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Evaluation of Rangeland Forage Improvement through Bush Controlling Techniques in Lowland Areas of Borana Zone, Southern Ethiopia

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ABSTRACT: A study was conducted in the Dirre and Yabello districts of Borana rangelands. The districts were selected purposively based on the severity of bush encroachments. A total of 5.4 hectares of bush encroached rangeland (2.7 ha in each district) was selected. The experiments had six treatments; 0% thinning (T 1),0% thinning Plus Fire (T2), 50% Thinning (T3), 50% thinning plus Fire (T4), thinning at 75% intensity only (T5)and thinning at 75% intensity and application of fire(T6) replicated three times. The treatments were applied on 18 different plots with an area of 30mx50m each. The collected data were analyzed using SAS software. The result showed that thinning the bush at 50% and 75% intensity combined with prescribed fire enhanced forage production while negatively influenced invasive woody shrubs and therefore would sustain the original savannas in Borana rangelands.

Keywords*:* Borana, Grass Biomass, Thinning, Species Richness, Agro-Ecologies

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INTRODUCTION

In Ethiopia, the major rangelands are found around the border area surrounded by the peak land (Mengistu, 2004). Nearly 65% of Ethiopia's land surface and all its rangelands are at risk of degradation due to recurrent drought, erratic rainfall, bush encroachment, overpopulation, overstocking, suppression of fire, and different anthropogenic factors (Bolo et al., 2019, Angassa and Oba, 2008, Gemado et al., 2006; Teshome et al., 2016). These factors led to a shortage of forage both in quantity and quality; increased mortality rate, reduction of vegetation cover, decrease species diversity, reduced herbaceous biomass and productivity of palatable species, changes in plant composition, reduction of livestock products like milk, meat and increased poverty in the pastoralist community (Ayana et al., 2012; and Joosten et al., 2012).

Past studies have shown that the Borana rangelands were among the major rangelands in Ethiopia where different animal species and plant diversities are available and pastoralists' livelihoods primarily depend on and are considered to be one of the few remaining sustainable pastoral systems in East Africa (Coppock, 1994; Cossins and Upton, 1987). In the Borana rangelands of southern Ethiopia, official suppression of fire in the early 1970s is perceived to have promoted the rapid expansion of bush encroachment (Oba et al., 2000). Since then, the savannah ecosystem of southern Ethiopia has been experiencing greater cattle population die-offs during periodic droughts (Cossins and Upton, 1988; Desta and Coppock, 2002) and deterioration of the rangeland due to bush encroachment, suppression of fire, and overgrazing (Angassa and Oba, 2008) and these led to a general decline in rangeland forage production and reduction of the productivity of herbaceous species, and potential grazing and/or browsing capacity of rangelands (Oba et al., 2000b; Gemedo et al., 2006a), which in turn causes severe economic losses (Mussa et al., 2017). By the mid of 1980s, about 40% of the Borana rangelands had been affected by bush encroachment (Eshete, Bille, and Corra, 1986), while recent studies indicated that bush encroachment at 52% of the total rangelands (Gemedo-Dalle, 2004).

Consequently, several research studies have been undertaken by different authors at different times and suggested that understanding the response of rangeland vegetation to different bush encroachment control methods could provide valuable information for designing successful and sustainable rangeland management options and bush encroachment control thereby improving the livelihood of pastoralists and agro-pastoralists in the area (Abdeta, 2011; Negasa et al., 2014; Teka et al., 2018).

Nowadays, the influence of bush encroachment on the performance of the livestock and pastoral economy is being recognized. Local and international non-governmental organizations and some government departments are conducting rangeland rehabilitation, involving hand clearing of woody species along highways and near settlements, on an experimental basis. It is an undeniable fact that Borana pastoral and agro-pastoral settings have been encroached by bush, shrubs, and acacia species like Acacia *drepanolobium,* Acacia *reficiens,* and Acacia *mellifera* over time has resulted in a loss of potential grazing sites within the settings being the most pressing development challenge in the locality (Oba, 1988; Teshoma et al., 2016). So far, little is known about the effects of bush encroachment control in response to encroaching woody plant species and thereby improving forage rangelands. Consequently, to improve and maintain forage production adequately in both quantity and quality of forage for livestock farming, adopting different forage improvement techniques and appropriate technologies are crucial in controlling bush encroachment and an appropriate way to sustain the economic viability of savanna rangelands (Smit, 2005; Manyeki et al., 2015; Harmse et al., 2016). This needs appropriate intervention timely, on research evidence-based and scientifically justifiable, and sound technological approaches. Therefore, the present study was designed to improve forage rangeland productivity and conservation systems and to test the effectiveness of bush thinning controlling techniques at different intensities with some combination of fire in selected Borana rangelands.

