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Effects of rangeland based integrated soil and water conservation practices on herbaceous species regeneration, diversity, biomass and growth of planted tree species in Haro-Bake Sub-Watershed, Yaballo District, and Southern Ethiopia

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Rangeland degradation is a significant threat to people in dryland areas, particularly in Sub-Saharan Africa like Ethiopia. Rehabilitation of degraded land is challenging due to moisture limitations and drought. This study evaluated rangeland-based integrated watershed management. Three soil and moisture conservation structures were applied, and multi-purpose tree/shrub species like *Faidherbia albida, Melia azedarach*, and *Moringa stenopetala* were planted. Data on indigenous plant species regeneration, diversity, species richness and biomass, survival rate, and height growth of planted tree species were collected. After the intervention, the indigenous plant species' regeneration, diversity, and richness significantly increased. The mean indigenous plant species richness, biomass, and basal cover were highest in half-moon followed by soil level bund and, lowest in control. The survival rate and the height growth of all planted MPTs species were better under Negarim and half-moon and lowest under control treatments. This suggests that soil and moisture conservation structures are more suitable than the conventional method of rehabilitation of indigenous plant species and tree planting. Even though the survival and growth of tree seedlings were best under Negarim, the herbaceous diversity, biomass, and basal cover of herbaceous were low, and construction of this structure was labor incentives than the other two structures.

Key words*:* Rangeland degradation, rangeland-based watershed**,** rehabilitation, soil and water conservation, species diversity, survival rate, tree growth.

INTRODUCTION

Rangelands are defined ecologically as "land on which the indigenous vegetation is predominantly grasses, grass-like plants that are grazed and have the potential to be grazed, and which is used as a natural ecosystem for the production of grazing livestock and wildlife" (Allen et al., 2011). However, in social terms, rangelands relate to

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the management unit of extensive livestock keepers and comprise a broader range of ecosystems and other resource zones, such as forest, wetlands, and ecosystems (Davies et al., 2015). The rangeland ecosystem contributes significantly to global economic value by providing ecosystem services and biodiversity products.

Rangelands serve as the foundation for societal economic and environmental benefits, notably for pastoralist populations. Rangeland ecosystems support a high number of endemic species (plants and animals) that are particularly suited to the changeable and harsh circumstances of these places, which include diverse habitats such as deserts, forests and woodlands, savannahs and steppes, wetlands, ponds, lakes, and rivers (Environment Management Group of the United Nations (Emg, 2011; Reid et al., 2014; Louhaichi et al., 2022). Many cultivated plants and livestock breeds originate in drylands; providing a genetic reservoir whose importance is increasing as climate change drives the demand for new adaptations and extinctions of wild breeds (Davies et al., 2012).

These massive benefits of the rangeland ecosystem are currently declining from time to time due to land degradation. Land degradation is widespread and is a serious threat affecting the livelihoods of 1.5 billion people worldwide of which $^1/_6$ of people reside in drylands (Yirdaw et al., 2017). Increasing weather variability and climate change are contributing to land and natural resource degradation (Malo et al., 2012) which, results in the degradation of vegetation cover and loss of biodiversity, soil erosion, depletion of organic matter, reduced rainwater infiltration and water-holding capacity of the soil and loss of productivity and has effects on wider rangeland ecological functions. Consequently, watershed-based development planning has been adopted as a key strategy by the Government of Ethiopia.

A watershed is defined as any surface area from which runoff resulting from rainfall is collected and drained through a common confluence point. A watershed is made up of natural resources like water, soil, and vegetative factors, and socioeconomic aspects that include people, their farming system (including livestock) interactions with land resources, coping strategies, social and economic activities, and cultural aspects (Lakew et al., 2005). Watershed management is the implementation of management systems that ensure the preservation, conservation, and sustainable exploitation of land resources. Watershed management is seen as a major component for soil, water, and vegetative cover conservation, rural community living standards improvement, and better environmental conditions. Participatory watershed development and management emphasizes a multi-disciplinary and multi-institutional approach for multiple interventions for the sound management of assets within a watershed with community participation.

In Ethiopia, watershed-based development planting was started in the 1980s for natural resource conservation and development programs (Lakew et al., 2005; Worku and Tripathi, 2015). The initial large-scale watershed-based development planning remained mostly unsatisfactory due to a lack of effective community participation and unmanageable planning units. Later on, a bottom-up basis using smaller units and following community-based approaches was introduced; consequently, significant results were obtained to combat land degradation and food insecurity in several regions (Lakew et al., 2005). From the 1990s, watershed management operations not only targeted conservation of soil, water, and vegetation, but also typically targeted resource use productivity, livelihood improvements, and poverty reduction objectives in addition to resource conservation.

In the early stages, participatory watershed development planning in Ethiopia mostly targeted the settled agricultural communities found in highland areas rather than the pastoralist and agro-pastoralist communities found in lowland areas. The main goal of introducing watershed management practices in Ethiopia in early stages was to treat the hillsides of the watershed, including gullies, and reduce soil erosion. Currently, watershed-based natural resource management is being implemented across all agro-ecologies in the country. The commonly implemented physical soil and water conservation structures in Ethiopia were soil bunds, fanajuu, trenches, micro-basin basins, stone bunds, cutoff drains, and eyebrows (Wolka et al., 2015).

