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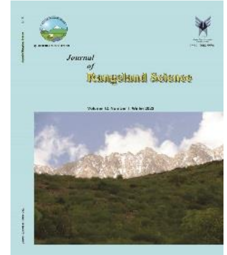

Research and Full Length Article:

Impact of Bush Encroachment Control on Rangeland Vegetation in the Rangelands of Bale, Southeastern Ethiopia

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Received on: 09/06/2020
Accepted on: 05/06/2021
DOI: 10.30495/RS.2022.682324
DOR: 20.1001.1.20089996.2021.12.1.8.3

Abstract. This study was conducted to examine impact of bush encroachment control on rangeland vegetation in the south eastern Ethiopia. The study targeted two main and dominant encroaching woody plant species, *Acacia bussei* and *Acacia aerfota*, and their effects on rangeland vegetation attribute dynamics in Raitu district of Bale zone, southeastern Ethiopia for two consecutive years. Rangeland site encroached by these two acacia species was replicated/divided into three plots, and each plot was subdivided into five sub-plots receive five treatments: cutting at 0.5 m above ground alone (T1), cutting at 0.5 m above ground and dissecting the stumps (T2), cutting at 0.5 m above ground and pouring chemicals on stumps (T3), cutting at 0.5 m above ground and debarking the stumps down into the soil surface (T4) and control (T5). Data on biomass, species richness, basal and litter covers, soil erosion and compaction, dead and re-sprouted encroaching tree/shrub species were collected. The applied treatments significantly influenced ($P<0.05$) basal cover, dry matter and the two encroaching tree species. The results of this study showed that T1 and T4 were good in controlling *A. aerfota* in that order. T4 and T3 had a significant effect on controlling A. bussie in their order. The most dominant grass and non-grass species observed after the control actions were *Cenchrus ciliaris*, *Bothriochloa radicans*, *Hibiscus aponerus*, *Pennisetum mezianum*, *Lintonia nutans*, *Chrysopogon plumulosus* and *Eragrostis papposa*. Therefore, controlling encroaching tree/shrub species had created a conducive grazing area with palatable herbaceous species for the livestock. The management of bush encroachment will contribute to stabilize rangelands and to minimize the negative effects of feed and food crises in the future.

Key words: Bale rangeland, Bush control, Grass and forbs, Vegetation dynamics

Introduction

Rangelands are referred as pristine or natural ecosystems in the arid or semi-arid areas predominantly occupied by a diversity of vegetation involving grasses, forbs, shrubs, and grass-like plants; and are primarily suited for grazing. Rangelands represent the largest land resource globally, accounting for about 25% of the total land surface (Zerga, 2015) for providing both ecologically and socio-economically beneficial ecosystem goods and services. However, woody plant proliferation, commonly known as bush encroachment, has been a growing concern for rangeland management globally. Bush encroachment substantially suppresses the growth of high- value herbaceous forage species in the understory, reduces indigenous plant biodiversity, and alters rangeland ecosystem functions (Mussa *et al.,* 2018). In addition, the reduced forage can threaten subsistence pastoralism that primarily rely on cattle grazing (Smith *et al.,* 2000).

About 65% of Ethiopia's land surface and all its rangelands are under threat of degradation by inappropriate rangeland management practices such as over utilization (Bolo *et al.*, 2019) and suppression of fire (Angassa and Oba, 2008). Such inappropriate rangeland management practices lead to the weakening of the grass sward through the overgrazing of the desirable grass species and subsequent replacement by woody plants. The replacement of desirable grasses by woody specie or bush encroachment is considered as a major threat to the conservation of herbaceous species, and it also reduces the potential grazing/browsing capacity of rangelands (Gemedo *et al.,* 2006a), which in turn causes severe economic losses (Mussa *et al.,* 2017). In addition, bush encroachments are affecting the livelihood of millions of pastoralists and a large part of it is dependent on extensive livestock husbandry for their livelihood (Mussa *et al.*, 2017).