THEORETICAL REVIEW

Rangelands are natural ecosystems in arid or semi-arid areas predominantly occupied by a diversity of vegetation involving grasses, forbs, shrubs, and woody plants that are primarily suitable for grazing (Zerga, 2015). They also described as areas of the world that are unsuited for cultivation due to their physical limitations such as low and erratic precipitation, rough topography, poor drainage, and cold temperatures yet are the main source of forage for free-ranging native and domestic animals, as well as a source of wood products, water, and wildlife (Stoddert *et al*., 1975). Rangelands represent much of the area where pastoral livestock production is a land use and the largest land resource globally, accounting for about 25% to 51% of the total earth's land area (Asner et al., 2004; Zerga, 2015) yet supporting 78% of worldwide grazing and providing both ecologically and socio-economically beneficial ecosystem goods and services.

Despite its contribution to the world, rangeland degradation continues to be a major hindrance to improving pastoral livelihoods in Ethiopia's lowlands (Hussein, 2021). Climate change, overgrazing, bush encroachment, population pressure, suppression of wildfire, elevated atmospheric $C0_{2,}$ recurrent drought, government policies, encroachment of rain-fed agriculture, and the demise of traditional resource management institutions are all believed to be major causes of rangeland degradation (Hoffman and Todd, 2000; Oba et al., 2000; Mengistu, 2002; Coppock, 1994; Kassahun, 2006; Coppock et al., 2007; Jane et al., 2019; Stevens et al., 2017). On the other hand, these factors led to a great influence on the sustainability of livestock production within the rangeland ecosystem globally (Sankaran et al., 2005; Kinyua et al., 2010)

METHODOLOGY

Description of the Study Area

The study was conducted in the Yabello and Dirre Districts of Borana Zone, in Southern Oromia National Regional State. Yabello District administrative town is known as Yabello; which is also a Zonal administrative town. Dirre district administrative town is known as Megga. Both Yabello and Dirre districts are located in Southern Ethiopia at a distance from Addis Ababa, the capital city of Ethiopia, 570 and 665 km respectively. Yabello District lies between $3^{0}8'$ 46″ to 7509′ 04″E N latitude and $3^{0}18'$ 03″ to $43^{0}04'$ 24″E longitude; and Dirre lies between $4^{0}{}_{N}$ to 4.38N latitude and 37^{0}E to 38.3^{0} E longitudes and is found south of Yabello district (BZoFED office, 2016). Generally, the Borana rangelands are found in the south most2 of the Ethiopian lowlands occupying a total land area of about 95 thousand square kilometers (McCarthy, Kamara, and Kirk, 2002, Mengistu, 2004). They are located at 4-6^{0}N and 36-42^{0}E sloping gently from 1600masl in the North East to about 750masl in the extreme South that borders Northern Kenya and about 1780masl in the central vicinity. The area is still predominantly in pastures comprised of flat plains forming the main parts of the range. There are occasional mountains, massive valleys, and depressions. Occupied almost entirely by pastoral populations, resource use on the Borana rangelands is largely communal, though with crop cultivation and private enclosures that appear to be increasing in recent decades. Rainfall delivery is bimodal; with the long rains accounting for 60% of the total rainfall falling between March and May and the short rains comprising 27% of the total rainfall falling between September and November. There is spatial and temporal variability in both the quantity and distribution of rainfall with an average annual rainfall varying from 353mm to about 900mm per annum (McCarthy, Kamara, and Kirk, 2002). A cool dry season occurs from June to August, while a warm dry season occurs from December to February.

