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Full Length Research Paper

Effectiveness of exclosures to control soil erosion and local community perception on soil erosion in Tigray, Ethiopia

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The study investigated how effective exclosures are in the fight against soil erosion and how they are perceived as a means to control soil erosion by the local community (farmers and local experts). The universal soil loss equation (USLE) used to estimate potential soil erosion. Data on local community perception obtained from a survey of 62 farm households and five local experts. In-depth interview, group discussion and non-participant field observation also carried out to obtain additional information. The USLE results agreed with the farmers' (67%) and local experts' opinion that erosion at study area is severe and affect the quality of lives of residents. Insignificant difference ($p > 0.05$) was observed in the estimated soil loss among treatments. However, the estimated soil loss from free grazing lands was hi-gher by 47% than soil loss from exclosures which illustrated that exclosures are effective to control soil erosion. The majority of farmers (70%) also rated exclosures effectiveness to control soil erosion as high. Local communities were optimistic about the chances to rehabilitate degraded lands and make them productive. The majority of farmers (60%) did not consider population growth as a cause of soil erosion. For the majority of interviewed farmers, poor land management is more important. Efforts to create awareness within the rural communities should focus on the link between high population gro-wth, environmental degradation and poverty. The optimistic view of local communities can be con-sidered as an asset for the planning and development of degraded lands rehabilitation efforts.

Key words: Ethiopia, exclosures, local experts, perception, rural community, soil erosion.

INTRODUCTION

Land degradation, which includes degradation of vegeta-tion cover, soil and nutrient depletion, is a major ecologi-cal and economical problem in Ethiopia (Haileslassie et al., 2005). Forests and the benefits they provide in the form of environmental protection, wood, food and income have an important and critical role in enabling people to secure a stable and adequate food supply. Deforestation and land degradation, however, are reducing the capacity of forests and the land to improve environmental condi-tions and to provide other benefits (Girma, 2001). Furth-ermore, land degradation, exacerbates drought and de-sertification (Sonneveld and Keyzer, 2002).

Tigray, the northernmost region of Ethiopia, suffers from

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extreme land degradation. Steep slopes have been cultivated for many centuries and are subject to serious soil erosion. High population growth, combined with slow increases in agricultural productivity has resulted in serious land use conflicts, particularly between the agricultural and forestry sector. To compensate for the low agricultural productivity, forest clearing for arable land has been the principal form of land use conversion in Ethiopia. Particularly in Tigray, this has led to accelerated soil erosion and deterioration of soil nutrient status (Nyssen et al., 2004). However, since few decades, Tigray is not only known for severe land degradation, but also for the concerted efforts to tackle these problems using land rehabilitation techniques, including construction of bench terraces and stone bunds[1], exclosures and forestation (Fitsum et al., 1999).

Exclosures are a type of land management implementted with the aim to improve environmental conditions on degraded and generally open access lands. Exclosures are areas where grazing and other agricultural land use are not allowed. This is implemented using guards, not fences since fences are more expensive. After implementation, natural regrowth of vegetation occurs, having a positive biophysical impact on formerly degraded commons. In places where exclosures are established, particularly in the northern part of Ethiopia they are areas of considerable species diversity (Tefera et al., 2005). The ability of these areas to recruit and sustain diverse vegetation and wild fauna is one measure of their contribution to biodiversity and forest resource conservation (Mastewal et al., 2007).

Earlier studies have clearly demonstrated that vegetation can play an important role to control soil erosion (Cerda, 1999; Descroix et al., 2001; Lopez et al., 1998; Sanchez et al., 2002). However, these studies were conducted under different conditions and none of these studies address exclosures' effectiveness to control soil erosion. For successful soil conservation planning, it is however, necessary to estimate the amount of soil loss under different conservation efforts in each situation.

Understanding farmers´ perception of natural resource management lays the foundation and is a key to improve the transparency and effectiveness of conservation of natural resources. It also helps to create a platform to enhance negotiations among farmers and outsiders (Wegayehu, 2006). Any endeavour attempting to develop sustainable and effective soil conservation policies, rules, regulations, institutions and strategies need to take farmers´ perception of resource management and use into account (Corbeels et al., 2000). Policy makers and development workers could have different perceptions and of-ten suggest different solutions for natural resource management (William et al., 2003). If conservation strategies do not take into account these differences in addition to farmers´ perception and their interest and needs, they are more likely to be ineffective and unsustainable (Okoba and Graaff, 2005; Shibru, 2001). Thus, when trying to find solutions to natural resources management problems, both the physical and socioeconomic realities of the environment have to be considered (Veihe, 2000).

Although restoring and buffering effects of exclosures have been studied recently (Aerts et al., 2004; Dereje et al., 2002; Descheemaeker et al., 2006a), these studies do not analyze how the causes, consequences and severity of soil erosion as well as the effectiveness of exclosures to control soil erosion is perceived by scientists and local community (farmers and local experts in the study area). The goals of this study were:

(i) To evaluate potential soil loss under different vegeta-tion cover and management practices (exclosures and fr-ee grazing lands).
(ii) To assess local community perception on the severity of soil erosion and effectiveness of exclosures to control soil erosion.
(iii) To compare local community perception with the potential soil loss determined by the available information.

MATERIALS AND METHODS

Study area

The study was conducted in Douga Tembein Woreda (district) in Tigray, the northernmost region of Ethiopia (Figure 1), located on the rift shoulder to the west of the Danakil depression. This area is located some 35 km west of Mekelle, regional capital of Tigray. Its elevation and morphology are typical for the northern Ethiopian highlands. The Atbara-Tekeze river system drains the study area to the Nile (Nyssen et al., 2002). Like more than 90% of the Ethiopian population, the residents of the study area live in rural areas.