Different methods of bush encroachment control have been suggested and applied. In general, bush encroachment can be controlled chemically, physically or biologically (Mussa *et al.*, 2017). According to Lesoli *et al.* (2013), a chemical method of bush encroachment control is the control of bush encroachment with the treatment of arboricides while mechanical control by felling and excavation of trees is the most selective one but it takes long time and can be quite expensive if heavy machines rather than manual labour are used. Biological control has been defined as the use of living organisms to reduce the vigour, reproductive capacity or effects of bush/tree. Biological control (bio-control) involves the deliberate introduction of invertebrates or diseases and aims to reduce the effects of ecological release (Lesoli *et al.,* 2013).

Bale rangelands as a part of southeast Ethiopia like other arid and semi-arid rangelands provide a diversity of uses including forage for livestock, wildlife habitat, medicinal plants, fuel wood and recreational activity for many years. However, these rangelands experience the increasing pressure from livestock and human populations as well as bush encroachments (Flintan *et al.,* 2011; Mussa *et al.,* 2017). Encroaching woody plant species such as *Acacia bussei* and *Acacia aerfota* and *Commiphora species* are identified as the most encroaching species (Abate *et al.,* 2010). Bush encroachment, the invasion and thickening cover of undesirable woody species with a decrease in grass productivity and biodiversity resulted in the reduced grazing/browsing capacity and concomitant economic losses (Mussa *et al.*, 2017). Hence, a decline in grazing capacity of rangelands due to bush encroachment is a key concern as it contributes to forage scarcity affecting the livestock economy

(Desta and Coppock, 2002) and livelihood of pastoralists (Bolo *et al.*, 2019).

Bush encroachment is considered a threat to forage production, which is the feed for the grazing livestock (Angassa and Oba, 2010). The threat to the pastoral economy by bush encroachment is often the main reason for the control of bush encroachment (Olson and Whitson, 2002).The rapid encroachment of woody plant species and associated ecological and socio-economic losses necessitate bush control to maintain the ecosystem integrity. Bush encroachment control is a worldwide concern in rangeland ecosystems where the problem seriously affects the pastoral industry (Mussa *et al.*, 2016; Bolo *et al.*, 2019) Bush control methods shift the rangeland vegetation from dominance by woody vegetation to dominance by herbaceous vegetation and create suitable habitat for grazers (Angassa and Oba, 2008). Thus, the production of herbaceous vegetation increases with reduction of woody plant species.

A number of studies (Angassa *et al.*, 2011; Negasa *et al.*, 2014; Teka *et al.*, 2018) have suggested that understanding the response of rangeland vegetation to different bush encroachment control methods could provide useful information for designing effective rangeland management/bush control programs. It further helps to ensure sustainable management of rangeland resources and bush encroachment control, thereby improving the livelihood of pastoralists in the region.

Control of bush encroachment has recruited herbaceous biomass and plant biodiversity, which has positive impact on the rangeland ecosystem, livestock production and livelihoods of the pastoral communities (Briske *et al.*, 2003; Negasa *et al.*, 2014). However, there were no tests of the rehabilitative effect of different bush encroachment control methods before this study in the southeastern Ethiopian rangelands. This study delivers scientific assessment of chemical and mechanical methods of bush encroachment control and thus, the study has been used as a basis for making decisions in rangeland management/bush control programs. Therefore, the general objective of this study was to investigate the impacts of mechanical and chemical method of bush encroachment control on rangeland vegetation in Bale zone, southeastern Ethiopia.

Materials and Methods

Description of study area

The study was conducted in Raitu district of Bale zone of Oromia national region, southeastern Ethiopia for two years (2016-17 and 2017-18). Raitu district is located at about 635 km southeast of the capital Addis Ababa and covers an area of about 8026.3 km^2 of land, and is geographically located at 41°25'44.736"E to 6°53'51.742"N (Fig. 1). The district was selected because of the existence of high bush encroachment problems. Its climate varies from hot to warm sub-moist plains (Sm1-1) sub-agro ecological zone. The rainfall pattern is bimodal with long rainy season from March - June and short rainy season from September – October and with mean annual rainfall about 450 mm. The production system in the district is pastoral (36%) and agropastoral (63%) (Abate *et al.*, 2010).