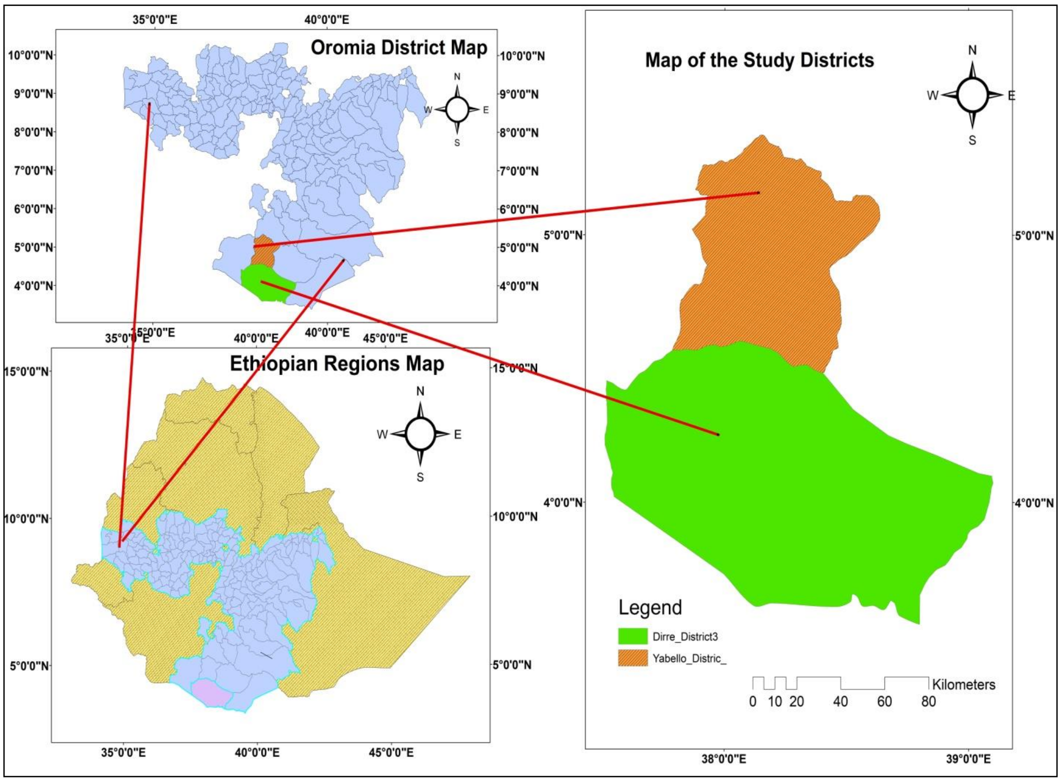

Figure 1. Map of the study area

The Site and Bush Species Selection

Based on the priority of the pastoral community, the two main and dominant woody plant encroacher tree/shrub species (A. drepanolobium and A. mellifera) for the two respective districts were selected. The selection of the encroacher tree species was based on their relative dominance over the respective districts. The most encroaching trees that have covered a wide range of grazing lands were identified and prioritized together with a pastoral community (elders, district and Peasant association leaders), researchers, and other stakeholders through participation and discussion. During the project conduction, indigenous knowledge of the community -was promoted through a participatory approach. Among the many encroaching tree species, the two noxious or harmful species were selected for the program in such a way that one species was assigned to one district and the same thing was applied to the rest of the species in the respective districts. In the implementation process, technical support, pastoralist, and all concerned bodies were involved. Monitoring and evaluation were carried out by a multi-disciplinary team of researchers, extension workers, and stakeholders.

Experimental Design and Sampling of Forage Species

A total of 5.4 ha (2.7 ha from each district) of land encroached by Acacia drepanolobim and Acacia mellifera was selected and divided into two plots and replicated three times in each district. Each replication with the area of 50 m × 30 m was again divided into six experimental plots: 0% thinning (T1), 0% thinning plus fire (T2), 50% thinning (T3), 50% thinning plus fire (T4), thinning at 75% intensity only (T5), thinning at 75% intensity and application of prescribed fire (T6) as shown in (Figure 2). A fire break of 10m in width was laid out in between each experimental plot. The plots were located adjacently on a homogenous area and treatments were allocated randomly to the plots. The target species was marked during the cutting process and the areas were fenced using locally available materials in consultation with the community and any livestock was not allowed to enter into the fenced area until the completion of the research. The treatment applications were employed in the first year of 2019 and the data before and after treatments' were collected after the rainy season in 2020 and 2021 respectivelyForage samples were collected from a total of 36 (18 from each district) main plots and an area of 50 × 30m (1500 m^2) from each plot before and after treatments (Figure 2). We designed and used a quadrate of a four-sided (square) frame of welded metal of 0.5 × 0.5 m (0.25 m^2) following the procedure recommended by Whalley and Hardy (2000) to measure the biomass during data collection in the field. Quadrates were randomly thrown to the back side to minimize any biases resulting from a selective position within each subplot and all the above-ground forage samples were collected in the field. A total of 180 (90 quadrates at each district) 5 times per plot were randomly thrown. Then, the names of each grass and non-grass species in a 0.5 × 0.5 m (0.25 m^2) area within each subplot were identified and recorded in the field with the help of key elder pastoralists', technical experts, and rangeland ecologists. The percentage of litter and basal covers were estimated using visual assessment in each quadrant. Then after, all grass and non-grass species reaped manually using sickles from subplots were identified on the field and separately put into plastic bags and were brought to Yabello Pastoral and Dryland Agriculture Research Center laboratory and oven dried at 105^{0}C for 24 hours to determine the biomass (Adesogan et al.200; ILCA, 1990; Rau et al., 2010). Lastly, the dry matter of each grass species and herbaceous was weighed after 24 hours using a sensitive balance and converted into kilogram per hectare (Kg ha^{-1}). Forage species identification was done in the field with the help of field identification keys and plates, using Flora of Ethiopia books, and Addis Ababa University national herbarium (Elmore et al., 2000; Gemedo-Dalle et al.2005).

Palatability of Forage Species

The palatability of grass and non-grass species were recorded and identified through a semi-structured focus group discussion that was held with the elder pastoralists who have deep knowledge about forage, District rangeland experts, and rangeland ecologists from our research center.

Grass and non-grass palatability was assessed and identified through semi-structured focus group discussions conducted with senior forage-savvy pastoralists at the research center, district rangeland experts, and rangeland ecologists.

