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Participatory Development of Soil Conservation Measures at the Debre-Mewi Watershed in the Upper Catchment of the Blue Nile Basin, Northwest Ethiopia

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Abstract

This study was carried out to assess the magnitude of soil erosion by water under different management practices [Fanyajuu with elephant grass (FEG), Fanyajuu with vetiver grass (FVG), sole Fanyajuu (SF) and non-conserved (NC) soil], evaluate response of crop yields, and develop appropriate soil conservation (SC) techniques through participatory approach. The experiment was conducted on farmers' fields in 2009 and 2010 at the Debre-Mewi Watershed (DMW) in northwest Ethiopia. The overall reductions in soil loss due to the FEG, FVG and SF were 75.1, 80.3 and 63.6%, respectively, as compared to the NC. The increments in grain yields due to the FEG, FVG and SF as compared to the yield on the NC soil were 51.5, 48.9 and 37.7%, respectively. It was observed that the SC measures were effective in the tested plots of the DMW in increasing yield and net return as compared to the control plot. Since the structural conservation measure (Fanyajuu) accompanied by grass species (Vetiver and Elephant grasses) were found to be more effective in reducing soil erosion and increasing crop production, they were selected as promising SC techniques by all stakeholders and recommended for promotion in the DMW and areas with similar agro-climatic and socioeconomic conditions.

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Introduction

Ethiopia has a total surface area of 112 million square kilometers of which 60% (Ethiopia, 1992) is estimated to be suitable for cultivation but cited as one of the country's most seriously affected by land degradation (Eyasu, 2002). In agreement with the foregoing facts, the Ethiopian Highlands Reclamation Study (EHRS) group (EHRS, 1984) estimated that 50% (25.2) of the Ethiopian Highlands [> 1500 meters above sea level (masl)] is significantly eroded and 25% (12.6 million ha) is seriously eroded. According to Herweg and Stillhardt (1999), the northwestern highland that is represented by the Anjeni Research Unit exhibited the highest soil erosion rates [130-170 tons (t) ha^{-1} per year] on cultivated plots and it was the highest among the nationwide monitoring sites. Unfavorable alteration in soil physical and chemical properties by erosion causes decline in soil productivity. Oyedele and Aina (1998) reported maize yield reduction of 10-17% on severely eroded land as compared with uneroded farm plots. Similarly, Oyedele and Aina (2006) found that the reduction in maize yield ranged from 3.2 t ha^{-1} on the non conserved (control) to 0.12 t ha^{-1} with the conserved soil.

Although it is recognized that soil conservation (SC) practices can substantially contribute to reversing soil degradation, the performances of past and ongoing SC programs in Ethiopia have, in most cases, been disappointing. Decisions on which type of SC measures to use and where to use them were not made by the farmers concerned; and only rarely was an attempt made to include indigenous experience and knowledge (Azene, 1997; Herweg and Ludi, 1999). The blanket approach of technology prescription without considering the socioeconomic context of the farmers always brings failure in adoption of technology. It needs to be tackled through new conservation strategies, approaches and technologies (Azene, 1997; Woldeamlak, 2003; Mitiku *et al.,* 2006).

The farmers in the Watershed suffer from the impacts of severe soil erosion by water on their farm and grazing lands. However, they hardly take actions to reduce soil erosion and runoff water. Thus, this study was conducted with specific objectives to assess the status of soil erosion in the DMW through actual survey at plot level and to evaluate the performance of SC techniques and crop yield responses to the SC measures with stakeholders.

Materials and methods

The study area

Debre-Mewi Watershed (DMW), is located between 11^{o} 20' and 11^{o} 21' N latitude
and 37^{o} 24' and 37^{o} 25' E longitude, in the western plateau of the Ethiopian highlands at the northern source region of the Blue Nile River. It is about 30 km southeast of Lake Tana and Bahir Dar city (Fig. 1). The elevation in the watershed extends from 2200 to 2360 meters above sea level.

The study area is almost crater-shaped having an outlet in its southwestern part (Fig. 2). The watershed is covered by recent deposits of volcanic materials containing alkaline to transitional basalt with of chains of volcanic hills and gently sloping mountains (Anteneh, 2009).

According to Addisalem (2009), the soils of the study area are Eutric Vertisols (33.28%; 181.0 ha), Eutric Luvisols (24.83%; 135.0 ha), Pellic Vertisols (19.55%; 106.32 ha), Eutric Cambisols (8.29%; 45.1 ha), Eutric Fluvisols (7.43%; 40.4 ha) and Eutric Aquic Vertisols (6.62%; 36.0 ha). The Vertisols, Luvisols and Fluvisols are found in gently undulating lands, while the other soil types occupy the higher altitudes.

According to the Ethiopian agro-climatic zonation (MOA, 1998), the study area falls in the *Weyna Dega* (sub-humid) climatic zone. A twenty four years (1986-2010) climatic data from a nearby meteorological station (Adet, 2240 masl; 10 km away from south of the study area) recorded an average annual precipitation of 1,167.1 mm which is characterized by a uni-modal rainfall pattern (Fig. 3). The mean annual temperature is 20.4 °C with mean annual maximum and minimum temperatures of 26.9 and 10.8 °C, respectively. The monthly mean temperature ranges from 17.2 °C in November and January to 22.1 °C in May.

The natural vegetation of the Watershed is characterized by very few forests at the eastern upland, scattered trees, and shrubs of different species. The dominant tree species of the natural forest are *Acacia abyssinica* Hochst and *Croton macrostachyus* Del., and the shrub species such as *Vernina amygdalina* Del., *Calpurnea aurea, Carissa edulis,* and *Bersama abyssinica*. Subsistence agriculture is the main livelihood of the community and crop-livestock mixed farming system is predominant. Crop production in the Watershed is exclusively based on rainfed agriculture. The crops commonly grown in order of decreasing area coverage are *teff (Eragrostis tef)*, maize *(Zea mays),* grass pea (*Lathyrus sativus*), bread wheat (*Triticum aestivum*), faba bean *(Vicia faba)*, potato *(Solanum tubersoum)*, and hot pepper (*Capsicum frutescence*).

