Evidence-based Soil Conservation Measures that Improve Soil Physical and Chemical Properties and Barley Yield

Soil degradation can be described as a reduction of resource potential by a combination of processes, such as soil erosion by water and wind, acting on the land and bringing about deterioration of the physical, chemical, and biological properties of soil (Maitima and Olson, 2001). Land degradation is a major environmental problem in Ethiopia and it is manifested mainly in the form of soil erosion, gully formation, soil fertility loss, and crop yield reduction. Some forms of land degradation are the result of normal natural processes of physical shaping of the landscape and high intensity of rainfall.

The scale of the problem, however, has dramatically increased in Ethiopia because of increase in deforestation, overgrazing, over-cultivation, inappropriate farming practices, and increasing human population pressure. The dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is an underlying cause of degradation of land and other natural resources (EPA, 1998). Removing vegetative cover on steep slopes for agricultural expansion, firewood and other wood requirements as well as for grazing space has paved the way for massive soil erosion.

Forest cover in the Ethiopian highlands as a whole is estimated to have decreased from 46% to 2.7% of the land area between the 1950s and the late 1980s (USAID, 2004). It is also estimated that more than 1.9 billion tons of soil are lost from the highlands of Ethiopia annually (EHRS, 1986). These highlands have, for millennia, been major centers of agricultural and economic activity. It has been estimated that around half the area of highlands (about 27 million ha) has been significantly eroded and over one-fourth has undergone serious erosion. Moreover, 2 million ha are considered permanently degraded and incapable of supporting cultivation (EHRS, 1986). In the Amhara Region, more specifically, soil loss due to water erosion is estimated to contribute 58% to total soil loss in the country (Tesfahun and Osman, 2003). This has already resulted in a reduction in an estimated agricultural productivity loss of 2% to 3% per year, taking a considerable area of arable land out of production. The situation is becoming critical because increasingly marginal lands are being cultivated, even on very steep slopes (Tesfahun and Osman, 2003).

The present study was conducted to investigate the effects of integrating physical and biological conservation measures on some soil physical and chemical properties and subsequently on the yield of crops in the Absela watershed of Banja Shikudad District in the West Gojjam Zone of the Amhara national regional state of Ethiopia.

The catchment and research approach

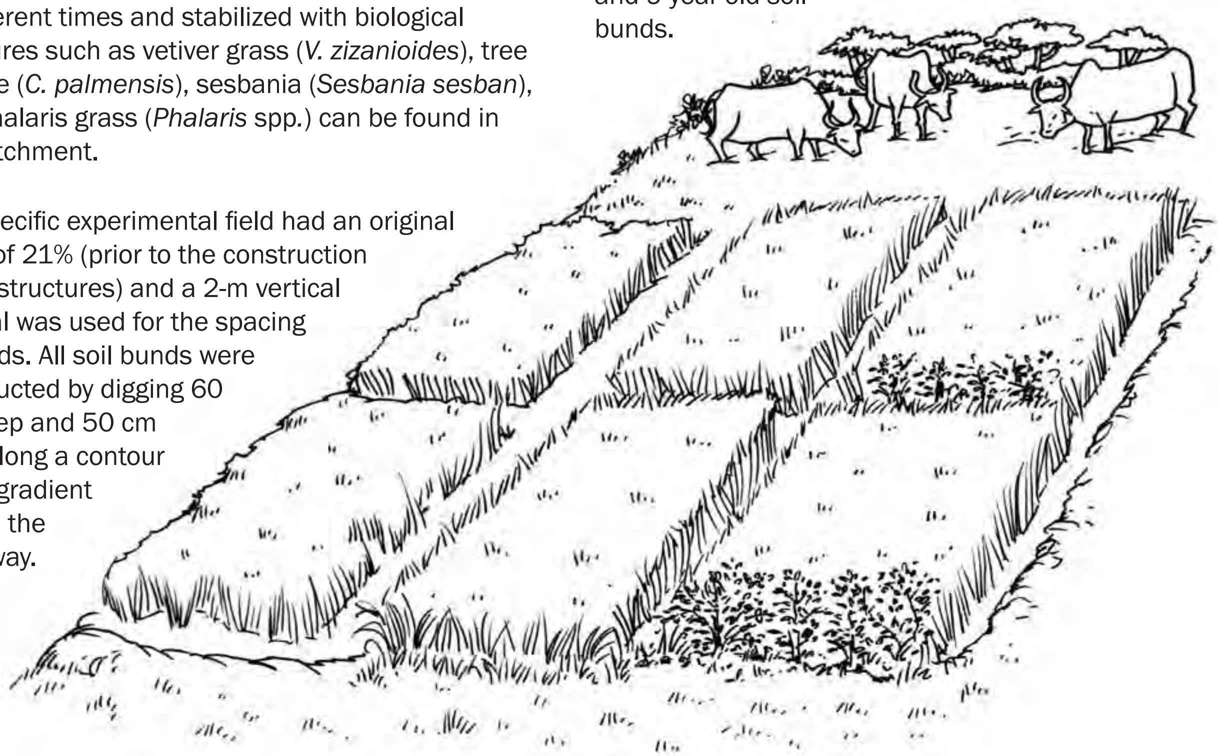
The catchment area was delineated in 1998 and different soil and water conservation (SWC) activities have been carried out since then. Soil bunds made at different times and stabilized with biological measures such as vetiver grass (*V. zizanioides*), tree lucerne (*C. palmensis*), sesbania (*Sesbania sesban*), and phalaris grass (*Phalaris* spp.) can be found in the catchment.

