Relationships between Plant Biomass and Species Richness under Different Farming Systems and Grazing Land Management in Montane Grasslands of Kokosa District, Southern Ethiopia

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Abstract: The study was conducted in a montane grassland of Kokosa District, West Arsi Zone of Oromia Region, southern Ethiopia. The objective of the study was to investigate the relationships between aboveground plant biomass and species richness in three farming systems and four grazing management systems. A total of 180 quadrats (each 1 m x 1 m) were sampled in the three farming systems (dominant livestock-*enset*, *enset*-livestock and *enset*-livestock-cereal) and four grazing management systems (communal, enclosure, stream bank and benchmark). All the farming system and grazing management have different management practices. Plant species composition and aboveground plant biomass at different sites were quantified. Altogether 50 plant species (34 grasses, 4 legumes, 3 sedges and 9 forbs) were recorded in the montane grassland of Kokosa District. Even though the majority of the plant species share the different farming systems and grazing management practices, the highest number of species (39) was recorded in the *enset*-livestock farming system, whereas the lowest (33) species were recorded in the *enset*- livestock-cereal farming system when all the grazing management and farming systems were combined. Significantly, the highest species richness (4.9 species m^{-2}) was recorded in the enclosure grazing management site whereas the lowest (3.4 species m^{-2}) was recorded in the benchmark grazing site when all grazing sites and farming systems were combined. The relationship between species richness and biomass was detected in the montane grassland. There was significant difference ($P \leq 0.05$) in species richness for a combination analysis of farming system by grazing management system of the montane grassland. The highest biomass was recorded in the benchmark grazing management sites while the lowest was recorded in the communal grazing sites. On the contrary, maximum species richness was found in the enclosure grazing management sites which had intermediate biomass yield and the lowest species richness was recorded in the benchmark grazing areas with the maximum biomass records. Thus, species richness was observed first to ascend along with biomass increment up to 1932 kg ha^{-1} and then declined at constant increase of biomass. An increase in biomass in the benchmark grazing sites was not accompanied by an increase in species richness suggesting the dominance of few species in these sites. The rationale behind this might be due to the competitive exclusion of the less competent species from the community at peak biomass production.

Keywords: Biomass; Farming System; Grazing Management; Montane Grassland; Species Richness

1. Introduction

Species richness is the most commonly reported diversity measurement within the community (Sanderson *et al.*, 2004). Variation in the patterns of species richness across geographical and environmental gradients has long attracted the interest of ecologists. As a result, several theories of species diversity have so far been advanced (Tilman, 1982; Huston, 1994; Rosenzweig, 1995; Gaston, 2000).

Investigation on the relationships between species richness and biomass or productivity has been a central focus in the community ecology (Mittlebach *et al.,* 2000; Cornwell and Grubb, 2003; Fox, 2003; Venterink *et al.,* 2003). This relationship has been investigated since the mid-1960s, but the causal mechanisms have been in dispute for long period (Oksanen, 1996; Brocque and Buckney, 2003). The relationship between herbaceous biomass and richness often has a hump-shape with a peak in species richness at a low to intermediate level of biomass (Grime, 1997). At a very low level of biomass, richness is primarily limited by the inability of a species to survive the abiotic conditions. In this range, an increase in biomass reflects a decrease in the harshness of the environment. Above some point roughly corresponding to the peak species richness, the abiotic environment is presumably amenable to most species.

At higher levels of biomass, the decline in species richness is believed to be due to competitive exclusion (Grime, 1973; Huston, 1994). Rosenzweig (1995) emphasized that it is the decline in species richness at high biomass level that is the unsolved puzzle, whereas the positive correlation between richness and biomass is inevitable and some authors report as more biomass, more individuals, and higher probability for more species (May, 1975; Oba *et al.*, 2001). Accordingly, the decline of species richness at high biomass production levels is the crucial question for its application in conservation and management of grassland (Van der Maarel, 1997; Oba *et al.*, 2001).

