Efficiency of soil and water conservation practices in different agro-ecological environments in the Upper Blue Nile Basin of Ethiopia (Postprint)

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Abstract

In developing countries such as Ethiopia, research to develop and promote soil and water conservation practices rarely addressed regional diversity. Using a water-balance approach in this study, we used runoff plots from three sites, each representing a different agro-ecological environment, e.g., high, mid and low in both elevation and rainfall, in the Upper Blue Nile Basin of Ethiopia to examine the runoff response and runoff conservation efficiency of a range of different soil and water conservation measures and their impacts on soil moisture. The plots at each site represented common land use types (cultivated vs. non-agricultural land use types) and slopes (gentle and steep). Seasonal runoff from control plots in the highlands ranged 214–560 versus 253–475 mm at midlands and 119–200 mm at lowlands. The three soil and water conservation techniques applied in cultivated land increased runoff conservation efficiency by 32% to 51%, depending on the site. At the moist subtropical site in a highland region, soil and water conservation increased soil moisture enough to potentially cause waterlogging, which was absent at the low-rainfall sites. Soil bunds combined with Vetiveria zizanioides grass in cultivated land and short trenches in grassland conserved the most runoff (51% and 55%, respectively). Runoff responses showed high spatial variation within and between land use types, causing high variation in soil and water conservation efficiency. Our results highlight the need to understand the role of the agro-ecological environment in the success of soil and water conservation measures to control runoff and hydrological dynamics. This understanding will support policy development to promote the adoption of suitable techniques that can be tested at other locations with similar soil, climatic, and topographic conditions.

Full Text

Preamble

Efficiency of soil and water conservation practices in different agro-ecological environments in the Upper Blue Nile Basin of Ethiopia

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Abstract

In developing countries such as Ethiopia, research to develop and promote soil and water conservation practices has rarely addressed regional diversity. Using a water-balance approach, this study employed runoff plots from three sites representing different agro-ecological environments (high, mid, and low elevations and rainfall levels) in the Upper Blue Nile Basin of Ethiopia to examine runoff response and runoff conservation efficiency across various soil and water conservation measures and their impacts on soil moisture. At each site, plots represented common land use types (cultivated versus non-agricultural) and slopes (gentle and steep). Seasonal runoff from control plots ranged from 214–560 mm in the highlands, 253–475 mm in the midlands, and 119–200 mm in the lowlands. The three soil and water conservation techniques applied to cultivated land increased runoff conservation efficiency by 32% to 51%, depending on the site. At the moist subtropical highland site, soil and water conservation increased soil moisture enough to potentially cause waterlogging, which was absent at the low-rainfall sites. Soil bunds combined with *Vetiveria zizanioides* grass in cultivated land and short trenches in grassland conserved the most runoff (51% and 55%, respectively). Runoff responses showed high spatial variation within and between land use types, causing high variation in soil and water conservation efficiency.

Our results highlight the need to understand the role of the agro-ecological environment in the success of soil and water conservation measures for controlling

runoff and hydrological dynamics. This understanding will support policy development to promote the adoption of suitable techniques that can be tested at other locations with similar soil, climatic, and topographic conditions.

Keywords: agro-ecology; drought-prone; runoff coefficient; runoff conservation efficiency; Ethiopia

1 Introduction

Over the last three decades, the government of Ethiopia and a consortium of donors have invested substantial resources to develop and promote sustainable land management practices as part of efforts to improve environmental conditions, ensure sustainable and increased agricultural production, and reduce poverty [?, ?, ?, ?, ?, ?, ?, ?]. Major physical soil and water conservation techniques used in the country include short trenches, soil and stone bunds, cut-off drains, check dams, hillside terraces, area closures, Fanya juu (a Swahili term meaning 'throw uphill'), and Zai pits (a Burkina Faso term referring to pits that retain compost and direct water into the soil surrounding plants).