Watershed-based development planning was thought to be unsuitable for agro-pastoralist and pastoralist areas because they typically move along transhumance pathways for grazing and adaptation to climatic and environmental circumstances (Lakew et al., 2005). One of the most important causes impacting livestock feed shortage is rangeland degradation, which is indicated by the potential of natural pasture, which has the highest grazing value for livestock production (Abel, 1993). Various collaborative watershed development projects involving government and non-governmental organizations (NGOs) have been implemented in different Ethiopian states, including pastoral areas which are thought to have significant changes in animal output. The increased availability of forages as a result of diverse land management, improved utilization of common property resources, and improved livestock management techniques linked with watershed development have increased livestock output.

Since the early 1990s, the Borana system of pastoral production has been on the decline (Bekele and Kebede, 2014). To overcome the rangeland degradation, different rangeland management strategies were introduced in Borana rangeland. Community-based watershed development programs have developed in Ethiopia, including pastoral areas, as a comprehensive

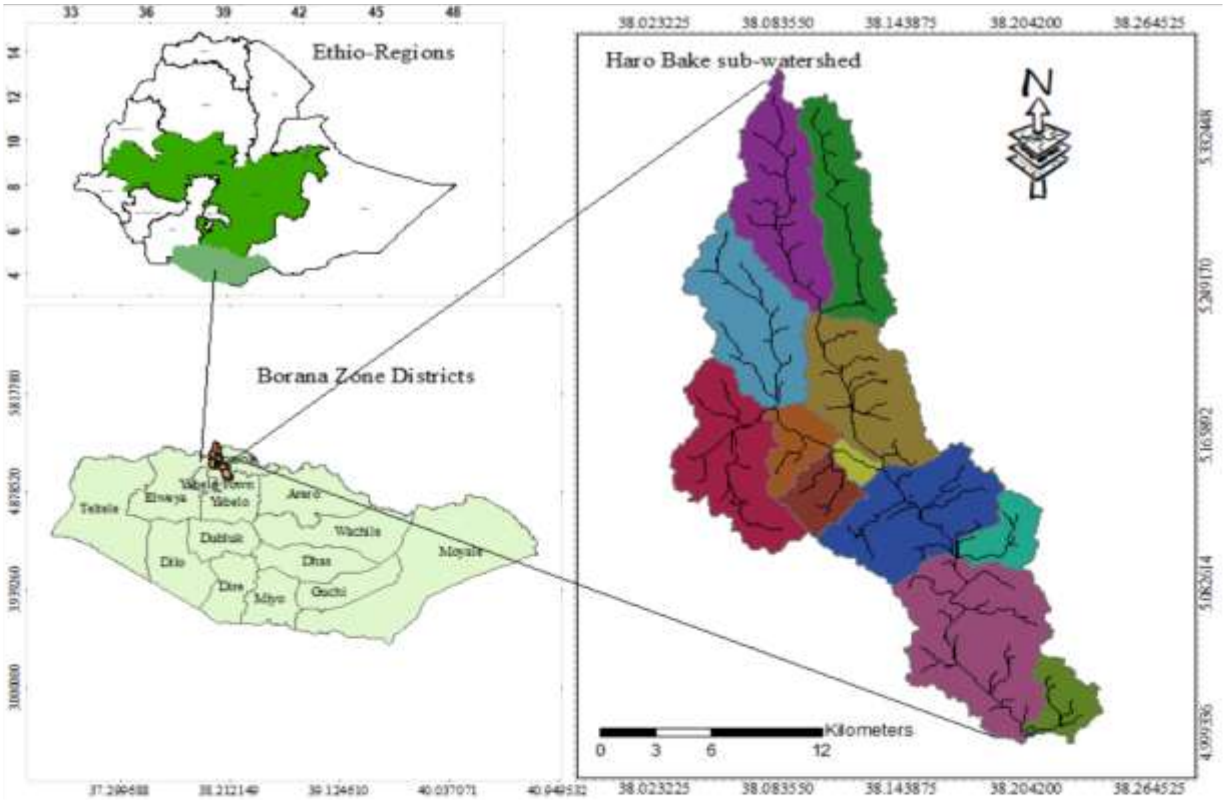

Figure 1. Map of the study watershed, and the layout of plots used for data collection.

development approach for the sustainable and effective use of natural resources for the benefit of the local community, with a focus on the rural poor. Different structures for conserving soil and water are not, however, tested in rangeland conditions. Therefore, it is necessary to research various Soil and Water Conservation (SWC) structures for the rehabilitation of native herbaceous plants and to enhance the survival of planted trees and shrubs in rangeland environments.

The choice of the Bake watershed for this research was made due to its catchment surrounding the Bake pond and the extreme degradation of the catchment. The rangeland-based watershed management project restored the micro watershed by establishing several soil and water conservation structures, such as soil berms, in response to the severity of the area's degradation.