The total land area of the district, woodland vegetation accounts for 43.3%, grassland 11.8%, cropland 18.2% and settlement 15.5% (Mussa *et al.*, 2017). The district lies at elevation of 500-1785 masl. Solancharks, fluvisols and xerosols are the main soil types of the district. The human population of the study district is estimated to be 43914 with a grazing livestock population of 45440 cattle, 76340 goats, 25824 sheep, 18967 camels, 6733 donkeys, 467 horses and 123 mules (CSA, 2015). Livestock is the main assets of the community; it is customary among this society to own as many animals as possible irrespective of the condition of the animals or availability of the pasture. The livestock is considered as a living bank for the pastoralists. This is partly because livestock is regarded as wealth and has prestige value, determining a man’s social position.

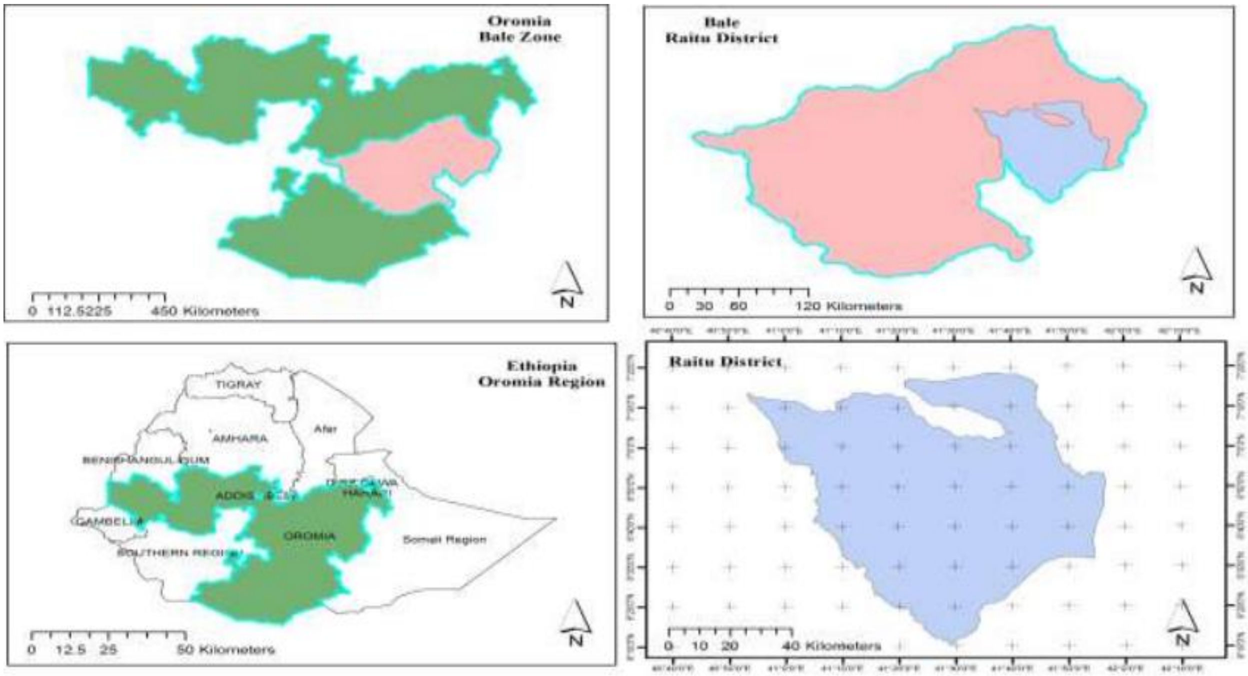

Fig. 1. Map of the study area (Raitu district, lowlands of Bale rangelands, southeast Ethiopia)