Recently, physical structures have been combined with biological measures such as vegetation establishment to protect soil against erosion [?]. However, despite these efforts, the sustainability of development work remains unclear. Due to low adoption rates, most promoted practices have been only partially successful, with some cases of disadoption or reduced use reported [?].

Past efforts to develop and promote soil and water conservation practices have neglected Ethiopia's pronounced regional diversity. [?, ?] found that intervention impacts were influenced by both measurement type and the agro-ecosystem under which they were implemented. Landscape, land use, soils, hydrological processes, and climate can be highly variable across regions, and their linkages to the success of environmental management practices are important aspects that must be understood and documented [?]. Additionally, [?] illustrated that the effectiveness of soil and water conservation practices depends on whether watershed runoff processes depend primarily on local ecosystem characteristics, topography, or a combination of the two. The suitability of any soil and water management practice depends greatly upon soil, topography, climate, cropping system, and resources available to farmers [?]. Overall, an agro-ecological approach can contribute substantially to sustainable agricultural intensification, but this must be supported by improved knowledge of optimal conservation measures for each combination of site type and land use [?].

In Ethiopia, rainfall distribution and amount show great spatial and temporal variation strongly influenced by altitude [?, ?, ?]. [?] suggested that temperature (determined by altitude) and rainfall are the two most important climatic factors affecting land management from farmers' and development agents' perspectives. [?] developed general soil and water conservation guidelines noting that climate varies greatly within Ethiopia, ranging from dry to wet and covering elevations from lowlands to highlands. Consequently, the same soil and water conservation techniques cannot be applied everywhere. This conclusion was based on a feasibility study of different physical conservation measures tested in micro-watersheds (soil conservation research sites) in different agro-ecology systems monitored 25 years ago [?].

Gradually, a few agro-ecology-based studies have emerged, but most focused on evaluating socioeconomic aspects [?, ?, ?, ?, ?]. Studies on conservation efficiency are few and have concentrated on combining a single agro-ecology with a specific conservation measure [?, ?, ?, ?, ?, ?]. However, these studies lack detailed information about hydrological dynamics created by conservation efforts across a range of land use, cover types, and slope classes. Best management practices should encompass measures that are useful, proven effective, cost-effective, and generally accepted among conservation experts and ultimate users for specific agro-ecology systems. Hence, critical analysis of runoff responses and efficiency of available measures under different agro-ecology systems is needed to evaluate which sustainable land management interventions are most likely to succeed in a given location. This suggests a need for analyses examining interactions between various location-specific factors. Such observations will provide greater insight into how soil and water conservation affects hydrological processes under different agro-ecology systems.

To address some of this knowledge gap, we used plot-level runoff measurements and hydrological analyses at three different agro-ecological sites in the Amhara and Benishangul Gumuz administrative regions of Ethiopia. Our objectives were (1) to analyze the spatial variability of rainfall-runoff relationships and their controlling factors, and (2) to determine the ability of different soil and water conservation practices to reduce runoff and improve soil moisture availability in typical agro-ecology systems in the Upper Blue Nile Basin of Ethiopia.

2.1 Study area

We established experimental runoff plots representing different land use and cover types and slope gradients at three experimental sites (Fig. 1 [Figure 1: see original paper]): the Guder and Aba Gerima watersheds from the Fagita Lekoma (10°57 -11°11 N, 36°40 -37°05 E) and Bahir Dar Zuria (11°25 -11°55 N, 37°04 -37°39 E) districts, respectively, of the Amhara Region, and the Dibatie watershed from the Dibatie District (10°01 -10°53 N, 36°04 -36°26 E) of the Benishangul Gumuz Region. These sites were selected to represent three important agro-ecology systems in the Upper Blue Nile Basin with different annual precipitation, elevation, experiences with soil and water conservation, soil erosion rates, and land use types (Tables 1 and 2).