The lithology of the study area comprises Mesozoic sedimentary rocks and tertiary basalt (Nyssen et al., 2002) . Soils of the study sites have developed in calcium carbonate-rich parent material of the Agula shale formation, which consists mainly of marl and limestone (Beyth, 1972). Using the FAO-UNESCO soil classification system, soils are classified as calcaric cambisols. In the study area, water erosion is extremely serious and it is common to observe soil surfaces that have been affected by sheet and rill erosion.

The study area has a semi-arid continental climate. Annual rainfall ranges from 290 to 900 mm yr^{-1} (millimeter per year) with an average value of 615 mm yr^{-1}. The rainy season starts in June, peaks in July and August and trails off in September. The number of annual rain days at the study sites range from 53 to 104 days yr^{-1} (days per year) with an average of 80 days yr^{-1}. Using the agro-climatic classification system, which is traditionally used in Ethiopia, all study sites are classified as 'Woyina Dega' or mid-altitude (1500 - 2500 m a.s.l.).

Typical land use in the study area is a combination of rangeland and exclosures on steep slopes and cropland in flat areas. Natural vegetation is largely dominated by *Acacia etbaica* (Figure 2) and *Eu clea schimperi* . The under-storey vegetation of the study sites is do-minated by a diverse assemblage of grass and herbs, most of which are palatable for livestock. Crops are mainly barley (*Hordeum vulgare*), tef (*Eragrostis tef*), and wheat (*Triticum aestivum*). Crop yields are low (average 500 kg ha^{-1}), with large variability depending on rainfall and landscape position. According to the district's is on average between 0.46 and 0.76 ha per household.

Experimental design

5 and 10 year old exclosures and adjacent common grazing lands

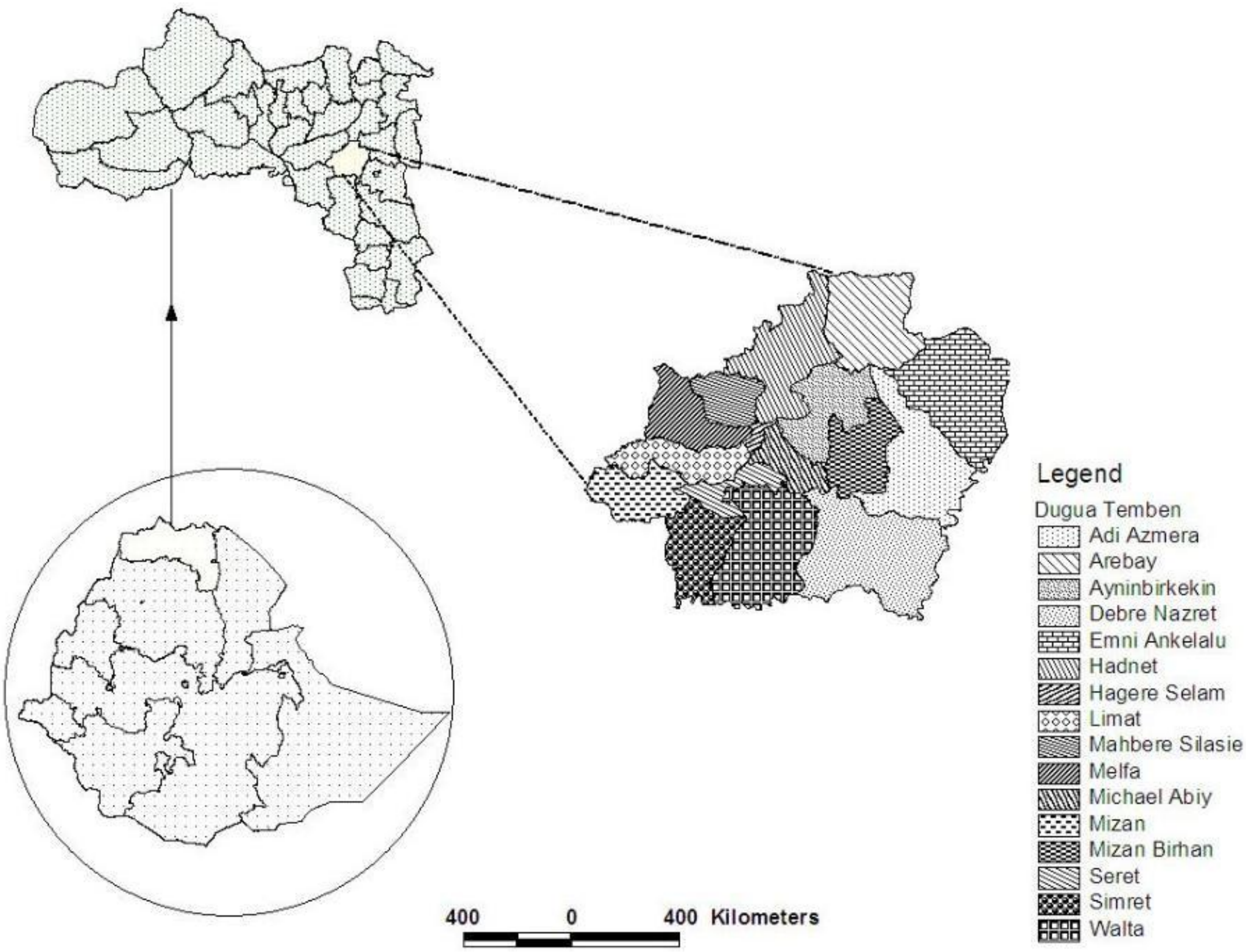

Figure 1. Location of the study area.

(controls, two in number: C1 and C2) were selected to examine the influence of age since protection. For each of the investigated land use categories, 3 replicates were selected which were all located on hill slopes. In total, twelve sites with similar lithology, soils, clima-te and land use and areas ranging from 3.5 to 48.5 ha were select-ed (Table 1) . Each of the study sites was divided into 3 slope positions: upper slope (US), middle slope (MS) and foot slope (FS), (Figure 2), bringing the total number of plots to 36. The US position is the uppermost portion of each study site. It receives little or no overland flow but may contribute runoff to down slope areas. The MS position receives overland flow from the upper slope and contributes runoff to the FS. The FS represents the lowest part of each study site and receives overland flow.

