On-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia

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Introduction

Since two decades, large areas of the Tigray Highlands, Northern Ethiopia (Figure 1), have been covered by stone bunds to control soil erosion (Figure 2). For this purpose, the farmers build strong walls along the contour with large rock fragments, using medium sized rock fragments (5 - 10 cm) as backfill. At the end of the work, the backfill is topped with small rock fragments (average diameter 2 cm), which act as a filter and retain sediment during major rainfall events (Nyssen et al., 2001). If off-site effects are definitely positive (improved hydrological conditions in the catchment, decreased sediment yield) (Nigussie et al., 2004), the on-site effects call for a more careful analysis.

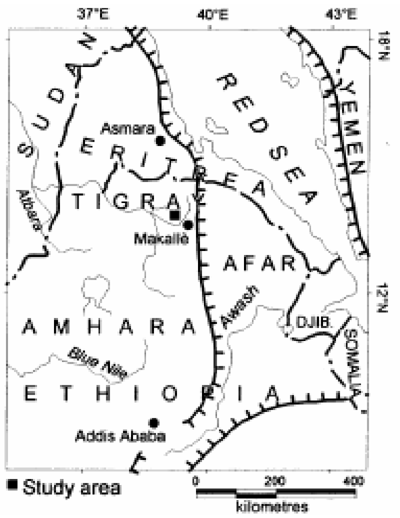

Figure 1. Location of the study area, Dogu'a Tembien in Northern Ethiopia (after Nyssen et al. 2001).

Figure 2. Stone bunds on cropland in May Leiba catchment, 12 km E of Hagere Selam town.

The impacts of the physical soil and water conservation measures can be classified into short- and long-term effects based on the time needed to become effective against soil erosion (Morgan 1995; Bosshart 1997). According to Bosshart (1997), the short-term effects of stone bunds are the reduction of slope length and the creation of small retention basins for runoff and sediment. They therefore reduce the quantity and eroding capacity of the overland flow. These effects appear immediately after the construction of the stone bunds and reduce soil

loss. The medium and long-term effects, according to this study, include the reduction in slope angle by forming bench terraces, development of vegetation cover on the bunds themselves and the change in land management. Based on studies of the Soil Conservation Research Project (SCRP) in Ethiopia (outside of Tigray), Herweg & Stillhardt (1999) state that well-established mechanical SWC measures retain most of the soil eroded in between the structures. Most of these studies were however done on erosion plots and concerned well managed and young structures.
Such type of terraces are often associated with a high spatial variability in soil fertility and crop response, due to the erosion and accumulation processes mentioned above. Especially when the fertility is concentrated in the top layer of the soil, truncation of the profile by tillage erosion (Nyssen et al., 2000) at the upper part of the field can bring an infertile layer of subsoil to the surface. A dramatic drop in yield can result from such fertility gradients and therefore poses a limitation on the long-term productivity of these systems. This problem remains a dominant issue in the debate about the sustainability of slow forming terraces (Turkelboom *et al.*, 1999; Herweg & Ludi, 1999; Dercon *et al.*, 2003; Dabney *et al.*, 1999).
As the importance of rock fragment cover in protection of arable land from soil erosion by water is well known (Wischmeier & Smith 1978; Römkens 1985; Poesen *et al*. 1994), it was also important to study the effect of stone removal for bund building.
Tentatives of introducing agroforestry trees on stone bunds generally failed, mainly due to lack of protection from browsing livestock, which has its origin in the ancient tradition of stubble grazing as well as in lack of awareness of the landholders (Hailu, 2003).
Finally, it proved important to go beyond sometimes superficial assessments of farmers' perception of soil and water conservation techniques and to carry out in depth participatory research on acceptance of stone bunds.
This study was conducted on farmers' fields, in order to quantify the efficiency, side effects and acceptance of stone bunds.

Materials and methods

This study was conducted in the northern Ethiopian Highlands and more specifically in Dogu'a Tembien district (Figure 1) around the market town Hagere Selam, located at an altitude of 2650 m a.s.l., about 50 km to the west of Mekelle, capital city of Tigray region. The Regional government of Tigray and NGOs like Relief Society of Tigray have implemented different types of stone bunds on cropland as well as on rangeland in all parts of the district. As a result, the larger part of Dogu'a Tembien is covered with stone bunds dating from different periods, and the district is representative for the Northern Ethiopian Highlands, particularly the Tigray highlands and midlands.

