# Changes in vegetation structure, aboveground biomass and soil quality in response to traditional grazing land management practices in the central highlands of Ethiopia

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**Abstract**

Despite shrinking pasture land in the central highlands of Ethiopia due to cropping, there has been little detailed work to evaluate effects of traditional grazing land management practices on vegetation and soil attributes. This study aimed to quantify vegetation structure, aboveground biomass yield and soil quality due to the impact of enclosure and open access management practices by using a sampling quadrat. Aboveground biomass yield for the grass species was 17.6 and 31.2% higher respectively, for the highland and mid-highland agro ecologies for enclosure areas compared to open access grazing. *Andropogon amethystinus* (Important value index (IVI) = 86.9) and *Pennisetum thunbergii* (IVI = 79.2), the most dominant and highest density, found in the enclosure area decreased from open access grazing land and replaced by more resistant to continuous heavy grazing, like *Eleusine floccifolia* (IVI=125.7) in the mid-highland area. Herbaceous species richness was better in open access grazing land than the enclosure area. Soil quality parameters such as total nitrogen, available phosphorous, calcium, sodium and cation exchange capacity were significantly higher for enclosure area than open access practice. In conclusion, enclosure area performed greater in most of the parameters considered than open access grazing land management practices at both agro ecologies.

**Keywords:** mixed crop-livestock system**;** enclosure; herbaceous species; important value index; open access

## Introduction

The mixed crop-livestock system of the highlands of Ethiopia occupies approximately 90 % of human and 60 % of livestock population (Hurni et al. 2010). In these production systems, livestock are dependent on a variety of feed resources that can vary both in quantity and quality throughout the year. Grazing is the predominant form of ruminant feed in the most parts of the extensive and smallholder mixed crop-livestock systems of Ethiopia (Alemayehu 2004). Fallow lands, permanent pasture lands during cropping season and croplands after crop harvest are among the dominant grazing areas (Lemma 2002).

Grazing land resources are shrinking due to intense degradation as a consequence of deforestation, agricultural land expansion and continuous heavy grazing (Mengistu et al. 2005). The evidence available on the impact of grazing systems on the dynamics of native vegetation and soils is inconsistent (Vetter and Bond 2012). Grazers alter landscape heterogeneity (Belsky 1992), rates of nutrient cycling (Frank et al. 1998), and vegetation composition and productivity (Eccard et al. 2000). Similarly, grazers affect different grassland ecosystems including increases (Pucheta et al. 2004), decreases (Gao et al. 2008) and no changes (McNaughton et al. 1998) in root system biomass and below ground net primary productivity. Additionally, others consider grazing as a positive process that improves plant production and survival (Papanastasis 2009), promotes biodiversity (O'Connor et al. 2010) and improves soil fertility. Light grazing increases aboveground biomass, canopy cover and height of the species, but from long-term experiences, moderate grazing would balance the biomass production of different species and livestock production (Wei et al. 2011; Venter et al. 2020).

According to Fekede (2013), pasture lands in the central highland areas have significantly dwindled and are limited to areas where conditions are adverse for cropping partly due to topographic, edaphic and climatic limitations. Consequently, livestock are forced to concentrate on very limited pastureland which in turn lead to reduced productivity in the long run and makes the mixed crop-livestock system unsustainable (Taddese et al. 2002). According to the same author, in those areas, animals will go extinct unless ecosystems are managed to feed people and protect wild species simultaneously. The massive deforestation and the resultant shortage of fuel wood led to the use of dung and agricultural residue as fuel which prevent nutrient recycling through manure. In order to utilize the available grazing lands in a sustainable manner, it appears important to evaluate the impacts of different traditional grazing land management practices for implementing knowledge based grazing land management strategies.

Numerous studies have been conducted on the effect of grazing pressure on plant and soil properties of grasslands, but most have been in the pastoral rangelands. Relatively, little research has been conducted to evaluate effect of different grazing land management practices on vegetation and soil attributes in the highland mixed crop-livestock system of Ethiopia (Taddese et al. 2002; Habtemicael et al. 2014). The available evidence so far showed that, better vegetation and soil attributes are obtained in moderate grazing than continuous heavy grazing. But, no study has been conducted using phytosociological data analysis method to quantify the impact of traditional grazing land management practices on vegetation and soil parameter attributes in the central highlands of Ethiopia. Such analysis is important to provide detailed information on vegetation status and also to offer insights on grazing land ecosystem function and its restoration in general. Therefore, this study was undertaken to quantify changes in vegetation structure, aboveground biomass yield and soil quality attributes in response to traditional grazing land management practices in mixed crop-livestock system in the central highlands of Ethiopia.

## Materials and Methods

### *Study area*

The study was conducted in Kofele district of West Arsi Zone of Oromia Regional State, Ethiopia located at 7º06'-7º07' N and 38º48'-38º49' E for highland and 7º00'-7º02' N and 38º48'-39º00' E for mid-highland (Figure 1). Kofele district is located at 305 km South of Addis Ababa. The agro ecologies of the district are highland (90%) and mid-highland (10%) having loam soil in the highland and sandy loam in mid-highland (District Agricultural and Natural Resource Management Office 2017; unpublished data). The district is found within 2200 - 3200 m.a.s.l. and receives an average rainfall of 1800 mm per annum and average temperature of 19.5

ºC. It has bi-modal rainfall distribution with the short rain starting from March to May and the main rainy season extending from June to September/October. The area is characterized as high potential for crop-livestock farming and cattle and sheep are the most predominant livestock species (CSA 2015). Farmers in the study area grow crops such as barely (*Hordeum vulgare*), wheat (*Triticum aestivum*), maize (*Zea mays*) and *enset* (*Ensete ventricosum*) as food crops and potato (*Solanum tuberosum*), head cabbage (*Brassica oleracea*), beetroot (*Beta vulgaris*) and carrot (*Daucus carota*) as cash crops (Hussein 2017).

