2004) annual yield declines of 0.14 and 0.21 % were assumed in Debre Mewi and Anjeni, respectively. Furthermore, yield declines of 0 and 0.5 % were assumed.

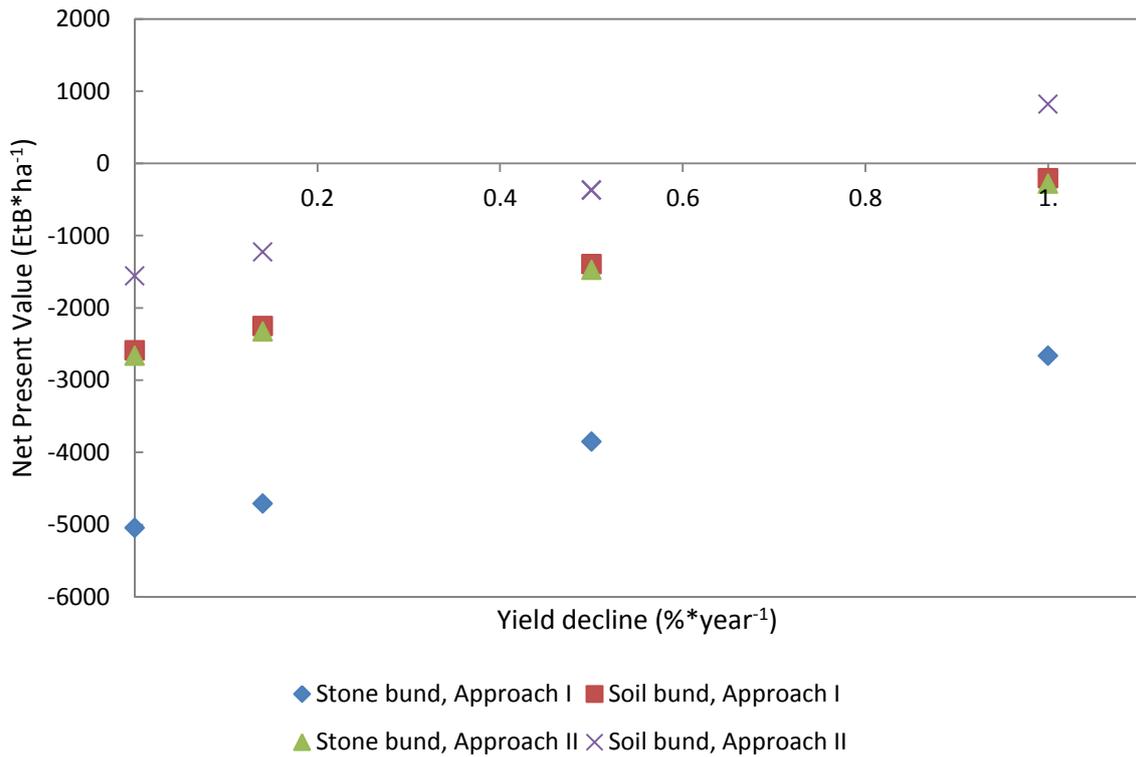


Figure 19 Sensitivity analysis of annual yield declines for NPVs of SWC techniques in Debre Mewi watershed (opportunity costs of labor: 7.5 EtB*PD⁻¹, discount rate: 12.5 %).

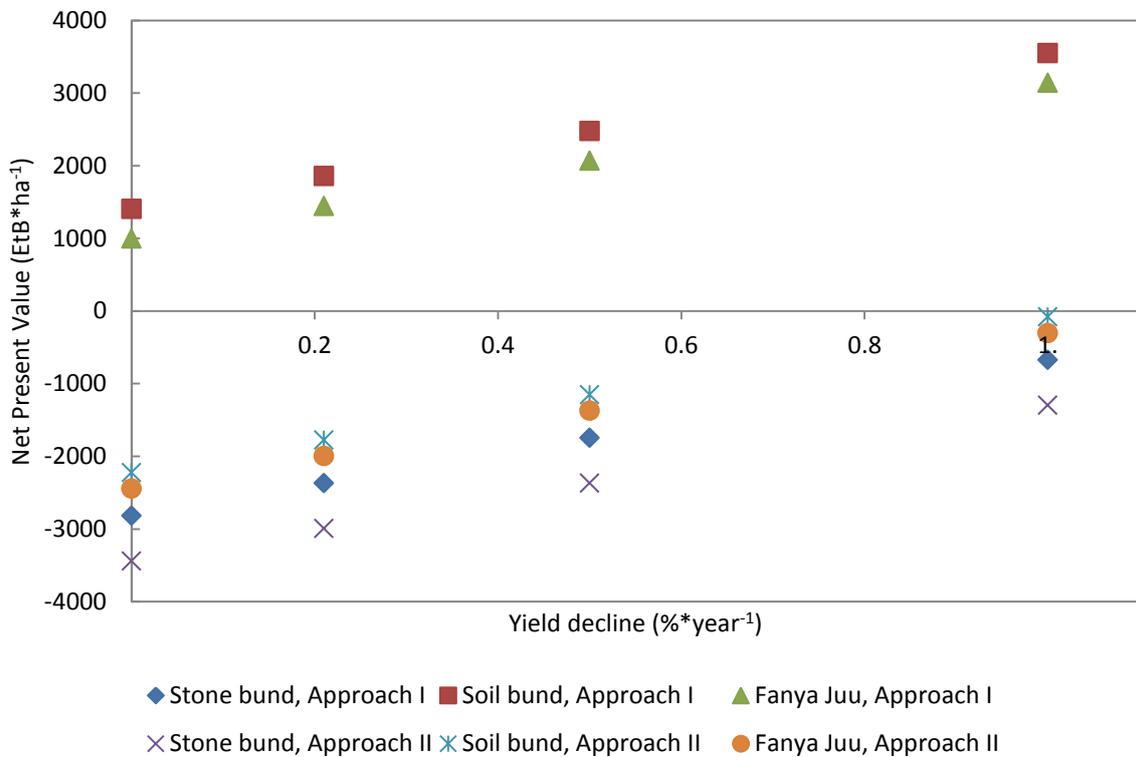


Figure 20 Sensitivity analysis of annual yield declines for NPVs of SWC techniques in Anjeni watershed (opportunity costs of labor: 7.5 EtB*PD⁻¹, discount rate: 12.5 %).

Results of the sensitivity analysis show that annual yield declines of 0.5 % or less do not justify the investment in SWC technologies in most cases. Soil bunds and *Fanya Juu* in Anjeni under Approach I have positive NPV with low annual yield declines. In the calculations for the CBA under Approach I it was assumed that in the second year after the construction, in- and output levels change to the currently observed in- and output levels of conserved plot. However, the values used in the calculations under Approach I already reflect the changes in production that have taken place in the past 27 years since the first *Fanya Juu* were constructed and might thus overestimate the profitability of the measures.

6. Conclusions and Recommendations

This research set out with two objectives: to investigate the on-site costs of soil degradation and to investigate the profitability of three different SWC line interventions in the watersheds of Debre Mewi and Anjeni. In the following chapter different types of on-site costs of soil erosion will be discussed. Secondly, conclusions and recommendations with respect to the economic efficiency of SWC line interventions in the two watersheds will be presented. Third, conclusions and recommendations concerning the local adaptation of SWC measures will be elaborated. Fourth, and last, conclusions about the limitations of the study will be presented and recommendations for future methodological improvements will be given.