Data source and analysis

Procedures, assessments of soil erosion and evaluation of soil conservation (SC) practices

In the effort for the development of appropriate soil conservation measures, first, the possible measures were listed and defined in such a way that they can be clearly identified and properly implemented. Secondly, the technical effectiveness of the alternative measures to reduce soil loss and increase yield was assessed. Following the assessment of the technical effectiveness, the suitability of the alternative measures for specific conditions, stakeholder's preference and the associated constraints were evaluated. Similarly, the cost-benefit scenario of the different soil conservation measures, in economic terms, was assessed. Lastly, selection was made based on the potential of the structure and grasses serving for SC as well as fulfilling the social and environmental situations' requirements.

The study was carried out for two seasons (2009 and 2010). The experimental plots were constructed on farmers' fields with average slope gradient of 20-22% and replicated three times. The plot sizes for all treatments and replications were 5 m wide and 12 m long (60 m² area) bordered by stone bunds (Plate 1) which were inserted into the soil to a depth of 20 cm and 25 cm high above the soil surface to prevent lateral flows from plots to plots. The conservation treatments used were Fanyajuu with elephant grass (FEG), Fanyajuu with vetivar grass (FVG), sole Fanyajuu (SF) and a control or non-conserved (NC) plots. Treatments were arranged (classified) into three slope positions (upper, middle and lower). The change in depth of the soil surface due to soil removal or deposition was determined using soil erosion pins which were inserted in each plot.

Amount of soil eroded, crop parameters (days to maturity, stand count, plant height, grain yield, above ground biomass), and stakeholders (farmers, development agents and researchers) feedback (visual assessment on the performance of the measures during farm visit which was rated as: 4 = very good, 3 = good, 2 = average, 1 = unsatisfactory) were recorded. A group of ten farmers, five development agents, and five researchers were participated throughout the appraisals and the scoring process. The conservation practices (FEG, FVG, SF, and NC) were evaluated from the perspectives of meeting the sustainable conservation functions. The evaluation criteria were made based on the knowledge and experiences of the stakeholders involved in the study, complemented by the observation of the test plots. Each practice was evaluated against a list of evaluation criteria independently, and was assessed on how distant they were from the threshold line of sustainability. As a rule-of-thumb, a practice is said to be sustainable if it performs $\geq$ 50% of the resultant value (Birru, 2007).

Data analysis

The changes in depth of the soil surface due to soil removal and/or deposition were determined using soil erosion pins and soil loss was calculated using the following formula (Azene, 1997):

$$T = \frac{\left[\frac{1}{2}\left(\frac{1}{2}L \times H\right) \times (W \times D)\right]}{A}$$

where T is soil loss in t ha^{-1} per year, H is average height of triangle in m which represent the average depth of soil eroded and/or deposited, W is the width of plot in m, D is bulk density of the soil (kg m^{-3}), ½ is constant in the formula for calculating area of a triangle, L is the plot length (spacing) between two adjacent measure of terrace (m), and A is the plot size (ha) estimated from the following relationship:

$$A = \frac{L \times W}{10000}$$

Clinometer was used to measure slope change (%) due to soil eroded or deposited from uphill per unit area as compared to the initial slope of the plot.

The cost effectiveness of the SC measures tested was analyzed considering the area lost due to the space occupied by SCs, labor required for implementation or construction of SC measures and planting material. The benefits of SC include fodder gained from land occupied by Fanyajuu and crop yield gained due to SC.

The potential of the SC structure and grasses as well as full filling the social and environmental requirements was evaluated with Multiple Objectives Decision Support System (MODSS). This model is appropriate to evaluate and appraise various SC and land management practices or land use systems from economic, ecological and social criteria/sustainability by rating 1-5 (Robinson, 2000 and Birru, 2007).

In order to determine statistical differences in soil loss among treatments, the data were subjected to a two-way analysis of variance (ANOVA) using MSTATC software (Gomez and Gomez, 1984). Duncan's Multiple Range Test was used to separate the means where significant differences were obtained. Single linear correlation analysis was also carried out by calculating correlation coefficients between yield and measured soil loss as affected by slope and conservation practices.

Results and discussion

Descriptions of selected soil characteristics of the study area

Some selected soil physico-chemical characteristics of the Eutric Cambisols of the experimental site are given in Table 1. The texture of the surface soil was clay loam. It had a bulk density value of 1.3 g cm^{3}. According to Tekalign (1991), the soil is classified as: pH as moderately acidic (5.5), low organic carbon (1.23%), and medium total N (0.12%). Medium available P (7.35 mg kg^{-1}) (Olsen *et al.*, 1954) and based on the ratings of Hazelton and Murphy (2007), the CEC (37.67 cmol$_{(+)}$ kg^{-1}) and percent base saturation (106.2) of the soil appeared to be a higher. The exchangeable cations are well distributed. According to FAO (2006) ratings, high value of Ca (35.26 cmol$_{(+)}$ kg^{-1}) and Mg (3.82 cmol$_{(+)}$ kg^{-1}); medium K (0.59 cmol$_{(+)}$ kg^{-1}) and Na (0.34 cmol$_{(+)}$ kg^{-1}).

Soil loss, crop parameters, economic valuation and development of sc techniques soil loss

The actual soil loss measured under the different treatments during the experimental period is presented in Table 2. The two years amount of soil eroded under FEG, FVG, SF and NC were 35.3, 28.0, 51.7 and 141.9 t ha^{-1}, respectively. All soil conservation treatments significantly reduced soil loss as compared to the control. Besides, treatments with combined structural and biological SC measures (FVG and FEG) significantly reduced soil loss as compared to the SF and the control. However, no significant differences (P > 0.05) were observed in soil loss between FVG and FEG treated plots. The result indicated that the mean to the soil eroded and that due to rill erosion at the NC were significantly ($P \leq 0.01$) higher than those from all conserved or treated plots (Table 2). Rills contributed the largest amount of soil loss as compared sheet loss and the damage was higher on NC. The two years amount of soil loss due to rill under FEG, FVG, SF and NC were 19.8, 15.4, 32.1 and 113.1 ton/ha, respectively. The overall percentage reduction in soil loss due to the FEG, FVG and SF were 75.1, 80.3 and 63.6% respectively, as compared to the NC (Fig. 4). The average slope reduction due to conservation measures were 2, 3 and 1% by FEG, FVG and SF, respectively. In the contrary, under NC plots slope was increased by 3% in two years period (Fig. 5).