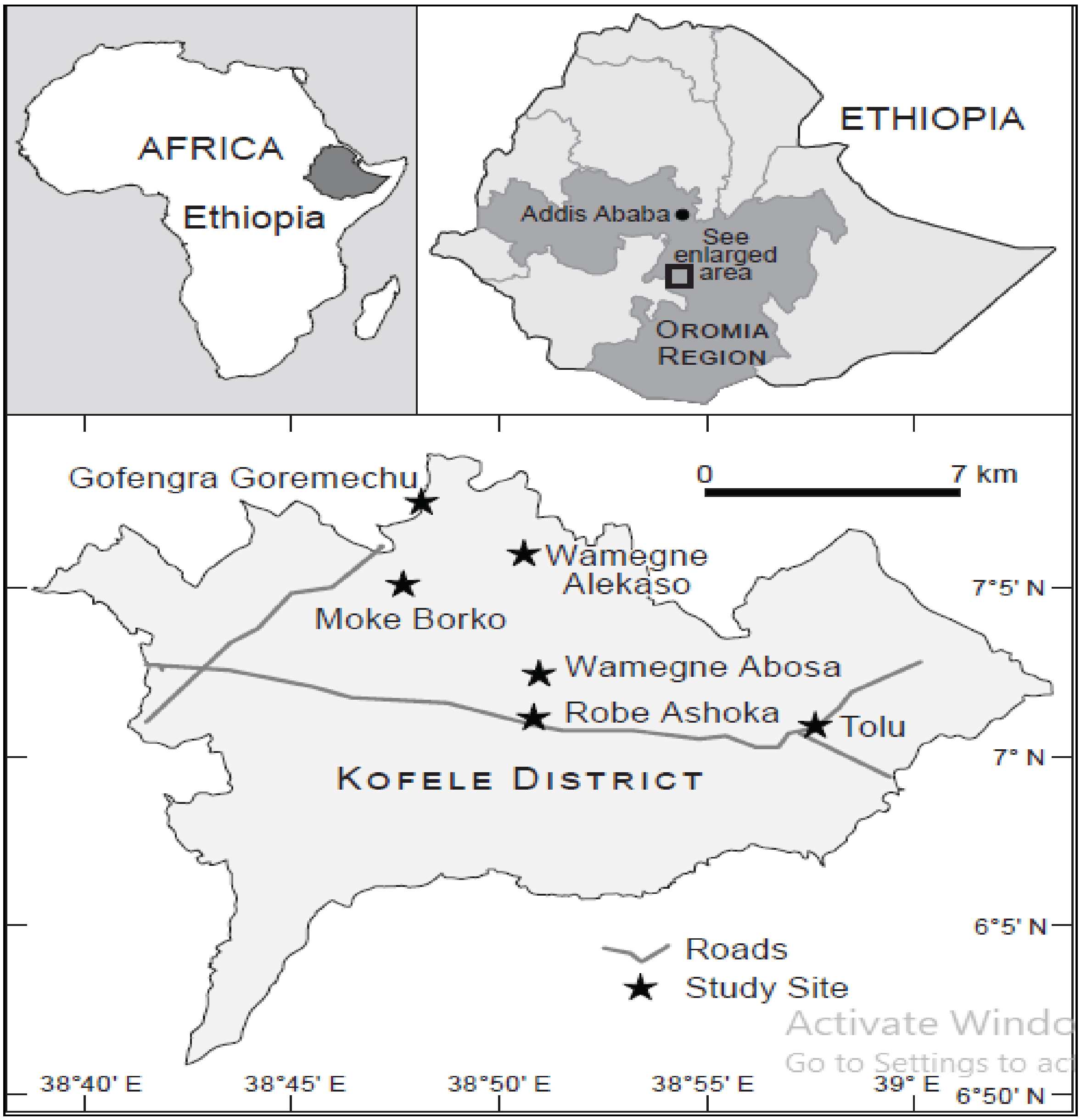



**Figure 1:** Map of the study area, Kofele district, central highlands of Ethiopia

### *Traditional grazing land management history*

The study area is historically (before 60 years) known for livestock rearing and cultivation of crops is relatively a recent phenomenon in the system. The major land use includes farmlands and grazing lands which in turn consist of enclosure area during rainy season which is traditionally known as "*Kalo*" and an openly grazed area (free grazing) throughout the year. The enclosure area refers to a specific land unit that is protected from the activities of particular class of animals by using appropriate barriers such as fencing and/or controlling the entrance of the animals following the onset of short rainy season. This particular type of grazing land is used for rotational stocking during short and main rainy seasons, cut and carry system and in rare cases used as conserved standing hay for use during the dry period. Open access grazing refers to an area of land which is exposed to unregulated and year round grazing by a large number of mixed livestock species. According to the information obtained from elder farmers in the study area, these traditional grazing land management practices have been evident for more than 30 years and such areas were purposively selected for the current study.

### *Site selection and study design*

Two traditional grazing land management practice sites, enclosure during wet season and the adjacent open access grazing land, were systematically selected based on the similarity in landscape and soil to minimise variability in the abiotic determinants of grassland vegetation composition and functioning. At both agro ecologies, 10 plots of 40 m x 40 m (five plots each from enclosure and the adjacent open access area) were established. All plots were enclosed uniformly for five months from May, 2018 to September, 2018. Along 10 m transects, sixteen 0.5 m x 0.5 m quadrats were nested per plot for sample collection (Figure 2). In total, 320 quadrats (two agro ecologies i.e. highland and mid-highland x two management systems x five plots x 16 quadrats) were used to collect pasture species samples. To avoid any edge effects, the plots were laid 50 m away from the boundaries of the enclosure and the adjacent open access, respectively.