2 controls were selected in the study to avoid at least the difference in inherent properties of the soil. Besides, paired exclosures and free grazing lands, which are adjacent to each other were selected to be sure that the land use of the 2 sites before the establishment of exclosure was similar. Soil, topographic and geomorphologic situation of the 2 controls are similar with the adjacent exclosures. However, the paired exclosures and free grazing lands are different in vegetation cover (Table 1) and grazing activities. In exclosures, controlled grazing using cut and carry system is practiced while in the controls, free grazing is the common practice. Harvesting of grass from exclosures for livestock feed and thatching made once in a year. Although there is variation with the strength and duration of rainy season, grass is harvested between the end of September and middle of October. In both paired exclosures and free grazing lands, physical soil and water conservation structures are constructed. However, the soil and water conservation structures are in better conditions in exclosures for livestock and human interference is restricted.

Soil erosion assessment

Soil erosion measurements are very time consuming. Because of the erratic nature of downpours, they should be conducted for years to yield reliable data. As we were mainly interested in the relative di-fferrences between exclosures and the degraded commons, we de-cided to use the universal soil loss equation (USLE) (Wischmeier, 1976). As the USLE has not been calibrated for our study sites, the outcomes should only be interpreted an approximation at best. The USLE is defined as: $A = R \times K \times L \times S \times C \times P$, where: A is the mean annual soil loss (Mg ha^{-1} yr^{-1}); R is rainfall erosivity factor and is obtained from the product of energy per unit area by the rainfall

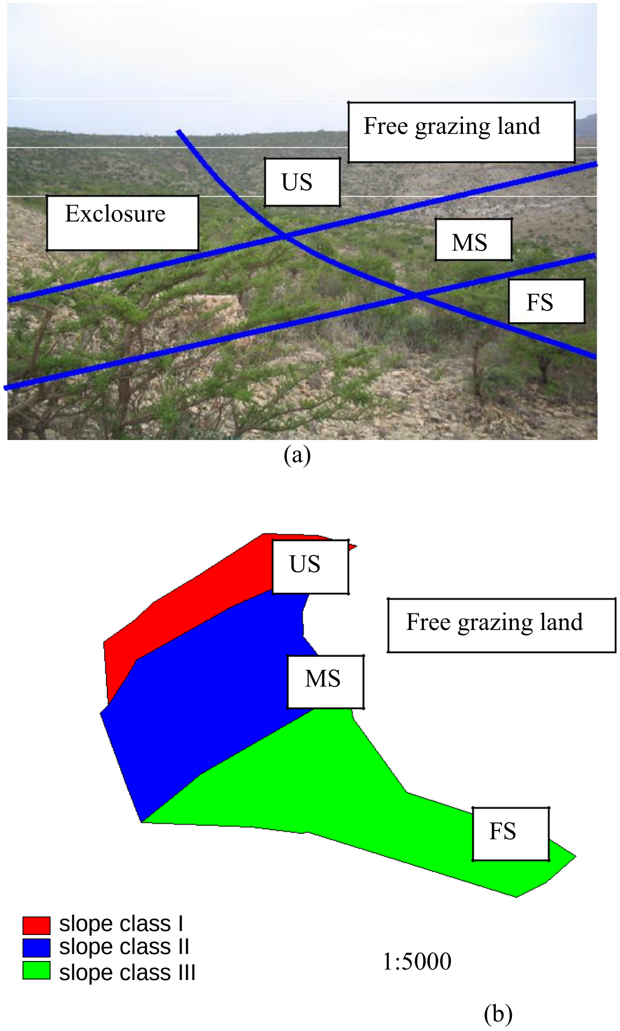

Figure 2. The westernmost study site (a), with examples of slope positionsin exclosures and free grazing lands (US: upper slope (slope class I); MS: middle slope (slope class II); FS: foot slope (slope class III)) and explaining drawing diagram (b). On the foreground: *Acacia etbaica.*

amount per unit time (that is, EI units, MJ (mega-joule) mm ha^{-1} h^{-1}); K (Mg ha^{-1} yr^{-1} per unit R) is the soil erodibility factor, which is a function of soil characteristics; L (dimensionless) is the slope length factor; S (dimensionless) is the slope steepness factor; C (dimensionless) is the cropping-management factor, that is, function of land use type and P (dimensionless) is the erosion-control practice factor (usually contours, strip cropping, or terraces). In this paper, the analysis of each factor was derived as follows:

Rainfall erosivity factor (R): The most suitable expression of the erosivity of rainfall is an index based on the kinetic energy of the rain. There are different formulas to calculate the R factor. For instance: (i) R = 9.28 × P - 8838, provided that KE (kinetic energy of the rain) > 25, where P is mean annual precipitation (Morgan, 1974, cited in Morgan, 1994), (ii) R = 0.276 × P × I_{30}. Mean annual EI_{30} (maximum 30 min erosivity index) , where P is mean annual precipitation (Foster et al., 1981, cited in Morgan, 1994).

These formulas have been applied in different parts of the world. The first equation appears to work well for Peninsular Malaysia, whereas the application for other countries has been less satisfactory. Especially with an annual rainfall below 900 mm (as is the case in part of the study site), the equation yields estimates of erosivety which are obviously without meaning (Morgan, 1994). The second equation needs the value of I_{30} (maximum 30 min intensity) for calculating of erosivity factor, which is difficult to get in context of the study area.

Taffa (2002) derived a single relationship between R value and a long term average annual rainfall (P) for Ethiopian condition as follows: R = 0.865 × P (P in mm). This equation is used in this study because it is possible to get long term average rainfall (P) of the study sites. 10 years annual rainfall data of the study site obtained from the Ethiopian metrological agency was used for the determination of R-factor value.

Soil erodibility factor (K): For this study, the K values were obtained from K-factor data table (Stone and Hilborn, 2000) based on % organic matter content and texture.