Several studies have indicated that the relationship may differ when a range of different habitats are analyzed together (Gross *et al.*, 2000; Virtanen *et al.*, 2000; Oba *et al.*, 2001). Thus, regional differences in species richness for a community type should be observed at all spatial scales. Species richness is correlated with productivity in most situations (Huston, 1994; Rosenzweig, 1995). In this

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regard, most of the studies, where biomass has been related to species richness, have been done in temperate grasslands (Waide *et al.*, 1999; Rydin and Barber, 2001) and wetlands (Grace and Jutila, 1999). Moreover, the relationship may differ depending on the geographical or taxonomical contexts the mechanisms underlying it being still unclear (Rosenzweig and Abramsky, 1993; Gaston, 2000). Cornwell and Grubb (2003) concluded that as ecology is a science of 'contingent generalizations', studies in varied biomes must continue to refine knowledge about where, at what scale and for which taxa the relationship of species richness and biomass is unimodal. However, no study has, to the best of our knowledge, evaluated the relationship between biomass and species richness in montane grasslands in Ethiopia. Therefore, the current study was designed to investigate the relationships between biomass and species richness in the montane grasslands of the Kokosa District under varied grazing management and farming systems.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Geographical Location and Climate

The study was conducted in the Kokosa District in West Arsi Zone of Oromia Region, Southern Ethiopia (Figure 1). The mean altitude of the District is 2650 meters above sea level (masl) with a mean annual rainfall of 1600 mm and mean annual temperature of 16 ºC. The District is characterized by a bimodal rainfall (two times showers within a year) with a total rainy season lasting over eight months in a year. The main rainy season is from late March to September. The short rainy season occurs from October to November. The typical dry season is from December to February.

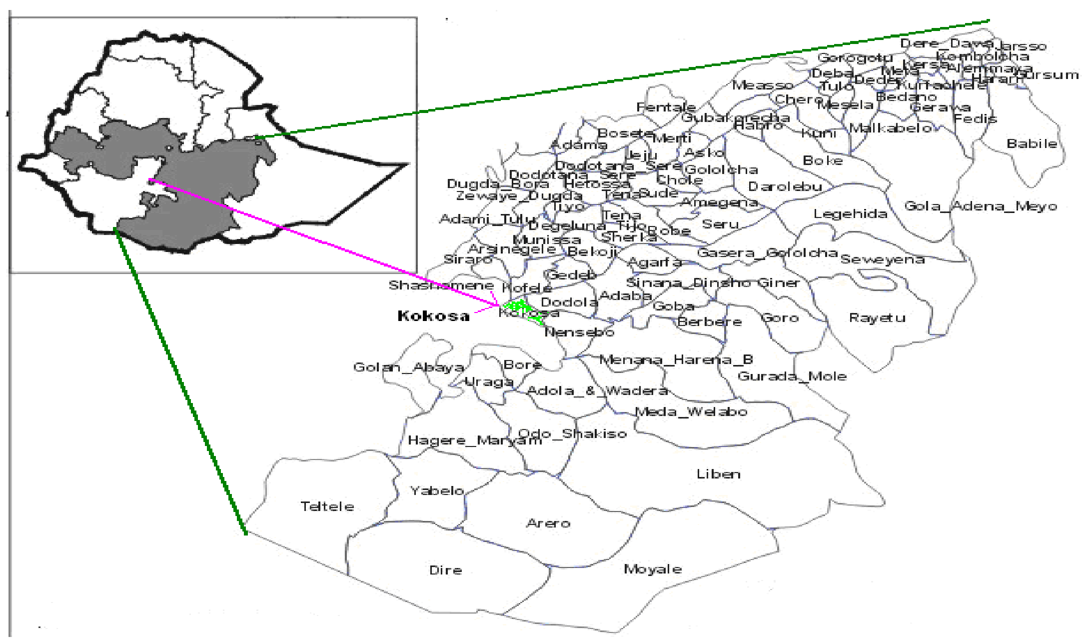

Figure 1. Location map of the study area.