Table 1. Selected soil physicho-chemical characteristics of the study site

Physical property	Value	Chemical property	Value
Sand (%)	38.7	pH in water (1:2.5)	5.52
Silt (%)	34.1	Electrical conductivity (1:2.5)	0.07
Clay (%)	27.2	Organic carbon (%)	1.23
Textural class	Clay loam	Total N (%)	0.12
Bulk density (g cm^{-3})	1.3	Available P (mg kg^{-1})	7.35
Field capacity (%)	39.9	Exchangeable Ca (cmol kg^{-1})	35.26
PWP (%)	21.9	Exchangeable Mg (cmol kg^{-1})	3.81
AWC (%)	18.1	Exchangeable K (cmol kg^{-1})	0.59
		Exchangeable Na (cmol kg^{-1})	0.34
		CEC (cmol kg^{-1})	37.67
		Base saturation (%)	106.2

PWP = Permanent wilting point, AWC = Available water holding capacity, CEC = Cation exchange capacity

Table 2. Two years total soil loss as affected by SC measures.

Treatment	Total soil loss (t ha^{-1})	Sheet loss (t ha^{-1})	Rill loss (t ha^{-1})
Non conservation	141.9a	28.8a	113.1a
Sole fanyajuu	51.7b	19.6b	32.1b
Fayajuu with vetivar grass	28.0c	12.6b	15.4c
Fanyajuu with elephant grass	35.3c	15.5b	19.8c
LSD	8.485**	9.58*	8.87**
CV (%)	13.51	52.49	19.97

Mean values within a column followed by the same letter are not significantly different at the specific probability level; *, ** = Significant at $P \leq 0.05$ and $P \leq 0.01$, respectively; LSD = least significant difference; CV = coefficient of variation

Table 3. Yield and yield components (wheat) as affected by SC measures.

Treatments	DPM	STD (/m^2)	PLH (cm)	FBM (g)	DBM (g/m^2)	GY (g/m^2)
Not conserved soil	107.1	84.8	82.26	809.26	680.83	207.9c
Sole fanyajuu	107.8	88.7	83.68	850.00	695.15	286.3b
Fanyawith Vetiver grass	107.9	93.5	84.57	877.00	710.88	309.6a
Fanyajuu with elephant grass	108.2	98.8	84.60	876.72	717.08	315.9a
LSD	NS	NS	NS	NS	NS	8.874**
CV (%)	1.23	10.9	3.79	10.50	11.13	4.72

Mean values within a column followed by the same letter are not significantly different *, ** Significant at 5% and 1% respectively, NS = non significant, DPM = days to physiological maturity, STD = stand count, PLH = plant height, DBM = dry biomass, FBM = fresh biomass/m^2, GY = grain yield/ m^2

Table 4. Correlation matrix among crop yield and soil parameters.

Soil parameters and grain yield	Inter-rill loss	Slope	Rill loss	Total loss
Grain yield	-0.56**	-0.60**	-0.90**	-0.93**
Inter-rill loss		0.39	0.38	0.61**
Slope			0.46*	0.5**
Rill loss				0.96**

Table 5. Economic analysis (Ethiopian birr) at Debre-Mewi Watershed for SC measures.

SCM	Inception costs					Benefits				
	FJCC	GPC	FC	TVC	CB	GYkg/67.5m^2	GP	GB	NB	NB (%)
FEG	20	3	50	73	60	21.26	148.84	208.84	135.84	23.41
FVG	20	3	0	23	nu	20.86	146.00	146.00	123.00	11.74
SF	20	0	0	20	0	19.31	135.14	135.14	115.14	4.59
NC	0	0	0	0	0	15.73	110.09	110.09	110.09	

FEG = Fanyajuu with elephant grass, FVG = Fanyajuu with vetevar grass, SF= Sole Fanyajuu and NC = No conservation practice, nu = not used yet, FJCC = fanyaju construction cost = 200 Mandays/1 km, GPC = grass planting cost = 30 mandays/1 km, 1 Manday = 20 Birr, FC = fencing cost, TVC = total variable cost, CB = cutting benefit, GY = grain yield, GP = grain price 7 birr/kg, GB = gross benefit, NB = net benefit, plot size of conserved plots = 13.5m*5 m =67.5 m^2 including Fanyajuu, while, for NC plot = 12 m * 5 m = 60 m^2 but yield was converted to 67.5 m^2 for compensation of the area occupied by the FJ, adjusted

Table 6. Summary for economic analysis of SC measures at Debre-Mewi Watershed for SC measures.

Treatment	Summary ha^{-1}		NB (EB) over control
	TVC (EB)	NB (EB)	
Fanyajuu with elephant grass	10,814.84	20,124.10	3814.47
Fanyajuu with vetiver grass	3407.40	18,222.60	1912.97
Sole fanyajuu	2963.00	17,057.00	747.37
No conservation	0.0	16.310	

TVC = Total variable cost, NB = Net benefit, EB = Ethiopian birr

Table 7. Soil conservation measures appraised weight (score) and (%) by stakeholders at Debre-Mewi Watershed

MGTO	Farmers		DA		Researchers		Overall mean		Score
	wt	%	wt	%	wt	%	wt	%	1 - 4
EGF	3.01	75.35	3.11	77.78	wt	83.75	3.16	78.96	3
VGF	3.29	82.36	3.60	89.44	3.35	90.69	3.51	87.50	3
SF	2.57	64.31	2.42	60.56	3.63	56.67	2.41	60.51	2
NC	1.84	45.90	1.47	36.67	2.24	31.67	1.54	38.08	1

Note: EGF = Elephant grass with Fanyajuu, VGF = Vetevar grass with Fanyajuu, SF= Sole Fanyajuu and NC = no conservation practice, DAs' = development agents, wt = weight; weight score: 4 = very good, 3 = good, 2 = average, 1 = not good; Percentage: $\geq$ 50% is sustainable

Table 8. Two years sediment accumulation of soil inside pit below the control plot