Slope length and Slope steepness (LS): The LS factor can be used in a single index, which expresses the ratio of soil loss as defined by Wischmeier and Smith (1978) and Stone and Hilborn (2000). According to these authors, the LS factor is given as:

$$LS = (0.065 + 0.0456S + 0.0065S^2)\,(X/22.1)^{NN}$$

Where X = slope length (m) and S = slope gradient (%). The values of X and S were derived from measurements done directly on the ground. To get X, the length of each strata of the specific study site was measured using a measuring tape. The slope gradient was measured using a clinometer in the field. The value of NN, which is a slope length exponent, varies from 0.2 - 0.5 depending on the slope (Stone and Hilborn, 2000; Wischmeier and Smith, 1978). The NN value for slope < 1% is 0.2, for slope between 1 and 3% is 0.3, for slope between 3 and 5% is 0.4 and for slope > 5% is 0.5.

Crop management factor (C): For this study, the C values were determined from a C factor data table based on vegetation canopy and percent cover as well as ground vegetation type and percent cover (Stone and Hilborn, 2000; Taffa, 2002). Vegetation survey was conducted to determine % vegetation cover of the study sites (Table 1). Vegetal canopy cover (woody species vegetation cover) was obtained from crown diameters assuming elliptical shape (Snowdon et al., 2002). Visual estimation was used to estimate the under-canopy vegetation cover.

Erosion management practice factor (P-value): In this study, P values were determined for conservation practices found in the study sites. The physical soil and water conservation practices prevailed in the study area are different types of terraces which include: stone bunds, stone faced trenches and micro-basins. The indicated conservation practices found in each of selected sites are constructed in combination for a better soil and water conservation. The erosion management practice factor was computed based on the type of conservation practices and slope gradient of each slope class (Taffa, 2002). The K, C, LS, P and R values of each landscape position of a land use within the study area are included in Table 2.

Assessment of local community perception

Data were obtained from a survey undertaken in 3 villages of the

Table 1. Average characteristics (n = 3) of the specific study sites.

Land use	LSP	Closed year	Area (ha)	SS (%)	SL (m)	Vegetal canopy		Ground vegetation		SOM (%)	Particle size distribution			Textural class
						Type	Cover	Type	Cover		% sand	%silt	%clay	
10 AC	US	1994/95	20.9	24	125	BU (2m)	43	TWSBG	58	2.4	61.2	24.5	14.2	SL
	MS		41.4	19	274	BU (2m)	31	TWSBG	60	2.8	62.3	22.4	15.3	SL
	FS		34.2	10	290	BU (2m)	32	TWSBG	52	3.0	59.9	24.8	15.3	SL
5 AC	US	1999/00	6.8	37	80	BU(.5m)	28	GTWSB	23	2.8	57.9	28.6	13.5	SL
	MS		6.8	33	73	BU(.5m)	30	GTWSB	38	3.1	53.1	29.6	17.3	SL
	FS		5.4	18	86	BU(.5m)	29	GTWSB	38	3.2	52.1	29.6	18.3	SL
C1	US	--	12.8	22	147	SBU	4	TWSB	5	1.5	62.3	18.7	19.0	SL
	MS		10.2	25	81	SBU	5	TWSB	5	1.5	62.8	21.3	15.8	SL
	FS		6.5	11	111	SBU	10	TWSB	9	1.9	62.3	21.3	16.4	SL
C2	US	--	10.8	27	82	SBU	6	TWSB	6	1.8	59.6	27.9	12.4	SL
	MS		7.8	29	64	SBU	7	TWSB	11	1.8	61.2	25.2	13.5	SL
	FS		7.3	13	80	SBU	4	TWSB	6	1.4	58.6	27.4	14.0	SL

Legend one: US; MS; and FS are upper, Middle and foot slope respectively.
Legend two: 10AC and 5AC are 10 and 5 years old exclosures, respectively.
Legend three: C_1 and C_2 are free grazing lands used as a control for 10 and 5 years exclosures respectively.
Legend four: TWSBG and GTWSB are tall weeds and short bushes with grasses and grasses with tall weeds and short bushes respectively.
Legend five: BU (2m) = bushes of 2 meter effective height; Bu (0.5) = bushes of 0.5 meter effective height and SBU= short bushes.
Legend six: LSP, SS and SL are landscape position, slope steepness and slope length respectively.

study sites (namely Adi-Azmera, Mizane Birhan and Aynberkekin). An agro-economic survey was conducted from January to March of 2004 using a structured survey questionnaire to obtain local community (farmers' and local experts) view of soil erosion problems and exclosures effecttiveness to control soil erosion. The questions pertained to 4 main topics:

(1) Farmers view on existence and severity of soil erosion.
(2) Immediate causes of soil erosion and their importance.
(3) Consequences of soil erosion.
(4) Exclosures effectiveness to control soil erosion.

Using systematic random sampling, 62 farm households were selected from 3 villages for personal interviews. The sampling was done using a list obtained from the respecttive village development agents. A household in this case consists of a cohort of one family made of a husband a wife and children with other dependents if any, living in the same house and depending on the same farm land and farm resources (Aklilu and Graaff, 2006). The main criteria used to select study the area of their expertise was soil and water conservation (two), forest management and use (one), livestock and grazing land management (one) and extension team leader (one). We use the term local communities to refer to farmers and local experts in the study area. The link between farmers and experts within the community is the advice and extension support provided by the experts and the acceptance of the extended technologies by the farmers. Additional information was obtained through indepth interviews and community group discussion. In each village, discussion groups were comprised of 6 to 10 people, both males and females of differrent ages (Lingen, 1997). Non-participant field observation (Kumar, 2005) was employed to have an overview of the severity of soil erosion and exclosures effectiveness to control soil erosion. The collected data were analyzed using content analysis (Bernard, 2006) (that is, who says what, to whom, why, to what extent and with what effect?) and descriptive statistics.