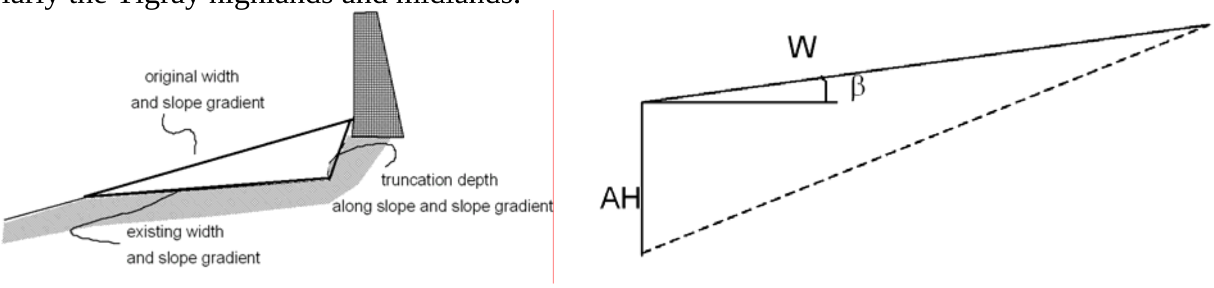

Figure 3. Cross-sectional area of truncated soil or 'tillage step' on foot of the upper bund (left) and (right) the accumulation zone (AZ). This consists of the accumulation width (W), the accumulation height (AH) behind the stone bunds and the slope gradient (β) of the AZ. (After Desta et al., 2004)

Qualitative and quantitative assessments of soil loss and sediment accumulation were based on technical descriptions of the 202 study plots, which comprise stone bunds aged from 3 to 21 years at their upper and lower side. Volumes of sediment accumulated behind stone bunds (Figure 3) were related to technical and environmental characteristics (Desta et al., 2004).

In-depth studies were carried out on the spatial variability of soil fertility of terraced land. Measurements of $pH_{(H2O)}$, $pH_{(KCl)}$, N_{tot}, C_{tot} and $CaCO_3$ along the slope were done on 20 representative fields. C_{org} was computed out of C_{tot} and $CaCO_3$ (Van Campenhout et al., 2004). Further, comparison to efficiency of grass strips (four experimental plots) (Nyssen, 2001), effects of excessive stone removal (Nyssen et al., 2001), as well as spatial and temporal behaviour of soil moisture around the bunds (Van Campenhout et al., 2004) were investigated. Possible side-effects related to runoff concentration were recorded along 4 km of stone bunds in various topographic positions (Van Campenhout, 2003).
Spatial variation of crop yield was measured in 143 plots in the (relatively dry) year 2002, and weighed against space occupied by bunds (Desta, 2003).
Participatory studies in 6 villages allowed to assess farmers' participation in, and acceptance of stone bunds (Gebremedhin, 2004). Naudts (2002) stayed in the house of a local farmer for about one month, in two villages. Participation in different agricultural activities, as well as several group discussions and 87 individual interview sessions, allowed to have a clear idea of the farming practices in these villages, as well as of the perceptions of the farmers with respect to soil conservation measures. Possibilities of introducing agroforestry trees on these stone bunds were studied by Hailu (2003) and are currently tested in the framework of the May Zegzeg Integrated Watershed Management Project (Nyssen & Amanuel, 2003).

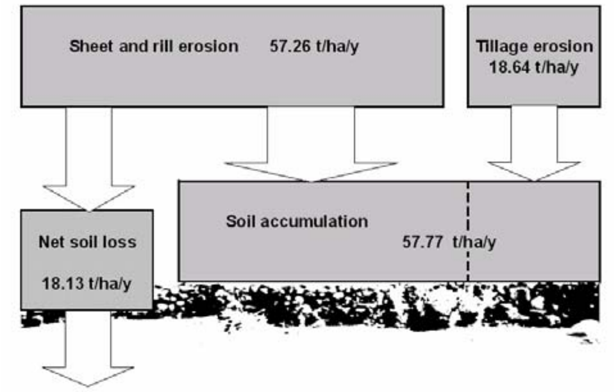

Figure 4. Average sediment budget for cropped plots with stone bunds in Tigray Highlands. 76 % of the total soil loss is trapped by the bunds. Tillage erosion is mainly induced by the bunds so that the effective soil loss reduction by the bunds is 68% of the soil loss due to sheet and rill erosion. 18 t ha^{-1} yr^{-1} of soil is still lost from the cropland treated with stone bunds. (After Desta et al., 2004)

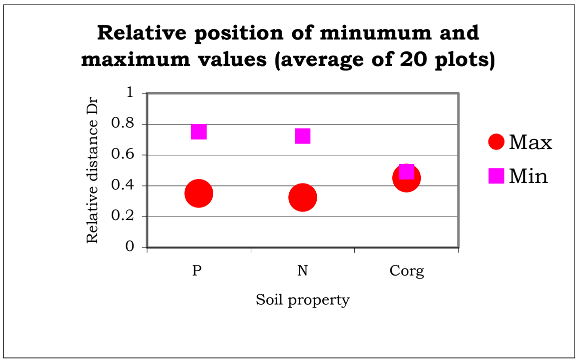

Figure 5. Relative position in the plot for the average minimum and maximum values of three soil fertility parameters. The closer these values are to each other, the less is the soil fertility gradient expressed. (After Van Campenhout et al., 2004)