Rep	BD (g cm^{-3})	L (m)	W (m)	D (m)	A (m^2)	VA (m^3)	V/A (m^3/m^2)	TA (ton/ha)	PM (ton/ha)
I	1.15	1.5	5.0	0.55	1.38	2.06	0.03	395.31	388.75
II	1.32	1.5	5.0	0.53	1.33	1.99	0.03	437.25	431.5
III	1.36	1.5	5.0	0.55	1.38	2.06	0.03	467.50	457.1
Mean	1.3	1.5	5.0	0.54	1.34	2.01	0.03	433.35	425.8

Rep = replication, BD = bulk density, L = Length, W = Width, D = Depth, A = cross-sectional area, VA = Volume accumulation, V/A = Volume/area, TA = Total accumulation, and PM = Plot measured

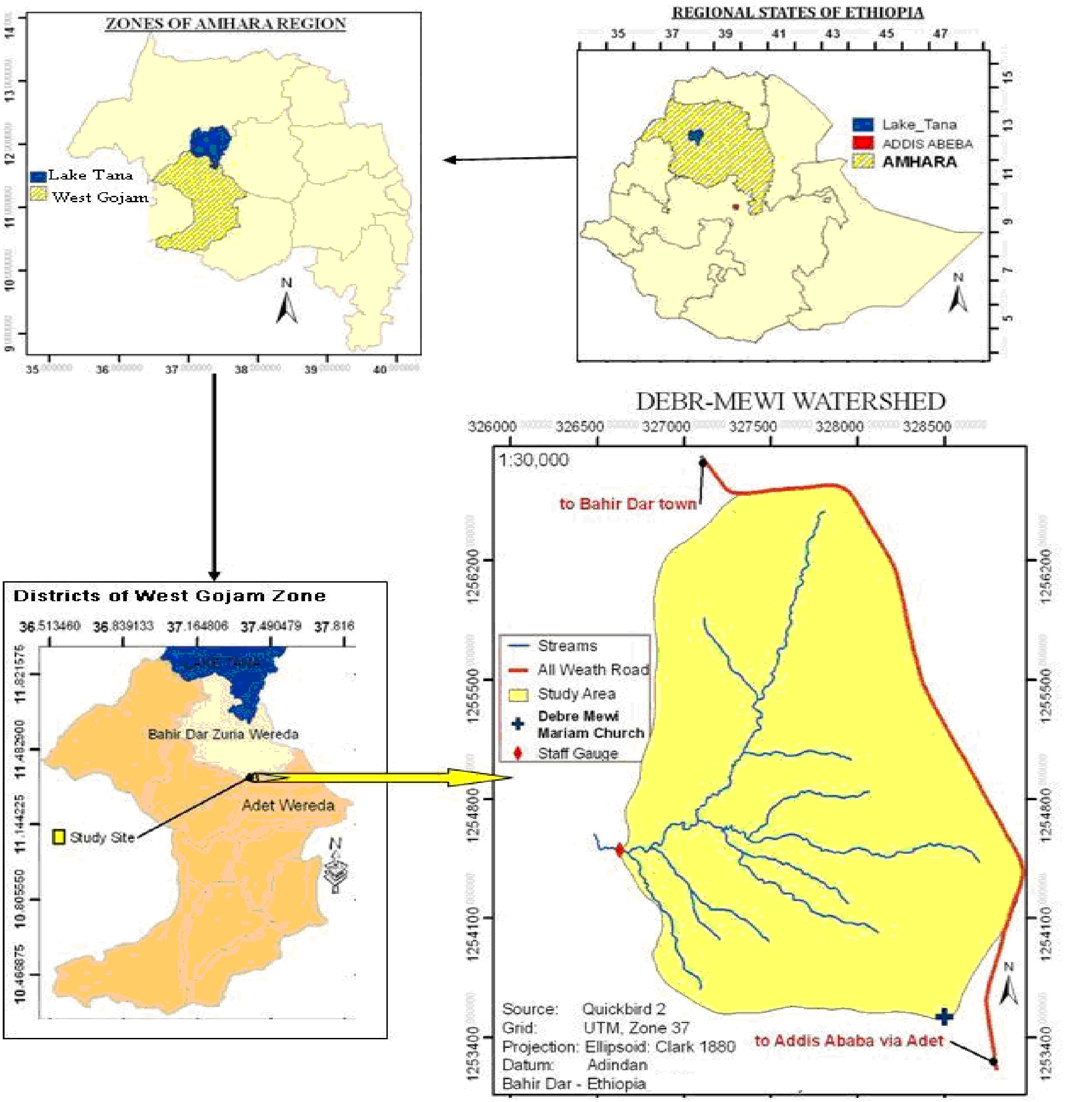

Fig.1. Location map of Debre-Mewi watershed.

These soil loss values are in consent with those of the previous studies, which reported soil loss values on different slopes and SC practices ranging from 16 to 300 t ha^{-1}yr^{-1} (Azene, 1997; Betru, 2003; Nyssen *et al*., 2007). In line with the soil loss reduction due to SC practices, Azene (1997) indicated that *kabs* (stone terrace) constructed on steeper slopes resulted in significant modification of slope from the initial slope of 25, 17, 32 and 38% resulting in a net decrease of 8, 5, 14 and 18% slope respectively in three years time. Results obtained from test plots at the Andit-Tid (north Shewa) SCRP site indicated that soil loss is reduced by 32% with graded bunds, 54% with graded Fanyajuu, and 66% with grass strip (Betru, 2003). On average, after stone bund building in Tigray, slope gradient decreases by 1% every 3 year (Nyssen *et al*., 2007)

The difference in soil loss among the upper, middle and lower position of the plots was very small. There was no significant difference among the three positions of the treated plots that showed except control plot higher soil loss at the lower position (133.1 upper; 138.9 mid and 154.1 lower positions).

This is in agreement with Assefa (2009) who reported the loss in the down slope position was significantly greater than with the mid and upslope fields of farmers practices.