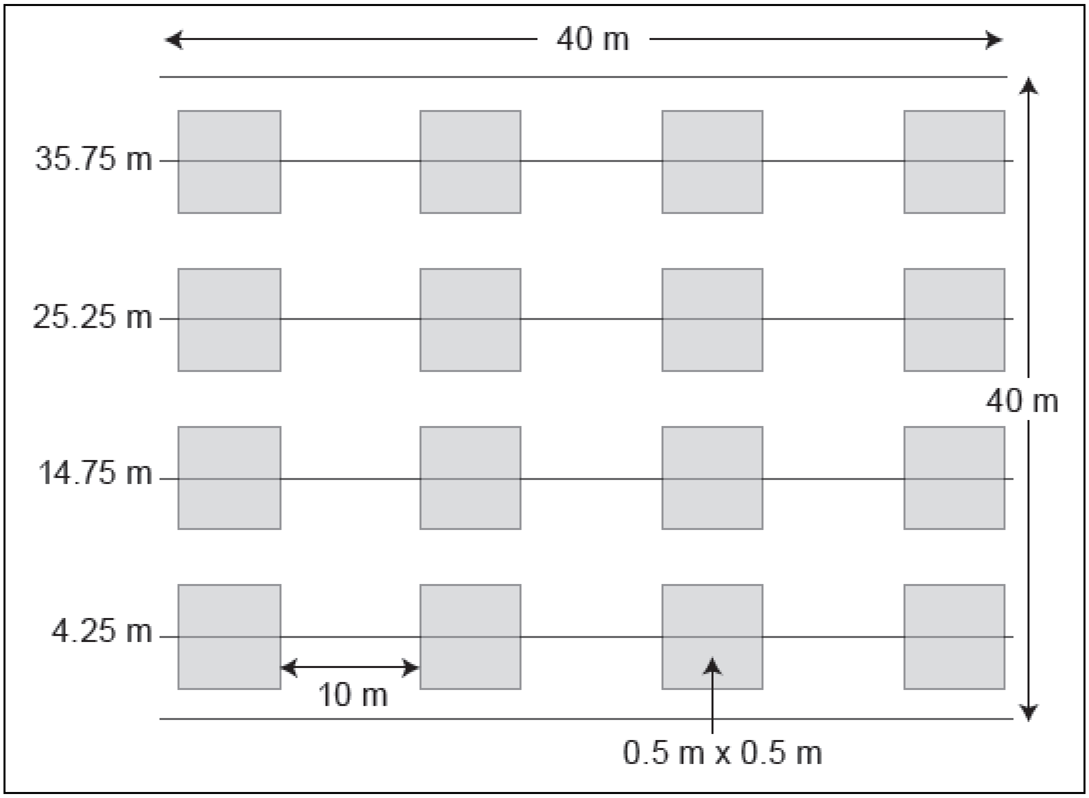



**Figure 2:** Sampling design and plot layout of the experimental site used for herbaceous species and soil sampling.

### *Vegetation sampling and analysis*

Vegetation sampling in individual enclosure and the adjacent open access grazing land were conducted in September, 2018 at the end of main rainy season at 50 % flowering and easily identified. Herbage biomass yield was determined by mowing the pasture at 5 cm aboveground using a sickle from an area of 0.25 $m^2$ quadrats and sorted by species and pooled to obtain enough quantities of individual species in the sampling area to allow investigation between species variability in terms of nutrient contents. Fresh biomass was immediately weighted by using scale. Forage species were identified by using guide books on the site and for those plant species that were difficult to identify at the field, their local names were recorded and herbarium specimens were collected, pressed and dried properly by using a plant presser and identified and confirmed at the national herbarium, Addis Ababa University, Ethiopia. Individual forage species in each quadrat were counted and weighted fresh to estimate biomass yield and vegetation composition were evaluated by analyzing the frequency, density, abundance and important value index (IVI) by using the following formula given by Mishra (1968) and Curtis and McIntosh (1951):

$$\text{Frequency} = \frac{\text{Total number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Relative Frequency} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100$$

$$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied}}$$

$$\text{Relative density} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats in which the species occurred}}$$

$$\text{Relative Dominance of Herbaceous Species} = \frac{\text{Basal area of a species}}{\text{Basal area of all the species}} \times 100$$

IVI = Relative frequency + Relative density + Relative dominance

The distribution of species similarity between enclosed area and open access grazing land were computed by using index of similarity which was calculated by applying formula given by Jaccard (Zobel etal. 1987):

$$IS_J = (C/A+B-C) \times 100$$

Where $IS_J$ = Jaccard's Index of Similarity, C= the number of species common to both grazing management practices; A = the number of species unique to enclosure area; B= the number of species unique to open access grazing area.

From pooled forage species across plots, 20 % of above ground biomass was taken and oven-dried to a constant weight at 60 $^0$C for 48 hours and used for dry matter determination. Species richness was estimated by counting all species within the sample quadrats. Species diversity was computed for each grazing land management practice using the Shannon–Wiener diversity index ($H'$) (Shannon and Wiener, 1963):

$$H' = -\sum_{i=1}^{s} Pi\ In\ Pi$$

Where s= number of species; pi = proportion of individuals or abundance of the $i^{th}$ species expressed as a proportion of total cover; and ln = log base n.

Equitability or species evenness was calculated using the formula given by Pielou (1969):

Equitability (J) = $H'/H'_{max}$

Where $H'_{max}$ = Maximum possible diversity; $H'$= Shannon–Wiener diversity index.

***Soil sampling and analyses***

Soil samples were collected from the center of 0.25 $m^2$ quadrats after aboveground biomass removed by using an Auger at a depths of 0 - 10, 10 - 20, 20 - 30, 30 - 40 and 40 - 50 cm. The soil samples at each plot were pooled to form one composite soil sample per sampling plot yielding a total of 20 soil samples for each depth (two management practices x 10 sample plots) to determine the cumulative effect of traditional grazing land management on soil attributes. Samples were taken to the lab, air dried, crushed and passed through a 1 mm and 2 mm mesh size sieve. Soil pH was determined by using pH meter in 1:2.5 soil water suspension ratios (Lewis and Freitas 1984). Electrical Conductivity (EC) was determined in a 1:2.5 soil water suspension following the steps and procedures suggested by Chopra and Kanwar (1976). Total N was determined using the Kjeldahl procedures suggested by Jackson (1970). Soil organic carbon (SOC) was determined following the method recommended by Walkley and Black (1934). Then, soil organic matter (SOM) was calculated by multiplying the percentage of the organic carbon by a factor of 1.724 following the method recommended by Brady and Weil (1999). The level of available phosphorous (P) was determined by using the methods and procedures specified by Olsen et al. (1954). Calcium (Ca) was determined by atomic absorption spectrometry and potassium (K) and sodium (Na) were determined by flame photometry. Texture was analysed by the hydrometer method (Bouyoucos 1962).

### *Statistical analyses*

The effect of traditional grazing management practices (enclosures area vs. open access grazed) i.e. independent variable on herbaceous aboveground biomass yield and proportions of different life forms, species frequency, abundance, density, richness and evenness and soil properties (dependent variables) were analyzed using ANOVA (SAS 9.1) by using the General Linear Model Procedure (SAS 2001). Twenty sampling plots and 16 quadrats per plot were used as replicates to assess the impact of traditional grazing land management practices on aboveground biomass yield and twenty sampling plots were used as a replicates for soil quality parameter analyses. Tukey's HSD test with $P < 0.05$ was employed for mean comparison. Before analyses, data were transformed to optimise normality and homogeneity of variance using Shapiro–Wilk test (Steel and Torrie 1980).

Principal component analyses (PCA) ordination was used to explain variance of analysed soil and/or vegetation attributes across the two management practices. Principal component analysis axis correlation coefficient was used to explain the location of the vegetation and soil attributes across the enclosure and open grazing. Principal component analysis was conducted using PAleontological Statistics (PAST) software package version 4.02 (Hammer et al. 2001).

## Results

### Effects of *grazing land management practices on vegetation biomass yield*

Aboveground biomass yield (mean) for enclosure area was higher ($P < 0.001$) than open access grazing in the mid-highland agro ecology (Table 1). Biomass yield obtained from enclosure area was 28.8% greater than open access grazing. Among the different botanical groups (grasses, legumes, sedges and forbs), the mean aboveground biomass yield for grass species from the enclosure area were higher ($P < 0.001$) than open access grazing at both agro ecologies.