RESULTS AND DISCUSSION

Evaluation of the relative effectiveness of exclosures to control soil erosion

Areas which are currently used as free grazing lands were affected more from water erosion than the exclosures. Also agricultural lands located below free grazing lands are strongly affected by erosion. The estimated weighted mean annual soil loss in exclosures varied between 2.6 and

Table 2. R, K, C, LS and P factors attributed to each landscape position of a land use.

Land use type	Replication	Landscape position	USLE- factors of soil erosion values				
			R	K	C	LS	P
10 yr AC	I	US	307.5	0.12	0.11	23.1	0.2
		MS	307.5	0.12	0.09	11.5	0.14
		FS	307.5	0.2	0.13	1.8	0.10
	II	US	307.5	0.04	0.04	2.9	0.12
		MS	307.5	0.04	0.04	19.3	0.18
		FS	307.5	0.04	0.04	9.6	0.16
	III	US	307.5	0.2	0.06	11.2	0.18
		MS	307.5	0.12	0.04	5.5	0.16
		FS	307.5	0.12	0.08	2.9	0.12
5 yr AC	I	US	307.5	0.26	0.13	12.7	0.18
		MS	307.5	0.26	0.11	5.6	0.14
		FS	307.5	0.26	0.08	3.9	0.12
	II	US	307.5	0.12	0.2	30.4	0.36
		MS	307.5	0.12	0.2	9.6	0.18
		FS	307.5	0.26	0.2	8.2	0.18
	III	US	307.5	0.12	0.13	17.5	0.2
		MS	307.5	0.14	0.13	31.4	0.36
		FS	307.5	0.12	0.13	5.9	0.18
C_1	I	US	307.5	0.2	0.4	5.9	0.14
		MS	307.5	0.05	0.4	15.3	0.2
		FS	307.5	0.05	0.4	3.0	0.12
	II	US	307.5	0.2	0.4	9.7	0.18
		MS	307.5	0.2	0.4	3.2	0.16
		FS	307.5	0.2	0.4	0.65	0.1
	III	US	307.5	0.05	0.4	16.1	0.2
		MS	307.5	0.12	0.4	13.9	0.18
		FS	307.5	0.12	0.4	7	0.18
C_2	I	US	307.5	0.14	0.4	4.3	0.14
		MS	307.5	0.14	0.24	9.6	0.18
		FS	307.5	0.14	0.42	9.9	0.18
	II	US	307.5	0.14	0.4	19.9	0.2
		MS	307.5	0.14	0.4	5.5	0.18
		FS	307.5	0.14	0.4	2.9	0.12
	III	US	307.5	0.14	0.45	13.5	0.2
		MS	307.5	0.14	0.45	22.2	0.28
		FS	307.5	0.14	0.45	0.67	0.1

98 Mg $ha^{-1}y^{-1}$ (Table 3). Estimated weighted mean annual soil erosion in free grazing lands varied between 25 and 121.5 Mg $ha^{-1}y^{-1}$. The lowest weighted average soil loss was estimated for a 10 year old exclosure (8.4 Mg ha^{-1} y^{-1}). A significant difference ($p < 0.05$) in the estimated soil loss among treatments was not observed. However, the soil loss from free grazing lands was 47% higher than the soil loss from exclosures. The soil loss from 5 year old exclosures was higher than the soil loss from the control group C1 (Table 3). The result of the study also revealed that the upper slope contributed more to soil erosion except in C1, where middle slope contributed more (Figure 3). This could be mainly explained by the difference in slope steepness and length and vegetation cover among the slope positions within a site (Tables 1 and 2).

Calculations indicated that topographical factors in the 5 year old exclosure greatly affected the estimated soil erosion. Using the same topography as C1, reduced the estimated soil erosion by 49% and resulted in a lower mean annual soil loss of the 5 years old exclosure compared to C1. Replacing the vegetation parameters in all unprotected areas of the study sites with those of the

Table 3. Estimated on - site soil erosion for the land uses and landscape positions using USLE.

Land use	Replication	Estimated soil loss (Mg ha^{-1} yr^{-1}) US	MS	FS	Weighted average (Mg ha^{-1} yr^{-1})
10 AC	I (31.1)	48.5 (4.8)	13.3 (12.6)	3.6 (13.7)	14.5
	II (48.5)	0.4 (10.5)	4.2 (22.0)	1.8 (16.0)	2.6
	III (16.9)	18.4 (5.6)	3.2 (6.8)	2.5 (4.5)	8.0
Weighted average		**16.2**	**6.8**	**2.6**	**AM = 8.4 (± 5.96)**
5 AC	I (7.5)	58.6 (2.2)	17.0 (3.2)	7.6 (2.1)	26.4
	II (5.4)	199.6 (2.2)	31.6 (1.2)	58.8 (2.0)	110.7
	III (6.1)	41.0 (2.4)	156.1 (2.4)	12.6 (1.3)	79.7
Weighted average		**98.0**	**68.7**	**27.7**	**AM = 72.2 (± 42.64)**
C1	I (7.8)	50.5 (4.3)	46.5 (1.4)	5.5 (2.1)	37.8
	II (3.5)	106.2 (1.8)	31.4 (0.9)	4.0 (0.8)	63.1
	III (18.2)	49.1 (6.7)	91.8 (7.9)	46.0 (3.6)	66.9
Weighted average		**57.6**	**80.2**	**27.9**	**AM = 55.9 (± 15.82)**
C2	I (5.8)	25.4 (1.9)	44.2 (2.6)	79.8 (1.3)	46.0
	II (15.1)	145.3 (6.5)	42.1 (3.6)	15.1 (5.0)	77.6
	III (5.0)	129.1 (2.4)	297.4 (1.6)	3.2 (1.0)	157.1
Weighted average		**121.5**	**96.2**	**25.0**	**AM = 93.6 (± 57.25)**
F value					**2.925**
P value					**0.099**

Legend one: AM = Arithmetic mean of the weighted average soil loss of each replication in each land use (it is equivalent to mean of mean).
Legend two: weighted average is estimated based on the area coverage of each slope position within and among replications.
Legend three: the values in brackets in column 2 -5 indicate the area of each slope class; while the values in brackets in column 6 indicate standard deviation of means.
Legend four: *not Significant (p > 0.05), but it indicates a trend toward significant different as the p – value is close to 0.05.