2.1.2. Topography and Vegetation

The topography of the District consists of complex features of landscape comprising of medium steep to gentle slope, hilly, mountainous and undulating features. Seasonally waterlogged grounds, which are less favorable for cereal crop cultivation, are common. The vegetation of the District is predominantly natural grassland with few patches of scattered trees. The forests occurring in limited areas are characterized by species such as *Juniperus procera*, *Podocarpus fulcatus*, *Hagenia abyssinica,* etc.

2.1.3. Farming System and Land Cover

In the Kokosa District, highland pastoralism has been the predominant farming system type for the last four to five decades (ABRDP, 1999; Daniel, 1999) where livestock production is the main source of livelihood and crop cultivation is a recently introduced component. At present, livestock production and *enset* cultivation are the major sources of livelihood. Barley, wheat and maize are among the few crops grown in the area mixed with *enset* cultivation. Cereal crop cultivation is less suitable in most areas of the District due to periodic frost attack and seasonally waterlogged grounds. The major grazing types in the District are enclosures, communal grazing lands, stream sides and bottom lands.

2.1.4. Human and Livestock Population

Kokosa District is one among the densely populated areas in the country. There are 169 persons per square kilometer (Zerihun, 2002). Human population of the District is about 117,401. Similarly, the livestock population constitutes 304,000 cattle, 80,154 small ruminants and 40,162 equines (MoARD, 2006).

2.2. Sampling Methods

The study was conducted from August to October, 2006 when most of the plant species are expected to be at peak flowering stages. Stratified random sampling method was used to determine the biomass and species richness at the study sites (Sokal and Rolf, 1981; Bowen and Starr, 1982). The study District was stratified into different farming systems (dominant livestock-*enset*, *enset*-livestock and *enset*-livestock-cereal) based on secondary information; site observations; and discussions with experts of respective agricultural development offices, community members and elders of the area. Each farming system was further stratified into communal, enclosure, stream bank grazing areas and benchmark sites.

The dominant livestock-*enset* lands are areas which have large number of livestock rearing and less *enset* cultivation. *Enset*-livestock lands are areas where *enset* cultivation is dominant and livestock production is a secondary activity. The *enset*-livestock-cereal lands are areas where integrated *enset*, livestock and cereal crop production is practiced. These areas are characterized with intensive grazing pressure due to cereal crops and *enset* encroachment.

The benchmark sites represent areas, which were protected from livestock grazing for about 5-10 years and had a relatively low grazing intensity and used for comparison purpose. School, church or mosque compounds were identified and used as benchmark sites in each farming system. The communal grazing areas are areas which are exposed to continuous defoliation, whereas the enclosure grazing areas are areas which were enclosed for one season to one year and intermediately grazed. The stream bank sites are grazing areas which are found at the periphery of water bodies and intensively grazed.

As the area coverage of each grazing type under the three land use systems were proportionally comparable, equal number of grazing sites were considered in each grazing type. Thus, a total of 12 sites (4 sites each) were considered in all the three farming systems. In each grazing site, a sampling block of 1000 m x 50 m was demarcated in continuous or in a separated form. The demarcated area was again further sub-divided into three plots of 250 m x 50 m. In each of the sub-divided plot, a belt transect of 20 m x 10 m was randomly laid out across the plots (Abule, 2003) towards north-south direction. Finally, five quadrats in each of the communal, enclosure, stream bank and benchmark areas each measuring 1 m x 1 m were randomly established at each corner and center of the belt transects. Accordingly, a total of 180 quadrats (each 1 m x 1 m) were sampled to estimate aboveground biomass (Brand and Goetz, 1986; Mannetje, 2000; Whaley and Hardy, 2000). In the entire quadrat, the herbaceous vegetations (grasses, legumes and forbs) were clipped at ground level using hand shears. The clipped herbaceous species were then sorted according to their species (grasses, legumes and forbs) and packed in labeled paper bags. Then the fresh herbages of each plant class were first air dried and finally oven dried at 70 ºC for 48 hours and weighed (Brand and Goetz, 1986; Roberts *et al*., 1993; Whaley and Hardy, 2000) using sensitive balance for oven dry matter weight determination. All the vascular plants rooted inside the 1 m^2 plots of the 180 quadrats were recorded. The altitude, longitude and latitude readings of the sampled grazing management sites within the farming system types were measured and recorded using GPS (Table 1).