Objectives

1) To restore degraded rangelands for improved forage production through the watershed management concept.
2) To evaluate selected soil and water conservation structures for indigenous herbaceous rehabilitation and growth and survival of planted tree species.
3) To create awareness of how to rehabilitate degraded rangeland on the watershed concept.

MATERIALS AND METHODS

Description of the study areas

Geographically speaking, the Borana zone is located between 36° and 42° E longitude and 4° to 6° N latitude (Figure 1). The Borana zone is located between 1000 and 1700 m above sea level and, is characterized by remote mountains and valleys (McCarthy et al., 2002; Coppock, 1994). The climate in Borana is classified as semi-arid to desert (Kamara et al., 2005; Haile et al., 2011), and there are 2 significant rainfall peaks: 59% of the annual precipitation falls between March and May and 27% between September and November (Coppock, 1994). Almost exclusively pastoral and agro-pastoral communities live in the topography, which is made up of isolated mountains, valleys, and depressions (Coppock, 1994).

For the Borana people, pastoralism is the primary source of income (Gelagay et al., 2007) and cattle, goats, sheep, and camels are important livestock species raised in the zone.

In the Borana zone, the Haro Bake sub-watershed was purposively selected. The watershed is geographically located in the Yaballo and Gomole districts of the Borana zone. The watershed catchment area elongated from the Yaballo district to the Dugda-dawa district of the West Guji zone. Within the sub-watershed, the micro-watershed was selected and delineated around Haro Bake Pond to demonstrate rangeland-based watershed management in the Borana condition. The rangeland around the pond is highly degraded due to high livestock entrance to the water point.

The livelihood of communities around the watershed was dominated by pastoralists (64%); however, owing to climate change the livelihood shift from the pastoral dominant household to a multi-income source was deep-rooted and emerged. During this study,

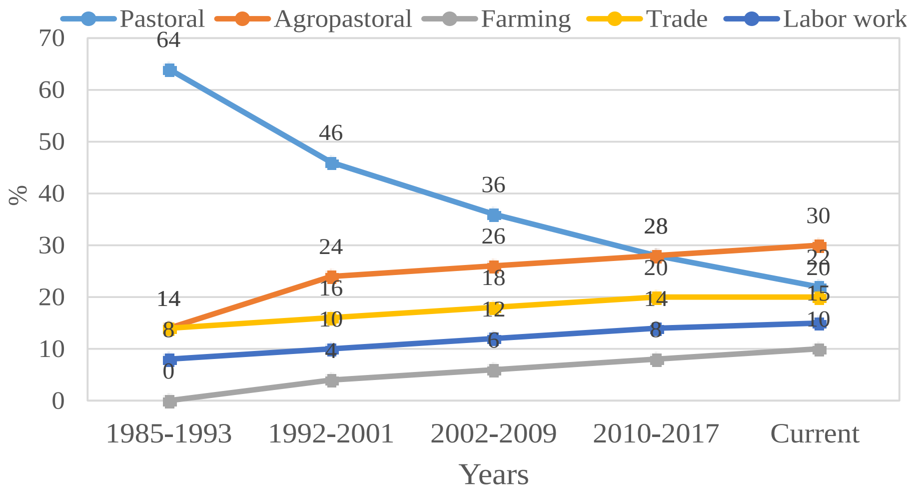

Figure 2. Trends of livelihood of communities around the Haro Bake watershed.

Figure 3. Stages of degraded land reseeding: a) Cultivation b) sowing c) germination stage d) vegetative stages e) harvesting.

the shift from pure pastoralism, agropastoralism, and trading was diluted with other income sources like labor work and other non-farm and non-pastoral income sources (Figure 2).

Method

Design of soil and water conservation structures

Four various soil and moisture conservation structures have been built in a chosen part of the watershed to assess the capacity of various soil and moisture conservation structures for moisture conservation. These various treatments were Negrium, half-moon, soil level bund, and control (only protecting from livestock instance). The chosen moisture conservation structures were set up using a randomized complete block design (RCBD) with three blocks/replications, each of which has four experimental plots. The experimental land was blocked along the slope of the geographic gradient and replicated three times.

In each plot and treatment, selected multipurpose tree species (*Melia azedarach*, *Faidherbia albida* and *Moringa stenopetala)* were planted at 2-m intervals during the main rain season. The species were selected based on their adaptability in the study area, growth performance, and their multi-functional benefits.

Management applied

Bush thinning

Bush encroachment is one of the major problems that affect rangeland productivity in Boran rangelands. The other factor affecting grass production in the watershed is the increasing density of woody plant species which reduces the production of grass species. Therefore, to facilitate grass biomass production bush management /thinning of unwanted bush plant species has been done. Some of the encroaching species thinned were *Acacia mellifera (*Saphansa gurraacha*)*, *Psiadia incana (*Qaxxee*)*, *Commiphora africana* (Hammeessa), *Euphorbia nubica* (Aannoo) and others *Acacia* species*.*

Reseeding

Areas within the watershed are highly degraded and they could not be rehabilitated from soil seed banks. They were re-seeded using two grass species recommended for degraded land rehabilitation in Boana condition. Rhodes grass (*Chloris gayana*) and *Cenchrus ciliaris* were the types of grass that were used reseeding. The stage of reseeding started with mechanical cultivation to increase the soil's moisture content in the root zone and to create a niche for the growth of indigenous and/or exotic plants (Figure 3).