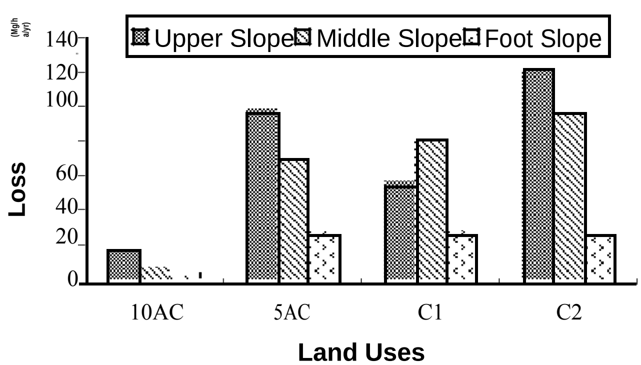

Figure 3. Contribution of slope position for the overall soil loss within a land use.

10 years old exclosure, reduced estimated soil erosion by 77% (from 52 to 12 Mg ha^{-1}y^{-1}). In contrast, replacing the vegetation parameters of the exclosures with those of the free grazing lands increased estimated soil erosion by 42% (from 52 to 89 Mg ha^{-1}y^{-1}).

In exclosures where the canopy of shrubs and understorey vegetation has been restored (Table 1), the soil surface is protected from the erosive energy of raindrops. In the highlands of Tigray, vegetation re-growth in exclosures has become an important measure to combat land degradation (Descheemaeker et al., 2006a, b). Runoff production in exclosures, measured using runoff plots (Descheemaeker et al., 2006b), is significantly reduced when a degraded area is allowed to rehabilitate after closure. Though runoff depth is significantly correlated with event variables such as rain depth, rainfall intensity, storm duration and soil water content, total vegetation cover is the most important variable explaining about 80% of the variation in runoff coefficients. Runoff was found to be negligible when the vegetation cover exceeds 65% (Descheemaeker et al., 2006b).

Soil water fluxes in exclosures are determined both by the rainfall regime and by extra water input through run-on from upslope (Descheemaeker et al., 2006b). Increased vegetation density in exclosures results in increased infiltration and higher transpiration, which in its turn triggers vegetation restoration through increased biomass production. With vegetation restoration, water use for biomass production also becomes more efficient. Vegetation restoration is responsible for the high infiltration capacity of the exclosures, but as transpiration is not increased at the same rate, the surplus infiltration drains beyond the root zone and contributes to groundwater recharge. This explains the earlier reported phenomenon (Nyssen et al., 2002) of improved spring discharge in lower parts of the landscape after degraded areas were turned into exclosures in Tigray.

Appropriate land-use and land management practices that maintain extensive ground cover are useful for reducing soil loss and sediment delivery. As run-off and soil loss are both inversely related to ground cover, forestation could increase surface roughness and reduce the impact of raindrops and the ability of running water to detach and transport sediment (Costin, 1980). De Ploey (1989) estimates that soil erosion rates on unprotected fields may be 100 - 1000 times higher than on fields with a permanent vegetation cover. Williamson et al. (1996) also shows that riparian buffer strips and hill slope forestation reduced sediment export by 85%.

The importance of soil cover to reduce soil erosion has also been shown in a study where soil loss decreased exponentially with increasing degree of cover using mulch (Becher, 2003). A study by Lopez et al. (1998) reveals that the median rate of soil erosion in different land uses decreases in the following pattern: bare soil > open canopy forest > pasture > closed canopy forest. Although the exclosures were effective in reducing erosion, the soil loss in exclosures was still higher than the soil tolerance limit for shallow and erodible soils in Ethiopian highlands which ranges between 2 and 5 Mg $ha^{-1}y^{-1}$ (Becher, 2003). This can be a result of the steep slopes in exclosures but it should be kept in mind that calculations were performed with an un- calibrated USLE so comparison of absolute values may be problematic.

The higher soil loss in the 5 year old exclosure than the control group C1 could be explained by the importance of the steep, long slope rather than by vegetation. As Chaplot and Bissonnais (2000) indicate, slope length and steepness have an important role in controlling the amount and runoff velocity, especially its potential to undercut vegetation and erode the soil underneath. Besides, the fact that exclosures are established in steep and degraded area resulted in insignificant difference ($p > 0.05$) in estimated soil loss among treatments.

Local community perception of soil erosion

All the local persons interviewed (62 farmers and 5 experts) perceived that soil erosion is a problem in the study area. Although the respondents do not perceive the severity of soil erosion similarly, most of the farmers (67%) and all local experts perceived that erosion is severe in their surroundings. 33% of the farmers described the severity of soil erosion as medium. These respondents stressed that the efforts made over the last 10 years in conserving degraded and agricultural lands has resulted in a decline of soil erosion. The field visit also revealed that conservation activities are contributing to rehabilitating degraded lands and regeneration of indigenous tree species which could result in a reduction in the rate of soil erosion.

The variation in perception among the respondents concerning the severity of soil erosion in the study area can be explained through the difference in exposure, position of their agricultural land, understanding of their environment or in realizing the impact of the ongoing soil and water conservation activities in their surrounding (Belaineh and Lars, 2005). The perception of most of the farmers engaged in individual interviews and group discussion on the severity of soil erosion is also supported by most of the studies conducted so far (Tefera et al., 2005; Tekle, 1999). Soil erosion is severe in all of Tigray and poses a major threat to continued agricultural production.