Table 1. Altitude, longitude and latitude readings of the sampling (grazing) sites within a farming system.

Farming system	Altitude (masl)	Longitude (E)	Latitude (N)
Dominant livestock-*enset*	2594	38^0 48'	6^0 27.84'
	2580	38^0 50'	6^0 27.78'
	2575	38^0 47'	6^0 27.12'
Enset-livestock	2600	38^0 47'	6^0 25.80'
	2629	38^0 47'	6^0 26.40'
	2636	38^0 47'	6^0 26.40'
Enset-livestock-cereal	2740	38^0 09'	6^0 28.92'
	2720	38^0 41'	6^0 28.32'
	2710	38^0 47'	6^0 26.52'

2.3. Statistical Analysis

The sampling quadrats of 1 m^2 from a belt transect of 20 m x 10 m were considered for biomass and species richness data analysis. This was done by sorting the data into separate farming system and the grazing types as well as for their combination to elucidate the relationship between species richness and biomass. Furthermore, logarithmic data transformation of biomass was made for the biomass data that did not fulfill the assumption of the analysis of variance. A two-way analysis of variance was computed to investigate the effects of farming system and the grazing type on aboveground biomass and richness of plant species following the Generalized Linear Model (GLM) procedure of SAS Version 8.1 (SAS Institute Inc., 1999). The least significant difference (LSD) test was employed for mean comparison.

3. Results and Discussion

3.1. Biomass Production

3.1.1. Dry Matter Biomass Production in Dominant Livestock-*Enset* Farming System

Table 2 depicts that the total dry matter biomass was highest in the benchmark sites followed by the enclosures while the least was recorded in the communal grazing areas. However, there were no significant variations in legume and grass dry matter biomass between benchmark and enclosure on the one hand and between communal and stream bank grazing areas on the other. The dry matter biomass contribution of grasses was very high while the contribution of legumes to the dry matter was the least. The dry matter biomass contribution of grasses, forbs and legumes in the predominantly livestock-*enset* farming system were about 81, 15 and 4%, respectively. The variation in dry matter yield among the grazing management systems might be due to the differences in the conditions of the grazing sites. There were fair condition in the communal grazing areas and along the stream banks and good to excellent condition class in the enclosure and benchmark grazing sites (Bekele, 2007). This result was in line with the earlier findings of Zerihun (1986), Gemedo (2004) and Manske (2004) who reported dominance of poor to fair range conditions of grazing areas exposed to continuous defoliation both in lowland and highland grazing areas.

Table 2. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly livestock-*enset* farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	286±53.7b	2234.0±163.8a	335.13±33.3b	2366.67±105.5a	13.5
Legumes	2.67±1.7b	190.67±38.4a	14.43±6.2b	116.17±39.9a	59.5
Forbs	46.67±37.7c	258.67±52.6b	69.30±10.6bc	633.11±97.9a	40.4
Total biomass	335.33±37.3c	2683± 167.9b	418.87±18.5c	3116±183.8a	11.9