Protections

The selected micro watershed areas have been protected from livestock entrance for the entire five years of the project period; however; wildlife like lesser kudu (*Tragelaphus imberbis*) and Grévy's zebra (*Equus grevyi*) have invaded and highly interfered with the vegetation during the dry season.

Table 1. Trends of plant species richness, evenness and diversity with management intervention (Means ± SE).

Variable	Species richness	Individuals	Shannon	Simpson 1-d	Evenness
Before inter.	4.75 ± 1.19[b]	9.25 ± 8.83[b]	1.38±0.61[b]	0.70 ± 0.04[b]	0.90± 0.03[a]
2015	13.75 ± 1.19[ab]	48.5 ± 8.83[ab]	2.25 ± 0.61[a]	0.85 ± 0.04[a]	0.72± 0.03[a]
2017	12.50 ± 1.19[ab]	49.75 ± 8.83[ab]	2.23 ± 0.61[a]	0.86 ± 0.04[a]	0.75± 0.03[a]
2018	26.75 ± 1.19[a]	222 ± 8.83[a]	2.44 ± 0.61[a]	0.84 ± 0.04[a]	0.45 ± 0.03[b]
P value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Data collection

Herbaceous plant species sampling

For the aim of gathering information on tree, shrub, and herbaceous species, multipurpose plots with nested square forms and dimensions of 20 m × 20 m and 1 m × 1 m are utilized. The plots were meticulously placed along the transect lines at intervals of roughly 100 m down the slope of the watershed. The biggest plots (20 m × 20 m) were used to collect information on the tree species, while the 1 m × 1 m plots, which were put along the largest plot's four corners and center, were used to sample seedlings, herbs, forbs, and grass species, as well as biomass. Data have been collected each year during the flowering stages following the main rainy seasons.

The herbaceous biomass was determined using destructive techniques. Following species identification, individual entire herbs, grasses, seedlings, and climbers were clipped to the ground in 1-m × 1-m subplots as grass and non-grass. Using a field balance, fresh weights of herbaceous plants were measured in the field. The entire samples were taken to the soil laboratory of the Yaballo Pastoral and Dryland Agriculture Research Centre, wrapped in polyethylene bags, and oven dried for 24 h at 60ºC to determine the biomass. In case the samples were too large to manage in the oven dry, sub-samples were taken to the laboratory. The oven dry weights were measured by using a sensitive balance (Denver Instrument balance, Max: 4100 g, D: 0.01 g). To get the herbaceous plants biomass per hectare basis, the five sub-sample plots from a main plot were averaged and converted to yield per hectare using the conversion factor.

The herbaceous biomass yields per plot were converted to a per hectare basis using the expansion factor (Equation 1) described by Pearson et al. (2005).

$$\text{Expansion factor} = \frac{10{,}000\text{m}^2}{Area\ of\ a\ plot} \quad (1)$$

Survival and growth performance data of planted tree species

The number of planted tree species surviving the dry seasons and the height of trees (from ground level to the tip of the plant) were recorded each year of the study time at the end of the main rainy seasons. The survival percentage of each species was calculated as the number of trees that survived the dry seasons divided by the initial tree number multiplied by 100, and the height was measured using a meter measuring stick.

Watershed feasibility data

The primary and secondary data were collected to evaluate the comparative economic benefit of the watershed. Accordingly, a Focus group discussion (FGD) was undertaken with 19 mixed-gender members composed from the surrounding households. Accordingly, socioeconomic data, production systems across the season, potential challenges and opportunities on watershed intervention practices and their impact on land degradation were collected.

Methods of data analysis

The plant diversity of the watershed was analyzed using PAST (version 3.10), Paleontological Statistical software (Hammer et al., 2001). The diversity results with other vegetative variables were analyzed using the General Linear Model (GLM) techniques of the statistical analysis system with IBM SPSS version 27. The acquired data were analyzed as descriptive statistics using SPSS software and Microsoft Excel for the economic feasibility analysis of watershed management.

RESULTS AND DISCUSSION

Trends of watershed management intervention on herbaceous plant species composition, diversity and biomass

The average herbaceous plant species richness was significantly different (*P* < 0.001) before and after watershed management intervention. The plant species richness significantly increased during the study years. The herbaceous species richness of the watershed was about 5 species before intervention and increased to about 27 plant species after intervention. Similarly, the number of individual herbaceous plants per plot significantly increased from 9.25 ± 8.83 before intervention to 222 ± 8.83 after 3 years of management (Table 1). The mean Shannon and Simpson diversity indices were significantly different before and after watershed management intervention (*P* < 0.001). The herbaceous plant species Shannon diversity indices of the study watershed were 1.38 ± 0.61 before intervention and increased to 2.44 ± 0.61 after intervention (Table 1).