Treatment Design		
Dirre district		
Replication 1	Replication 2	Replication 3
T1	T2	T5
T3	T6	T2
T6	T4	T3
T5	T3	T1
T2	T1	T4
T4	T5	T6
Yabello district		
Replication 1	Replication 2	Replication 3
T4	T5	T4
T2	T1	T6
T5	T3	T1
T6	T6	T3
T3	T4	T2
T1	T2	T5

Note: T1 = 0% thinning
T2 = 0% thinning + Fire Application
T3 = 50% thinning
T4 = 50% thinning + Fire Application
T5 = 75% thinning
T6 = 75% thinning + Fire Application

Figure 2. Field layout of the experimental plots

RESULTS

The Effect of Bush-Controlling Techniques on Vegetation Attributes

The dry matter production of above-ground biomass of the individual grass and non-grass species in kg ha^{-1}, species richness for grass and non-grass in number, basal cover, and litter cover in percentage across the treatments at Yabello district within the six treatments plots were presented in Table 1. Accordingly, the dry matter production of grass biomass (GB) and non-grass biomass (NGB) as well as grass species richness (GSR) did not show any significance ($P > 0.05$). Although there were no statistically significant differences observed among the treatments- T6, T1, and T5 were outperforming as compared to the others. On the other hand, a significant effect among treatments was observed for non-grass species richness (NGSR), basal cover (BC), and litter cover (LC). The NGSR was significantly ($P < 0.05$) higher for T4 and T6 while BC was significantly ($P < 0.05$) higher for T6. Moreover, a significantly higher LC was attained for T4 and T6 than for the other treatments.

Table 1. Mean values for vegetation attributes across treatments in the Yabello district

Treatments	GB (Kg/ha)	GSR (n)	NGB (Kg/ha)	NGSR (n)	BC (%)	LC (%)
1	1712±953.77	2±0.26	126±57.39	1.5±0.22^{ab}	21.6±4.22^{b}	43.27±8.48^{b}
2	747±152.56	2±0.17	108±34.57	1±0.00^{b}	24±3.31^{b}	50.46±3.29^{ab}
3	1227±269.21	2±0.21	108±40.92	1.33±0.21^{ab}	31.13±4.4^{ab}	56.18±4.24^{ab}
4	869±136.88	2±0.0	75±29.11	1.67±0.21^{a}	30.75±4.28^{ab}	61.77±7.62^{a}
5	1900±971.6	2±0.26	103±25.49	1.33±0.21^{ab}	31.14±3.9^{ab}	54.27±3.52^{ab}
6	2869±1487.15	2±0.17	123±55.54	1.67±0.21^{a}	38.65±5.32^{a}	62.67±5.16^{a}
P-value	0.36	0.77	0.93	0.04	0.04	0.04

Key: Means with the same letter superscripts along the columns were not significantly different (p>0.05)

Note: T1= 0% thinning, T2= 0% thinning + Fire, T3= 50% thinning, T4= 50% thinning + Fire, T5=75% thinning, T6= 75% thinning + Fire, **GB**= Grass Biomass; **GSR**= Grass Species Richness; **NGB**=Non-grass Biomass; **NGSR**=Non-grass species richness; **BC**=Basal Cover; **LC**= Litter Cover.

The mean values for vegetation attributes of grass biomass, grass species richness, non-grass biomass, non-grass species richness, basal cover, and litter cover before and after treatment application at the Yabello district were presented and summarized in Table 2. The result shows that there were no significant differences between before and after treatment application for GSR, NGSR, BC, and LC in the study area. However, GB and NGB were significantly ($P < 0.05$) higher after the treatment application than before the treatment application. The pooled average (± SE) total grass biomass in kg ha^{-1} for before and after treatments at Yabello district was 635.63±87.22 and 2472.42±603.11 respectively.

Table 2. Mean values for vegetation attributes between before and after treatment applications in the Yabello district

Period of treatment application	GB (Kg/ha)	GSR (n)	NGB (Kg/ha)	NGSR (n)	BC (%)	LC (%)
Before	635.63±87.22^{b}	1.78±0.10	165.87±25.28^{a}	1.28±0.11	28.37±2.89	57.47±4.27
After	2472.42±603.11^{a}	2±0.11	48.17±6.31^{b}	1.56±0.12	30.72±2.41	52.07±2.34
P-value	0.005	0.17	0.0004	0.07	0.52	0.24

Key: Means with the same letter superscripts along the columns were not significantly different (p>0.05)

Note: **GB**= Grass Biomass; **GSR**= Grass Species Richness; **NGB**=Non-grass Biomass; **NGSR**=Non-grass species richness; **BC**=Basal Cover; **LC**= Litter Cover.

Table 3 presents the above-ground biomass yield for grass and non-grass species in kg ha^{-1}, species richness for grass and non-grass in number, basal cover, and litter cover in percentage across the treatments at Dire district. Accordingly, GSR, NGSR, and LC did not show any significant difference among treatments (P > 0.05). Although non-significant, T6, T1, and T5 were outperforming as compared to others. On the other hand, GB, NGB, and BC showed a significant difference among treatments. Accordingly, grass biomass was significantly (P < 0.05) higher for T4 while NGB was significantly (P < 0.05) higher for T6. Moreover, a higher percentage of BC was attained for T4 and T6.