Respondents put forward several alternative causes of soil erosion; a few natural and many linked to land use. According to most of the interviewed farmers (72.5%), the main causes of soil erosion were overgrazing, deforestation and poor land management (e.g. free grazing, cultivation of steep and marginal lands without implementing appropriate SWC measures). In addition to these, the local experts considered population growth and poorly constructed roads as a cause of soil erosion. It was observed that no local expert pointed out at least one natural cause of soil erosion such as topography, erratic rainfall, soil characteristics or drought.

The alternative causes forwarded by the respondents coincide with the results of many studies (Feoli et al., 2002; Girma, 2001). Although erosion is a natural process, which persistently changes the surface in all climatic zones of the earth, soil erosion is generally considered to be one of the most serious impacts of deforestation. Although it was not suggested by the respondents, erratic rainfall in the study area is also responsible for the existing severe soil erosion (Nyssen et al., 2004). Insufficient rainfall in general and drought in particular cause soil erosion since they reduce grass cover which protects the ground (Thurow and Taylor, 1999) . Moreover, poorly con-structed roads could be a reason for severe soil erosion (Bochet et al., 2005; Nyssen et al., 2002). However, it was not perceived by the interviewed farmers and most of the local experts.

Although there is no general agreement on the importance of the different causes of soil erosion among the respondents, most of the farmers (61%) put deforestation as first and nearly 32% ranked it as second. The study al-so revealed that according to the local community, poor land management is more important than overgrazing and over population in causing soil erosion. Only 1.6% of the farmers did not consider deforestation as a cause while over-population and overgrazing were not considered as a cause by 59.7 and 27.4% of the farmers. Poor land management was not considered a cause of soil erosion by 16% of the farmers. In contrast to this, the experts put deforestation, population growth and poor land management as equally important causes of soil erosion. This could be explained by the difference between the local experts and communities in understanding the interrelationship among the main causes of soil erosion.

The farming system in rural Ethiopia is mainly labour intensive and involves the use of livestock traction power. Besides, natural resource conservation activities taking place in Ethiopia usually depend on manpower. Large family members in rural Ethiopia are considered as a power and a labour resource for diverse activities including land cultivation and rehabilitation. As a result, farmers do not consider population growth and grazing of animals as a principal threat to land degradation. The ranking of poor land management in the first rank to cause soil erosion could also be related with farmers observation of the positive impact of rehabilitation of degraded lands through exclosures establishment and soil and water conservation activities taking place in their surroundings. Nyssen et al. (2007) found that irrespective of the increase in population, soil and water conservation and land rehabilitation efforts such as establishment of exclosures in Tigray results in decrease of sheet and rill erosion rates. Besides, infiltration and spring discharge are enhanced; vegetation cover and crop production have improved. These impacts are quantified by a comprehensive comparison of the current landscape with coverage of 30 year old photographs and substantiated by field investigations. Furthermore, the reason for placing poor land management in the first rank rather than overgrazing and over population could be poverty of the local community and the inability to cope for the high cost of soil conservation practices (Scherr, 2000).

The view of most of the farmers' about the relationship between rapid population growth and soil erosion do not agree with some studies conducted in the northern highlands of Ethiopia. In the last 2 - 3 decades the Ethiopian population showed rapid growth (CSA, 2006) . This in turn increases pressure on agricultural land and reduces the carrying capacity of the environment (Ejigu, 1999).

Most of the farmers (56%) and all experts considered fragmentation of agricultural and grazing lands, decline of soil fertility, and decline of crop yield (which in turn leads to poverty) as the main consequences of soil erosion. Decline in soil fertility and yields were perceived by 76% of the experts and 82% of the farmers as main consequence of soil erosion. Reduced accessibility between villages as a result of large gullies is also mentioned by some of the farmers (16%).

The main explanation why farmers perceive decline of yield as main consequence of soil erosion is probably caused by the fragmentation and decline of soil fertility which farmers can easily recognize (Aklilu and Graaff, 2006). As indicated by Greenland et al. (1994), the immediate consequence of land degradation is reduced crop yield followed by economic decline and social stress.

A study conducted by Tilahun (1996) in the same administrative region as our study also reports difficulties in land preparation and changes in crop choice as a consequence of soil erosion.

Local community perception of exclosures effectiveness to reduce erosion and increase productivity

Unlike the experts, who evaluated exclosures effectiveness to control soil erosion as high, the farmers had different perception. 30% of the respondents evaluated exclosures effectiveness as medium. These farmers perceive that exclosures could have a great potential to reduce the capacity of the rain drops to detach the soil. However, once the runoff is generated, exclosures can not stop the transport of soil eroded from agricultural lands located below. They suggested that exclosures should be supported by additional soil and water conservation measures to be more effective. However, most of the respondents (70%), consider exclosures as highly effective to reduce the generation of runoff and overland flow velocity because of the growth of grasses and shrubs.

Most residents of the study area think that erosion can be reduced and they had a number of ideas how to achieve this. The general opinion was that if the gullies are controlled through the construction of check dams and if watersheds are treated with soil and water conservation structures and protected from human activities and livestock grazing, the degraded lands can be rehabilitated and used for crop production and grazing lands as well as for reforestation. The respondents were optimistic about the possibilities of rehabilitating degraded lands and make them productive.

All of the respondents perceived that there is no negative effect of closing areas from the interference of human being and livestock to rehabilitate degraded lands. They have explained that in their observation it is positive for their lives and livelihoods.

The observation of most of the farmers (70%) on exclosure effectiveness to reduce soil erosion agrees with the results of this study and with those of Descheemaeker et al. (2006a, b) and Nyssen et al. (2007). Although most of the respondents are optimistic in rehabilitating degraded lands and convert them to productive lands, it is worth mentioning that many consider soil erosion to be an integral part of the broader problems of access to finances, infrastructure, poor community relations, inadequate land and uncertain tenure (Berhanu et al., 2003; Muluneh, 2003) . If these could be resolved then land degradation might be reduced.

The majority of the farmers (90%) and all the experts perceived that there is a difference in crop production between farms located below exclosures and below free grazing lands (Tables 4 and 5). According to the respondents the possible reasons for the difference include:

Table 4. Estimated crop production according to farmers.