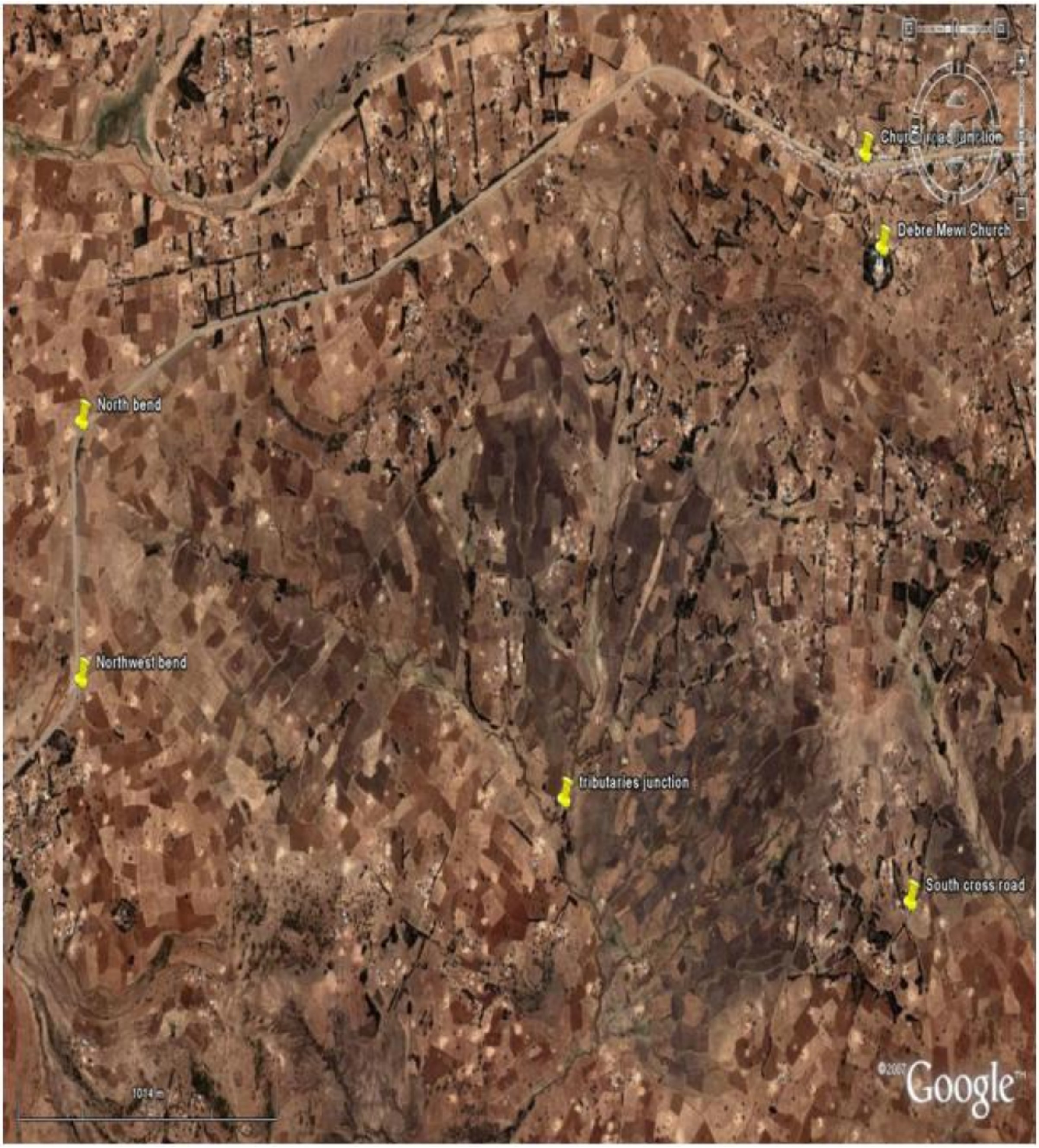

Fig. 2. Aerial view of the landscape of Debre-Mewi watershed (image from Google Earth, 2007).

Crop parameters

Although there was no significant ($P > 0.05$) effect of soil conservation on days to maturity, stand count, plant height and dry biomass, the use of these measures showed an increasing mean value in these crop parameters (Table 3). The order of these crop parameters obtained was FEG > FVG > SF > NC.

Significant differences ($P \leq 0.01$) due to SC treatments were observed with respect to grain yield (Table 3). The soil conservation measures highly significantly increased grain yield as compared to the control (Table 3 and Plate 2). With FEG (315.9 g m^{-2}) and FVG (309.6 g m^{-2}), significantly higher yield were produced than the NC (207.9 g/m²). Though soil loss under FVG was lower than FEG, yield in FEG was slightly greater than that of FVG in two years of the study. This may result from the lower biomass produced with vetiver grass (first copping season) compared to elephant grass (Plate 2) or the slow improvement in soil quality with implementation of conservation practices. But in the second season, vetiver grass formed a dense permanent hedge and strong root system so that conserve and binds the soil very well (Plate 2).

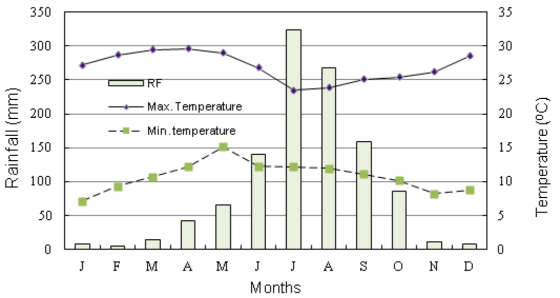

Fig. 3. Mean monthly rainfall (RF), maximum and minimum temperatures (Temp) of the Debre-Mewi Watershed (1986 -2010).

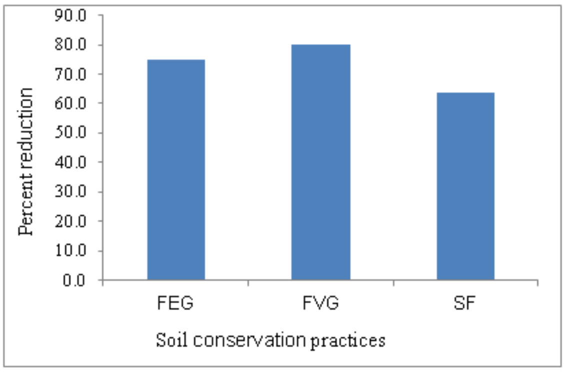

Fig. 4. Percent Reduction in soil loss due to the soil conservation practices as compared to the control (EGF = Elephant grass with Fanyajuu, VGF = Vetevar grass with Fanyajuu, SF= Sole Fanyajuu).