6.1. On-site costs of soil erosion

Concerning the on-site costs of soil erosion in the watershed of Debre Mewi a distinction has to be made between sheet and rill erosion on private crop land and gully erosion on public and private grazing land. Sheet and rill erosion reduce yields and lead to a loss of inputs while gully erosion incurs costs through the reduction of cultivable land.

Sheet and rill erosion

USLE estimates and previous research show that unprotected fields in both watersheds suffer considerably from soil erosion. Group- and individual interviews conducted with land users in the watershed showed that farmers perceive that soil erosion on agricultural land is reducing yields. Moreover, controlling soil erosion has the added benefit of preventing fertilizers and seeds from being washed away during rain events.

Yield estimates by farmers did not allow drawing final conclusions whether or not SWC measures improved yields. Varying inputs levels of organic and inorganic fertilizers as well as improved and traditional seed varieties obscured the potential effects of SWC measures on crop yields.

Gully erosion

Transect walks and field observations showed severe gully erosion especially in the bottom of the watershed. Tebebu, Abiy et al. (2010) estimated soil loss due to gully erosion in a sub-watershed of Debre Mewi watershed. They estimated that in the years between 1981 and 2008 the average annual soil loss was equivalent to 31 t*ha^{-1} . Furthermore, the authors concluded that the gully erosion rate had significantly increased since 2007, with an estimated soil loss of 530 t*ha^{-1} after the rainy season 2008. The gullies are usually initiated on public grazing land. Informal interviews with farmers and field observation showed that the expansion of gullies on private agricultural land has become more severe in recent years (Figure 21).



Figure 21 Gully erosion threatening agricultural fields in Debre Mewi watershed

Photos: Dirk Rolker, 2011

The average revenues of crop production on plots not treated with SWC measures in Debre Mewi is 6262 EtB*ha⁻¹. In 2010, the 30 farm households sampled for this research in Debre Mewi earned on average 2615 EtB from crop sales. The average size of an agricultural field in the watershed is around 0.42 ha. Assuming that a field next to an active erosion gully decreases in size by 10 % would mean that farm household income from crop sales is reduced by about 185 EtB or 7 %.

6.2. Economic efficiency of SWC investments

Kappel (1996, p. 17) points out that “farmers will become interested in [...] [an SWC] measure only if they are able to recognize the yield losses due to soil erosion and if that knowledge represents a high degree of certainty. Likewise, they must be certain of the positive impact of the soil conservation method”. Farmers in both watersheds perceive soil erosion as detrimental to their crop production. In the same manner, they perceive SWC line interventions as being beneficial for crop production. 100 % of the interviewed farmers stated that SWC minimizes soil and nutrient losses. 70 % of the farmers in Debre Mewi and 86.7 % of the farmers in Anjeni stated that SWC line interventions lead to yield increases. During individual and group interviews farmers often mentioned that the construction of SWC line interventions and the subsequent progressively forming terraces have the additional advantage of preventing fertilizers and seeds from being washed away.

Two different approaches to evaluate the economic efficiency of SWC investments have shown that in Approach I soil bunds and *Fanya Juu* in Anjeni are profitable investments. It can be concluded that this result is due to the fact that some of the values used in the calculations are based from plots with SWC measures that were constructed 27 years ago. On these plots, soil bunds and *Fanya Juu* have stabilized into bench terraces which considerably reduce erosion and increases soil depth. Under Approach II, all technologies except soil bunds remain unprofitable. In order to become profitable yield increases of 11 up to 15 % are needed. Furthermore, financial CBA of SWC line interventions has shown that stone bunds are least profitable due to high initial labor investments.

Intensifying agricultural production

According to Herweg and Ludi “the need to keep conservation costs low and to increase production calls for intensified production” (Herweg and Ludi, 1999, p. 112). One of the ways to intensify agricultural production is to increase the use of organic and inorganic fertilizers. However, in light of the recent spike in fertilizer prices (see section 5.2.3) 50 % of farmers in Debre Mewi and 65.5 % of farmers in Debre Mewi are reducing the amount of mineral fertilizers to save money. As has been shown, increasing the amount of manure and compost proves to have some difficulties concerning the transport of the organic fertilizers.

Grass from SWC structures

Kassie et al. (2008) measured the impact of *Fanya Juu* bunds on the value of crop production in Anjeni by means of various statistical techniques. The authors concluded that the value of crop production for plots with bunds was lower than for plots without bunds. At the time of the study only few farmers were planting high-value fodder crops on the bunds, despite long-term experience with SWC in the watershed. The study finally suggests that additional extension effort should be put in the promotion of the production of these fodder crops.

Tenge et al. (2005, p. 364) performed Cost-Benefit Analyses for bench terraces, *Fanya Juu* and grass strips in the West Usambara highlands in Tanzania. The authors concluded that farmers could increase the benefits of SWC measures by “growing relatively high value crops such as vegetables and banana, which have relatively low investment costs”. The authors further state that “these crops need to be managed properly, because SWC structures alone may not improve crop yields”.

The Watershed Development Guidelines (MoARD, 2005) recommend to apply compost on terraced fields and to exploit the increasing residual soil moisture behind the bunds by growing cash crops and seasonal crops along the bunds. Field observations and farmer interviews have shown that the cultivation of high value crops is still not widely spread in Anjeni watershed. Similarly, farmers in Debre Mewi only let indigenous grass varieties and various weeds take over the free space on the bunds. Only few farmers took to planting higher value crops on or along the bunds on their fields (e.g. Lupine as shown in Figure 22).



Figure 22 Soil bund cultivated with white lupine (*Lupinus albus*) in Debre Mewi watershed.

Photo: Dirk Rolker, 2011

For the future it can be recommended that farmers plant higher yielding varieties like Elephant grass (*Pennisetum purpureum*) instead of letting naturally occurring varieties take over. Furthermore, growing cash- or higher value crops on or along the bunds will help to make SWC more profitable.

6.3. Design of SWC measures

Farm household interviews and field measurements showed that design and implementation of SWC measures in Anjeni and Debre Mewi watershed differs considerably from official design recommendations. The spacing between bunds as chosen by the farmers follows a more flexible approach and is generally wider than recommend by the MoARD. Apparently, farmers and local DAs do not give much consideration to the slope of a field when choosing the spacing during the construction of the bunds. Consequently, reduction of cultivable area through locally adapted SWC is much lower (around 5 %) than in case of introduced SWC (up to 25 % on steep slopes).

6.4. Limitations of the study

The methodology applied in this research has several limitations and areas of improvement. First of all, the limited number of observations for crop production is a source of uncertainty. It is possible, that a higher number of estimates by farmers will allow drawing conclusions on whether SWC increases crop yields. In order to conduct CBA under Approach I, with comparable crop rotations, values in the 'with' situations had to be supplemented with figures from the 'without' situation. Future studies should therefore either be based on a higher number of estimates or empirical yield measurements. In this way uncertainties can be reduced and conclusions drawn from the data will become stronger. It could be that stone bunds in Debre Mewi are established on marginal soils, with limited soil depth. In such a case a comparison between with and without cases in CBA (with different soil depth) is not appropriate. The without case plots should then also have shallow soils.