Each study site has been part of the national government's regular extension programs and other public-based soil and water conservation interventions, though experiences with externally funded programs have varied greatly [?]. The Aba Gerima watershed has been part of the Water and Land Resource Centre, funded by the Swiss Agency for Development and Cooperation, since 2011. The Guder watershed received support for soil and water conservation initiatives from the World Bank under the Sustainable Land Management Programme since 2008. Dibatie has had no external funding support for conservation projects.

The major and most common soil and water conservation measures implemented in the Upper Blue Nile Basin of Ethiopia include soil bunds (raised soil embankments created by moving ditch material downhill to block water flow), Fanya juu (raised soil embankments created by moving ditch material upslope), short trenches (excavated along the contour on hillsides), and soil bunds combined with vegetation establishment to protect the soil [?] (Fig. 2 [Figure 2: see original paper]). Soil bunds and Fanya juu were constructed by building soil walls (about 0.5–1.0 m high) along the contour, with similar dimensions of 1.6 m wide and 6.0 m long, with variable spacing depending on land use and slope. Soil-faced short trenches were constructed by excavating trenches 0.5 m deep, 1.4 m wide, and 1.5–2.5 m long, with 1.7 m spacing between trenches along the contour.

Although the overall slope at each site does not change, the effective slope length (the distance between conservation structures) decreases. The principle is to reduce the speed of flowing water when it contacts each structure and the volume of water that reaches the slope downhill of that structure, thereby reducing runoff volume. Soil and water conservation measures are applied to both even and uneven grounds in the Upper Blue Nile Basin using different designs.

2.2 Instrumentation and data collection

Each study site was equipped with a temperature sensor and datalogger (Mini-diver, Schlumberger Water Services, Netherlands) and one manual rain gauge. The datalogger was programmed to measure maximum and minimum air temperature at 10-minute intervals. We screened this data by extracting the maximum and minimum temperatures from 144 daily readings and calculated a daily average temperature, which we used to calculate potential evapotranspiration at each site. The rain gauge recorded daily rainfall during the rainy season from June to October 2015. More than 86% of regional rainfall is concentrated in these months [?].

We measured runoff at the plot scale using 42 runoff plots (30 m long × 6 m wide each) across the three agro-ecology systems: 18 at Guder, 12 at Aba Gerima, and 12 at Debatie. We used four treatments for cultivated land on gentle and steep slopes, and two treatments for non-agricultural land on steep slopes. Each agro-ecology system comprised cultivated land in two slope ranges (5% and 15%), grazing land (15% slope), and degraded bush (35% slope) plots. The Guder site had two additional main land use types: *Acacia decurrens* plantations (5% and 25% slopes) and *Eucalyptus* spp. plantations (25% slopes). We divided plots into gentle slopes (<15°) and steep slopes ($ $15°).

Each cultivated land plot had a different soil and water conservation treatment (soil bund, Fanya juu, soil bund with vegetation establishment, and a control without treatment). Each non-agricultural land use type (grazing land, degraded bush, *A. decurrens* plantations, and *Eucalyptus* spp. plantations) had two treatments (short trenches and control). Based on the availability of sufficient soil and plant species and ongoing sustainable land management practices, details of the soil bund with vegetation establishment treatment varied among sites. In Guder cultivated land plots, soil bunds were reinforced and stabilized by planting vegetation such as tree lucerne (*Cytisus proliferus*) and densho grass (*Pennisetum pedicellatum*) together, whereas elephant grass (*Pennisetum purpureum*) and vetiver grass (*Vetiveria zizanioides*) were planted at the Aba Gerima and Debatie sites, respectively.