Table 3. Mean values for vegetation attributes across treatments in the Dirre district

Treatments	GB (Kg/ha)	GSR (n)	NGB (Kg/ha)	NGSR (n)	BC (%)	LC (%)
1	1071.8±79.55^{ab}	2.2±0.21	172.93±29.39^{b}	1.5±0.25	37.77±11.73ab	51.03±11.5
2	602.53±260.44^{b}	2.2±0.46	105.76±39.41^{b}	1.87±0.39	28.92±11.28^{b}	43.9±8.07
3	1173.87±401.32^{ab}	2.03±0.35	242±87.83^{b}	1.7±0.51	46±13.56^{ab}	50.83±11.92
4	1537.07±297.96^{a}	1.77±0.31	217.87±73.80^{b}	2.07±0.56	50.4±11.29^{a}	64.6±8.26
5	1130.67±342.45^{ab}	2.07±0.25	194.53±61.15^{b}	1.5±0.33	37.53±10.07^{ab}	44.32±10.17
6	1272.3±298.86^{ab}	1.93±0.23	513.73±160.79^{a}	1.33±0.17	54.63±14.41^{a}	65.03±12.41
P-value	0.04	0.76	0.05	0.46	0.03	0.26

Key: Means with the same letter superscripts along the columns were not significantly different (p>0.05)

Note:**GB**= Grass Biomass; **GSR**= Grass Species Richness; **NGB**=Non-grass Biomass; **NGSR**=Non-grass species richness; **BC**=Basal Cover; **LC**= Litter Cover, T1= 0% thinning, T2= 0% thinning + Fire, T3= 50% thinning, T4= 50% thinning + Fire, T5=75% thinning, T6= 75% thinning + Fire

Table 4 presents the mean values for vegetation attributes of GB, GSR, NGB, NGSR, BC, and LC before and after treatment application at Dirre district. A non-significant effect between before and after treatment application was attained for NGB in the study area. Although there was no significant difference observed, higher NGB was observed after-treatment application However, GB, GSR, NGSR, BC, and LC showed significantly ($P < 0.05$) higher for after-treatment application than before treatment application.

Grass biomass was increased from 836.49±120.41 kg ha^{-1} before the treatment application to 1,426.28±191.0 kg ha^{-1} after the treatment application. The basal cover significantly increased from 20.15±2.84 % before the treatment application to 64.93±5.35 % after the treatment application (Table 4). Litter cover was significantly increased from 36.94±4.05% before the treatment application to 69.63±5.11 % after the treatment application.

Table 4. Mean values for vegetation attributes between before and after treatment applications in the Dirre district

Treatment application period	GB (Kg/ha)	GSR (n)	NGB (Kg/ha)	NGSR (n)	BC (%)	LC (%)
Before	836.49±120.41^{b}	1.56±0.12^{b}	230.89±67.01	1.06±0.06^{b}	20.15±2.84^{a}	36.94±4.05^{b}
After	1426.28±191.03^{a}	2.51±0.14^{a}	251.39±43.44	2.27±0.23^{a}	64.93±5.35^{b}	69.63±5.11^{a}
P-value	0.01	0.0001	0.78	0.0001	0.0001	0.0001

Key: Means with the same letter superscripts along the columns were not significantly different (p>0.05)

Note:**GB**= Grass Biomass; **GSR**= Grass Species Richness; **NGB**=Non-grass Biomass; **NGSR**=Non-grass species richness; **BC**=Basal Cover; **LC**= Litter Cover

Botanical Composition of Herbaceous Species

In both study sites (Dirre and Yabello) districts, we collected, identified, and recorded the numbers of all herbaceous species from the sample quadrates after treatment application. Accordingly, a total of 52 herbaceous species out of which 27 were grass species and 25 were non-grass species were recorded respectively (Table 5 and 6). We identified and recorded 4 annual and 12 perennial grass species and 4 annual and 10 perennial non-grass species in the Dirre district (Table 5). In the meantime, a total of 22 herbaceous species out of which 11 grass species and 11 were non-grass species were collected at Yabello. We also identified and recorded 3 annual and 8 perennial grass species and 1 annual and 10 perennial non-grass species in the Yabello district (Table 6). The grass species *Cenchrus Ciliaris*, *Eragrostis papposa, Setaria verticillate*, *Chrysopogon aucheri*, Daraa Xuxii(Scientifically unknown), and *Pennisetummezianum* were the most frequently observed and most abundant at Dirre district respectively. On the other hand, the grass species *Sporoboluspyramidalis*, *Sesamothamnusrivae*, *Aristidakenyensis*, *Digitaria milanjiana*, *Commelina Africana*, *Panicum maximum,* and *Pennisetummezianum* were the most frequently observed and most abundant at Yabello district respectively

Forage palatability was grouped into four classes: highly palatable, palatable, less palatable, and not palatable by grazers/livestock preference based on elder pastoralists' assessment (Tabe 5 and 6). The highly palatable forages are highly selected by livestock and given preference during grazing. 'Palatable' forages are those which are found the in good condition and increase with moderate overgrazing. 'Less palatable' are those which increase with severe overgrazing. 'Not palatable' forages are those which are not preferred or edible completely by livestock species (Negassa et al., 2014). Among the total 16 identified grass species, there were 50 %, 37.5 %, and 12.5% of the grass species were highly palatable, palatable, and less palatable respectively as assessed by livestock or grazers at the Dirre site (Table 5). While at the Yabello site, out of 11 identified grass species 6 (54.5%) and 5(45.5%) were highly palatable and palatable respectively (Table 6). Moreover, In the Dirre site out of 13 identified and recorded non-grass species, 15.4%, 53.8 and 30.8% were categorized as palatable, less palatable, and not palatable by grazers or browsers respectively. There were no grass species that were identified as unpalatable in the Dirre and the Yabello sites.