Moreover, the exact relationship between soil erosion and agricultural productivity as well as the effectiveness of adapted SWC measures remains unknown. For this research it was crudely assumed

that yields on unprotected plots decline by a flat rate of 1 % annually due to soil erosion and that yields on plots with SWC measures do not decline any further after the construction of SWC. However, calculations by Ludi (2004) indicate that yield declines due to soil erosion might be much lower than 1 %. In addition, it is possible that adapted SWC measures do not sufficiently reduce erosion to stop the progressive yield decline. Moreover, in approaches I and II yields were assumed to decline in due to soil disturbances in year one, and year one and two, respectively. However, some authors (de Graaff, 1996) argue that yields decline caused by soil disturbances affect even longer time periods. Similarly, Herweg and Ludi (1999) remarked that in the first five to eight years after the construction yields on terraced fields hardly increase.

Therefore, future studies should empirically determine the effect of the local design of SWC measures on soil erosion. Moreover, time series of measured soil erosion and crop yield data should be used to establish an empirical relation between soil erosion and agricultural productivity.

Finally, off-site effects of soil erosion were not included in this study. The most common off-site effects are sedimentation in reservoirs and waterways, decline in water quality and contamination of drinking water, gully erosion and deposition of eroded materials on farmland (Stocking and Murnaghan, 2001). Tenge et al. (2005) have pointed out that “in order to prevent [...] off-site effects individual farmers, need to be motivated first, because the final decision to adopt SWC measures is made by an individual”. Still, it is recommended that future studies include off-site effects soil erosion. While a conservation measure might not be profitable from a private-economic point of view it is still very well possible that an investment is profitable at another level, e.g. at watershed level. In that case an economic CBA should be performed.

According to Hengsdijk et al. (2005) “agro-ecological tools are hardly available to assess effects of soil and water conservation practices in an integrated way at different spatial and temporal scales”. However, in order to assess the effects of SWC technologies at different scales, not just farm level, these tools are needed. Future studies should therefore focus on developing suitable methodologies and on incorporating off-site costs and benefits of SWC measures.

7. References

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Appendix I

Farm household survey

Farm household survey

Code No.: _____
Date: _____
With/ Without _____

Watershed	Debre Mewi	<input type="checkbox"/>	Anjenie	<input type="checkbox"/>
District	Yilmana Densa	<input type="checkbox"/>	Bahir Dar Zuria	<input type="checkbox"/>
Village/ Got/ Sub-Kebele	_____			
Altitude	masl	_____		
Name of farmer	_____			
Total farm size	timad/ gemed	_____		



1. Farm household characteristics

Name		HH	2	3	4	5	6	7	8	9	10	11
Sex	Male=1, Female=2											
Age	Years											
Relation with head	Code 1											
Level of schooling	Code 2											
Main Occupation	Code 3											
Farming experience	Years											
Farming contribution	Code 4											

- Code 1** 1= Spouse 2= Son/ Daughter 3= Father/ Mother
 4= Grand child 5= Brother/ Sister 6= Grand parents
 7= Other relative 8= Non-relative
- Code 2** 1= Illiterate 2= Read and Write 3= Primary School (1-6 Grade)
 4= Junior Secondary (7-8 Grade) 5= Secondary school (9-10 Grade) 6= Preparatory (10-12 Grade)
 7= College/ University
- Code 3** 1= Farming 2= Housewife 3= Student
 4= Dependent 5= Watching after animals 6= Off-farm activity
 7= Government employee 8= Other, specify
- Code 4** 1= Full time 2= During peak period 3= Not at all

2. Plot characteristics

Parcel ID		1	2	3	4	5	6	7	8
Parcel size	timad/ gemed								
Distance from home	minutes								
Position in watershed	Code 5								
Tenure arrangement	Code 6								
Soil type	Code 8								
Slope class	Code 9 (see chart)								
Soil depth	Code 10								
Soil depth	cm								
Fertility status	Code 12								
Extent of soil erosion	Code 13								
Soil and Water Conservation	1=Yes, 2=No								
Acacia trees on plot	No.								
Other:	No.								
	No.								
	No.								

- Code 5** 1= Upstream 2= Downstream 3= Middle
 4= Outside
- Code 6** 1= Own 2= Rent in 3= Shared-in
 4= Shared-out 5= Rent out
- Code 8** 1= Black 2= Red 3= Brown (Silehana)
 4= Yellow 5= Rocky (Shinala)
- Code 9** 1= 0-2% 2= 0-5% 3= 5-10%
 4= 10-15% 5= 15-20% 6= 20-30%
 7= 30-40% 8= 40-50%
- Code 10** 1= Deep 2= Medium 3= Shallow
- Code 11** 1= Clay 2= Loam 3= Sand
- Code 12** 1= High 2= Medium 3= Low
- Code 13** 1= High 2= Medium 3= Low 4= None

3. Crop production

Main season (Meher)

Cultivation in the last two years, main season

Plot ID	1	2	3	4	5	6	7
Parcel ID							
Plot size	Timad/ gemed						
2010	Code 14						
Intercropped with	Code 14						
Intercropped with	Code 14						
2009	Code 14						
Code 14	1= Teff 2= Wheat 3= Barley 4= Maize 5= Faba bean 6= Field pea 7= Finger millet 8= Potato 9= Grass pea 10= Gomen 11= Noug 12= Line seed						

Material input 2010, main season

Plot ID	1	2	3	4	5	6	7
Main: Seed							
Local	Amount	kg					
Improved	Amount	kg					
Inter1: Seed							
Local	Amount	kg					
Improved	Amount	kg					
Inter2: Seed							
Local	Amount	kg					
Improved	Amount	kg					
Fertilizer							
DAP	Amount	kg					
Urea	Amount	kg					
Manure	Amount	kg					
Compost	Amount	kg					
Pesticides							
Herbicides	Amount	l					
Insecticides	Amount	l					

Fertilizer use 2011

	2010	2011
Fertilizer		
DAP	Amount	kg
Urea	Amount	kg

Labor input 2010, main season

Plot ID	1	2	3	4	5	6	7
Land preparation	Labor input	MD					
	Family labor	MD					
	Debo labor	MD					

4

	Wonfel labor	MD					
	Hired labor	MD					
	Oxen	Oxen*day					
Planting/ Seeding	Labor input	MD					
	Family labor	MD					
	Debo labor	MD					
	Wonfel labor	MD					
	Hired labor	MD					
	Oxen	Oxen*day					
Fertilizer application	Labor input	MD					
Manuring	Labor input	Min*day^-1					
	Labor input	Days*year^-1					
Composting	Labor input	MD					
	Family labor	MD					
	Hired labor	MD					
Weeding	Labor input	MD					
	Family labor	MD					
	Debo labor	MD					
	Wonfel labor	MD					
	Hired labor	MD					
Spraying	Labor input	Hours					
Main: Harvesting	Labor input	MD					
	Family labor	MD					
	Debo labor	MD					
	Wonfel labor	MD					
	Hired labor	MD					
Main: Threshing and transport	Labor input	MD					
	Family labor	MD					
	Debo labor	MD					
	Wonfel labor	MD					
	Hired labor	MD					
	Oxen	Oxen*day					
Inter1: Harvesting	Labor input	MD					
	Family labor	MD					
	Debo labor	MD					
	Wonfel labor	MD					
	Hired labor	MD					
Inter1: Threshing and transport	Labor input	MD					
	Family labor	MD					
	Debo labor	MD					
	Wonfel labor	MD					
	Hired labor	MD					
	Oxen	Oxen*day					