At the lower end of each plot, we excavated a 9.7-m^3 pit with a trapezoidal cross-section (Fig. 3 [Figure 3: see original paper]) and lined it with impermeable geomembrane plastic to collect sediment and runoff. The pits were designed to accommodate maximum runoff from extreme rainfall events, predicted using anticipated rainfall (based on historical records at the nearest meteorological station) and a runoff coefficient of 46% [**?**, **?**]. Runoff depth corresponding to each daily rainfall event was recorded and used for runoff analysis. We established an equation relating water depth in the pit to pit volume by adding known water volumes. Based on this relationship, runoff volume was calculated from runoff depth measurements taken every morning at approximately 08:00 LST using a measuring tape at an average of six points in the pit to account for depth variations due to bottom irregularities. Direct rainfall into the pit (estimated from rain gauges) was subtracted from the total. Plots were also bounded at the sides to prevent runoff and sediment inflow from adjacent areas using corrugated metal sheets inserted 15 cm into the ground and protruding 20 cm above ground (Fig. 3c). Finally, runoff depth was calculated by dividing the net runoff volume collected from the pit by the runoff plot area.

We determined various soil variables to characterize each site (Table 1). Three samples were taken from the top 30 cm of the soil profile at 10-cm intervals for each land use type and analyzed to determine texture using the hydrometric method [**?**]. The average of the particle-size distributions was used to characterize the site. Undisturbed soil samples were taken to 30 cm depth at 10-cm intervals using a 100 cm^3 core sampler to determine soil bulk density. Samples were oven-dried at 105°C for 24 hours and weighed. Bulk density was determined by dividing the weight of oven-dried soil by the soil core volume. Soil penetration resistance (SPR, kPa) was measured using a hand-operated soil cone penetrometer (Hand penetrometer, Eijkelkamp Company, Netherlands) with a 2-cm^2 cone base and a driving shaft graduated at 5-cm intervals. For each site, we calculated SPR as the average of 30 observations.

2.3 Data analysis

We analyzed plot data for seasonal runoff, runoff coefficient (RC), runoff conservation efficiency (RCE), and seasonal soil moisture availability. We quantified relationships between daily rainfall and runoff depth through regression analysis. RC was calculated by Equation 1:

$$RC = \frac{\text{Runoff depth}}{\text{Rainfall depth}} \times 100\% \quad (1)$$

Runoff conservation efficiency (RCE) in each plot was calculated relative to runoff in the corresponding control plot using Equation 2 [**?**, **?**]:

$$RCE = \frac{A - B}{A} \times 100\% \quad (2)$$

where A is runoff loss (mm) from the control plot and B is runoff loss (mm) from the corresponding plot with a conservation measure.

Seasonal moisture conservation efficiency was measured by the change in seasonal water availability analyzed for all runoff plots using the water-balance equation (Eq. 3; [**?**]):

$$\Delta S = P - Q - ET \quad (3)$$

where ΔS (mm) is the seasonal change in moisture stored in the soil (including deep percolation beyond the soil zone), P is seasonal precipitation (mm), Q is seasonal measured runoff (mm), and ET is seasonal evapotranspiration (mm). Since accurate field measurements are often difficult to acquire, evapotranspiration is usually estimated as potential evapotranspiration (PET). Given limited long-term meteorological data for the study watersheds, we used the temperature-based method (Eq. 4) developed by [**?**] to calculate PET:

$$PET = 0.0023 \times (T_{mean} + 17.8) \times (T_{max} - T_{min})^{0.5} \times R_a \quad (4)$$

where R is solar radiation (mm/day) estimated based on the approach suggested by [**?**], T is daily maximum temperature (°C), and T is daily minimum temperature (°C).

3.1 Runoff variability within and between agro-ecology systems

Table 3 summarizes cumulative rainfall, cumulative runoff during the rainy season, RC, and RCE for all plots. Seasonal rainfall totaled 1568 mm for Guder, 1402 mm for Aba Gerima, and 881 mm for Debatie. Seasonal runoff from control plots ranged from 214–560 mm in the Guder watershed, 253–475 mm at Aba Gerima, and 119–200 mm at Debatie. The highest runoff was 560 mm in grazing land control plots on steep slopes at Guder (GR2), and the lowest was 81 mm in short trench plots on steep slopes at Debatie (DB2). Cumulative runoff was lowest at Debatie, the site with by far the lowest precipitation. Changes in precipitation regimes clearly have the potential to profoundly affect runoff and soil erosion. [?] confirmed that precipitation has a linear relationship with runoff and soil erosion, with little difference in runoff response to changes in storm frequency or intensity.