This result was in agreement with the findings of other researchers who obtained the best crop yield with proper soil conservation and fertilizer application. Since erosion reduces yield (Kebrom, 1999; Walley *et al.*, 1999; Sonneveld and Keyzer, 2003; Nyssen *et al.*, 2004 and Haileslassie *et al.*, 2005), the lowest yield was obtained under NC (non conserved plot). On severely eroded soils, less yield has obtained than on slightly and moderately eroded phases (Mokma and Seitz, 1992).

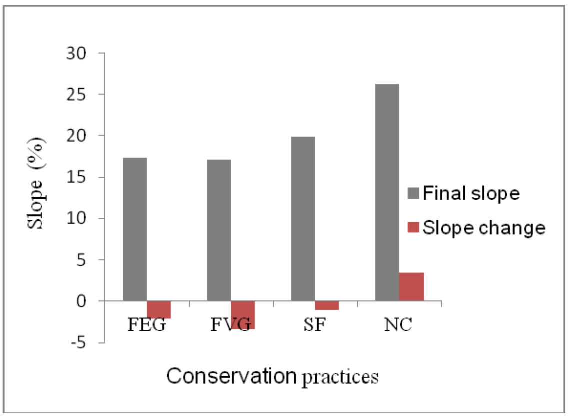

Fig. 5. Changes in slope gradients due to soil movement and effect of SC practices (EGF = Elephant grass with Fanya juu, VGF = Vetevar grass with Fanya juu, SF= Sole Fanya juu, NC = no conservation practices).

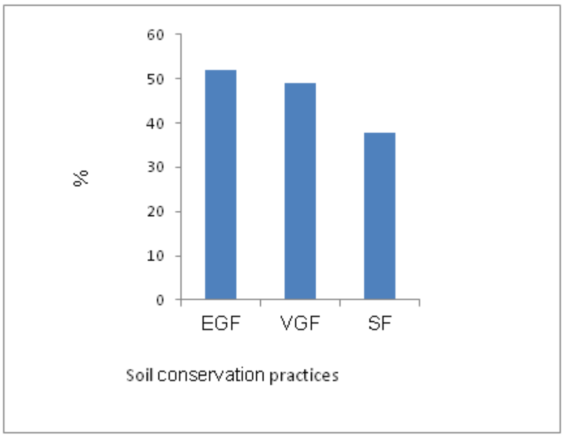

Fig. 6. Yield increments (%) by SC as compared to the non-conserved soil.

The overall percentage increments in yield due to FEG, FVG and SF were 51.5, 48.9 and 37.7% respectively as compared to NC (Fig. 6). There are also similar reports in other studies. For instance, the average barley yields of above the bund (soil accumulation area) was 43% higher than below the bund (soil loss area) of fanyajuu terraces in the Andit Tid area of northern Shoa, Ethiopia (Yohannes, 1989). Gebre Egziabher (1988) also found that soil bunds are effective in controlling soil erosion in a study from the Gununo twin watershed, Sidamo Research Unit of SCRP. Yields of maize were found to be higher in the soil accumulation zone (above bunds) than in the soil loss zone (below bunds).

Plate 1. Field plots layout (A), sediment collection pit at the lower slope positions of the control plot (B) and grass treated bund (C).

Simple correlation coefficient among grain yield and inter-rill, slope, rill and total loss gave a negative value of r = -0.56**, -0.60**, -0.90** and -0.93**, respectively (Table 4). These indicate that higher erosion rate have contributed to grain yield reduction. Valdés (1994) assessed the relationship between erosion and yield using linear regression analysis in two areas of Honduras. The analysis produces negative relationships with correlation coefficients, R^2, of 0.73 and 0.77 respectively, indicating a high level of explanation. The same author assessed the economic viability of investment for scenarios with and without soil conservation measures. It is assumed that for scenarios without conservation, production ceases when yields fall to a specific level below which production is assumed to be no longer profitable. In scenarios with conservation, the analysis limits yields such that they cannot increase above the maximum sustainable yield that can be achieved in the region.

Plate 2. Fanyajuu with elephant grass performs well in SC (A and B) during the first cropping season while vetiver not (C) but both of them established well (D) in the second year.

Valuation of on-site effect of soil conservation

The impacts of SC measures on agricultural production are complex and highly situation specific. A farmer may experience loss in crop area due to the occupation of land by conservation measures. Excessive increase in soil moisture capacity can also cause water logging and reduce yields, etc. Therefore, to see the validity of these conservation measures in different situations, economic analysis was performed (Tables 5 and 6). In this study, land management becomes the single largest factor influencing the performance of the crop production. Moreover, the same amount of other inputs was applied to all treatments. Therefore, direct costs incurred in this study were labor cost for Fanyajuu (F) construction, grass planting and fencing costs. The major benefit of the conservation technologies considered in the analysis is the saved yield due to reduced amount of soil erosion. Therefore, the tangible benefit from these technologies is the conserved amount of wheat yield multiplied by the unit price of wheat during entire period. The other benefit of adopting conservation technologies is the improvement in the soil organic matter which increases soil quality and ultimately the value of land. However, these values are not considered in the analysis. Nevertheless, value of fodder from Elephant grass (EG) hedges are additional benefit of the hedge rows system (Plate 3).

Plate 3. Fodder from Elephant grass hedges are additional benefit for the farmers.

Plate 4. Sediment accumulation inside pits from the 3 replications of the control plot.

It was observed that SC measures were effective in tested plots of DMW in increasing yield and net return as compared to the control plot. The variable cost was the highest under EGF, but in spite of this, SC method proved profitable as compared to other treatments. The net benefit was increased by 23.41, 11.74 and 4.59% under EGF, VGF and SF, respectively over the control.

The profitability analysis of the same SC methods in hectare bases for wheat crop is given in Table 6. Although the variable cost was higher than the others, net return obtained was found greatest under EGF that was followed by VGF. The yield obtained under EGF was the highest among all treatments. Therefore, the net benefit in Ethiopian birr was 3814.47, 1912.97, and 747.37 under EGF, VGF and SF, respectively over the control. Though the Vetiver grass did not provide additional benefit in two years time, it was more efficient in control of soil erosion than even Elephant grass (Plate 2 D). It could also provide thatch grass from which farmers can use for various household activities in the long run. That is why it was selected as the best soil control measure by farmers, development experts and researchers as we see in the next section.