The effects of the physical SWC supported with reseeding and multi-purpose tree planting on herbaceous plant diversity were evaluated. No significant difference was observed among the treatments of SWC + reseeding, SWC + reseeding + tree planning, SWC

Table 2. Mean annual herbaceous plant species richness, evenness and diversity under different management interventions (Means ± SE).

Treatments	Richness	Individuals	Simpson	Shannon	Evenness
SWC+ reseeding	16.67 ± 1.64[a]	240.33 ± 57.57[a]	0.66 ± 0.11[a]	1.71 ± 0.29[a]	0.37 ± 0.14[a]
SWC + reseeding + trees planting	13.00 ± 1.64[a]	187.33 ± 57.57[a]	0.58 ± 0.11[a]	1.4 ± 0.29[a]	0.42 ± 0.14[a]
Structure only	12.67 ± 1.64[a]	122.00 ± 57.57[a]	0.63 ± 0.11[a]	1.47 ± 0.29[a]	0.52 ± 0.14[a]
Closure only	9.67 ± 1.64[a]	134.33 ± 57.57[a]	0.62 ± 0.11[a]	1.54 ± 0.29[a]	0.38 ± 0.14[a]
P- value	0.13	0.63	0.82	0.80	0.91

structure only, and closure plot in terms of herbaceous plant species richness, number of individual plants per plot, and Shannon diversity indices (Table 2).

The results of this study agree with those of Ombega et al. (2017) who reported that rehabilitation of degraded rangeland through the establishment of soil and water conservation structures had a higher herbaceous species diversity, species richness, relative abundance, composition, and biomass production than the degraded area. Research in northern Ethiopia found that treated areas utilizing SWC structures have increased plant species variety and richness than untreated ones (Dimtsu et al., 2018). Similar findings were made by Singh et al. (2011), who studied the degraded Aravalli hills in Western India. They discovered that regions with soil and water conservation structures had higher plant species diversity.

In the research region, the construction of soil and water conservation structures decreased runoff and erosion while trapping seeds of several plant species that had been transported there by runoff. Construction of the SWC aided soil seed bank regeneration; moreover, root cutting during the construction of the structures facilitated the sprouting of indigenous tree species, which in turn increased the richness, abundance, and diversity of native plant species. It has been discovered that restoring degraded regions that support soil and water conservation structures reduces soil erosion, which improves soil fertility, vegetation regrowth, and plant biodiversity (Singh et al., 2011; Tongway and Ludwig, 2012). This finding of the current study is in line with a study conducted in Southern Ethiopia, which found after 10 years of intervention, plant cover increased as a result of the adoption of integrated SWC practices, according to research by Dessale et al. (2020). Similarly, a study found that plot areas treated with SWC measures had better vegetation cover and plant species variety than untreated plot areas (Meresa et al., 2021).

The Shannon diversity index of the study site was low both before and after rehabilitation. This may be because of the dominance of a few plant species on the site. Shannon diversity index (H) increases with increasing species richness, as well as increasing equal distribution of species, and decreases with the dominance of a few species (unequal distribution of species) and reduction in species richness (Mühlenberg, 1993). Dominance directly affects ecosystem functions such as process rates via species identity (the dominant trait) and evenness (the frequency distribution of traits), and indirectly alters the relationship between process rates and species richness. Dominance also influences the temporal and spatial variability of aggregate community properties and compositional stability (Hillebrand et al., 2008).

The herbaceous plant species richness showed significant differences among the three soil and water conservation structures under study (Table 3). The highest herbaceous plant species richness was recorded in half-moon soil and water conservation structure; whereas, the lowest plant species richness was recorded in a plot of the control treatment (protected, but no SWC structures). However, there was no significance among the three SWC structures in terms of the number of individual herbaceous plant species per plot, Shannon diversity indices, and evenness. Louhaichi et al. (2022) indicated semi-circular bunds micro-catchments are an appropriate practice for the rehabilitation of degraded rangeland.

Effects of biophysical SWC on biomass production and basal cover

As the primary objective of the rangeland-based watershed management is pasture improvement, trends of grasses and non-grass biomass and basal cover were evaluated throughout the study years (Table 4). Grass and non-grass dry biomass production were significantly different during the study years. The grass dry biomass production was significantly increased from 0.05 ± 0.1 t/ha to 1.50 ± 0.1t/ha after intervention. The mean non-grass biomass was 0.03 ± 0.06 t/ha in 2015 and increased to 0.56 ± 0.06 t/ha after 3 years. The herbaceous plant basal cover also similarly significantly increased during the study years (Table 4). The impacts assessment in the Medego watershed in the Tigray region, northern Ethiopia indicated that SWC measures increased the grasses biomass by 65%, and grasses species diversity by > 30% (Mekonen and Tesfahunegn, 2011).

Grass biomass and herbaceous basal cover were

Table 3. Herbaceous plant species richness, number of individuals, diversity and evenness under different soil and water conservation structures (Means ± SE).