Table 5. Overall collected grass and Non-grass species at Dirre Site

No	Scientific Name	Local Name	Growth form	Palatability	Life form	Frequency
1.	Cenchrus Ciliaris	Matagudeessa	Grass	Highly palatable	Perennial	47.8
2.	*Justiciaodora*	Agaggaroo Harree	Non-grass	Less palatable	Perennial	25.6
3.	Eragrostis papposa	Saamphillee	Grass	Palatable	Annual	24.4
4.	*Setaria verticillata*	Raphuphaa	Grass	Palatable	Annual	24.4
5.	Dyschoriste hildebrandtii	Gurbii Gaalaa	Non grass	Less palatable	Perennial	20.0
6.	Chrysopogon aucheri	Alalo	Grass	Highly palatable	Perennial	18.9
7.	Daraaraa Xuxii (not known)	Daraaraa Xuxii	Grass	Less palatable	Perennial	18.9
8.	*Pennisetummezia num*	Ogondhichoo	Grass	Palatable	Perennial	17.8
9.	*Sporobolus pyramidalis*	Bukkicha	Grass	Less Palatable	Perennial	16.7
10.	*Aristidakenyensis*	Biilaa	Grass	Palatable	Perennial	12.2
11.	*Commelina africana*	Qaayyoo	Grass	Highly palatable	Annual	11.1
12.	Ononnuu (not known)	Ononnuu	Non-grass	Not palatable	Perennial	11.1
13.	*Setariaincrassata*	Maxxannee	Non grass	Not palatable	Annual	8.9
14.	*Digitaria milanjiana*	Hiddoo	Grass	Highly palatable	Perennial	7.8
15.	*Digitaria naghellensis*	Ilmogora	Grass	Highly palatable	Perennial	4.4
16.	*Cynodon dactylon*	Sardoo	Grass	Highly palatable	Perennial	4.4

17.	*Heteropogonconto rtu*	Seericha	Grass	Highly palatable	Perennial	3.3
18.	*Panicum maximum*	Loloqaa	Grass	Palatable	Perennial	3.3
19.	Saalticha (not known)	Saalticha	Grass	Palatable	Annual	3.3
20.	*Bothriochloainscu lpta*	Luuculee	Grass	Highly palatable	Perennial	3.3
21.	*Tagetes minuta*	Sunkii	Non-grass	Less palatable	Annual	3.3
22.	*Oxygonumsinuat um*	Mogoraa	Non-grass	Palatable	Annual	3.3
23.	*Tephrosia pentaphylla*	Darguu	Non-grass	Not palatable	Perennial	3.3
24.	*Pupalia Lappacea*	Anqarree	Non-grass	Less palatable	Annual	3.3
25.	*Hibiscus crassinervius*	Bungaala	Non grass	Less Palatable	Perennial	3.3
26.	*Chionothrixlatifol ia*	Garbicha	Non grass	Palatable	Perennial	3.3
27.	Asuraa (not known)	Asuraa	Non-grass	Not palatable	Perennial	2.2
28.	*Cladostigmahildeb randtioides*	Gaalee	Non-grass	Less palatable	Perennial	2.2
29.	Endostemen tereticaulis	Urgoo	Non-grass	Less palatable	Perennial	1.1
30.	*Salvadorapersica*	Aadee	Non-grass	Less palatable	Perennial	1.1

Table 6. Overall collected grass and non-grass species at Yabello Site

No	Scientific name	Local Name	Growth form	Palatability	Life form	Frequency
1.	Dyschoriste hildebrandtii	Gurbii Gaalaa	Non grass	Less Palatable	Perennial	38.9
2.	*Sporoboluspyramid alis*	Bukkicha	Grass	Palatable	Perennial	36.7
3.	*Sesamothamnusriv ae*	Laafaa	Grass	Palatable	Perennial	25.6
4.	*Aristidakenyensis*	Biilaa	Grass	Palatable	Perennial	17.8
5.	*Tephrosia pentaphylla*	Darguu	Non-grass	Less palatable	Perennial	12.2
6.	*Dichrostachysciner ea*	Jirmee	Non-grass	Less Palatable	Perennial	12.2
7.	*Digitaria milanjiana*	Hiddoo	Grass	Highly palatable	Perennial	11.1