The specific experimental field had an original slope of 21% (prior to the construction of the structures) and a 2-m vertical interval was used for the spacing of bunds. All soil bunds were constructed by digging 60 cm deep and 50 cm wide along a contour at 1% gradient toward the waterway. The soil that was thrown downhill was used to make embankments having a bottom width of 75 cm and a top width of 50 cm. Where the bunds were stabilized with vetiver, tillers of the same were planted at the upper position of the soil bund with a spacing of 30 cm in a single row, and where it was stabilized with lucerne tree, seedlings were planted at the top of the soil embankment with 50-cm spacing in a single row (Tadele *et al.*, 2011).

The vetiver tillers and lucerne seedlings were planted in the main rainy season in the same year as the structures were installed. The trees used to stabilize the bund were pruned each year before the onset of the main rainy season to avoid the shading effect after they mature. The pruned materials were largely used as fuel wood, fodder for cattle, and sometimes as fencing material. Some of the fallen plant parts were sometimes added to the soil. However, there were also some bunds with no trees planted around them and some areas of land that were not terraced. The latter were used as control plots for the experiment.

The research approach consisted of an analysis of plots with five different treatments, replicated four times.

These were control (non-conserved plots), 6-year-old soil bunds with lucerne tree, 9-year-old soil bunds with lucerne tree, 9-year-old soil bunds with vetiver, and 9-year-old soil bunds.



Results

Organic matter and total nitrogen

The non-conserved plots had the lowest mean value of organic matter when compared with all the other plots with some kind of treatment. Conserving soil using soil bunds or integrating soil bunds with biological measures significantly improved soil organic matter (Table 1). The major reasons for the buildup of organic matter in the conserved plots were the reduction in slope height, the significant decline in the speed of runoff, and the accumulation of organic matter in the interterrace space. Moreover, the addition of biomass from the bunds themselves improved the soil. Soil treated with conservation measures become an important sink of carbon, which, in turn, improve the soil physical and chemical properties and supply nutrients to the plants.

The result for total nitrogen content was similar and is linked to the finding on organic matter, since this is its major source. Generally, the inclusion of leguminous plant species on farmland improves soil fertility by improving the organic matter and total nitrogen contents of the soil through the addition of leaf litter and other parts of trees on top of the deposition of the nutrients in the interterrace spaces.

Bulk density and infiltration rate

The plots without any conservation were found to exhibit significantly higher mean bulk density than those with conservation measures. This could be attributed to the presence of higher organic matter in those soils (Table 1). Soils with high bulk density tend to restrict root penetration and hinder water and air transfer in the soil system. The 9-year-old soil bund and the 9-year-old soil bund stabilized with lucerne tree and vetiver had higher mean infiltration rates than the younger soil bunds and the untreated plots. Low infiltration rates are causes of exacerbated surface runoff and removal of nutrients from the soil system. This will eventually reduce soil organic matter, soil nutrients, and crop yield.

Interterrace slope and bund height

Sole soil bunds and soil bunds treated with biological measures reduced the interterrace slope more significantly than did the untreated fields (Fig. 1). The deposition of soil materials and debris on the upper position of soil bunds (usually called accumulation zone) increased the height of the bunds year after year, thereby reducing the interterrace slope between two successive structures. Differences in the length of time since the bunds had been installed also brought about a variation in interterrace slope. This meant that older bunds had a lower interterrace slope than younger ones. Specifically, the 9-year-old soil bunds had significantly lower interterrace slope than the 6-year-old soil bunds stabilized with similar plant species and the nontreated plots.