5

Inter2: Harvesting	Labor input	MD								
	Family labor	MD								
	Debo labor	MD								
	Wonfel labor	MD								
	Hired labor	MD								
Inter 2: Threshing and transport	Labor input	MD								
	Family labor	MD								
	Debo labor	MD								
	Wonfel labor	MD								
	Hired labor	MD								
	Oxen	Oxen*day								

Harvest 2010, main season

Plot ID			1	2	3	4	5	6	7
Crop/ Grain	Amount	Kg							
<i>Intercropped with</i>	Amount	Kg							
<i>Intercropped with</i>	Amount	Kg							
Straw	Amount	Shekim							
<i>Intercropped with</i>	Amount	Shekim							
<i>Intercropped with</i>	Amount	Shekim							

Second season with residual moisture

Cultivation in the last two years, second season

Plot ID			1	2	3	4	5	6	7
Parcel ID									
Plot size	Timad/ gemed								
2010	Code 14								
2009	Code 14								
Code 14	1= Teff	2= Wheat	3= Barley	4= Maize	5= Faba bean				
	6= Field pea	7= Finger millet	8= Potato	9= Grass pea	10= Gomen				
	11= Noug	12= Line seed							

Material input 2010, second season

Plot ID			1	2	3	4	5	6	7
Main: Seed									
<i>Local</i>	Amount	kg							
<i>Improved</i>	Amount	kg							
Fertilizer									
<i>DAP</i>	Amount	kg							
<i>Urea</i>	Amount	kg							
Manure	Amount	kg							
Compost	Amount	kg							
Pesticides									
<i>Herbicides</i>	Amount	l							
<i>Insecticides</i>	Amount	l							

Labor input 2010, second season

Plot ID			1	2	3	4	5	6	7
Land preparation	Labor input	MD							
	Family labor	MD							
	Hired labor	MD							
	Oxen	Oxen*day							
Planting/ Seeding	Labor input	MD							
	Family labor	MD							
	Hired labor	MD							
	Oxen	Oxen*day							
Fertilizer application	Labor Input	MD							
Manuring	Labor input	Min*day^-1							
	Labor input	Days*year^-1							
Composting	Labor input	MD							
	Family labor	MD							
	Hired labor	MD							
Weeding	Labor input	MD							
	Family labor	MD							
	Debo labor	MD							
	Wonfel labor	MD							
	Hired labor	MD							
Spraying	Labor input	Hours							
Harvesting	Labor input	MD							
	Family labor	MD							
	Debo labor	MD							
	Wonfel labor	MD							
	Hired labor	MD							
Threshing and transport	Labor input	MD							
	Family labor	MD							
	Debo labor	MD							
	Wonfel labor	MD							
	Hired labor	MD							
	Oxen	Oxen*day							

Harvest 2010, second season

Plot ID			1	2	3	4	5	6	7
Crop/ Grain	Amount	kg							
Straw	Amount	shekim							

How do you cope with rising fertilizer prices?

- Decreasing the amount of fertilizer utilization
- Decreasing the land rented in
- Shifting from cereal crop to pulse crop
- Shifting to compost and manure or increasing the utilization of compost or manure
- Other, specify

4. Soil and Water Conservation

Construction

Parcel ID		1	2	3	4	5	6	7	8
Technique	Code 15								
Construction	Year in E.C.								
Rows	No.								
Average length	meter								
Average width	cm								
Average height	cm								
Average distance	meter								
Grass on risers	1=Yes, 2=No								
Construction: Labor	MD								
Construction: Family labor	MD								
Construction: Mass mobilization	MD								
Construction: Hired labor	MD								
Construction: Hired labor cost	Birr*day ⁻¹								
Construction: Oxendays	No.*days								
Code 15	1= None 2= Stone bund 3= Soil bund 4= Fanya Juu 5= Grass strips 6= Other, specify								

Equipment for construction

Parcel ID		1	2	3	4	5	6	7	8
Poles	Amount	No.							
	Price	Birr							
Hand hoe	Amount	No.							
	Price	Birr							
	Life time	Years							
Spade	Amount	No.							
	Price	Birr							
	Life time	Years							
Other:	Amount	No.							
	Price	Birr							
	Amount	No.							
	Price	Birr							
	Amount	No.							
	Price	Birr							

Annual Maintenance

Parcel ID		1	2	3	4	5	6	7	8
Maintenance: Labor	MD								
Maintenance: Family labor	MD								
Maintenance: Hired labor	MD								
Maintenance: Hired labor cost	Birr*day ⁻¹								
Maintenance: Oxendays	No.*days								
Grass harvested	Shekim*year ⁻¹								
Present state of maintenance	Code 17								
Code 17	1= Very good 2= Good 3= Medium 4= Bad 5= Very bad								

What is the extent of impact on soil erosion on your crop yield?

Severe Moderate No impact

Can soil erosion be effectively controlled?

Yes No

Which approach do you prefer to implement SWC measures and why?

Individual Group approach Both

.....

What benefits do you get from the implementation of introduced SWC measures?

Benefit	Rating	Comment
Minimize soil/nutrient loss		
Increased water retention		
Improved soil fertility		
Increased yield		
Terraces as feed source for livestock		
None		
Others, specify		

Rating 1= No benefit 2= Small 3= Medium 4= Large benefits

What kind of problems do SWC cause?

Benefit	Rating	Comment
Complicates ploughing with oxen		
High labor requirement of construction		
Harbor rodents/pests		
Weeds		
Overlap with off-farm work		
Reduce cultivable area		
None		
Others, specify		

Rating 1= No problem 2= Small 3= Medium 4= Serious problem

(For non-adopters) Why have you not invested in SWC so far?

.....
.....

5. Observations and Comments

.....
.....
.....
.....
.....

Appendix II

Prices of agricultural outputs

Table 41 Prices of agricultural outputs in Debre Mewi and Anjeni watersheds

Crop	Grain prices (EtB*100 kg ⁻¹)			
	Debre Mewi	Anjeni		Average
		Harvest	Off-season	
tef	650	600	750	675
wheat	500	400	750	575
barley	350	300	500	400
maize	250	230	500	365
grass pea	600	-	-	-
potato	200	170	240	205
gomen	-	975	1250	1112.5
faba bean	700	600	1200	900

Source: Own compilation from group interviews and agricultural cooperative data

Appendix III

USLE factors

R factor

$$R = 0.36x + 47.6 \quad \text{Source: Kaltenrieder (2007)}$$

x = yearly precipitation in mm

K factor

Soil color	K factor
black	0.15
brown	0.20
red	0.25
yellow	0.30

Source: Hurni (1985)

LS factor

$$LS = \left(\frac{\lambda}{22.13} \right)^m (0.0065 + 0.045S + 0.0065S^2) \quad \text{Source: Bewket and Teferi (2009)}$$

λ = slope length in m

m = exponent depending on slope, dimensionless (0.5 for slopes >5 %, 0.4 for slopes 3-5 %, 0.3 for slopes 1-3 %, 0.2 for slopes <1 %)

S = slope steepness in %

C factor

Crop	C(P) factor	C factor
grass	0.050	0.001
maize	0.050	0.050
lupine	0.050	0.050
barley	0.300	0.350
tef	0.700	0.800
noug	0.450	0.500
faba bean	0.500	0.550
forest		0.050
finger millet	0.400	0.450
potato	0.050	0.050
wheat	0.400	0.450

Source: Kaltenrieder (2007)

Appendix IV

USLE soil erosion estimates

Table 42 USLE estimates Debre Mewi watershed.