Results and discussion

Based on measurements on 202 plots, average sediment accumulation rate behind stone bunds is 58 t ha^{-1} y^{-1}. The difference between the total mean annual soil loss due to sheet and rill erosion (57 t ha^{-1} y^{-1}) as well as tillage erosion (19 t ha^{-1} y^{-1}) and the mean annual sediment accumulation beyond the bunds is the net soil loss or the current soil loss on the cropland treated by stone bunds (Figure 4). Considerable amounts of soil are still lost from the cropland, on average 18 t ha^{-1} yr^{-1}. The Universal Soil Loss Equation's P-factor for stone bunds was estimated at 0.32. One-metre-wide grass strips proved as effective as stone bunds to control soil erosion on slopes <0.1, but accumulation rates were less than half of those behind stone bunds on slopes of 0.25-0.3. Sediment accumulation volumes increase with slope gradient and bund spacing, but decrease with bund age. Especially when the depression behind the bunds gets filled with sediment, their trapping efficiency strongly decreases.
Truncation of the soil profile at the lower side of the bund does not lead to important soil fer-

tility decrease at the upper side of the plot (Figure 5), mainly because the dominant soil types in the study area (Regosols, Vertisols and Vertic Cambisols) do not have pronounced vertical fertility gradients.

Stone bunds enhance soil moisture storage on both sides of the bund, especially on loamy and sandy soils, as well as deeper in the profile; 0.05-0.1 g g^{-1} more soil moisture at a depth of 1-1.5 m persists for at least two months after the end of the rainy season (Figure 6).

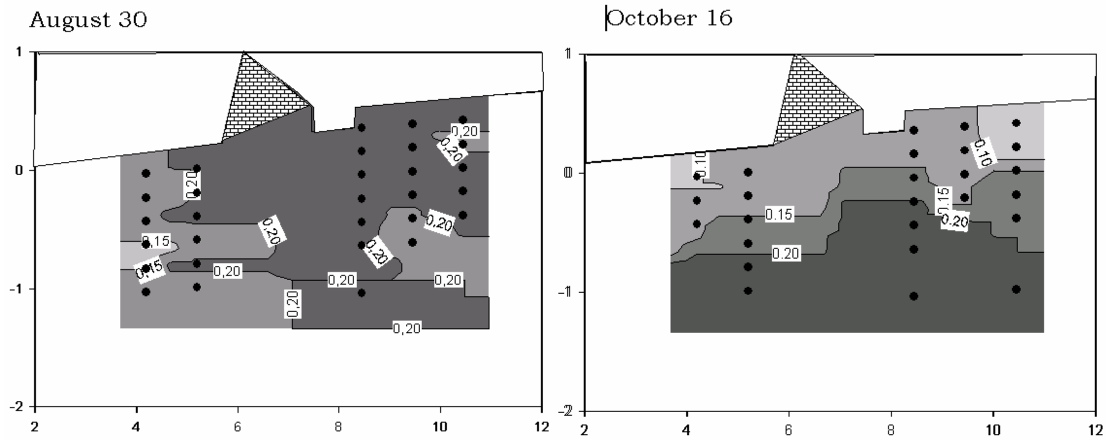

Figure 6. Especially in limestone areas, soil moisture is enhanced up- and downslope of the bunds (darker colour on the cross-sections) and residual moisture stays high several months after the end of the rainy season (right). Black dots correspond to the position of samples analysed for moisture content (g g^{-1}); curves were interpolated between these points. (After Van Campenhout, 2003)

In some cases, stone bund building leads to excessive removal of small stones from the field surface (Figure 7) and hence to an up to threefold increase in water erosion rates (Table 1). However, the resulting positive relationship between rock fragment cover and grain and straw yield was weak. This might be explained by the fact that the experimental plot did not suffer from drought in the years when the experiment was carried out, due to soil and climatic conditions. Detailed analysis showed that cover by medium and large rock fragments (> 2 cm diameter) showed an optimal percentage cover above which crop yields decrease. The use of stone rich soil, rather than stones, as backfill for bunds alleviates the problem of rock fragment cover removal.