According to Hudson (1992) the grass should be vigorous, easily propagated, provide good quantity of palatable fodder and not invasive into the crop area in order to be effective. In this case, elephant grass fulfills the criteria. However, livestock must be kept away from this grass. That is why fencing was considered in the variable cost. Grass which is unsuitable for fodder can be used, such as Vetiver grass (Vetivera zizanioides). Vetiver is quite commonly used for this purpose since it can be grown almost universally (Morgan and Rickson, 1995). Generally, application of SC measures significantly increased the grain yield of the study site.

Development of sustainable land management options

Soil and cropping management practices (improved and traditional practices) were evaluated to see if they meet the various functions of sustainability (economic, ecological and social functions) (Birru, 2007). The values as percentage and weight (score) in the appraisals by different stakeholder for SC measures are shown in Table 7. Of the tested of management alternatives, all groups (farmers, development experts and researchers) gave the highest value for VGF followed by EGF and SF. As a result, the overall mean were about 87.50, 78.96, 60.51 and 38.08% for VGF, EGF, SF, and NC, respectively. As a rule-of-thumb, any management practice whose overall value is less than 50% is said to be unsustainable (Birru, 2007). In this regard, all groups scored low value to the control plot (NC). The overall weight score value for NC also less than 2 and is said to be unsustainable (unsatisfactory) (Table 7).

Plate 5. Human interference (A), livestock (B) and crop management (barley crop at early stage (C) and at maturity (D) and its consequences on land degradation in the Debre Mewi Watershed.

Criteria such as biophysical, economic, and social impacts were given highest value by farmers, development agents, and researchers particularly for VGF and EGF (Appendix B Table B1 and B2). As a result, the highest overall mean value was 88.06 (for both biophysical and economic), and 86.39% (social impacts) given for VGF. The value of social impact (convenience, simplicity, operational overlap and risk) given by the farmers for EGF (59.38%) is smaller than that of VGF (78.75%).This could be due to the advantage with Vetiver grass which will not be browsed easily by animals so that no additional expense is required for keeping them on their farms. Although the figures are higher than those given by the farmers, the same trend was occurred appraised by the development agents and researchers. Since Vetiver grass proved to be the most effective soil erosion control option, the technology was best appraised by all stakeholders. On the other hand, the lowest overall mean value was 26.94, 39.72 and 47.57% for criteria biophysical, economic and social impacts of NC plot, respectively.

Impacts of soil erosion on land resources

The two years measured cumulative sediment inside pits below control (NC) plot for three replications was presented in Plate 4. The mean sediment volume accumulated in the pit was 2.01 m^3. Comparison of the two years measured soil loss (t ha^{-1}) of the 3 plots with the sediment arrested in the pits reveals that the total soil accumulated in the pit (433.35 t ha^{-1}) is slightly greater than the total soil eroded from plots (425.80 t ha^{-1}) (Table 8). This might be due to the movement and deposition of soils that are eroded from one meter spacing between plots. However, extreme care should be taken during measurement to remove the sediment before overflowing by the storm. Otherwise, the method is realized to be simple, educational and demonstrative to farmers.

A four kilometer main road boundary of the watershed concentrate runoff which is diverted towards the farmers fields causing very deep gullies in the arable and grazing lands (Plate 5 and 6). In line with this, Nyssen *et al.* (2002) concluded that roads concentrate runoff, significantly increasing the formation of gullies, as well as changing the size and shape of watershed. Besides the soil loss through erosion, loss of species diversity was found to be critical in the watershed (Plate 6). Because of this mismanagement of the land resources, gullies are frequent and considerable area of the watershed has become no longer able to produce crop/grass resulting in expansion of rock-outcrop. Thus, from the status of land cover and its dynamics it is evident that considerable areas of the study areas are exposed to land degradation. As a result during the analysis period large areas of the study site was exposed to the processes of soil erosion and immense loss of biodiversity.

Conclusions

Land degradation caused by soil erosion is a major threat to the sustainability of agriculture. The measured soil loss in the experimental plots revealed that soil erosion is a threat to agricultural production in the study area suggesting the need for conservation measures. This study revealed that, structural conservation measure (Fanyajuu) accompanied by grass species (Vetivar and Elephant grasses) are found to be effective methods of soil erosion control.

Adverse effects of erosion on crop yield and productivity can be mitigated by adopting proper soil conservation practices. The field experiment revealed that SC measures were profitable and gave net increased income over farmer's practices in wheat (2-years) cropping season.

Ensuring the full involvement of stakeholders in the process of identifying problems, planning solutions, and implementation and evaluation of outcomes is not only an option but also a necessity to a successful sustainable land management. Our research results regarding the SC appraisals indicate that shared knowledge among stakeholders was found to be higher. Participatory research approach used in this study has tried to narrow the knowledge gap among the stakeholders. In conclusion, the problem of land degradation needs to be addressed in the context of participatory integrated watershed approach.

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References

Addisalem A. 2009. Agricultural land suitability evaluation for rainfed crops using GIS and RS techniques: A Case Study of Debre-Mewi Watershed. M. Sc. Thesis, Bahir Dar University, Ethiopia.

Anteneh Z. 2009. Geological controls in the formations and expansions of gullies over hill slope hydrological processes in the highlands of Ethiopia, Northern Blue Nile Region. MSc Thesis, Cornell University and Bahir Dar University, Bahir Dar, Ethiopia.

Assefa D. 2009. Assessment of upland erosion processes and farmer's perception of land conservation in Debre-Mewi Watershed, near Lake Tana, Ethiopia. M.Sc Thesis Thesis, Cornell University and Bahir Dar University, Bahir Dar, Ethiopia.

Azene B. 1997. A participatory agroforestry approach for soil and water conservation in Ethiopia. PhD Thesis, Wageningen Agricutureal University, The Netherlands.

Betru N. 2003. Soil and water conservation program in the Amhara National Regional State. In

Tilahun Amede (ed.). 2003. Natural Resource Degradation and Environmental Concerns in the Amhara National Regional State: Impact on Food Security. Ethiopian Soil Science Society. Pp. 173-183.