Aboveground biomass yield for the grass species was 17.6 and 31.2% higher respectively, in the highland and mid-highland agro ecologies for enclosure areas compared to open access grazing. The proportion of grass among the botanical groups was 76.3 and 69.6 % from highland and 92.9 and 83.7 % from mid-highland for enclosure and open access grazing land respectively, which has the highest share among the botanical component groups. No statistical difference ($P > 0.05$) was observed for sedges between the two grazing land management practices at both agro ecologies and the mean above ground biomass yield for forbs in open access grazing was higher ($P < 0.001$) than the enclosure area at highland agro ecology.

**Table 1**: Total aboveground herbaceous biomass yield and proportions for botanical groups on dry matter basis (t/ha) under the two traditional grazing land management practices in the central highlands of Ethiopia (mean ± SEM).

| Vegetation variables | Agro ecology | | | |
|---|---|---|---|---|
| | Highland | | Mid-highland | |
| | Enclosure | Open access | Enclosure | Open access |
| Total aboveground biomass | 3.26 ± 0.19 | 3.07 ± 0.16 | $6.62 \pm 0.36^{a}$ | $4.71 \pm 0.47^{b}$ |
| Herbaceous components | | | | |
| Grasses | $2.61 \pm 0.20^{a}$ | $2.15 \pm 0.20^{b}$ | $6.18 \pm 0.36^{a}$ | $4.25 \pm 0.47^{b}$ |
| Legumes | $0.12 \pm 0.04^{b}$ | $0.42 \pm 0.12^{a}$ | 0.27 ± 0.04 | 0.28 ± 0.06 |
| Sedges | 0.23 ± 0.05 | 0.14 ± 0.03 | 0.17 ± 0.03 | 0.16 ± 0.03 |
| Forbs | $0.39 \pm 0.04^{b}$ | $0.56 \pm 0.07^{a}$ | 0.17 ± 0.03 | 0.21 ± 0.03 |

[a,b] Different superscripts within the row for each agro ecology show significant difference ($P < 0.05$). SEM = standard error of mean.

### *Effects of grazing land management practices on herbaceous species composition*

In the highland agro ecology, a total of 29 herbaceous species were recorded of which 22 and 27 herbaceous species were recorded for the enclosure and open access grazing area, respectively (Table 2). From identified herbaceous species, *Andropogon amethystinus* (IVI = 86.9) was the most dominant and the highest density perennial grass. *Pennisetum thunbergii* (IVI = 79.2) and *Centella asiatica* (IVI = 35.8) were the co-dominant forage species in the enclosure area. On the other hand, in the open access grazing area, *Pennisetum thunbergii* (IVI = 100.6) was the most dominant with the higher density and *Andropogon amethystinus* (IVI = 44.2) and *Centella*

**Table 2**: Herbaceous species attributes for enclosure vs. open access traditional grazing land management practices in the highland agro ecology

| Species scientific name | Frequency | | Abundance | | Density | | A/F | | IVI | |
|---|---|---|---|---|---|---|---|---|---|---|
| | E | O | E | O | E | O | E | O | E | O |
| **Grasses** | | | | | | | | | | |
| *Andropogon amethystinus* | 81.3 | 60.4 | 798.0 | 305.9 | 648.4 | 184.8 | 9.8 | 5.1 | 86.8 | 44.2 |
| *Brachiaria scalaris* | 2.1 | 2.1 | 66.0 | 10.0 | 1.4 | 0.2 | 31.7 | 4.8 | 0.4 | 0.4 |
| *Cynodon dactylon* | 0.0 | 43.8 | 0.0 | 71.6 | 0.0 | 31.3 | 0.0 | 1.6 | 0.0 | 11.9 |
| *Eragrostis botryodes* | 2.1 | 8.3 | 11.0 | 55.8 | 0.2 | 4.6 | 5.3 | 6.7 | 0.7 | 1.7 |
| *Eragrostis tenuifolia* | 6.3 | 10.4 | 14.3 | 36.2 | 0.9 | 3.8 | 2.3 | 3.5 | 1.0 | 2.1 |
| *Helictotrichon elongatum* | 25.0 | 10.4 | 36.3 | 93.2 | 9.1 | 9.7 | 1.5 | 8.9 | 0.5 | 3.9 |
| *Ischaemum afrum* | 2.1 | 12.5 | 24.0 | 88.2 | 0.5 | 11.0 | 11.5 | 7.1 | 0.4 | 5.9 |
| *Pennisetum humile* | 0.0 | 12.5 | 0.0 | 34.7 | 0.0 | 4.3 | 0.0 | 2.8 | 0.0 | 3.1 |
| *Pennisetum sphacelatum* | 0.0 | 12.5 | 0.0 | 54.0 | 0.0 | 6.8 | 0.0 | 4.3 | 0.0 | 4.7 |
| *Pennisetum thunbergii* | 95.8 | 97.9 | 471.0 | 401.1 | 451.4 | 392.7 | 4.9 | 4.1 | 79.2 | 100.6 |
| *Sporobolus pyramidalis* | 0.0 | 4.2 | 0.0 | 40.5 | 0.0 | 1.7 | 0.0 | 9.7 | 0.0 | 1.58 |
| **Legumes** | | | | | | | | | | |
| *Trifolium cryptopodium* | 16.7 | 8.3 | 53.6 | 79.8 | 8.9 | 6.6 | 3.2 | 9.6 | 3.2 | 2.0 |
| *Trifolium mattirolianum* | 12.5 | 12.5 | 69.2 | 87.7 | 8.6 | 11.0 | 5.5 | 7.0 | 4.4 | 2.9 |
| *Trifolium simense* | 4.2 | 18.8 | 128.0 | 141.0 | 5.3 | 26.4 | 30.7 | 7.5 | 7.1 | 5.6 |
| *Trifolium tembense* | 20.8 | 50.0 | 50.9 | 59.2 | 10.6 | 29.6 | 2.4 | 1.2 | 4.1 | 12.7 |
| **Sedges** | | | | | | | | | | |
| *Cyperus rigidifolius* | 81.3 | 50.0 | 74.5 | 40.7 | 60.5 | 20.3 | 0.9 | 0.8 | 18.8 | 12.5 |
| *Cyperus rubicundus* | 0.0 | 4.2 | 0.0 | 20 | 0.0 | 0.8 | 0.0 | 4.8 | 0.0 | 0.7 |
| *Cyperus papyrus* | 6.3 | 6.3 | 178.0 | 24.0 | 11.1 | 1.5 | 28.5 | 3.8 | 1.8 | 1.4 |
| *Scleria hispidula* | 37.5 | 4.2 | 71.0 | 108.0 | 26.6 | 4.5 | 1.9 | 25.9 | 7.6 | 1.2 |
| *Scleria schimperiana* | 20.8 | 0.0 | 190.7 | 0.0 | 39.7 | 0.0 | 9.2 | 0.0 | 6.4 | 0.6 |
| **Forbs** | | | | | | | | | | |
| *Alchemilla pedata* | 4.2 | 18.8 | 62.0 | 50.8 | 2.6 | 9.5 | 14.9 | 2.7 | 0.8 | 3.9 |
| *Centella asiatica* | 93.8 | 75.0 | 314.7 | 259.9 | 295.0 | 195.0 | 3.4 | 3.5 | 35.8 | 36.5 |
| *Cerastium octandrum* | 0.0 | 4.2 | 0.0 | 10.0 | 0.0 | 0.4 | 0.0 | 2.4 | 0.0 | 1.1 |
| *Crepis schultzii* | 0.0 | 25.0 | 0.0 | 49.2 | 0.0 | 12.3 | 0.0 | 2.0 | 0.1 | 5.9 |
| *Cyanotis barbata* | 4.2 | 0.0 | 29.0 | 0.0 | 1.2 | 0.0 | 7.0 | 0.0 | 0.8 | 0.0 |
| *Haplocarpha hastata* | 47.9 | 22.9 | 19.0 | 11.8 | 9.1 | 2.7 | 0.4 | 0.5 | 8.5 | 5.8 |
| *Oldenlandia monanthos* | 12.5 | 14.6 | 104.5 | 23.7 | 13.1 | 3.5 | 8.4 | 1.6 | 3.3 | 2.7 |
| *Satureja paradoxa* | 4.2 | 6.3 | 27.0 | 20.7 | 1.1 | 1.3 | 6.5 | 3.3 | 0.8 | 1.1 |
| *Uebelinia abyssinica* | 85.4 | 89.6 | 55.0 | 48.0 | 47.0 | 43.0 | 0.6 | 0.5 | 22.7 | 23.3 |