Methodology

Site selection and Field layouts

Local community leaders and elders (pastoralists' representatives) and the pastoral officers who have a deep knowledge about the intended sites were purposely selected to take part in site selection. Meetings and discussions were held with government officials, local community leaders and elders to raise awareness on the objectives of the study. Through discussion between the community leaders and elders, the encroaching tree/shrubs (*Acacia bussei* and *Acacia aerfota*) were ranked as the first and second most encroacher tree/shrub species in the study district. Finally, based upon the consensus reached by the community, three sites encroached predominantly by encroaching tree/shrubs (*Acacia bussei* and *Acacia aerfota*) and located adjacently on a homogenous area were delineated for the planned activity.

In each site, five 10×100 m plots were demarcated, cut and stump to four treatments and control plot with no cutting. The five treatments were allocated randomly to the plots. Woody plants were randomly marked for the removal during the thinning process and the areas were fenced using local materials in consultation with the community. The trees were cut from the ground at 5-15 cm alone (T1), trees were cut from the ground at 5-15 cm and the stumps dissected (T2) to facilitate rainwater penetration and rotting of the stumps, the trees were cut from the ground at 5-15 cm and the stumps were completely covered with 2, 4-D herbicide (T3), the trees were cut from the ground at 5-15 cm and the stumps were debarked down into the soil surface (T4) and no cutting of tress (T5). Differently treated stumps were identified by the presence of a one-meter piece of metal rod standing beside each stump and painted in a different color at the top depending on the treatment.

Data Collection

Herbaceous vegetation

The samplings of herbaceous vegetation were carried out at the end of each main growing season to the end of April 2017-2018. During this time of the year, the plants have reached seasonal maturity and can easily be identified. At each plot, all treatments were randomly distributed to five sub plots. Five quadrats were randomly recorded for sampling of herbaceous vegetation in each plot of the sampling sites, totaling 100 (4 sites x 5 plot x 5 quadrats). During each sampling process, all the herbaceous species were identified and numbers of individuals of each species (i.e., relative abundance) per 0.25 m^2 and the species richness were determined. Unidentified herbs and forbs with their local names were transported to herbarium (Addis Ababa University) for identification. Cover percent of each species or categories of species (including unidentified herbaceous and leguminous species) were determined using visual assessment in each quadrant. Within each quadrant, all herbaceous plants in the sample quadrant were harvested using shear, and harvested samples were oven-drying at 105ºC for 24 hr and weighing for the purpose of dry matter estimation.

The basal and litter covers were estimated using visual assessment in each quadrat. The basal and litter covers and estimated soil erosion and compaction percent were obtained by randomly throwing five 0.5 m × 0.5 m quadrats within each plot. Soil compaction percent was estimated by assessing the degree of inserting any sharpened materials (sharpened trees were used in this study) into the soil. The assessment of soil erosion was also determined based on the method described by Baars *et al.* (1997). The values in percent given are as follows: no soil movement (0% to 15%), slight sand mulch (16% to 30%), slope-sided pedestals (31% to 45%), steep-sided pedestals (46% to 60%), pavements (61% to 75%) and gullies (76% to 100%).

Woody vegetation

Data on standing woody plant were collected before treatment application in 2017. However, data on dead and re-sprouted woody plants were collected in the first year after treatment application by counting stumps coppicing or dead under observation due to treatment effects. Responses of individual woody species were analyzed in terms of plant mortality or cut-stump percent mortality (number of individuals totally killed ⁄number of pretreatment individuals for the species x 100) and coppicing percent (number of individual coppicing post treatment⁄ number of pretreatment individuals for the species x 100).

Data analysis

Variables for analyses were species composition, basal cover, species richness and dry matter yield of herbaceous vegetation as well as stump death and stump coppicing percent of woody plants. One-way ANOVA using SAS (9.3) with bush control method as categorical predictors or factors and herbaceous vegetation parameter as well as stump death and stump coppicing percent of woody plants as dependent variables were performed to test the factors main effects on all variables. The values of the probability lower than 0.05 ($P<0.05$) were regarded as statistically significant. Significant differences among mean values were regarded using least significant difference (LSD) method.