Birru Y. 2007. Land degradation and options for sustainable land management in Lake Tana Basin (LTB), Amhara Region, Ethiopia. PhD dissertation. Switzerland.

EHRS (Ethiopian Highlands Reclamation Study). 1984. Annual Report (1983-1984) of the Ethiopian Highlands Reclamation Study, Addis Ababa.

Ethiopia. 1992. National Report on Environment and Development: A report prepared for United Nations Conference on Environment and Development in Rio de Janeiro, Brazil. Transitional Government of Ethiopia Addis Ababa, Ethiopia.

Eyasu E. 2002. Farmers perceptions of soil fertility. PhD Theses, School of Development Studies of The University of East Angla Published by Institute for Sustainable Development Addis Ababa, Ethiopia.

FAO (Food and Agriculture Organization). 2006. Plant nutrition for food security: A guide for integrated nutrient management. FAO, Fertilizer and Plant Nutrition Bulletin 16, Rome.

Gebre Egziabher A. 1988. Socio-economic and ecological analysis of soil conservation in Ethiopia: Cases from Gununo Twin catchments. M.Sc. Thesis, Agricultural University of Norway (NLH).

Gomez AK, Gomez, AA. 1984. Statistical procedure for agricultural research 2nd ed. Inter national Rice Research Institute Book. A Wiley Inter science Publication New York.

Haileslassie A, Priess J, Veldkamp E, Demil T, Lesschen, J. P. 2005. Assessment of Soil nutrient depletion and its spatial variability on smallholders' mixed farming Systems in Ethiopia using partial versus full nutrient balances, Agric. Ecosys. Environ. 108.

Hazelton P, Murphy B. 2007. Interpreting soil test results: What do all the numbers mean? 2nd Edition. CSIRO Publishing. p. 152.

Herweg K, Ludi E. 1999. The performance of selected soil and water conservation measures- case studies from Ethiopia and Eritrea. Catena, **36,** 99-144.

Herweg K, Stillhardt B. 1999. The variability of soil erosion in the highlands of Ethiopia and Eritrea, Research Report (42). Soil Conservation Research.

Hudson NW. 1992. Field measurement of soil erosion and runoff. In FAO Bulletin No 68. Silsoe Associates. Amphil. Belford, United Kingdom.

Kebrom T. 1999. Land degradation problems and their implications for food shortages in South Wello, Ethiopia, Environ. Manage., **23 (4),** 419-427.

Mitiku H, Herwig K, Stillhardt B. 2006. Sustainable land management- A new Approach to Soil and Water Conservation in Ethiopia. Mekelle, Ethiopia. Mekelle University; Center for Development and Environment (CDE), University of Bern and Swiss National Center of Competence in research (NCCR) North-South. p. 269.

MOA (Ministry of Agriculture). 1998. Agro-ecological zones of Ethiopia, Natural Resources Management and Regulatory Department, Addis Ababa, Ethiopia.

Mokma D. L, Seitz MA. 1992. Effect of soil erosion on corn yields on Marlette soil in South-Central Michigan. J. Soil and Water Cons., 47: 325-327.

Morgan RPC, Rickson RJ. 1995. Water erosion control. pp. 133-199. In: R.P.C. Morgan and R.J. Rickson (eds.), Slope stabilization and erosion control: a bioengineering approach. E & FN Spon, London.

Nyssen J, Poesen J, Moeyersons J, Luyten C, Veyerety Picot, M, Deckers J, Mitiku H, Govers G. 2002. Impact of road building on gully erosion risk: a case study from the northern Ethiopia highlands. Earth Surface Processesses and Landforms **27,** 1267-1283.

Nyssen J, Poesen J, Moeyersons J, Deckers J, Mitiku H, Lang A. 2004. Human impact on the environment in the Ethiopian and Eritrean highlands-a state of the art, Earth Sci. Rev. **64,** 273-320.

Nyssen J, Munro R.N, Mitiku H, Poesen J, Descheemaeker K, Nigussie H, Moeyersons J, Govers G, Deckers J. 2007. Understanding the environmental changes in Tigray: a photographic record over 30 years. Tigray Livelihood Papers No. 3, VLIR – Mekelle University IUC Programme and Zala-Daget Project, p. 82.

Olsen SR, Cole CV, Watanabe FS, Dean L.A. 1954. Estimation of available phosphorus in soil by extraction with sodium bicarbonate USDA, Circ 939.

Oyedele DJ, Aina PO. 1998. A study of soil factors in relation to erosion and yield of maize on a Nigerian soil. Soil. Till Res., **48,** 115-125.

Oyedele DJ, Aina PO. 2006. Response of soil properties and maize yield to simulated erosion by artificial topsoil removal. Plant Soil. 284: 375-384.

Robinson J. 2000. Motivating stakeholders to participate in natural resource management: Assesment of the outcomes from a multiple objective decision support system. Natural Resource Management **3**(2), 25-30. The University of Queensland, Australia.

Sonneveld BG, Keyzer J S. 2003. Land under pressure: soil conservation concerns and opportunities for Ethiopia, Land Degrad. Dev. **14,** 5-23.

Tekalign T. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

Tilahun Y. 1996. Impacts of conservation bunds on crop yields in Degua Tembien, northern Ethiopia. M.Sc. thesis, Agricultural University of Norway (NLH).

Valdés PA. 1994. Economic analysis of soil conservation in Honduras *in* E. Lutz, S. Pagiola, & C. Reiche (eds) *Economic and institutional analyses of soil conservation projects in Central America and the Caribbean*. World Bank Environment Paper No. 8, The World Bank, Washington DC p. 63-74.

Walley, FL, Lafond GP, Matus A, Kessel CV. 1999. Water use efficiency and carbonisotopic compostition in reduced tillage system. Soil Sci. Soc. Am.J., **63,** 356-361.

Woldeamlak B. 2003. Towards integrated watershed management in highland Ethiopia: the Chemoga watershed case study. PhD Thesis. Wageningen University, The Netherlands.

Yohannes GM. 1989. Crop production and conservation methods in Andit Tid area, northern Shoa. Soil Conservation Research Project, Addis Ababa.