Figure 7. Stone collection for stone bund building (After Nyssen et al., 2001)

Treatment[b]	Rock fragment cover[c] (%)	Slope gradient (m m^{-1})	Soil flux by runoff (kg m^{-1} yr^{-1})
all	0.6	0.13	27.4
	(+/- 1.3)	(+/- 0.01)	(+/- 5.7)
half	13.8	0.12	19.6
	(+/- 2.4)	(+/- 0.02)	(+/- 10.4)
control	18.1	0.12	8.7
	(+/- 3.7)	(+/- 0.01)	(+/- 4.6)

[a] Means of treatments (st. dev. between brackets); [b] Treatment given to the subplots at the start of the experiment. all = all rock fragments removed; half = 50 % of the rock fragments removed; control = no rock fragments removed.
[c] Rock fragment cover measured on 27.5.1999, i.e. just after the first tillage operation.

Table 1. Soil fluxes due to water erosion on experimental plot for stone removal in 1999[a] (After Nyssen et al., 2001)

Negative effects of runoff concentration or crop burial due to bunds (Figure 8) were only found over 60 m along 4 km of studied bunds, which is, according to the farmers, much less than damage by rill erosion before bund building.

Protection from the soil against erosion is the best-known advantage of stone bunds (cited by about 90 % of the interviewed farmers). Accumulation of (often very fertile) sediments and the improved infiltration of runoff water are answers that are given by about 20 % of the interviewed farmers. The most cited (26 %) disadvantage of stone bunds is the fact that they attract rats. In the village of Agerba (on basalt), 18 % of the farmers estimate that the stone bunds take too much place in the middle of their fields. The farmers of Hechi (on limestone) did not give this answer. Table 2 shows that a majority of the farmers in the Tembien Highlands realises maintenance works on the stone bunds in their fields (79 % in Agerba, 93 % in Hechi). A third topic concerned the willingness to accept an additional stone bund in the middle of a field of arable land. The overall farmer's perception of stone bunds is presented in Table 3.

This year, did you do some maintenance works on the stone bunds in your fields (rebuilding collapsed parts, arranging stones,….) ?			
	Village of Agerba (n = 33)	Village of Hechi (n = 28)	Total (n = 61)
Maintenance	26 (78,8 %)	26 (92,9 %)	52 (85,2 %)
No Maintenance	7 (21,2 %)	2 (7,1 %)	9 (14,8 %)

Table 2 . Farmers' attitudes towards stone bunds (After Naudts, 2002)

	Village of Agerba (n = 33)	Village of Hechi (n = 28)	Total (n = 61)
Positive	20 (60,1 %)	26 (92,9 %)	46 (75,4 %)
Negative	13 (39,4 %)	2 (7,1 %)	15 (24,6 %)

Table 3. Synthesis : Farmers' perceptions of stone bunds (After Naudts, 2002)

On plots with stone bunds (between 3 and 21 years old) there is an average increase in grain yield of 53 % in the lower part of the plot, as compared to the middle and upper parts (Figure 9). Taking into account space occupied by the bunds, they have nevertheless led in 2002 to a yield improvement from 0.584 to 0.65 t ha^{-1}. At current density, maintenance rates and building expenditure, stone bund building costs 4.7 € ha^{-1} y^{-1}, significantly less than the financial benefits from yield improvement (13.2 € ha^{-1} y^{-1}). Moreover, the enhanced moisture storage in deep soil horizons indicates that, with controlled grazing, the stone bund areas can be made more productive through tree planting, as proven in a participatory experiment introducing agroforestry on stone bunds.

Figure 8. Crop burial due to rapid accumulation of sediment behind a stone bund near Hagere Selam. Though impressive, this occurs only along 1.2 % of the stone bunds.

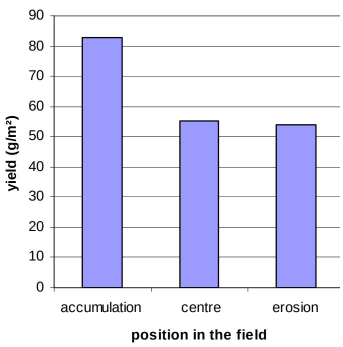

Figure 9. Comparison of average grain yield (g m^{-2}) on the accumulation zone, the middle zone and the soil loss zone of a plot bounded by stone bunds (n = 150) (After Desta, 2003).

Figure 10. The building of stone faced trenches, i.e. stone bunds along tied ridges, allows the use of stone rich soil as backfill for the stone bunds and enhances infiltration.

Conclusions

From the technical, ecological and economical point of view, the extensive use of stone bunds, involving people's participation, is a positive operation. Soil loss by sheet and rill erosion is decreased by 68 %, infiltration enhanced and crop yields slighly improved.

A recommendation resulting from the study on stone removal is to rely on the farmers' experience: smaller rock fragments should never be removed from the fields' surface during soil and water conservation works; instead rock fragment rich soil can be used to top the stone bunds. This is done in case of 'stone faced trench' building (Figure 10).

Overall, 75.4 % of the farmers are in favour of stone bund building on their land, which is a clear indication that the local community perceives this conservation measure as being beneficial.

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