S/N	Crop type	Production (qt./ha)							
		Farm land below exclosure				Farm land below free grazing land			
		Good year		Bad year		Good year		Bad year	
		WF	WOF	WF	WOF	WF	WOF	WF	WOF
1	Wheat	7.9	5.9	3.2	2.4	5.1	3.1	1.3	0.7
2	Barley	10.1	7.9	4.4	3.3	5.9	4.1	1.8	1.0
3	Teff	4.4	3.0	2.0	1.2	2.3	1.5	0.8	0.6

Legend one: WF and WOF are with and without fertilizer respectively.
Legend two: qt. refers to quintal and equivalent to 100 kg.

Table 5. Estimated crop production according to experts.

S/N	Crop type	Production (qt./ha)							
		Farm land below exclosure				Farm land below free grazing land			
		Good year		Bad year		Good year		Bad year	
		WF	WOF	WF	WOF	WF	WOF	WF	WOF
1	Wheat	15	7	5	1-3	13	5	4	0 - 1.5
2	Barley	15	7	6	1-3	13	5	4	0 - 1.5
3	Teff	8	5	3	1-2	7	4	5	0 - 1

Legend: Total number of local experts interviewed = 5.

(i) The difference in soil erosion between farm lands located below exclosures and free grazing lands
(ii) The difference in fertilizer and seeds loss and
(iii) Low incidence of crop destruction caused by livestock in farm lands located below exclosures.

However, 10% of the respondents perceived that there is no difference in crop production, because they perceived that farm lands below exclosures are more susceptible to attacks by rats and other pests and weed infestation. In their opinion, this counterbalances the positive effect of exclosures.

The observations of most of the farmers (90%) on exclosure effectiveness to increase crop productivity agree with those of Aklilu and Graaff (2006) in the central Ethiopian highlands, Dejene et al. (1997) in Tanzania and Visser et al. (2002) in Burkina Faso and reflect the inverse relationship between crop yield and rate of soil erosion. Annually, Ethiopia loses over 1.5 billion tons of topsoil from the highlands by erosion (Hurni, 1983a, b) . This could have added about 1 - 1.5 million tons of grain to the country's harvest. During the dry season, wind erosion is severe in arid and semiarid regions. In the rainy season, water erosion and tillage erosion removes soil layers and carries them away from farmer's fields to bodies of water or other land, which results in the loss of valuable nutrients that are necessary for crops to grow. However, the observation of few farmers (10%) that exclosures' effectiveness to increase production is counterbalanced by rat attack and pest and weed infestation needs further study.

Local experts' estimation of crop production was higher than farmers' estimation (Table 4, Table 5). Farmers usually underestimate or do not tell the truth especially on some sensitive issues like productivity of their land and type and amount of resources they have. This is mainly because the local peoples relate such question with aid. They perceive that, if they tell the truth for the researcher or any body who works in governmental organization (GO) and non governmental organization (NGOs), they will miss the aid that they can get from GO's or NGO's. On the other hand, because local experts implement ongoing development efforts, they could also exaggerate the positive effect of exclosures in increasing crop yield through its effect of reducing soil erosion.

Efforts exerted by farmers

Of the interviewed farmers, 98% indicated that they have been trying to reverse the negative effects of soil erosion caused by water through the implementation of different soil and water conservation structures. They were also actively participating in a reforestation program of open and degraded lands. Most of the respondents confirmed that they observed a positive change in crop production after they implemented soil and water conservation practices in their farm land. According to most of the respondents, attempts to reverse the negative effects of soil erosion are a necessity to escape from hunger and poverty.

There is a general perception that the society should

Figure 4. Stone bunds in Douga, Tembein, Tigray, Ethiopia.

actively participate in the government initiated soil and water conservation program with labour, material and local or indigenous knowledge. In addition to this, they stressed that rehabilitation of degraded lands through exclosures should continue to bring change and improve the environment.

Conclusions

In this study, we estimated the potential soil loss under different vegetation cover and compared the estimated soil loss with the perception of the local community on the effectiveness of exclosures to control soil erosion. Our estimations showed that exclosures have the potential to reduce water erosion. The local community has made the important link between soil loss and low agricultural production and the link between land use and erosion. In general, local community perceptions on soil erosion and the role of exclosures at Douga Tembein correspond quite well with the estimated soil loss amounts and other published information. The optimistic view of the local community to rehabilitate degraded lands and make them productive may be interpreted as an asset for projects working to rehabilitate degraded dry lands. It was worrying that the local community did not consider population growth and some natural factors as causes for soil erosion. Thus, an education program to improve awareness of natural resource management should focus on the link between uncontrolled population growth, environmental degradation and poverty.

Notes

i.) Stone bunds are defined as embankments of stones built along the contour across sloping land to reduce or stop the velocity of overland flow, consequently to reduce soil erosion (Desta et al., 2005). Stone bunds have been introduced in Tigray since the late 1970s (Munro et al., 2008). Farmers build these walls with large rock fragments; medium sized rock fragments (5 - 10 cm) are used as backfill (Figure 4). Stone bunds reduce annual soil loss due to water erosion with an average value of 68% (Desta et al., 2005). Furthermore, the positive effects of stone bunds on water harvesting, runoff reduction and crop yield have also been verified (Nyssen et al., 2007; Vancampenhout et al., 2006).

ii.) Exclosures was put into practice through the joint initiative of local communities, governmental and non-governmental organizations (TFAP, 1996). This joint initiative gives an opportunity to the local communities' participate from the project initiation to monitoring and evaluation stages. Exclosures are also main places where physical soil and water conservation measures are constructed through food and cash for work. Hence, the local communities consider exclosures as a means to generate income. More specifically, the guards who are members of the local community are also paid in the form of grain (90 kg) in a monthly basis. There is also a continuous follow up regarding the strength of exclosures management by all involved parties mentioned above. It is due to all these reasons that exclosures are protected from the interference of livestock and human being for long period of time.

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