Results and Discussions

Botanical composition of herbaceous species

In the study area, a total of 30 herbaceous species were recorded from the sample quadrants studied, which included 21 grass species and 9 herbaceous species (Tab 1). From 21 grass species, 11 were annual grasses whereas 10 were perennial grass species. The annual grass took the highest share (36.7%) followed by perennial grasses (33.3%) and all the remaining percentage formed non-graminoid forbs. In this study, the term "non-graminoid" is used to include all herbaceous families other than Poaceae (grass family). In line with the study by Negasa *et al.* (2014) and Worku and T/Yohannes (2018), the current study showed the greatest contribution of grass for vegetation of the study areas after treatment application. The high proportion of grass species might be attributed to the removal of encroaching tree/shrub species which have had a negative impact on the grass species through competing for nutrients, water and light (Negasa *et al.*, 2014).

Table 1. Overall herbaceous species recorded from sampling sites in the study area

No	Botanical name	Family	Hab	Life form[1]	Frequency (%)
1	*Aristida adscensionis*	Poaceae	Grass	A	4.1
2	*Aristida adoensis*	Poaceae	Grass	A	6.9
3	*Bothriochloa radicans*	Poaceae	Grass	P	8.8
4	*Cenchrus ciliaris*	Poaceae	Grass	P	11.3
5	*Chloris gayana Kunth*	Poaceae	Grass	P	1.3
6	*Chrysopogon plumulosus*	Poaceae	Grass	P	1.2
7	*Commelina benghalensis*	Commelinaceae	Herb	P	0.4
8	*Crotalaria albicaulis*	Fabaceae	Legume	P	0.2
9	*Cynodon dactylon* (L.) Pers.	Poaceae	Grass	P	3.7
10	*Cyperus rotundus* (L.)	Cyperaceae	Sedge	P	0.3
11	*Dactyloctenium aegyptium*	Poaceae	Grass	A	7.1
12	*Digitaria ternate*	Poaceae	Grass	A	1.2
13	*Digitaria velutina* (Forskk)	Poaceae	Grass	A	0.4
14	*Eragrostis cilianensis*	Poaceae	Grass	A	2.3
15	*Eragrostis papposa* (Steud)	Poaceae	Grass	A	2.3
16	*Flaveria trinervia* (Spr.) Mohr	Asteraceae	Herb	A	0.3
17	*Hibiscus aponerus*	Malvaceae	Herb	A	0.3
18	*Heteropogon contortus* (L.) Beauv	Poaceae	Grass	P	1.9
19	*Lintonia nutans*	Poaceae	Grass	A	0.8
20	*Ocimum basilicum* (L.)	Lamiaceae	Herb	A	8.5
21	*Panicum coloratum* (L.)	Poaceae	Grass	P	6.2
22	*Panicum maximum* Jacq.	Poaceae	Grass	P	5.4
23	*Paspalidium desertorum* (A.Rich)	Poaceae	Grass	A	3.1
24	*Setaria verticillata*	Poaceae	Grass	A	0.3
25	*Solanum incanum* (L.)	Solanaceae	Herb	A	0.3
26	*Sporobolus panicoides* (A.Rich)	Poaceae	Grass	A	5.4
27	*Tephrosia subtriflora*	Fabaceae	Legume	P	0.4
28	*Tragus barteronianus*	Poaceae	Grass	P	3.9
29	*Tragus racemosus*	Poaceae	Grass	P	3.1
30	*Tribulus terrestris*	Zygophyllaceae	Herb	A	0.6

P = Perennial, A = Annual;

[1]Source: Hedberg and Edwards (1989), Phillips (1995) and Clayton *et al.* (2002)