The grazing land site on a steep slope (GR2) generated the highest seasonal runoff at Guder (560 mm), followed by the same site type at Aba Gerima (475 mm) and Debatie (134 mm). The high runoff in Guder might be related to frequent animal trampling because the site was used for grazing livestock. As a result, we found compacted topsoil surfaces in grazing lands, with the highest soil penetration resistance (SPR ranging from 1990–2210 kPa), versus a maximum of 1100–1660 kPa for other land use types. This reduced infiltration and thereby increased runoff. A similar analysis for the Upper Blue Nile Basin showed that cattle on wet grazing soils caused additional compaction in the top 30 cm soil layers [?], leading to higher runoff production.

Although higher surface runoff is expected from control plots on steeper slopes (35%), surface runoff from degraded bush plots was lower than that from other land use types, except for cultivated land at Aba Gerima (Table 3). This can be explained, on one hand, by the direct effect of raindrop interception by the vegetation canopy, which dissipates energy and creates infiltration pathways [?, ?, ?]. On the other hand, vegetation decreases runoff indirectly by improving soil physical properties through organic matter incorporation (16.7% in Guder; [?]) and soil loosening by growing roots, thereby increasing infiltration rate [?]. [?] explained this differently, reporting that RC decreased with increasing slope due to higher coarse particle content in the soil, which promoted infiltration. Similarly, [?] illustrated that for saturation-excess runoff, water infiltrates on hillsides while erosion-inducing runoff occurs in flatter, downslope landscape parts. This, in turn, affects hydrology, as excess water flows more rapidly to valley bottoms as lateral flow, leading to gully formation [?]. All these factors may have combined to overwhelm the slope effect.

3.2 Variability of rainfall-runoff responses within and across the three agro-ecosystems

Considering interactions between soil and water conservation measures and the two dominant land use types—cultivated land on steep slopes (CL2) and grazing land (GR2)—we calculated rainfall thresholds required to generate runoff for both at each agro-ecology system (Fig. 4 [Figure 4: see original paper]; Table 4). Threshold rainfall can be determined by plotting daily runoff depth against corresponding rainfall depth (Fig. 4) and performing least-squares regression [?, ?]. The slope of the regression line represents how rapidly runoff depth increases with rainfall depth after exceeding the rainfall threshold. Threshold rainfall values were selected based on the probability that 80% of events below the threshold level would fail to produce runoff. Higher rainfall thresholds and lower curve slopes indicate higher infiltration rates and greater soil storage capacity in the agro-ecology system [?, ?].

The largest rainfall event was 97 mm at Guder, versus 78 mm at Aba Gerima and 53 mm at Debatie. In the Guder watershed, rainfall threshold values for runoff generation were 6 mm and 5 mm in cultivated land (CL2) and grazing land (GR2) on steep slopes, respectively (Table 4). For the same land use types, the largest threshold values were obtained at Dibatie and Aba Gerima sites, with thresholds exceeding 10 mm and 9 mm, respectively. The slope of the rainfall-runoff curve also varied widely among plots, with values of 0.10–0.45. Soil and water conservation practices using vegetated soil bunds and short trenches in cultivated and grazing land plots resulted in lower curve slopes than corresponding control plots at all three sites (Table 4), attributable to runoff storage in depressions and slowed runoff flow by conservation structures.