A/F = abundance to frequency ration; E = enclosure; O = open access; IVI = important value index

*asiatica* (IVI = 36.5) were the co-dominant herbaceous species. Four grass species (*Cynodon dactylon, Pennisetum humile, Pennisetum sphacelatum and Sporobolus pyramidalis*) and two forbs (*Cerastium octandrum and Crepis schultzii*) which were recorded in open access grazing were absent from enclosure area. *Pennisetum thunbergii* and *Andropogon amethystinus* (grass), *Cyperus rigidifolius* (sedge) and *Centella asiatica* and *Uebelinia abyssinica* (forb) were the most frequently appeared species among others.

**Table 3:** Herbaceous species attributes of enclosure and open access traditional grazing land management practices from the mid-highland agro ecology.

| Species scientific name | Frequency | | Abundance | | Density | | A/F | | IVI | |
|---|---|---|---|---|---|---|---|---|---|---|
| | E | O | E | O | E | O | E | O | E | O |
| **Grasses** | | | | | | | | | | |
| *Andropogon amethystinus* | 52.1 | 47.9 | 425.7 | 146.1 | 221.7 | 70.0 | 8.2 | 3.0 | 67.3 | 29.6 |
| *Cynodon dactylon* | 10.4 | 4.2 | 8.6 | 15.5 | 0.9 | 0.6 | 0.8 | 3.7 | 2.2 | 0.9 |
| *Eleusine floccifolia* | 97.9 | 66.7 | 224.9 | 304.8 | 220.2 | 203.2 | 2.3 | 4.6 | 119.5 | 125.7 |
| *Eragrostis botryodes* | 0.0 | 8.3 | 0.0 | 214.5 | 0.0 | 17.9 | 0.0 | 25.7 | 0.0 | 6.0 |
| *Pennisetum humile* | 10.4 | 4.2 | 17.4 | 2.5 | 1.8 | 0.1 | 1.7 | 0.6 | 2.5 | 0.8 |
| *Pennisetum thunbergii* | 4.2 | 41.7 | 47.5 | 156.7 | 2.0 | 65.3 | 11.4 | 3.8 | 1.4 | 25.7 |
| *Poa leptoclada* | 39.6 | 25.0 | 61.6 | 30.8 | 24.4 | 7.7 | 1.6 | 1.2 | 13.1 | 7.2 |
| *Snowdenia polystachya* | 4.2 | 0.0 | 42.5 | 0.0 | 1.8 | 0.0 | 10.2 | 0.0 | 1.4 | 0.0 |
| *Sporobolus pyramidalis* | 50 | 31.3 | 59.6 | 57.1 | 29.8 | 17.9 | 1.2 | 1.8 | 19.5 | 15.6 |
| **Legumes** | | | | | | | | | | |
| *Trifolium cryptopodium* | 20.8 | 22.9 | 25.3 | 52.4 | 5.3 | 12.0 | 1.2 | 2.3 | 5.1 | 7.8 |
| *Trifolium mattirolianum* | 0.0 | 8.3 | 0.0 | 60.5 | 0.0 | 5.0 | 0.0 | 7.3 | 0.0 | 3.2 |
| *Trifolium rueppellianum* | 0.0 | 12.5 | 0.0 | 27.8 | 0.0 | 3.5 | 0.0 | 2.2 | 0.0 | 4.0 |
| *Trifolium simense* | 14.6 | 6.3 | 74.9 | 70.0 | 10.9 | 4.4 | 5.1 | 11.2 | 4.7 | 2.5 |
| *Trifolium tembense* | 64.6 | 31.3 | 78.6 | 56.2 | 50.8 | 17.6 | 1.2 | 1.8 | 23.8 | 10.2 |
| **Sedges** | | | | | | | | | | |
| *Cyperus rigidifolius* | 62.5 | 62.5 | 30.4 | 33.4 | 19 | 20.9 | 0.5 | 0.5 | 16.7 | 18 |
| *Cyperus papyrus* | 0.0 | 12.5 | 0.0 | 8.5 | 0.0 | 1.1 | 0.0 | 0.7 | 0.0 | 2.7 |
| *Scleria hispidula* | 0.0 | 4.2 | 0.0 | 44 | 0.0 | 1.8 | 0.0 | 10.6 | 0.0 | 1.2 |
| *Scleria schimperiana* | 0.0 | 22.9 | 0.0 | 51.9 | 0.0 | 11.9 | 0.0 | 2.3 | 0.0 | 7.1 |
| **Forbs** | | | | | | | | | | |
| *Agrocharis melanantha* | 14.6 | 0.0 | 12.0 | 0.0 | 1.8 | 0.0 | 0.8 | 0.0 | 3.2 | 0.0 |
| *Alchemilla pedata* | 8.3 | 0.0 | 23.0 | 0.0 | 1.9 | 0.0 | 2.8 | 0.0 | 2.0 | 0.0 |
| *Centella asiatica* | 4.2 | 0.0 | 2.0 | 0.0 | 0.1 | 0.0 | 0.5 | 0.0 | 0.8 | 0.0 |
| *Cerastium octandrum* | 16.7 | 54.2 | 12.9 | 27.4 | 2.1 | 14.8 | 0.8 | 0.5 | 3.7 | 15 |
| *Cyanotis barbata* | 0.0 | 22.9 | 0.0 | 16.1 | 0.0 | 3.7 | 0.0 | 0.7 | 0.0 | 6.1 |
| *Haplocarpha hastata* | 10.4 | 6.3 | 24.0 | 43.0 | 2.5 | 2.7 | 2.3 | 6.9 | 2.5 | 1.8 |
| *Satureja paradoxa* | 25.0 | 6.3 | 46.5 | 16.0 | 11.6 | 1.0 | 1.9 | 2.6 | 7.4 | 1.4 |
| *Uebelinia abyssinica* | 12.5 | 27.1 | 17.5 | 25.8 | 2.2 | 7.0 | 1.4 | 1.0 | 3.1 | 7.4 |