SWC structure	Richness	Individuals	Simson	Shannon	Evenness
Control	11.66^{b}	85.67^{a}	0.74^{a}	1.75^{b}	0.58^{ab}
Negarim	12.67^{b}	113.67^{a}	0.75^{a}	1.79^{ab}	0.5^{b}
Soil level Bund	13.67^{b}	85.67^{a}	0.82^{a}	2.13^{a}	0.64^{a}
Half-moon	16.33^{a}	134.33^{a}	0.79^{a}	2.05^{ab}	0.53^{ab}
Std. Error	±0.89	±17.5	±0.03	±0.12	±0.04
P -value	0.01	0.17	0.28	0.096	0.08

Table 4. Trends of M± std. Error of herbaceous biomass and basal cover of the watershed (Means ± SE).

Variable	Grass biomass (t/ha)	Non-grass biomass(t/ha)	Basal cover (%)
2015	$0.05±0.1^{c}$	$0.03±0.06^{c}$	$4.975±1.55^{c}$
2017	$1.09±0.1^{b}$	$0.34±0.06^{b}$	$23.85±1.55^{b}$
2018	$1.50±0.1^{a}$	$0.56±0.06^{a}$	$42.78±1.55^{a}$
P –value	< 0.001	< 0.001	< 0.001

Table 5. Herbaceous plant Biomass and basal cover in the study area (M ±SE).

Treatments	Grass biomass (t/ha)	Non-grass biomass (t/ha)	Basal cover (%)
Control (no structures)	$1.33±0.29^{b}$	$0.14±0.16^{a}$	$23.51±4.76^{ab}$
Negarim	$1.34±0.29^{b}$	$0.24±0.16^{a}$	$18.63±4.76^{b}$
Soil level bund	$2.58±0.29^{a}$	$0.53±0.16^{a}$	$27.63±4.76^{ab}$
Half moon	$1.93±0.29^{ab}$	$0.24 ± 0.16^{a}$	$41.88±4.76^{a}$
P- value	0.02	0.38	0.01

significantly different among the 3 soil and moisture conservation structures (treatments) and control (Table 5). However, non-grass biomass did not show a significant difference. Grass biomass and herbaceous basal cover were best in soil level bund and half-moon soil and moisture conservation structures. The grass biomass production and herbaceous basal cover were lowest in Negarim and control compared to other structures. Under Negarim soil and water conservation structures herbaceous diversity, grass biomass, and basal cover were low, however; the survival and growth of planted tree seedlings were better than the other 2 structures. The construction of this structure was also cost and labor effective leading to incentives for their use according to the perception of the pastoralists. Therefore, if the primary objectives of land management are rangeland (grass production) Negarim is not recommendable in Borana condition.

Effects of soil and moisture conservation structures on survival rate and growth of planted tree species

The survival rates of the selected tree species (*Melia azedarach*, *Faidherbia albida* and *Moringa stenopetala)* were best performing in Negarim and half-moon, followed by soil level bund and it was very poor in planting pits (control) treatments; decreasing to 0 at the end of the experiment (2019) (Figure 4). The survival rate of *M. azedarach* in negarim, half-moon, and soil level bund were 59.07, 50.363 and 46.24%, respectively at the end of the study years, while that of *F. albida* was 48.64, 47.5 and 38.85%, respectively. The survival rate of *M. stenopetala* was the best compared to other species and it was 59.86, 55.43 and 48.49% in Negarim, half-moon and soil level bund, respectively. The trend of survival rate of planted tree species decreased during the study years for all species.

This study showed that moisture conservation structures significantly affected the survival rate and growth of planted tree species. The results agree with different studies which showed the survival rate of different multipurpose tree species seedlings planted using moisture conservation structures were best than tree seedlings planted in normal pits (Mamo et al., 2016; Tadele et al., 2018; Kelil et al., 2021).