8.	*Commelinaafricana*	Qaayyoo	Grass	Highly palatable	Annual	11.1
9.	*Panicum maximum*	Loloqaa	Grass	Palatable		11.1
10	*Pennisetummezianum*	Ogondhichoo	Grass	Palatable	Perennial	11.1
11	Chrysopogon aucheri	Alalo	Grass	Highly palatable	Perennial	6.7
12	*Cladostigmahildebrandtioides*	Gaalee	Non-grass	Less Palatable	Perennial	6.7
13	Cenchrus Ciliaris	Matagudeessa	Grass	Highly palatable	Perennial	5.6
14	*Salvadorapersica*	Aadee	Non-grass	Less Palatable	Perennial	4.4
15	*Incinni* (not known)	Incinni	Non-grass	Less Palatable	Perennial	4.4
16	*Setariaverticillata*	Raphuphaa	Grass	Highly palatable	Annual	2.2
17	*Chlorophytumgallabatense*	Mirtuu	Non-grass	Not palatable	Annual	2.2
18	*Justiciaodora*	Agaggaroo Harree	Non-grass	Palatable	Perennial	2.2
19	*Heteropogoncontortu*	Seericha	Grass	Highly palatable	Perennial	1.1
20	not known	Qurmeessa	Non-grass	Not palatable	Perennial	1.1
21	Makkanniisa (not known)	Makkanniisa	Non-grass	Not palatable	Perennial	1.1
22	Endostemen tereticaulis	Urgoo	Non-grass	Not palatable	Perennial	1.1

DISCUSSION

The Effect of Bush-Controlling Techniques on Vegetation Attributes (Dry Matter, Species Richness, Basal Cover, And Litter Cover)

The main objectives of the current study were to improve rangeland productivity and conservation systems and to test the effectiveness of bush-controlling techniques at different intensities with the combination of fire in selected Borana rangelands. The result showed that the forage productions of grass and non-grass biomass in response to 50% (T4) and 75% (T6) thinning combined with prescribed fire application were significantly increased ($p<0.05$) compared to non-thinned and no fire application plots at Dirre site. Moreover, the forage productions of aboveground grass biomass in response to the duration of bush controlling techniques application significantly increased ($p<0.05$) from 635.63 to 2472.42 kg ha^{-1} at Yabello and 836.49 kg ha^{-1} to 1,426.28 kg ha^{-1} at Dirre for before the treatment application and after the treatment application respectively. While the production of Non-Grass Biomass production in response to the duration of treatment application significantly improved after treatment application at the Yabello site. The result clearly showed that thinning combined with prescribed fire increased grass biomass production almost by 289 and 70.5% after treatment application at Yabello and Dirre sites respectively. The incremental in forage biomass production could be attributed to the thinning combined with prescribed fire application that reduced the canopy of encroaching woody invasive trees/shrubs which compete for water, nutrients, and sunlight. This study is in line with the finding of Gilo and Kelkay (2017) who reported that the production biomass yield of forage was significantly higher in the prescribed fire-managed rangeland than in the communal and enclosure grazing area. Similarly, the study conducted by Fentahun et al. (2020) also confirmed that higher biomass production was observed in ranch grazing sites than in open-communal and woody-covered grazing areas in the Yabello rangelands. In line with the present study, the findings of Musa and Yunus (2022) and Ombega et al. (2017) reported that higher dry matter yield was recorded in the plots treated with the bush control technique compared to untreated and degraded rangelands.

Non-Grass Species Richness (NGSR) and Basal Cover (BC) in response to 50% thinning combined with prescribed fire application (T4) was significantly higher compared to non-thinned treatments at Yabello. Moreover, the incremental percentage in Litter Cover (LC) in response to 75% thinning accompanied by fire application was significantly greater ($p<0.05$) at Yabello. On the other hand, BC in response to 50% (T4) and 75% (T6) thinning combined with prescribed fire application was significantly improved ($p<0.05$) compared to non-thinned and no fire application plots at Dire. Moreover, Grass Species Richness (GSR), NGSR, BC, and LC in response to a duration of treatment application (thinning and fire) significantly increased ($p<0.05$) from 1.56 to 2.51 in number, from 1.06 to 2.27 in number, 20.15 to 64.93 % and 36.94 % to 69.63 % before and after treatment application at Dirre respectively; indicating that the BC and LC improved more than thrice and doubled compared to the before -treatment application largely due to thinning and fire application effect. The incremental in the grass and non-grass species richness, basal cover, and litter cover percentage after treatments application could be associated with reduced soil erosion as a result of regenerated grass and non-grass species and thinned encroaching bush/shrubs' species density that is combined with fire improved soil moisture, increase herbaceous production and desirable shifts in herbaceous composition. This finding is in agreement with Negasa et al. (2014), Hare et al. (2021), and Musa and Yusuf (2022) who reported that biomass, species composition; basal cover, and litter cover for herbaceous species were significantly increased following the application of bush control techniques.