Plot ID	Crop	Soil	SWC	Area/ ha	Slope/ %	Slope length/ m	m	R-factor	K-factor	LS-factor	C-factor	A/ t*ha ⁻¹ *year ⁻¹
AA	Maize	Red	none	0.17	15.10	208.00	0.50	501.2	0.25	6.65	0.05	41.6
AB	Maize	Red	soil bund	0.13	9.40	18.00	0.50	501.2	0.25	0.91	0.05	5.7
AB	Maize	Red	soil bund	0.08	9.40	14.00	0.50	501.2	0.25	0.80	0.05	5.0
AB	Finger Millet	Red	soil bund	0.39	9.40	53.00	0.50	501.2	0.25	1.55	0.4	77.9
AC	Maize	Yellow	soil bund	0.17	15.40	30.00	0.50	501.2	0.3	2.61	0.05	19.6
AC	Maize	Yellow	soil bund	0.20	15.40	36.00	0.50	501.2	0.3	2.86	0.05	21.5
AC	Maize	Yellow	soil bund	0.15	15.40	36.00	0.50	501.2	0.3	2.86	0.05	21.5
AD	Maize	Red	none	0.30	11.90	165.00	0.50	501.2	0.25	3.99	0.05	25.0
AE	Grass	Red	none	0.10	10.00	135.00	0.50	501.2	0.25	2.73	0.05	17.1
AF	Barley	Red	none	0.05	9.00	57.00	0.50	501.2	0.25	1.51	0.3	56.6
AF	Potato	Red	none	0.04	9.00	57.00	0.50	501.2	0.25	1.51	0.05	9.4
AF	Potato	Red	none	0.11	9.00	57.00	0.50	501.2	0.25	1.51	0.05	9.4
AG	Maize	Yellow	none	0.41	15.30	133.00	0.50	501.2	0.3	5.43	0.05	40.9
Q	Tef	Brown	none	0.43	11.40	114.00	0.50	501.2	0.2	3.10	0.7	217.3
R	Barley	Black	none	0.45	8.10	180.00	0.50	501.2	0.15	2.27	0.3	51.3
S	Noug	Red	soil bund	0.18	5.80	53.00	0.50	501.2	0.25	0.75	0.45	42.4
S	Finger Millet	Red	soil bund	0.21	5.80	33.00	0.50	501.2	0.25	0.59	0.4	29.8
S	Finger Millet	Red	soil bund	0.15	5.80	20.50	0.50	501.2	0.25	0.47	0.4	23.5
S	Finger Millet	Red	soil bund	0.18	5.80	25.00	0.50	501.2	0.25	0.52	0.4	25.9
T	Finger Millet	Black	none	0.56	6.50	100.00	0.50	501.2	0.15	1.22	0.4	36.7
T	Finger Millet	Black	none	0.22	6.50	100.00	0.50	501.2	0.15	1.22	0.4	36.7
U	Maize	Yellow	stone bund	0.34	10.50	41.00	0.50	501.2	0.3	1.63	0.05	12.2
V	Faba Bean	Yellow	stone bund	0.11	24.20	14.00	0.50	501.2	0.3	3.90	0.5	293.1

V	Faba Bean	Yellow	stone bund	0.10	24.20	16.00	0.50	501.2	0.3	4.17	0.5	313.4
Z	Maize	Yellow	stone bund	0.28	19.00	54.0	0.50	501.2	0.3	5.01	0.05	37.7
Z	Maize	Yellow	stone bund	0.05	19.00	12.0	0.50	501.2	0.3	2.36	0.05	17.8
Z	Potato	Yellow	stone bund	0.04	19.00	9.8	0.50	501.2	0.3	2.13	0.05	16.0

Table 43 USLE estimates in Anjeni watershed.

Plot ID	Crop	Soil	SWC	Area/ ha	Slope/ %	Slope length/ m	m	R-factor	K-factor	LS-factor	C-factor	A/ t*ha-1*year-1
A	Grass	Red	<i>Fanya Juu</i>	0.06	8.60	19.50	0.50	692.00	0.25	0.82	0.05	7.10
A	Grass	Red	<i>Fanya Juu</i>	0.08	8.60	23.00	0.50	692.00	0.25	0.89	0.05	7.71
A	Barley	Red	<i>Fanya Juu</i>	0.05	8.60	15.00	0.50	692.00	0.25	0.72	0.30	37.36
A	Barley	Red	<i>Fanya Juu</i>	0.05	8.60	22.00	0.50	692.00	0.25	0.87	0.30	45.24
A	Barley	Red	<i>Fanya Juu</i>	0.02	8.60	13.00	0.50	692.00	0.25	0.67	0.30	34.78
A	Barley	Red	<i>Fanya Juu</i>	0.04	8.60	23.50	0.50	692.00	0.25	0.90	0.30	46.76
A	Barley	Red	<i>Fanya Juu</i>	0.04	8.60	31.50	0.50	692.00	0.25	1.04	0.30	54.13
B	Tef	Red	<i>Fanya Juu</i>	0.15	9.50	53.00	0.50	692.00	0.25	1.58	0.70	191.27
B	Tef	Red	<i>Fanya Juu</i>	0.15	9.50	28.00	0.50	692.00	0.25	1.15	0.70	139.03
B	Maize	Red	<i>Fanya Juu</i>	0.12	9.50	18.50	0.50	692.00	0.25	0.93	0.05	8.07
B	Maize	Red	<i>Fanya Juu</i>	0.24	9.50	26.00	0.50	692.00	0.25	1.11	0.05	9.57
B	Barley	Red	<i>Fanya Juu</i>	0.55	9.50	48.00	0.50	692.00	0.25	1.50	0.30	78.01
F	Eucalyptus	Brown	<i>Fanya Juu</i>	0.01	10.00	3.00	0.50	692.00	0.20	0.41	0.00	0.00
F	Grass	Brown	<i>Fanya Juu</i>	0.03	10.00	7.00	0.50	692.00	0.20	0.62	0.05	4.31
F	Wheat	Brown	<i>Fanya Juu</i>	0.09	10.00	20.50	0.50	692.00	0.20	1.06	0.40	58.96
F	Tef	Brown	<i>Fanya Juu</i>	0.06	10.00	16.50	0.50	692.00	0.20	0.96	0.70	92.56
F	Tef	Brown	<i>Fanya Juu</i>	0.08	10.00	22.50	0.50	692.00	0.20	1.12	0.70	108.09
F	Tef	Brown	<i>Fanya Juu</i>	0.11	10.00	50.00	0.50	692.00	0.20	1.66	0.70	161.13
G	Tef	Red	<i>Fanya Juu</i>	0.06	11.20	74.00	0.50	692.00	0.25	2.42	0.70	293.61
G	Tef	Red	<i>Fanya Juu</i>	0.03	11.20	15.00	0.50	692.00	0.25	1.09	0.70	132.19
G	Tef	Red	<i>Fanya Juu</i>	0.07	11.20	29.00	0.50	692.00	0.25	1.52	0.70	183.80
G	Tef	Red	<i>Fanya Juu</i>	0.04	11.20	16.00	0.50	692.00	0.25	1.13	0.70	136.52
G	Tef	Red	<i>Fanya Juu</i>	0.03	11.20	13.00	0.50	692.00	0.25	1.02	0.70	123.06