Similarly, the older soil bunds treated with or without vegetative measures had higher bund heights than the non-treated fields (Fig. 2). It was apparent that bund height was negatively correlated with interterrace slope.

Barley yield

Barley grain yields were higher in plots that were treated with soil bunds or soil bunds treated with biological measures compared with the untreated plots (Table 2). This could be associated with the accumulation of organic matter, total nitrogen, and probably other nutrients in the interterrace space, coupled with other desirable changes in the soil's physical and chemical properties brought about by the implemented conservation measures. Looking at the field yield performance, there was also a fertility

***Table 1**. Effects of SWC measures on physical and chemical properties of soil.**

Treatment	Organic matter (%)	Total nitrogen (%)	Soil bulk density (g cm^{-3})	Infiltration rate (cm h^{-1})
Control (nonconserved land)	1.577 d	0.125 c	1.38 a	0.24 b
6-yr-old soil bunds + lucerne tree	2.470 c	0.173 bc	1.26 b	0.28 b
9-yr-old soil bunds + lucerne tree	5.017 a	0.277 a	1.29 b	0.73 a
9-yr-old soil bunds + vetiver	3.306 b	0.215 b	1.25 b	0.82 a
9-yr-old soil bunds	5.478 a	0.284 a	1.27 b	0.88 a