Throughout the study years, the growth in height of *M.*

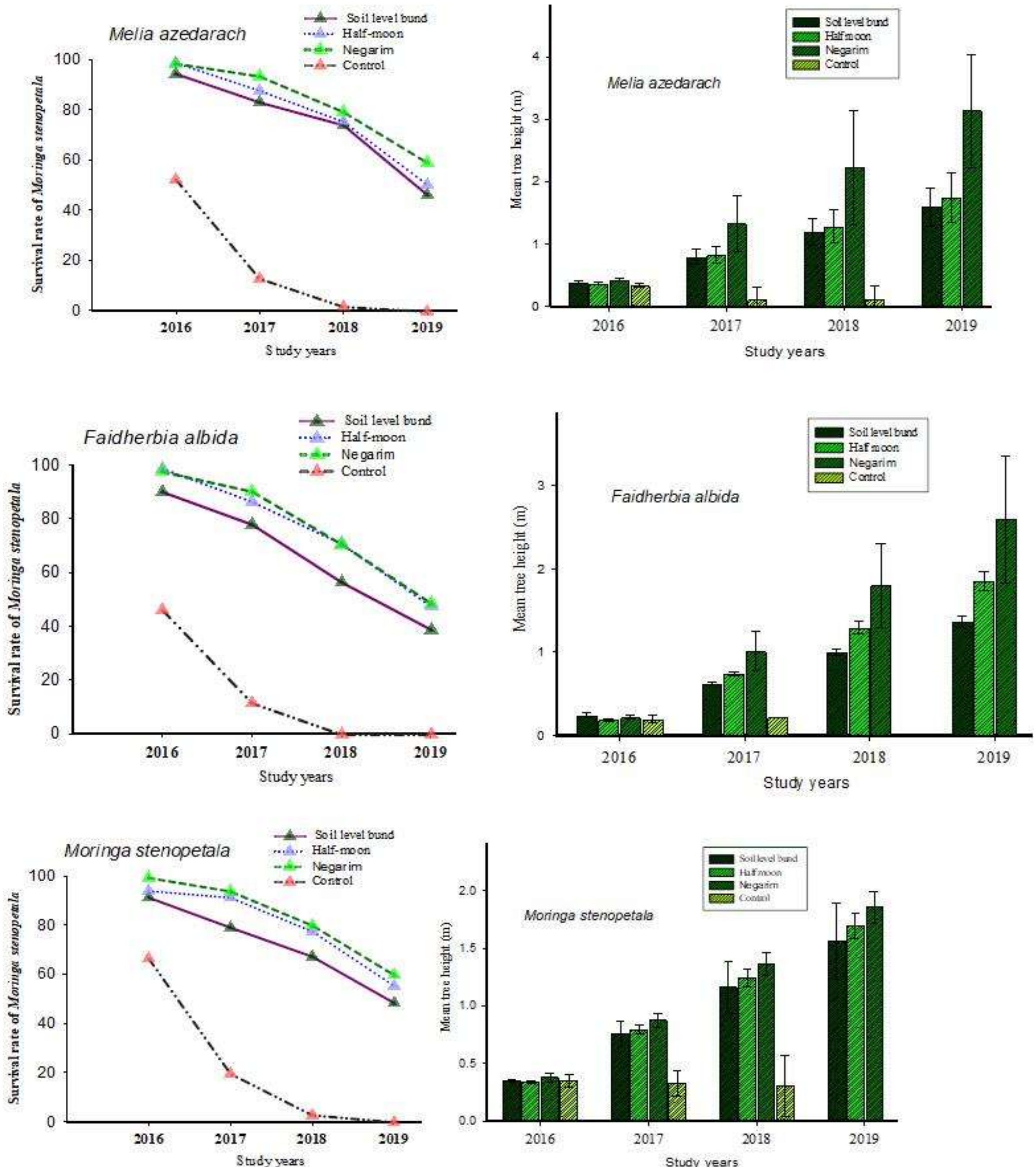

Figure 4. Survival (%) and mean tree height (m) for *M. azedarach*, *F. albida* and *M. stenopetala* under soil level bund, half-moon, Nigarem and control (pit only) treatments through sequential periods from June 2016 to June 2019.

azedarach, *F. albida* and *M. stenopetala* planted in Negarim and half-moon were the largest followed by soil level bund (Figure 4). The average height *F. albida* trees seedlings planted in Negarim, half-moon, and soil level bund were 2.59, 1.85 and 1.37 m, respectively, at the 4th year after planting, whereas that of *Melia azedarach* was 3.13, 1.74 and 1.64 m, respectively. The average heights of *M. stenopetala* seedlings planted in the Negarim, half-

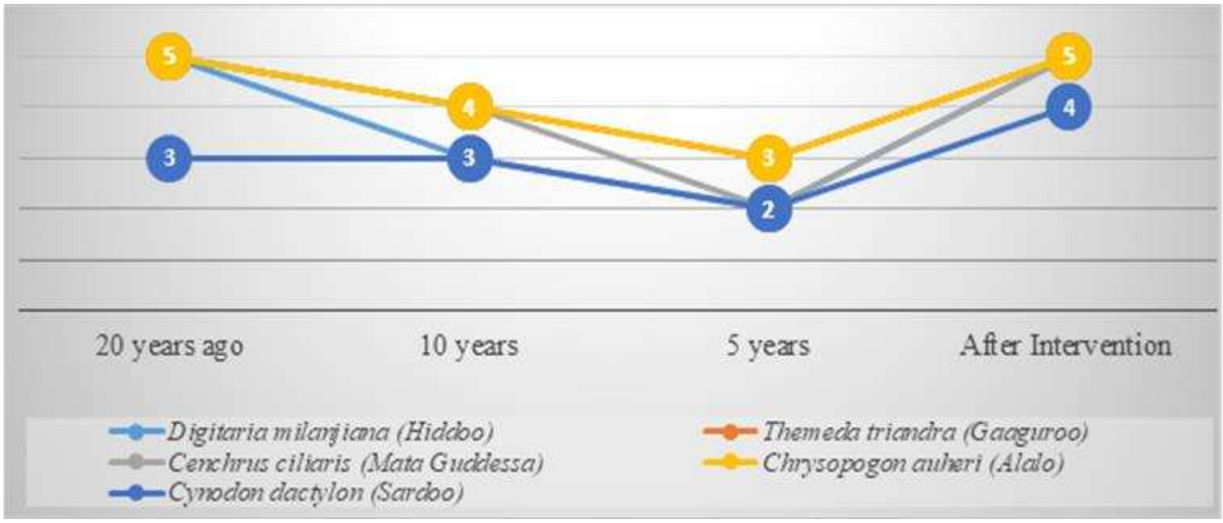

Figure 5. View of local communities on availability of selected grasses spices in the watershed areas: grasses availability (5 = Very high availability; 4 = high; 3 = Medium; 2 = Low; 1 = Very low; 0 = None).