A/F = abundance to frequency ration; E = enclosure; O =open access; IVI=important value index

In the mid-highland agro ecology, a total of 26 herbaceous species were recorded of which 19 and 22 herbaceous species were recorded for the enclosure and open access grazing area, respectively (Table 3). Among the identified species from enclosure area, *Eleusine floccifolia* (IVI = 119.5) was the most dominant, abundant with the highest density species followed by *Andropogon amethystinus* (IVI = 67.3), *Trifolium tembense* (IVI = 23.8), *Sporobolus pyramidalis* (IVI = 19.5) and *Cyperus rigidifolius* (IVI = 16.7) as co-dominant species. Similarly, in open access grazing area, *Eleusine floccifolia* (IVI = 125.7) was the most dominant, abundant with highest density species with co-dominant species such as *Andropogon amethystinus* (IVI = 29.6), *Pennisetum thunbergii* (IVI = 25.7), *Cyperus rigidifolius* (IVI = 18), *Sporobolus pyramidalis* (IVI = 15.6) *and Cerastium octandrum* (IVI = 15). Two annual legumes (*Trifolium mattirolianum* and *Trifolium rueppellianum)* and three annual sedges (*Cyperus papyrus; Scleria hispidula; Scleria schimperiana)* which were recorded in open access grazing were absent from enclosure area. Three perennial forbs present in enclosure area (*Agrocharis melanantha, Alchemilla pedata* and *Centella asiatica*) were not recorded in open access grazing area.

***Effects of grazing land management practices on species richness, diversity and similarity indexes***

Herbaceous species richness was higher in open access grazing area than the enclosure area for both agro ecologies. While herbaceous species evenness and Shannon diversity index was similar between the grazing management systems in the highland agro ecology. The values for species evenness and Shannon diversity index were slightly higher in open access grazing than enclosure area in the mid-highland agro ecology. The overlap of herbaceous species across the two grazing regime were similar for both agro ecology as indicated by Jaccard's index of similarity (Table 4).

**Table 4:** Herbaceous species richness, evenness, diversity and similarity indexes across the two traditional grazing land management practices in the central highlands of Ethiopia.

| Index | Agro ecology | | | |
|---|---|---|---|---|
| | Highland | | Mid-highland | |
| | Enclosure | Open access | Enclosure | Open access |
| Species richness | 22 | 27 | 19 | 22 |
| Species evenness | 0.54 | 0.52 | 0.54 | 0.67 |
| Shannon diversity index (H') | 1.68 | 1.71 | 1.59 | 2.07 |
| Maximum possible diversity (Hmax) | 3.09 | 3.29 | 2.94 | 3.09 |
| Jaccard's Index of Similarity ($IS_J$) | 68.9 | | 57.7 | |

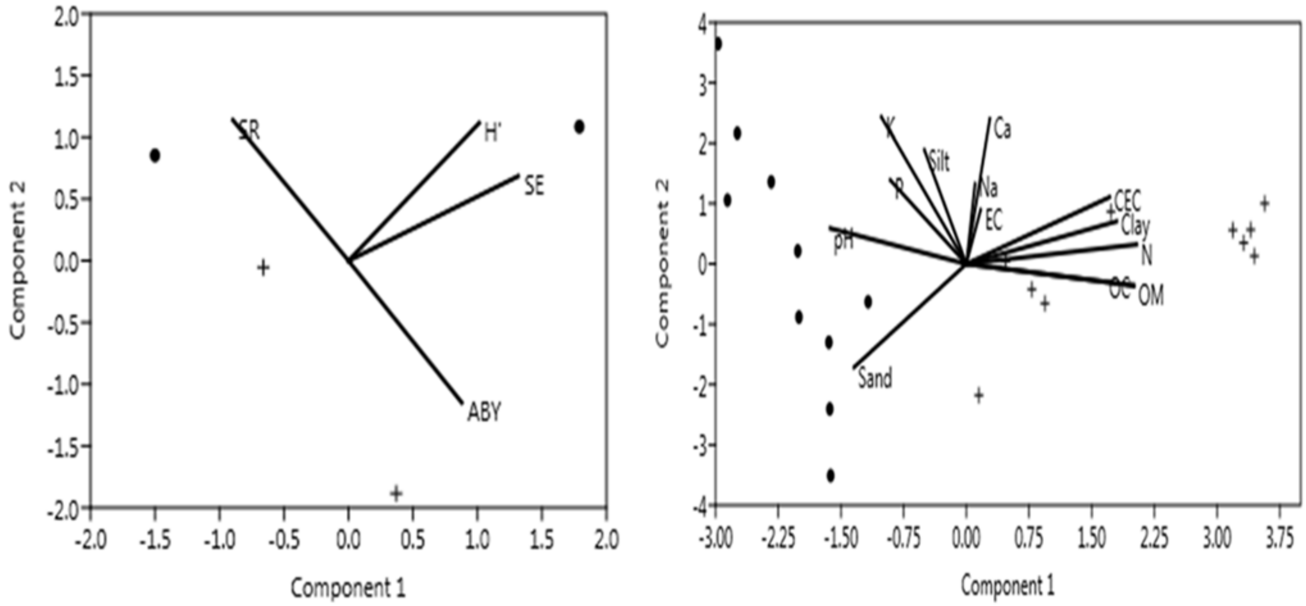
**Table 5**: Soil physico-chemical properties (mean ± SEM, 0-20 cm depth) for enclosure and open access grazing land management practices