G	Tef	Red	<i>Fanya Juu</i>	0.03	11.20	9.00	0.50	692.00	0.25	0.85	0.70	102.39
G	Tef	Red	<i>Fanya Juu</i>	0.02	11.20	9.00	0.50	692.00	0.25	0.85	0.70	102.39
G	Faba bean	Red	<i>Fanya Juu</i>	0.10	11.20	31.50	0.50	692.00	0.25	1.58	0.50	136.83
H	Lupine	Red	<i>Fanya Juu</i>	0.04	12.00	8.00	0.50	692.00	0.25	0.89	0.05	7.71
H	Lupine	Red	<i>Fanya Juu</i>	0.08	12.00	15.00	0.50	692.00	0.25	1.22	0.05	10.56
H	Grass	Red	<i>Fanya Juu</i>	0.02	12.00	7.00	0.50	692.00	0.25	0.83	0.05	7.21
H	Eucalyptus	Red	<i>Fanya Juu</i>	0.04	12.00	20.00	0.50	692.00	0.25	1.41	0.00	0.00
K	Maize	Yellow	<i>Fanya Juu</i>	0.09	8.80	22.00	0.50	692.00	0.30	0.90	0.05	9.38
K	Maize	Yellow	<i>Fanya Juu</i>	0.07	8.80	18.00	0.50	692.00	0.30	0.82	0.05	8.48
K	Maize	Yellow	<i>Fanya Juu</i>	0.11	8.80	36.00	0.50	692.00	0.30	1.16	0.05	11.99
L	Potato	Brown	<i>Fanya Juu</i>	0.06	14.90	12.50	0.50	692.00	0.20	1.59	0.05	11.03
L	Tef	Brown	<i>Fanya Juu</i>	0.09	14.90	15.50	0.50	692.00	0.20	1.77	0.70	171.89
L	Tef	Brown	<i>Fanya Juu</i>	0.13	14.90	21.50	0.50	692.00	0.20	2.09	0.70	202.45
L	Tef	Brown	<i>Fanya Juu</i>	0.09	14.90	15.00	0.50	692.00	0.20	1.75	0.70	169.10
L	Tef	Brown	<i>Fanya Juu</i>	0.08	14.90	21.00	0.50	692.00	0.20	2.07	0.70	200.08
M	Maize	Red	<i>Fanya Juu</i>	0.04	13.50	19.00	0.50	692.00	0.25	1.67	0.05	14.42
M	Maize	Red	<i>Fanya Juu</i>	0.04	13.50	19.50	0.50	692.00	0.25	1.69	0.05	14.60
M	Maize	Red	<i>Fanya Juu</i>	0.02	13.50	9.30	0.50	692.00	0.25	1.17	0.05	10.09
M	Maize	Red	<i>Fanya Juu</i>	0.04	13.50	13.50	0.50	692.00	0.25	1.40	0.05	12.15
M	Maize	Red	<i>Fanya Juu</i>	0.05	13.50	19.50	0.50	692.00	0.25	1.69	0.05	14.60
M	Maize	Red	<i>Fanya Juu</i>	0.06	13.50	28.00	0.50	692.00	0.25	2.02	0.05	17.50
M	Maize	Red	<i>Fanya Juu</i>	0.05	13.50	30.50	0.50	692.00	0.25	2.11	0.05	18.26
C	Barley	Red	none	0.10	43.50	25.00	0.50	692.00	0.25	15.16	0.30	786.82
D	Maize	Brown	none	0.25	14.60	89.00	0.50	692.00	0.20	4.11	0.05	28.44
N	Maize	Red	none	0.17	11.90	140.00	0.50	692.00	0.25	3.68	0.05	31.82
O	Maize	Red	none	0.08	7.10	46.00	0.50	692.00	0.25	0.94	0.05	8.15
P	Maize	Brown	none	0.20	15.40	82.00	0.50	692.00	0.20	4.31	0.05	29.85

Appendix V

CBA Debre Mewi

Table 44 Approach I: CBA of stone bunds in Debre Mewi (yield decline (without case): 1 %, discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 20 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1038	0	0	-1038
1	6262	3348	2915	4414	3337	1078	0	0	-94	-1837	-1931
2	6200	3348	2852	5886	3337	2549	0	0	-94	-303	-397
3	6137	3348	2790	5886	3337	2549	0	0	-94	-241	-334
4	6075	3348	2727	5886	3337	2549	0	0	-94	-178	-272
5	6012	3348	2664	5886	3337	2549	0	0	-94	-115	-209
6	5949	3348	2602	5886	3337	2549	0	0	-94	-53	-146
7	5887	3348	2539	5886	3337	2549	0	0	-94	10	-84
8	5824	3348	2476	5886	3337	2549	0	0	-94	73	-21
9	5761	3348	2414	5886	3337	2549	0	0	-94	135	41
10	5699	3348	2351	5886	3337	2549	0	0	-94	198	104
11	5636	3348	2289	5886	3337	2549	0	0	-94	260	167
12	5574	3348	2226	5886	3337	2549	0	0	-94	323	229
13	5511	3348	2163	5886	3337	2549	0	0	-94	386	292
14	5448	3348	2101	5886	3337	2549	0	0	-94	448	355
15	5386	3348	2038	5886	3337	2549	0	0	-94	511	417
16	5323	3348	1975	5886	3337	2549	0	0	-94	574	480
17	5260	3348	1913	5886	3337	2549	0	0	-94	636	542
18	5198	3348	1850	5886	3337	2549	0	0	-94	699	605
19	5135	3348	1788	5886	3337	2549	0	0	-94	761	668
20	5073	3348	1725	5886	3337	2549	0	0	-94	824	730
										NPV	-2.663
										IRR	0%

Table 45 Approach II: CBA of stone bunds in Debre Mewi (yield decline: 1 % (without case), yield increase: 10 % (with case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 20 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1038	0	0	-1038
1	6262	3348	2915	3018	3227	-209	0	0	-94	-3123	-3217
2	6200	3348	2852	4528	3227	1301	0	0	-94	-1552	-1645
3	6137	3348	2790	6641	3227	3414	0	0	-94	624	530
4	6075	3348	2727	6641	3227	3414	0	0	-94	687	593
5	6012	3348	2664	6641	3227	3414	0	0	-94	749	656
6	5949	3348	2602	6641	3227	3414	0	0	-94	812	718
7	5887	3348	2539	6641	3227	3414	0	0	-94	875	781
8	5824	3348	2476	6641	3227	3414	0	0	-94	937	843
9	5761	3348	2414	6641	3227	3414	0	0	-94	1000	906
10	5699	3348	2351	6641	3227	3414	0	0	-94	1062	969
11	5636	3348	2289	6641	3227	3414	0	0	-94	1125	1031
12	5574	3348	2226	6641	3227	3414	0	0	-94	1188	1094
13	5511	3348	2163	6641	3227	3414	0	0	-94	1250	1157
14	5448	3348	2101	6641	3227	3414	0	0	-94	1313	1219
15	5386	3348	2038	6641	3227	3414	0	0	-94	1375	1282
16	5323	3348	1975	6641	3227	3414	0	0	-94	1438	1344
17	5260	3348	1913	6641	3227	3414	0	0	-94	1501	1407
18	5198	3348	1850	6641	3227	3414	0	0	-94	1563	1470
19	5135	3348	1788	6641	3227	3414	0	0	-94	1626	1532
20	5073	3348	1725	6641	3227	3414	0	0	-94	1689	1595
										NPV	-281
										IRR	12%