moon, and soil level bund were 1.85, 1.69 and 1.56 m, respectively at 4th year after planting. However, due to recurrent drought and wild animal competition throughout the study years, the growth of planted multi-purpose tree species was low compared to the growth nature of these tree species in other areas.

This study provides empirical threads of evidence for planting multi-purpose trees and shrub species under rangeland-based watershed management and the effects of moisture conservation structures on the survival and height growth of selected multi-purpose tree species. The growth in height and survival rate of selected tree species planted under the moisture conservation structures were greater than tree seedlings planted under control (normal planting pits) because of the additional moisture that the structures gathered. Negarim had substantial advantages for the survival and growth of the selected tree species.

The finding of this study is consistent with those of Obala et al. (2022), who found Negarim micro-catchment provided more moisture to the plants which improved plant development and survival rates compared to plantings under no catchment. Micro-moisture conservation structures in general have a significant contribution to plant survival and growth in the study area. This finding is in line with other studies that indicated that seedlings grown on moisture harvesting structures were significantly thicker, taller, and had higher survival rates than those grown on the normal pits (Mamo et al., 2016; Tadele et al., 2018; Gebru et al., 2019; Kelil et al., 2021).

Comparative advantage of integrated watershed management (WSM) in Haro-bake sub-watershed

Based on the assessment through focus group discussion (FGD) with local communities around the watershed, positive impacts were achieved. Before the intervention, the watershed around the Bake Dam was highly degraded, with a low vegetation cove, high gully and soil erosion, and low availability of grass. After 5 years of integrated watershed management intervention; however, these problems were declined in the eyes of society. All of the important grass and tree species have recovered beyond the expectations of the surrounding communities.

Beyond the availability of various vegetation, the most important selected grass species like *Chrysopogon auheri* (Alalo), *Themeda triandra* (Gaaguroo), *Cenchrus ciliaris* (Mata Guddessa), *Cynodon dactylon* (Sardoo) and *Digitaria milanjiana* (Hiddoo) have recovered. The surrounding communities harvested hay from the watershed during drought years, which exaggerates the importance of this watershed. Beyond the recovery of grass species, the great advantage of this watershed is its significant impact on controlling soil erosion, and the serious gullies in the watershed were maintained. Though there were several gullies in the watershed at the beginning of delineation, after 5 years most of the gullies were rehabilitated, which resulted in reducing situation problems on the Haro-bake artificial pond. This advantage has created great pleasure for the surrounding communities. Figure 5 shows the view of local communities on availability of selected grasses spices in the watershed areas: grasses availability.

CONCLUSIONS AND RECOMMENDATIONS

Rangeland-based integrated soil and moisture conservation structures were evaluated in the Haro Bake watershed and have shown significant effects on the rehabilitation of indigenous plants and the survival and growth performance of planted tree species. Our study found that degraded land rehabilitation intervention, using soil moisture conservation structures, significantly increased the regeneration of indigenous plant species. The species richness of native plant species, as well as their numbers, grass biomass, and basal cover, all increased dramatically as a result of the intervention. The half-moon had the highest average diversity, richness, and population of native plant species, followed by the soil level bund, while the control (normal pit) had the lowest average biomass and basal cover of grasses. This may be attributed to the reduced runoff and erosion caused by the structures, as well as the trapping of seeds from various plant species transported by runoff from other locations. Moreover, root cutting during the construction of soil and water conservation structures promotes the regeneration of sprouts, contributing to increased diversity and richness of native plant species. However, under Negarim, diversity, grass biomass, and basal cover were low, and its construction was labor-intensive. The survival and growth performance of planted multi-purpose tree species were best in Negarim and half-moon, followed by soil level bund. In contrast, all tree species planted in the control treatments (normal pits) died within three years after planting. Local communities in the vicinity of the Haro Bake watershed reported that all important grasses and tree species had recovered beyond expectations. They confirmed that the watershed provided livestock feed benefits for local communities, especially during the dry season. Thus, half-moon and soil level bund soil moisture conservation structures were recommended for the rehabilitation of herbaceous plants. Meanwhile, Negarim and half-moon are considered more suitable for planting multi-purpose trees and shrub species in the watershed. Further studies are needed to introduce and evaluate other soil and water conservation structures in rangeland management, as well as to assess the adoption of soil and water conservation practices among pastoralist communities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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