| Parameters | Highland | | Mid-highland | |
|---|---|---|---|---|
| | Enclosure | Open access | Enclosure | Open access |
| pH | 5.4 ± 0.2 | 5.3 ± 0.2 | 5.8 ± 0.18 | 5.9 ± 0.04 |
| EC (ds/m) | 0.012 ± 0.009 | 0.001 ± 0.0001 | 0.008 ± 0.007 | 0.009 ± 0.006 |
| SOC (%) | 9.5 ± 1.9 | 7.6 ± 1.1 | 5.6 ± 1.0 | 5.9 ± 1.2 |
| SOM (%) | 16.4 ± 3.2 | 13.1 ± 1.9 | 9.7 ± 1.8 | 10.3 ± 2.1 |
| AP (mg/kg) | 9.6 ± 1.3 | 11.3 ± 3.5 | $21.9^{a} \pm 2.1$ | $10.0^{b} \pm 3.3$ |
| TN (%) | $0.51^{a} \pm 0.09$ | $0.42^{b} \pm 0.09$ | 0.35 ± 0.04 | 0.35 ± 0.04 |
| CEC (Cmol(+)/Kg) | $34.1^{a} \pm 2.6$ | $28.7^{b} \pm 1.1$ | $27.2^{a} \pm 1.1$ | $20.2^{b} \pm 1.7$ |
| Ca ($Cmol_k$/kg) | 44.0 ± 6.5 | 36.9 ± 6.2 | $44.3^{a} \pm 3.6$ | $36.2^{b} \pm 4.3$ |
| K ($Cmol_k$/kg) | 9.4 ± 1.1 | 10.3 ± 1.0 | $12.4^{a} \pm 0.7$ | $9.9^{b} \pm 1.3$ |
| Na ($Cmol_k$/kg) | 21.6 ± 1.1 | 21.5 ± 1.0 | 21.6 ± 0.1 | 21.2 ± 0.4 |
| Texture | | | | |
| Sand (%) | 39.8 ± 2.9 | 45.5 ± 4.4 | 50.3 ± 4.3 | 49.8 ± 3.1 |
| Silt (%) | 21.2 ± 2.2 | 21.5 ± 2.9 | 23.3 ± 4.6 | 23.2 ± 2.3 |
| Clay (%) | 39.0 ± 2.2 | 33.0 ± 3.6 | 26.3 ± 1.7 | 27.8 ± 2.3 |

[a, b,] Different letters within each row indicate significant difference for the two grazing land management practices ($p < 0.05$) for each agro-ecology. AP= available phosphorous; Ca=calcium; CEC= cation exchange capacity; EC=electric conductivity; K=potassium; Na=sodium; SOC=soil organic carbon; SEM=standard error of mean; SOM= soil organic matter; TN=total nitrogen

*Effects of grazing land management practices on soil physico-chemical properties*

The mean soil physio-chemical properties under the two traditional grazing land management practices are presented in Table 5. From the highland agro ecology, soil total N and cation exchange capacity (CEC) were higher ($P < 0.05$) for enclosure area than open access grazing practices. Similarly, from mid-highland agro ecology, available P, CEC, Ca and K were greater ($P < 0.05$) for enclosure area than open access grazing practices. However, no differences ($P > 0.05$) were observed between the two grazing land management practices for the rest parameters considered respectively, for the two agro ecologies.




(a) (b)

**Figure 3**: Principal component analysis correlation (% variance) diagram based on vegetation and soil parameter attributes in the central highlands of Ethiopia (enclosure area = filled plus shape; open access area = dot shape: (a) vegetation attributes (ABY=aboveground biomass yield; SR=species richness; SE=species evenness; H' = Shannon diversity index) and (b) soil parameter attributes (N=nitrogen; P=phosphorus; K=potassium; Ca=calcium; Na=sodium; EC=electric conductivity; OC=organic carbon; OM=organic matter; CEC=cataion exchange capacity).

*Vegetation and soil attribute ordination and analyses*

The PCA correlation variance of aboveground biomass yield, species richness, species evenness and Shannon diversity index showed distinct separation (Figure 3 (a)) with principal component

1 accounting for 50.21% (eigenvalue = 2.00) and principal component 2 accounting for 45.54% (eigenvalue = 1.82) of the total explained variance in relation to the open grazing and enclosures areas. Similarly, PCA of soil parameters characteristics showed distinct separation (Figure 3 (b)) between the open grazing and enclosure areas with principal component 1 accounting for 44.33% (eigenvalue = 5.76), principal component 2 accounting for 20.18% (eigenvalue = 2.62) and principal component 3 accounting for 12.83 (eigenvalue = 1.66).

## Discussion

### *Vegetation biomass across traditional grazing land management practices*

The lower aboveground biomass yield in the grass species in an open access grazing land in the current study showed the consequences of overgrazing due to year round stocking which is the principal driving forces for land degradation if open access grazing practices continuous. Many previous findings (Gebremedhin et al. 2017; Mekuria et al. 2018; Tiscornia et al. 2019) observed that overgrazing (human-induced processes) was the most driving forces for land degradation which is the direct effects of land use change. The result of this study agrees with the findings of Tadesse et al. (2002), Yayneshet et al. (2009) and Habtemicael et al. (2014) who found higher above ground biomass yield in the enclosure area as compared to free grazing in the highland mixed crop-livestock farming system of Ethiopia mainly due to reduced grazing disturbance by livestock. Similarly, Gebregergs et al. (2018) observed greater aboveground biomass yield from cut and carry than open grazing lands in semi-arid areas of Tselemti district in the north western Tigray region of Ethiopia. The higher aboveground biomass yield recorded for the *Trifolium* species in open access than enclosure area might be associated to the stimulatory effect of grazing on the growth of palatable leguminous plant species as observed by Taddese et al. (2002) who found more of this species in area where there is livestock grazing than no grazing practices. The higher proportion of forbs species recorded in freely grazed area than seasonally grazed area in the highland agro ecology in the current study also supported by Bilotta et al. (2007), who reported that heavily grazed sites were dominated by annual forbs and weedy species. Similarly, Holechek et al. (2005) reported that overgrazing allows the invasion of annual forbs and grasses.