**Means in a column followed by the same letter are not statistically different at $p \leq 0.05$.*

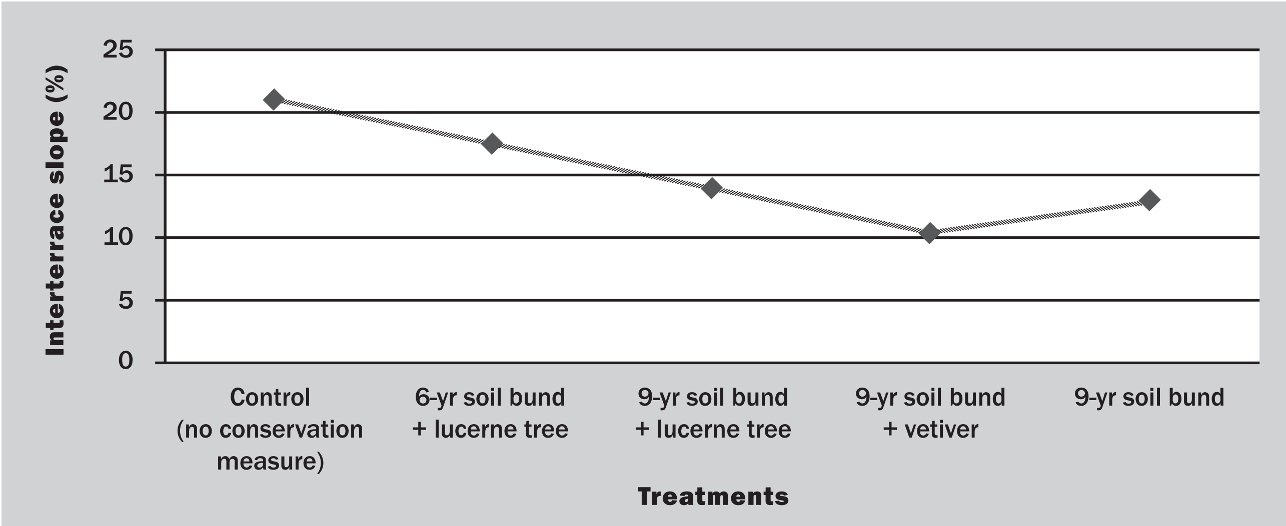


Fig. 1. *Effect of SWC measures on interterrace slope.*

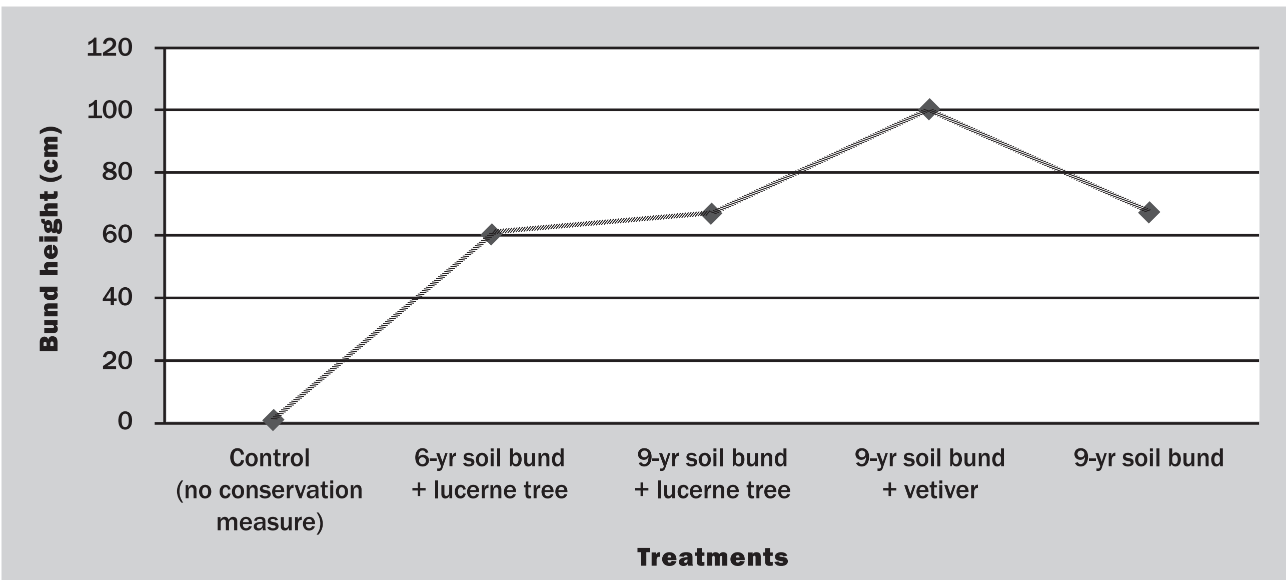


Fig. 2. *Effect of SWC measures on bund height.*

gradient within the interterrace space, and higher yields were recorded in the deposition zone than in the loss zone.

Challenges in implementing conservation measures

Not all farmers who lived and worked in the watershed were convinced of the benefits of the intervention. The result was that not all the fields were consistently treated with the conservation measures planned. Ironically, the lack of a consistent implementation provided the opportunity underlying this study of control plots. The other major challenge

Table 2. *Effects of conservation measures on grain yield and yield components at the soil deposition zone.*

Treatment	Grain yield (kg ha^{-1})*
Control (nonconserved land)	561.25 d
6-yr-old soil bunds + lucerne tree	1284.25 c
9-yr-old soil bunds + lucerne tree	1878.75 a
9-yr-old soil bunds + vetiver	1187.50 c
9-yr-old soil bunds	1712.50 b

* *Means in a column followed by the same letter are not statistically different at $p \leq 0.05$.*

was maintaining the structures, even those initially convinced sometimes damaged the bunds because they could not see any benefits directly in the short run. This is beginning to change as farmers in the neighborhoods of conserved land start to see the benefits over time. Similarly, free grazing, which was previously a major problem in maintaining biophysical structures, has recently decreased in importance as a constraint.

Conclusions and recommendations

Bund construction, integrated with biological measures, led to a reduction in slopes and generated a number of improvements in the soil. The study also recorded that the older bunds showed greater benefits. However, the bunds do not necessarily ensure the improvement of land productivity in the entire area unless agronomic and vegetative soil management practices are employed on the bunds. The highest yields were obtained in areas in which the soil settles—i.e., the accumulation zone—which shows the presence of a fertility gradient within the interterrace space. Among the benefits were improved nutrient content in the soil (i.e., organic matter and nitrogen content) and an increased ability of the soil to absorb rainfall (i.e., its infiltration rate). The conservation measures also decreased soil density.

Overall, the recommendations of the study are that degraded agricultural land should be rehabilitated through the implementation of integrated SWC measures (physical and biological). These will reverse degradation and increase the productivity of the land. Ideally, bunds should be stabilized with tree species, which should be pruned and the plant material incorporated into the soil for better effect. However, SWC measures will only be successful if farmers are involved at all stages, starting from planning through to monitoring and maintenance. In particular, bylaws that restrict the cutting of trees and free grazing are critically important if the benefits are to be sustained in the long term.

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