Bush control effects on basal cover, dry matter yield and species richness

Tables 2 and 3 presented the effect of bush control on percentage of basal cover, dry matter yield and species richness. The basal and grass cover varied among bush control effects and there were significantly higher ($p<0.05$) values of the basal and grass cover from the plot treated by T3 (trees cutting and debarking the stumps down into the soil surface). The result of the study also showed the highest basal and grass cover in the plots treated with different bush control techniques than control plots (Tables 2 and 3). The high basal cover and high percentage of grass cover in the study area could be associated with the reduced soil erosion by 3.3% and reduced encroaching tree species densities which created a conducive environment for recruiting new grass species. Furthermore, canopy gaps created by tree/shrub removal are expected to result in the increased herbaceous cover, diversity and abundance due to the reduced competition for water and nutrients as well as the increased availability of light (Casado *et al.,* 2004). In line with this finding, Karuaera (2011) found that non-encroached sites had a higher grass cover than the bush-encroached sites.

Dry matter yield and species richness were the highest for T3 (Table 2). Higher dry matter yield in the plots treated with bush control techniques might be attributed to the increment in basal cover percent and the regeneration of grasses in the plots bush encroachment reduced. This finding indicated that grass species is negatively correlated with woody plant density, which is in accordance with Abule *et al.* (2007) and Negassa *et al.* (2014). Increased density of woody plants beyond a critical density suppresses herbaceous growth and its production in semi-arid ecosystems (Richter *et al.,* 2001).

Table 2. Effect of bush control on dry matter, species richness, grass and non-grass cover

Treatments	DM (gm/m^2)	Species richness	Grass Cover (%)	Non grass Cover (%)
1- Cutting at 0.5 m above ground	96.3 c	8.0 a	52.6 b	7.4b
2- Cutting at 0.5 m+dissecting the stumps	101.0b	6.2ab	61.0 b	8.0b
3- Cutting at 0.5 m + pouring chemicals	117.0a	8.2a	71.7 a	4.3c
4- Cutting at 0.5 m+debarking the stumps	108.6ab	5.5a	69.0 a	2.3c
5 (Control)	49.6d	5.0c	20.5 c	11.0a
Overall mean	97.3	7.94	55.0	6.6
±SE	4.2	3.7	1.6	2.1
CV (%)	19.5	2.3	9.8	1.2

Means in the same column followed by the same letter were not significantly different ($p > 0.05$).

Bush control effects on litter covers, soil erosion and soil compaction

The results of this study showed that bush control effect influenced litter covers, the soil erosion and compaction (Tab 3). Litter cover percent was higher in the plot treated with bush control techniques. The reductions in soil erosion and compaction might be due to the increment in basal cover. Negasa *et al.* (2014) in line with the result of this study, they reported higher litter cover in the plots bush control action applied. The results of this study showed that bush control effect influenced both the soil erosion and compaction (Tab 3). The soil erosion and compaction percent were lower in the plots treated with bush control techniques. The reductions in soil erosion and compaction might be due to the increment in basal cover. Hence, erosion losses are minimized and large quantities of root and aboveground biomass are returned to the soil. This in turn increases water infiltration rates into the soil and decreases runoff (Jiang *et al.*, 1996). Besides, reduction in soil erosion and soil compaction could be explained by complete removal of bush density normally accompanied by an increase in herbaceous production and desirable shifts in herbaceous species composition (Ward, 2005; Gemedo *et al.*, 2006b; Negase *et al.*, 2014), mainly due to zero or less competition for available soil water, nutrient and light.

Table 3. Effects of bush control on soil basal cover, litter cover, soil erosion and soil compaction

Treatments	Basal Cover (%)	Litter Cover (%)	Soil Erosion (%)	Soil Compaction (%)
1- Cutting at 0.5 m above ground	60.0c	19.6b	9.3c	31.6b
2- Cutting at 0.5 m+dissecting the stumps	69.0b	22.1b	9.6bc	26.1c
3- Cutting at 0.5 m + pouring chemicals	86.0a	32.4a	10.2b	28.7c
4- Cutting at 0.5 m+debarking the stumps	71.3b	29.8a	9.2c	34.5b
5 (Control)	31.5d	11.0c	11.3a	48.2a
Overall mean	63.56	22.98	9.92	33.82
±SE	4.6	3.2	1.5	4.3
CV (%)	11	9.5	2.3	9.8

Key: Means in the same column followed by the same letter were not significantly different ($p > 0.05$).