***Herbaceous species composition across traditional grazing land management practices***

Information about vegetation status of a species and patter of association of dominancy of species in a community can be provided by analyzing IVI for each species (Parthasarathy and Karthikeyan 1997). Analysis of IVI in the two traditional grazing land management practices represented different combinations of species with different dominants and co-dominants. The higher domination with highest IVI for few species in enclosure area at both agro ecology in the current study agrees with Haftay (2017), who showed that variation of herb distribution in the enclosure areas may be attributed to the survival and reproduction of maximum species due to moderate level of species competition during early regeneration which has led to the domination of only a few species in his study conducted in Harishin Rangelands of Eastern Ethiopia. This condition has affected the plant species which are susceptible to species' inter-competition. Similarly, Grime (1973) noted that with an increase in environmental stress, the species adapted to low levels of environmental stress lose their competitive advantage whereas those that are more resistant to environmental stress can increase in abundance.

*Andropogon amethystinus*, the most desirable and dominant perennial grass species, in the enclosure area in the highland agro ecology declined when open access grazing was practiced, and this might be due to the inability of the species to tolerate heavy grazing than other climatic conditions, as the two grazing regimes were located within the same agro ecology and similar climate. The dominance of *Eleusine floccifolia*, a perennial grass species with tough branching rhizome, in both grazing practices in mid-highland agro ecology might be due to longer dry season period compared to highland agro ecology in which both grazing areas grazed freely for a longer period until the onset of short rainy season when the enclosure area protected from the entrance of the animals. The higher proportions of annual *Trifolium* species recorded in open access grazing than enclosure area in the mid-highland agro ecology for this study agrees with the finding of Taddese et al. (2002) who recorded *Trifolium* species only in grazed plots as compared to none grazed plots in mixed crop-livestock system in western highlands of Ethiopia. This indicates that livestock grazing is more advantageous in the growth of palatable leguminous plant species compared to none grazed plots. Similarly, the absence of the majority of annual sedge species in the enclosure area in the current study in mid-highland agro ecology showed the dominance of annual species in open access grazing than enclosure area which confirms the previous finding (Bilotta et al. 2007). But many of the annual plants promoted by heavy grazing have low production potential due to their small size and short growing cycle (Zerihun and Mohamed Saleem 2000). However, grazing can dramatically change the species composition of grazing systems overtime (Milchunas and Lauenroth 1993). The presence of chronic over grazing over many years (Bard et al. 2000) in the mixed crop-livestock system of northern Ethiopia has changed the species composition of the grazing lands in ways that greatly differed from the seasonal grazing and cut and carry regimes.

***Species richness, diversity and similarity indexes***

Greater herbaceous species richness was observed in the current study for open access grazing area than enclosure area at both agro ecologies where a slightly higher Shannon diversity index, maximum possible diversity and species evenness were recorded for open access grazing land practices at mid-highland agro ecology. This finding agree with the finding of Pokharel et al. (2007), who observed higher species richness in open plots in two seasons than controlled plots in their study conducted in Trans-Himalayan Rangeland. Similarly, the findings of the present study are in agreement with the generalization made by Sternberg et al. (2000), who reported that continuous grazing increases species richness but reduced by heavy grazing. Many previous studies (Mwendera et al. 1997; Taddese et al. 2002; Tessema et al. 2011) reported that light or moderate grazing increases species richness when compared to no grazing and heavy grazing practice. The overlap in enclosure area and open access grazing land uniformly at both agro ecologies as measured by Jaccard's index of similarity indicates that the two grazing regimes share many of the same species.

***Soil physico-chemical properties across grazing land management practices***

Continuous heavy grazing reduces soil total N which has its own consequences on biomass yield and quality of the pasture. The higher soil total N found in this study in the highland agro ecology for enclosure area as compared to the open access area agree with the finding of Habtemicael et al. (2014) who reported highest soil total N in areas under cut and carry or seasonal grazing management practices than continuous stocking in eastern zone of Tigrai, northern Ethiopia. Similarly, Jeddi and Chaieb (2009) obtained greater total N in 12 year exclosure than continuous grazing from their study conducted in degraded arid environments of South Tunisia. Although urine and faeces depositions increase soil N and P in many grazed systems (Augustine 2003), this was not observed in the current study for areas under open access grazing management practices where livestock freely graze on year-round basis. This might be due to dung collection by children for fuel which was a case reported earlier in the mixed crop-livestock system in the highland areas (Girma et al. 2003). Cation exchange capacity was greater in enclosure area than open access, and this might be due to higher concentration of SOC in enclosure area than open access grazing (Table 5).

The reduction in soil available P, CEC, Ca and K in the open access grazing land could be the results of heavy grazing year round and have a consequence on pasture productivity. The higher soil available P observed for enclosure area compared to the open access grazing area in the mid-highland agro ecology did not agree with the findings of previous studies (Jeddi and Chaieb 2009; Teague et al. 2011; Habtemicael et al. 2014) that showed insignificant difference in available P due to different grazing land management practices. The current results in soil Ca and K concentration were in line with Jeddi and Chaieb (2009) who showed greater soil Ca and K in exclosure area than free grazing. Similar finding was observed by Haftay (2017) who reported higher soil available K in enclosure area than open access grazing land management practices (Table 5). Even though figuratively higher, the concentration of SOC and SOM were not significant ($P > 0.05$) due to grazing land management practices at both agro ecologies and this disagree with the earlier result reported by Haftay (2017) who found higher SOC and SOM for enclosure area than open access grazing.

## Conclusion

The finding in the present study examined the impact of enclosure and open access traditional grazing land management practices on aboveground biomass yield, species richness and diversity and soil quality parameters in the mixed crop-livestock system in the central highlands of Ethiopia. The results showed that these two distinct grazing land management practices differentially affected the parameters evaluated. Above ground biomass yield decreased significantly in an open access grazing area as a consequence of overgrazing due to continuous uncontrolled stocking which lead to land degradation. The abundance and density of some palatable and dominant perennial grass species in the enclosure area decreased from open access grazing land due to the inability of the species to tolerate continuous stocking. On the other side, herbaceous species richness was higher in open access grazing land than the enclosure area. The stress of continuous stocking in an open access grazing land also decreased soil quality parameters such as total N, available P, Ca, Na and CEC which in turn affects grazing land productivity. It can be concluded that enclosures has a positive effect in increasing grazing land productivity and maintain soil fertility. Therefore, within the declined grazing land due to different driving forces mainly human population coupled with expansions of cultivated land, implementation of enclosure practices play an important role in increasing feed resource availability, environmental sustainability and productivity of the farming system in the study area.

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