Runoff response to rainfall at the moist subtropical site (Guder) began sooner (i.e., lower rainfall threshold) than at the humid subtropical (Aba Gerima) and tropical hot humid (Debatie) sites (Table 4). [?] reported that Guder receives long-lasting rainfall events with small amounts, yet has a longer rainy season than other western and central highland sites, with a higher proportion of rainfall (63%) from light events that influences subsequent soil moisture availability. Additionally, the heavy soils of the Guder watershed (Table 1) tend to retain moisture longer, which can lower threshold rainfall compared to other sites. Therefore, small precipitation increases could cause waterlogging and damage soil and water conservation structures if subsequent precipitation occurs as intense storms depositing more rain than the threshold value.

On average, rainfall threshold values at our study sites are higher than those in semi-arid regions of northern Ethiopia (the Tigray region). For example, [?] obtained threshold values ranging from 3–16 mm in plots with different land use types. Similarly, [?] reported that rainfall events >2 mm produced runoff in cultivated land, whereas events >3 mm produced runoff in grazing land and plantation areas. This illustrates lower vegetation canopy interception capacity at semi-arid sites and lower soil infiltration capacity in drier environments [?].

It is worth noting that experimental plot dimensions (5 m × 2 m and 10 m × 2 m in previous studies, much smaller than the present study) can strongly affect results, as runoff amount is strongly influenced by scale effects [?].

3.3 Effects of soil and water conservation measures on RC and RCE

Seasonal rainfall lost as runoff from control plots in the Guder watershed ranged from 14%-36%, versus 18%-40% at Aba Gerima and 14%-23% at Dibatie (Table 3), demonstrating high RC variability across the three environments. RC also differed between control and treatment plots at each site.

Monthly RC was highest in July and August for most treatments and decreased during September and October at all sites (Fig. 5 [Figure 5: see original paper]), explained by decreasing rainfall at the rainy season' s end combined with increasing vegetation cover during the rainy season, which would decrease runoff generation.

The knowledge provided by this study about RC of various land use types under different agro-ecology systems is essential for supporting runoff estimates from given watersheds under specific land uses. This can help land managers design appropriate water-harvesting structures such as drainage canals, waterways, and reservoirs, and predict flood hazards [?, ?].

At Guder, RCE of soil and water conservation measures ranged from 27%-47%, versus 25%-51% at Dibatie and 35%-55% at Aba Gerima (Table 3). Generally, the highest RCE was obtained for plots treated with soil bunds combined with vegetation establishment, based on the average for cultivated land. Soil bunds combined with vetiver grass (*V. zizanioides*) at Debatie were more effective (RCE, 51%) than those with tree lucerne (*C. proliferus*), densho grass (*P. pedicellatum*; RCE, 32%), and elephant grass (*P. purpureum*; RCE, 36%). In contrast, [?] obtained the lowest runoff values for soil bunds combined with elephant grass, followed by soil bunds combined with the legume species *Tephrosia* in northwestern Ethiopian highlands, and suggested that vetiver grass required a longer establishment period before efficient soil and water conservation. For non-agricultural land plots, the highest RCE (55%) was obtained in GR2 plots treated with short trenches at the Aba Gerima site. On average, establishment of soil and water conservation measures decreased runoff by 35%, 41%, and 42% at Guder, Dibatie, and Aba Gerima sites, respectively.

Thus, strong evidence indicates that adopting soil and water conservation practices can reduce runoff more in low-rainfall areas than in high-rainfall areas because dry soils have higher infiltration capacity than wet soils during the rainy season.

Higher RCE was obtained in all treatments on gentle slopes than in comparable treatments on steep slopes due to greater differences in runoff between treated and control plots. Generally, creating short trenches and soil bunds combined with vegetation establishment produced better runoff reduction than other practices, especially in grazing land and cultivated land.