Table 46 Approach I: CBA of soil bunds in Debre Mewi (yield decline: 1 % (without case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 20 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-663	0	0	-663
1	6262	3348	2915	4391	3123	1268	84	0	-56	-1647	-1619
2	6200	3348	2852	5854	3123	2732	113	0	-56	-121	-64
3	6137	3348	2790	5854	3123	2732	113	0	-56	-58	-2
4	6075	3348	2727	5854	3123	2732	113	0	-56	5	61
5	6012	3348	2664	5854	3123	2732	113	0	-56	67	124
6	5949	3348	2602	5854	3123	2732	113	0	-56	130	186
7	5887	3348	2539	5854	3123	2732	113	0	-56	193	249
8	5824	3348	2476	5854	3123	2732	113	0	-56	255	311
9	5761	3348	2414	5854	3123	2732	113	0	-56	318	374
10	5699	3348	2351	5854	3123	2732	113	0	-56	380	437
11	5636	3348	2289	5854	3123	2732	113	0	-56	443	499
12	5574	3348	2226	5854	3123	2732	113	0	-56	506	562
13	5511	3348	2163	5854	3123	2732	113	0	-56	568	624
14	5448	3348	2101	5854	3123	2732	113	0	-56	631	687
15	5386	3348	2038	5854	3123	2732	113	0	-56	693	750
16	5323	3348	1975	5854	3123	2732	113	0	-56	756	812
17	5260	3348	1913	5854	3123	2732	113	0	-56	819	875
18	5198	3348	1850	5854	3123	2732	113	0	-56	881	938
19	5135	3348	1788	5854	3123	2732	113	0	-56	944	1000
20	5073	3348	1725	5854	3123	2732	113	0	-56	1007	1063
										NPV	-205
										IRR	11%

Table 47 Approach II: CBA of soil bunds in Debre Mewi (yield decline: 1 % (without case), yield increase: 10 % (with case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 20 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-663	0	0	-663
1	6262	3348	2915	2989	3195	-207	84	0	-56	-3121	-3093
2	6200	3348	2852	4483	3195	1288	113	0	-56	-1564	-1508
3	6137	3348	2790	6575	3195	3380	113	0	-56	590	647
4	6075	3348	2727	6575	3195	3380	113	0	-56	653	709
5	6012	3348	2664	6575	3195	3380	113	0	-56	716	772
6	5949	3348	2602	6575	3195	3380	113	0	-56	778	834
7	5887	3348	2539	6575	3195	3380	113	0	-56	841	897
8	5824	3348	2476	6575	3195	3380	113	0	-56	903	960
9	5761	3348	2414	6575	3195	3380	113	0	-56	966	1022
10	5699	3348	2351	6575	3195	3380	113	0	-56	1029	1085
11	5636	3348	2289	6575	3195	3380	113	0	-56	1091	1148
12	5574	3348	2226	6575	3195	3380	113	0	-56	1154	1210
13	5511	3348	2163	6575	3195	3380	113	0	-56	1217	1273
14	5448	3348	2101	6575	3195	3380	113	0	-56	1279	1335
15	5386	3348	2038	6575	3195	3380	113	0	-56	1342	1398
16	5323	3348	1975	6575	3195	3380	113	0	-56	1404	1461
17	5260	3348	1913	6575	3195	3380	113	0	-56	1467	1523
18	5198	3348	1850	6575	3195	3380	113	0	-56	1530	1586
19	5135	3348	1788	6575	3195	3380	113	0	-56	1592	1649
20	5073	3348	1725	6575	3195	3380	113	0	-56	1655	1711
										NPV	82
										IRR	15%

CBA Anjeni

Table 48 Approach I: CBA of stone bunds in Anjeni (yield decline: 1 % (without case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 20 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1038	0	0	-1038
1	5638	3467	2172	3782	2918	864	0	0	-94	-1307	-1401
2	5582	3467	2115	5043	2918	2125	0	0	-94	10	-84
3	5525	3467	2059	5043	2918	2125	0	0	-94	66	-27
4	5469	3467	2002	5043	2918	2125	0	0	-94	123	29
5	5412	3467	1946	5043	2918	2125	0	0	-94	179	85
6	5356	3467	1890	5043	2918	2125	0	0	-94	236	142
7	5300	3467	1833	5043	2918	2125	0	0	-94	292	198
8	5243	3467	1777	5043	2918	2125	0	0	-94	348	255
9	5187	3467	1720	5043	2918	2125	0	0	-94	405	311
10	5131	3467	1664	5043	2918	2125	0	0	-94	461	367
11	5074	3467	1608	5043	2918	2125	0	0	-94	517	424
12	5018	3467	1551	5043	2918	2125	0	0	-94	574	480
13	4961	3467	1495	5043	2918	2125	0	0	-94	630	536
14	4905	3467	1439	5043	2918	2125	0	0	-94	687	593
15	4849	3467	1382	5043	2918	2125	0	0	-94	743	649
16	4792	3467	1326	5043	2918	2125	0	0	-94	799	706
17	4736	3467	1269	5043	2918	2125	0	0	-94	856	762
18	4680	3467	1213	5043	2918	2125	0	0	-94	912	818
19	4623	3467	1157	5043	2918	2125	0	0	-94	969	875
20	4567	3467	1100	5043	2918	2125	0	0	-94	1025	931
										NPV	-677
										IRR	9%

Table 49 Approach II: CBA of stone bunds in Anjeni (yield decline: 1% (without case), yield increase: 10% (with case), discount rate: 12.5%, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 20 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1038	0	0	-1038
1	5638	3467	2172	2702	3467	-764	0	0	-94	-2936	-3030
2	5582	3467	2115	4053	3467	587	0	0	-94	-1529	-1622
3	5525	3467	2059	5944	3467	2478	0	0	-94	419	325
4	5469	3467	2002	5944	3467	2478	0	0	-94	476	382
5	5412	3467	1946	5944	3467	2478	0	0	-94	532	438
6	5356	3467	1890	5944	3467	2478	0	0	-94	588	495
7	5300	3467	1833	5944	3467	2478	0	0	-94	645	551
8	5243	3467	1777	5944	3467	2478	0	0	-94	701	607
9	5187	3467	1720	5944	3467	2478	0	0	-94	757	664
10	5131	3467	1664	5944	3467	2478	0	0	-94	814	720
11	5074	3467	1608	5944	3467	2478	0	0	-94	870	776
12	5018	3467	1551	5944	3467	2478	0	0	-94	927	833
13	4961	3467	1495	5944	3467	2478	0	0	-94	983	889
14	4905	3467	1439	5944	3467	2478	0	0	-94	1039	946
15	4849	3467	1382	5944	3467	2478	0	0	-94	1096	1002
16	4792	3467	1326	5944	3467	2478	0	0	-94	1152	1058
17	4736	3467	1269	5944	3467	2478	0	0	-94	1209	1115
18	4680	3467	1213	5944	3467	2478	0	0	-94	1265	1171
19	4623	3467	1157	5944	3467	2478	0	0	-94	1321	1228
20	4567	3467	1100	5944	3467	2478	0	0	-94	1378	1284
										NPV	-1,301
										IRR	9%