**Means within a row followed by the same letter are not significantly different at P ≤ 0.05. SE = Standard error*

3.1.2. Dry Matter Biomass Production in *Enset*-Livestock Farming System

The study showed that the dry matter production of the grasses, legumes and forbs in the benchmark sites in the predominantly *enset*-livestock farming systems were significantly (P ≤ 0.05) higher than in the other grazing types (Table 3). On the other hand, the dry biomass yield of legumes showed an increasing trend when the grazing intensity changed from the heavily grazed communal and stream bank areas to the moderately grazed enclosure and benchmark grazing areas. The lower contribution of the overall legume dry biomass in the communal and stream bank grazing areas might be attributed to the higher trampling pressure and the inability of legumes to withstand heavy grazing pressure. The low legume dry matter biomass on the other hand might indicate the poor forage quality of the natural pasture in the District (Kidane, 1993; Tsige-yohannes, 1999). In line with this, van Soest (1982) and Sleugh *et al.* (2000) also confirmed that legumes increase the quality and quantity of pastures through atmospheric N-fixation.

3.1.3. Dry Matter Biomass Production in *Enset*-Livestock-Cereal Farming System

Table 4 below depicts the dry matter biomass in the *enset*-livestock-cereal farming system. The Table reveals that the benchmark grazing areas had a significantly (P ≤ 0.05) higher grass and legume biomass than the other grazing types. The study indicated that the total dry matter biomass of the herbaceous plants in the grasslands changed from 609 kg ha^{-1} in the heavily grazed communal grazing areas to 4166 kg ha^{-1} in the benchmark sites in the *enset*-livestock-cereal based farming system of the study area (Table 4).

Table 3. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly *enset*-livestock farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	323.33±22.0d	2398.00±65.0b	582.23±65.0c	2798.33±105.0a	6.32
Legumes	0.433±0.4c	227.10±67.0b	2.67±2.3c	355.10±30.9a	43.74
Forbs	21.23±10.0c	369.10±109.0b	24.43±8.7c	732.40±39.6a	35.33
Total biomass	345.00±23.0c	2889.00±144.0b	609.33±69.0c	3885.00±7.7a	11.07

**Means within a row followed by the same letter are not significantly different at P ≤ 0.05. SE = Standard error*

Table 4. Mean (± SE) dry matter biomass production (kg ha^{-1}) by species of the different grazing types in the predominantly *enset*-livestock-cereal farming system.

Plant species*	Grazing management types				Coefficient of variation (%)
	Communal	Enclosure	Stream bank	Benchmark	
Grasses	595.53±62.0c	2818.20±91.0b	560.93±56.0c	3238.53±80.0a	7.1
Legumes	4.23±3.0c	96.36±47.0b	2.33±0.0c	226.53±0.0a	49.9
Forbs	9.23±3.0b	315.13±55.0a	26.47±14.0b	455.64±91.0a	46.2
Total biomass	609.00±57.0c	3193.00±113.0b	589.73±67.0c	4166.00±138.0a	6.8

**Means within a row followed by the same letter are not significantly different at $P \leq 0.05$. SE = Standard error*

3.1.4. Interaction Effects of Farming System and Grazing Management on Dry Biomass Production

The variation in mean biomass was highly significant ($P \leq 0.001$) due to farming systems and grazing management types (Table 5). The change in biomass yield may be due to the overriding influences of grazing intensity, size of pasture land and length of grazing periods. This indicates that biomass yield can be influenced by different farming systems and grazing management practices. The variation in biomass was significant ($P \leq 0.05$) due to the interaction effect between farming system and grazing management systems. The mean biomass of the grassland recorded was 1903.1 kg ha^{-1} (Table 6). The *enset*-livestock-cereal farming system had the highest mean biomass while the lowest biomass was recorded in the dominantly livestock-*enset* farming system. The benchmark grazing area has the highest mean biomass followed by enclosure grazing areas while the communal grazing area has the lowest mean biomass.