The Response of Grass Species Composition to Bush Controlling Techniques

The result of the current study indicated that the number of grass species regenerated in response to thinning and prescribed fire application after treatment was by far greater compared to before treatment application. Out of identified grass species after treatment application, perennial grass species had the highest and most abundant (72.7%) followed by annual grass(27.3) at Yabello while 75% were perennials and 25% were annual grass identified and registered at Dirre respectively. The grass species *Cenchrus Ciliari, Eragrostis papposa, Setaria verticillata*, *Chrysopogon aucheri*, and *Pennisetummezianum* were the most frequently observed and most abundant in Dirre while *Sporoboluspyramidalis*, *Sesamothamnusrivae*, *Aristidakenyensis*, *Digitaria milanjiana*, *Commelina Africana*, *Panicum maximum,* and *Pennisetummezianum* were the most frequently observed and most abundant at Yabello district respectively. Those grasses have the highest nutritive value and most highly preferred and appreciated grass species by grazers(Gemado Delle,2020). The high proportion of these grass species regenerated after treatment application could be attributed to controlling encroaching bush/shrub species through thinning and prescribed fire applications that compete for nutrients, water, and light. In line with this study, the previous studies conducted by Gilo and Kelkay (2017) reported that the composition of herbaceous species was higher in prescribed fire-managed rangeland areas than in grazing enclosures and communally graze areas. These findings also confirmed the previous findings of Negasa et al. (2014), Mureithi et al. (2016), and Musa and Yunus(2022) who found that the greatest contribution of grass species was due to the removal of encroaching tree/shrubs species. The study conducted by Ombega et al.(2017) confirmed that species richness, relative and diversity of perennial grass were significantly increased downslope and were higher in rehabilitated than degraded areas.

Palatability of the Grass Species

Out of identified grass species, 50%, 37.5%, and 12.5% of grass species were highly palatable, palatable, and less palatable respectively at Yabello while 54.5 and 45.5% of grass species were highly palatable and palatable at Dirre sites respectively, indicating that the proportion of palatable grass species was higher in plots treated with thinning combined with prescribed fire application compared to other non-thinned rangeland plots. In the present study, it was noted that thinning of invasive bushes and shrubs and prescribed fire application enhanced the abundance of highly palatable and palatable classes of grass species over some time after thinning. It has also been revealed that appropriate bush-controlling techniques will improve rangeland conditions thereby increasing the abundance of palatable grass species while decreasing encroaching shrubs and bush species that suppress the growth of grass species through their canopies competing for water, nutrients, and sunlight. In line with this study, the findings of Gilo and Kelkay (2017) reported that a high proportion of desirable grass species was recorded in the prescribed fire-managed rangeland than in the communal grazing area. Moreover, similar findings by Stephen (2019) and Sang-Hyum et al.(2018) reported an abundance of palatable grass species in response to thinning and clearance has increased the abundance of palatable grass species in rangelands through increasing utilization of sunlight use by remaining understory plants.

CONCLUSIONS AND RECOMMENDATIONS

Bush encroachment remains an important factor hindering livestock production and the livelihood of Borana pastoralists. The present study aimed to improve forage production through bush encroachment controlling techniques at different intensities. According to our result, T4 (50% thinning and prescribed fire) and T6 (75% thinning and prescribed fire) significantly improved forage production of rangelands, basal cover, litter cover, species richness, and grass species composition after treatment application than the before treatment application. In general, the result of the current study showed that the thinning and prescribed fire application improved forage/biomass production, and regenerated different types of grass species but negatively influenced woody plants and infestation of invasive tree/shrub species.

Particularly, our findings highlight that thinning followed by prescribed fire was able to regenerate and enhance the abundance of highly palatable and palatable annual and perennial grass species after treatment application. Moreover, the forage production in response to different bush-controlling techniques would have considerable implications for rangeland improvement, conservation system, conservation policy, and strategy which in the long term is supposed to be promoted through pastoralists' participatory research and extension and this in turn will improves livestock productivity, and the livelihoods of the pastoralists and help minimize the shortage of feed for the livestock in Borana. Therefore, the study recommends that thinning of a bush to 50% and 75% thinning intensity combined with prescribed fire application at some interval would sustain the original savannas of semi-arid Borana rangelands in particular and in similar agro-ecologies of world rangelands in general and improve forage production for grazers and browsers in the future. Moreover, further studies on rangeland improvement techniques through thinning of invasive bushes/shrubs in the study area are highly recommended.

FURTHER STUDY

Building on the findings of the present study, future advanced research should focus on refining the integration of bush thinning and prescribed fire regimes to optimize rangeland restoration while minimizing potential ecological trade-offs. This includes investigating the long-term ecological dynamics of repeated treatments, the resilience and succession patterns of herbaceous and woody vegetation, and the threshold levels of bush cover that balance biodiversity conservation with forage productivity. Furthermore, incorporating remote sensing and geospatial technologies could enhance monitoring of rangeland responses at larger scales, while socio-economic studies should assess the adoption potential, cost-effectiveness, and labor implications of these interventions among pastoral communities. Participatory action research involving local stakeholders is essential to co-develop adaptable, site-specific rangeland management frameworks that align ecological goals with pastoralists' knowledge systems, needs, and adaptive capacities. Such interdisciplinary and transdisciplinary approaches will be critical to inform evidence-based policies and strategies aimed at reversing land degradation, securing sustainable livestock production, and improving the resilience of pastoral livelihoods in Borana and similar semi-arid ecosystems globally.

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