Table 50 Approach I: CBA of soil bunds in Anjeni (yield decline: 1 % (without case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 10 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1225	0	0	-1225
1	5638	3467	2172	4377	3305	1072	320	0	-113	-1100	-892
2	5582	3467	2115	5835	3305	2530	320	0	-113	415	623
3	5525	3467	2059	5835	3305	2530	320	0	-113	472	679
4	5469	3467	2002	5835	3305	2530	320	0	-113	528	736
5	5412	3467	1946	5835	3305	2530	320	0	-113	584	792
6	5356	3467	1890	5835	3305	2530	320	0	-113	641	848
7	5300	3467	1833	5835	3305	2530	320	0	-113	697	905
8	5243	3467	1777	5835	3305	2530	320	0	-113	754	961
9	5187	3467	1720	5835	3305	2530	320	0	-113	810	1017
10	5131	3467	1664	5835	3305	2530	320	0	-113	866	1074
11	5074	3467	1608	5835	3305	2530	320	0	-113	923	1130
12	5018	3467	1551	5835	3305	2530	320	0	-113	979	1187
13	4961	3467	1495	5835	3305	2530	320	0	-113	1035	1243
14	4905	3467	1439	5835	3305	2530	320	0	-113	1092	1299
15	4849	3467	1382	5835	3305	2530	320	0	-113	1148	1356
16	4792	3467	1326	5835	3305	2530	320	0	-113	1205	1412
17	4736	3467	1269	5835	3305	2530	320	0	-113	1261	1469
18	4680	3467	1213	5835	3305	2530	320	0	-113	1317	1525
19	4623	3467	1157	5835	3305	2530	320	0	-113	1374	1581
20	4567	3467	1100	5835	3305	2530	320	0	-113	1430	1638
										NPV	3.547
										IRR	32%

Table 51 Approach II: CBA of soil bunds in Anjeni (yield decline: 1 % (without case), yield increase: 10 % (with case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 10 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1225	0	0	-1225
1	5638	3467	2172	2658	3467	-808	320	0	-113	-2980	-2772
2	5582	3467	2115	3987	3467	521	320	0	-113	-1594	-1387
3	5525	3467	2059	5848	3467	2382	320	0	-113	323	531
4	5469	3467	2002	5848	3467	2382	320	0	-113	379	587
5	5412	3467	1946	5848	3467	2382	320	0	-113	436	643
6	5356	3467	1890	5848	3467	2382	320	0	-113	492	700
7	5300	3467	1833	5848	3467	2382	320	0	-113	549	756
8	5243	3467	1777	5848	3467	2382	320	0	-113	605	812
9	5187	3467	1720	5848	3467	2382	320	0	-113	661	869
10	5131	3467	1664	5848	3467	2382	320	0	-113	718	925
11	5074	3467	1608	5848	3467	2382	320	0	-113	774	982
12	5018	3467	1551	5848	3467	2382	320	0	-113	830	1038
13	4961	3467	1495	5848	3467	2382	320	0	-113	887	1094
14	4905	3467	1439	5848	3467	2382	320	0	-113	943	1151
15	4849	3467	1382	5848	3467	2382	320	0	-113	1000	1207
16	4792	3467	1326	5848	3467	2382	320	0	-113	1056	1263
17	4736	3467	1269	5848	3467	2382	320	0	-113	1112	1320
18	4680	3467	1213	5848	3467	2382	320	0	-113	1169	1376
19	4623	3467	1157	5848	3467	2382	320	0	-113	1225	1433
20	4567	3467	1100	5848	3467	2382	320	0	-113	1282	1489
										NPV	-84
										IRR	12%

Table 52 Approach I: CBA of *Fanya Juu* in Anjeni (yield decline: 1 % (without case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 15 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1100	0	0	-1100
1	5638	3467	2172	4384	3302	1083	213	0	-100	-1089	-976
2	5582	3467	2115	5846	3302	2544	213	0	-100	429	542
3	5525	3467	2059	5846	3302	2544	213	0	-100	485	599
4	5469	3467	2002	5846	3302	2544	213	0	-100	542	655
5	5412	3467	1946	5846	3302	2544	213	0	-100	598	711
6	5356	3467	1890	5846	3302	2544	213	0	-100	654	768
7	5300	3467	1833	5846	3302	2544	213	0	-100	711	824
8	5243	3467	1777	5846	3302	2544	213	0	-100	767	880
9	5187	3467	1720	5846	3302	2544	213	0	-100	824	937
10	5131	3467	1664	5846	3302	2544	213	0	-100	880	993
11	5074	3467	1608	5846	3302	2544	213	0	-100	936	1050
12	5018	3467	1551	5846	3302	2544	213	0	-100	993	1106
13	4961	3467	1495	5846	3302	2544	213	0	-100	1049	1162
14	4905	3467	1439	5846	3302	2544	213	0	-100	1105	1219
15	4849	3467	1382	5846	3302	2544	213	0	-100	1162	1275
16	4792	3467	1326	5846	3302	2544	213	0	-100	1218	1332
17	4736	3467	1269	5846	3302	2544	213	0	-100	1275	1388
18	4680	3467	1213	5846	3302	2544	213	0	-100	1331	1444
19	4623	3467	1157	5846	3302	2544	213	0	-100	1387	1501
20	4567	3467	1100	5846	3302	2544	213	0	-100	1444	1557
										NPV	3.138
										IRR	30%

Table 53 Approach II: CBA of *Fanya Juu* in Anjeni (yield decline: 1 % (without case), yield increase: 10 % (with case), discount rate: 12.5 %, Opportunity costs of labor: 7.5 EtB*PD⁻¹, Distance between bunds: 15 m)

Year	Without			With						Difference (PD*ha ⁻¹)	Cash-flow (PD*ha ⁻¹)
	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Crop revenues (PD*ha ⁻¹)	Costs (PD*ha ⁻¹)	Gross Margin (PD*ha ⁻¹)	Grass revenues (PD*ha ⁻¹)	Investment costs (PD*ha ⁻¹)	Maintenance cost (PD*ha ⁻¹)		
0	0	0	0	0	0	0	0	-1100	0	0	-1100
1	5638	3467	2172	2680	3467	-787	213	0	-100	-2958	-2845
2	5582	3467	2115	4020	3467	553	213	0	-100	-1562	-1448
3	5525	3467	2059	5896	3467	2429	213	0	-100	371	484
4	5469	3467	2002	5896	3467	2429	213	0	-100	427	540
5	5412	3467	1946	5896	3467	2429	213	0	-100	483	597
6	5356	3467	1890	5896	3467	2429	213	0	-100	540	653
7	5300	3467	1833	5896	3467	2429	213	0	-100	596	709
8	5243	3467	1777	5896	3467	2429	213	0	-100	653	766
9	5187	3467	1720	5896	3467	2429	213	0	-100	709	822
10	5131	3467	1664	5896	3467	2429	213	0	-100	765	879
11	5074	3467	1608	5896	3467	2429	213	0	-100	822	935
12	5018	3467	1551	5896	3467	2429	213	0	-100	878	991
13	4961	3467	1495	5896	3467	2429	213	0	-100	934	1048
14	4905	3467	1439	5896	3467	2429	213	0	-100	991	1104
15	4849	3467	1382	5896	3467	2429	213	0	-100	1047	1160
16	4792	3467	1326	5896	3467	2429	213	0	-100	1104	1217
17	4736	3467	1269	5896	3467	2429	213	0	-100	1160	1273
18	4680	3467	1213	5896	3467	2429	213	0	-100	1216	1330
19	4623	3467	1157	5896	3467	2429	213	0	-100	1273	1386
20	4567	3467	1100	5896	3467	2429	213	0	-100	1329	1442
										NPV	-304
										IRR	12%