3.2. Herbaceous Species Richness and Its Response to the Interaction Effect

Altogether 50 plant species (34 species of grasses, 4 species of legumes, 3 species of sedges and 9 species of forbs) were recorded in the grassland (Table 7). Even though the majority of the plant species share the different farming system and grazing management types, the highest number of species (39) was recorded in the *enset*-livestock farming system. The identified species belonged to 11 families of which the family *Poaceae* dominates (68%) the herbaceous species. Getachew (2005) and Gemedo (2006) reported similar results that most grazing areas have been dominated by grasses of few species. Out of the total grass species identified, the highly desirable, intermediate desirable and least desirable species comprise for 58, 24 and 19%, respectively. The higher proportion of desirable plant species in the study area in general implies that the area is characterized as good grazing condition.

Table 5. Analysis of variance for the interaction effect of farming system and grazing type on dry matter biomass in the Kokosa District.

Source	Degrees of freedom	Sum of square	Mean of square	F-Value	Pr > F
Farming system	2	869285.5	434642.76	13.85	0.000
Grazing type	3	85237086.0	28412362.10	905.08	0.000
Farming system x grazing type	6	494255.9	82375.98	2.62	0.048

R^2= 0.99; Root MSE = 177.18; Coefficient of variation (CV) = 8.96%

Table 6. Interaction effect of farming system and grazing management on biomass (kg ha^{-1}) production.

Farming system	Grazing management*				Mean	LSD (0.05)
	Communal	Enclosure	Stream bank	Benchmark		
Dominant livestock-*enset*	335.0	2683.0	418.0	3116.0	1638.0	367.9
Enset-livestock	345.0	2889.0	609.0	3885.0	1932.0	408.5
Enset-livestock-cereal	609.0	3193.0	589.0	4166.0	2139.3	267.6
Mean	429.7	2921.7	539.3	3722.3	1903.1	
SE (±)	39.1	141.6	51.5	109.8		

**LSD = Least significant difference; SE = Standard error*

Table 7. List of plant species recorded in the montane grassland of Kokosa District.

Botanical name	Life time	Family name	Desirability
Grasses			
Agrostis lanchnatha	Annual/Perennial	*Poaceae*	Highly desirable (decreaser)
Agrostis schimperana	Annual	*Poaceae*	Highly desirable (decreaser)
Andropogon chrysostachyus	Perennial	*Poaceae*	Least desirable (invader)
Andropogon gayanus	Perennial	*Poaceae*	Highly desirable (decreaser)
Bromus leptoclade	Annual	*Poaceae*	Highly desirable (decreaser)
Cynodon dactylon	Perennial	*Poaceae*	Highly desirable (decreaser)
Danthonia subulata	Perennial	*Poaceae*	Least desirable (invader)
Digitaria decumbens	Perennial	*Poaceae*	Intermediate desirable (increaser)
Digitaria adscendens	Annual	*Poaceae*	Intermediate desirable (increaser)
Digitaria scalarum	Perennial	*Poaceae*	Intermediate desirable (increaser)
Digitaria velutina	Annual	*Poaceae*	Intermediate desirable (increaser)
Eleusine floccifolia	Perennial	*Poaceae*	Least desirable (invader)
Enneapogon cenchroides	Annual/Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis atroverens	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis curvula	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis racemosa	Annual	*Poaceae*	Highly desirable (decreaser)
Eragrostis superb	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis sp	Annual/Perennial	*Poaceae*	Intermediate desirable (increaser)
Eriochrysis pallid	Perennial	*Poaceae*	Intermediate desirable (increaser)
Eragrostis tenuifolia	Annual	*Poaceae*	Intermediate desirable (increaser)
Lolium multiflorum	Annual	*Poaceae*	Highly desirable (decrease)
Microchloa kunthii	Perennial	*Poaceae*	Intermediate desirable (increaser)
Pennisetum glabrum	Perennial	*Poaceae*	Least desirable (invader)
Pennisetum schimperi	Perennial	*Poaceae*	Least desirable (invader)
Pennisetum stramineum	Perennial	*Poaceae*	Intermediate desirable (increaser)
Pentaschistis borussica	Perennial	*Poaceae*	Least desirable (invader)
Phalaris arundinacea	Perennial	*Poaceae*	Highly desirable (decreaser)
Poa leptoclade	Annual	Poaceae	Highly desirable (decreaser)
Poa sp.	Annual	*Poaceae*	Intermediate desirable (increaser)
Setaria incrassate	Perennial	*Poaceae*	Highly desirable (decreaser)
Setaria sphacela	Perennial	*Poaceae*	Highly desirable (decreaser)
Sporobolus natalensis	Perennial	*Poaceae*	Least desirable (invader)
Sporobolus pyramidalis	Perennial	*Poaceae*	Intermediate desirable (increaser)
Sporobolus spicatus	Perennial	*Poaceae*	Intermediate desirable (increaser)
Legumes			
Indigofera spinosa	Perennial	*Papplinoideae*	
Indigofera volkensii	Perennial	*Papilionoieae*	
Trifolium rueppellianum	Annual	*Papilionoideae*	
Trifolium sp	-	*Papilionoideae*	
Sedge species			
Cyperus flavenscens	Perennial	*Cyperaceae*	
Cyperus teneristolon	Perennial	*Cyperaceae*	
Cyperus obtusiflorus	Annual	*Cyperaceae*	
Forbs			
Amaranthus dubius	Annual	*Amaranthaceae*	
Asystasia schimperi	Annual	*Acanthaceae*	
Bidens hildebrandtii	Annual	*Asteraceae*	
Commelina forskalaei	Annual	*Commelinaceae*	
Coriandrum sativum	Annual	*Umbelliferacea*	
Echinops pappi	Perennial	*Acanthaceae*	
Haplocoelum foliolosum	Annual	*Rosaceae*	
Kedrostis foetidissima	Perennial	*Cucurbitaceae*	
Ocimum basilicum	Annual	*Lamiaceae*	