Response of *A. bussie* and *A. aerfota* to bush controls

Table 4 presented the effects of bush control on woody plant species. Stump death of *A. bussie* was the highest for T4 (cutting at 0.5 m above ground and debarking) (75.6%) and that of *A. aerfota* was the highest for T1 (cutting at 0.5 m alone) (74.3%). However, we observed during the experiment that T3 was effective only on aged *A. bussie and A. aerfota* rather than on the juveniles, and hence, the level of vulnerability might be related to tree sizes and stage of growth (Clark and Wilson, 2001; Sawadogo *et al.*, 2002; Negasa *et al.*, 2014). A similar finding in Burkina Faso (Sawadogo *et al.*, 2002) and semi-arid rangelands of Ethiopia (Negassa *et al.*, 2014) showed that probability of mortality among woody species is the greatest immediately after disturbance. The dead stumps were *A. aerfota* 50.2%, which was somehow higher than dead stumps of *A. bussei* (48%) showing that *A. aerfota* was more susceptible to the applied treatments than *A.*

bussie (Tab 4). Previous studies have indicated that woody species have different strategies for survival (Negasa *et al.*, 2014).

Table 4. Effects of bush control on *Acacia bussei* and *Acacia aerfota*

Treatments	*Acacia aerfota*		*Acacia bussie*	
	Stump Death (%)	Stump Coppicing (%)	Stump Death (%)	Stump Coppicing (%)
1- Cutting at 0.5 m above ground	74.3a	25.7b	33.8c	76.2a
2- Cutting at 0.5 m+dissecting the stumps	52.3c	48.7a	62.3b	37.7b
3- Cutting at 0.5 m + pouring chemicals	53.4b	46.6a	68.3b	31.7b
4- Cutting at 0.5 m+debarking the stumps	68.7b	31.3b	75.6a	24.4c
5 (Control)	2.3d	3.7c	0.0d	0.0d
Overall mean	50.2	31.2	48	34
±SE	4.6	4.1	12	14
CV (%)	28.2	32	67.4	71.3

Means in the same column followed by the same letter were not significantly different (p> 0.05).

Conclusions

The study aimed to test bush encroachment control methods, an important factor hampering livestock production and improved living standards of the Bale pastoral community. The grazing system of the Bale rangelands has become increasingly unsuitable in recent decades due to range degradation in the form of woody plant encroachment. The widespread use of different bush encroachment control techniques would serve to stabilize forage supply in these semi-arid rangelands by improving overall forage production. The bush control improves species richness, basal cover and dry matter production. According to our results, T1 (cutting at 0.5 m alone) and T4 (cutting at 0.5 m above ground and debarking) were effective in controlling *A. aerfota* and *A. bussie*, respectively. Changes in vegetation structure from thicket forming bush encroachment into open grasslands have recruited herbaceous biomass and plant biodiversity which has a positive impact on the rangeland ecosystem, livestock production and livelihoods of the pastoral communities.

Responses of individual encroaching woody species to the different control methods have important implications for management, conservation policy and public education, which in the future should be promoted through pastoralist participatory research and extension. The management of bush encroachment will contribute to stabilize rangelands, livestock productivity and pastoralist livelihoods and minimize the negative effects of feed and food crises in the future.

Acknowledgements

The authors gratefully acknowledge the financial support from the Ethiopian Institute of Agricultural Research (EIAR) to conduct the study. We would also like to thank pastoral communities and officials in the study areas for their cooperation and assistance during fieldwork. We are also thankful to our Friend, Jeilan Adem, for his assistance in all aspects during the study period.

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