3.4 Effects of soil and water conservation on soil moisture availability

The combination of distinctive agro-ecology system features, soil and water conservation practices, and associated hydrological processes affected seasonal water availability in the plots (Fig. 6 [Figure 6: see original paper]). Seasonal potential evapotranspiration values were 579 mm, 675 mm, and 732 mm for Guder, Dibatie, and Aba Gerima sites, respectively, determined by the [?] equation. Soil water availability (Fig. 6) obtained through the water-balance method ranged from 428-830 mm, 394-515 mm, and 7-124 mm for Guder, Aba Gerima, and Dibatie sites, respectively. These range differences can be attributed to variations in rainfall frequency (amount), soil type, runoff amount (Table 3), and potential evaporation among the different agro-ecology systems. On average, implementing soil and water conservation measures increased seasonal water availability by about 139 mm compared to control plots at Guder, versus 130 mm and 67 mm at Aba Gerima and Dibatie sites, respectively (Fig. 6). This indicates that infiltration and runoff dynamics were also influenced by slope length, because reducing slope length through conservation structure installation increased storage and thereby reduced runoff volume.

Our results indicated that areas with higher rainfall (e.g., Guder) had higher potential soil moisture and therefore a lower rainfall threshold to generate runoff. This decreased the conservation efficiency of various soil and water conservation practices (Table 3). Consequently, management practices played a more important role. It is more necessary to choose and design optimal structures for these sites—i.e., where more runoff occurs, there is greater sediment transport capacity. Hence, to control erosion and offsite sediment transport, soil and water conservation planners need to focus on safely disposing of runoff to avoid crop damage risk from flooding or increase sediment deposition opportunities from overland flow. This understanding helps balance soil erosion effects against the moisture retention/shedding effects of different measures.

[?] illustrated that runoff control requires careful consideration of soil and water conservation structure design in relation to site characteristics. For example, in sub-humid or wetter areas with high rainfall, managers must prioritize both soil conservation and drainage of excess water. Additionally, [?] reported that in wet areas, investments in soil and water conservation may not be profitable at the farm level, although there are positive social benefits from controlling runoff and soil erosion at regional levels.

Although many methods discussed in this paper have been tried in the study area, they have not been widely adopted and have sometimes been dis-adopted where implemented. To solve these problems, government and other stakeholders must increase knowledge transfer (extension) services to demonstrate successful technique use. Additionally, all conservation structures require ongoing maintenance. This agro-ecological classification and related information assists in utilizing research and field experience from one location for other places with identical soil, climatic, and topographic conditions.

4 Conclusions

This study provides an overview of hydrological dynamics and the effectiveness of soil and water conservation practices for reducing runoff under common agro-ecology systems in the Upper Blue Nile Basin of Ethiopia. These results can guide managers toward optimal soil and water conservation measure choices under specific site conditions. Our study revealed that runoff responses and runoff conservation efficiency to soil and water conservation practices were highly variable both within and between agro-ecology systems. This high variation could be attributed to several factors including soil type (permeability), land use types, soil water availability, runoff response to rainfall, and prevailing climatic conditions (precipitation and potential evapotranspiration). These practices were highly effective in controlling runoff in humid subtropical (Moist Weyna Dega) and tropical hot humid (Moist Kolla) agro-ecology systems, with average runoff reductions of 42% and 41%, respectively. The moist subtropical region (Guder) had higher potential soil moisture availability but a lower rainfall threshold to generate runoff. From these findings, implementing short trenches (humid subtropical) in grazing land maximized runoff conservation efficiency (55%) due to temporary water storage in short trenches followed by infiltration. In contrast, vegetated bunds would be most effective in cultivated land, and short trenches would be effective in the two plantation types.

Our results demonstrate the importance of studying each combination of agro-ecology system, site, and climate to scientifically determine optimal conservation measures for that combination, rather than making blanket recommendations for all systems that likely provide suboptimal results for many combinations. This understanding and the present results will help managers choose the most effective conservation measures based on field trials and test whether they will be equally applicable at other locations with similar soil, climatic, and topographic conditions.

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Note: Figure translations are in progress. See original paper for figures.