The mean species richness in a sample quadrat of 1 m^2 varied slightly for grazing types and farming systems. Table 8 indicates that the mean species richness in the communal, enclosures, stream bank and benchmark grazing areas varied from 4.1-4.7, 4.6-5.5, 3.8-4.4 and 3.0-4.3, respectively. The study suggested that in the predominantly livestock-*enset* farming system, there was a significant difference ($P \leq 0.05$) in the richness of the herbaceous species between the communal areas and the enclosures, between the enclosures and the stream banks, and between the enclosures and benchmarks. This result is supported by previous findings of Gross *et al.* (2000), Virtanen *et al.* (2000) and Oba *et al.*(2001). However, there was no significant variation between the communal areas and the stream banks. The highest species richness was observed in the enclosure grazing areas while the least was recorded in the benchmark sites that were protected from livestock grazing for a longer period of time in the dominant livestock-*enset*. This might be because moderate grazing enhanced the richness of plant species by suppressing the dominant species that might otherwise take dominance in the area and then eliminate the less competitive species in the system (Fuhlendorf, 2001).

This result implies that grazing promoted the richness of the herbaceous species although that depended on the intensity of the grazing pressure on the vegetation cover. According to this and other studies (Zerihun and Saleem, 2000; Kamau, 2004), the high species richness in the moderately grazed enclosure areas and the declined species richness in the benchmark sites indicated that livestock grazing played an integral role in maintaining and dispersing the herbaceous species thereby increasing the richness of species in the areas with moderate grazing intensity. Similarly, McNaughton (1979) reported that the reason for the decline of the species richness in the enclosed Serengeti grasslands was due to the enclosing of the area for long period of time.

In this study, the mean species richness in a quadrat of 1 m^2 was found to be 4.3, 4.9, 4.2 and 3.4 in the communal, enclosure, stream bank and benchmark areas, respectively (Table 8). This result was similar with the overall species richness (2.5 to 4.1) reported by Guretzky *et al.* (2005) in pastures that were managed with continuous and rotational grazing areas. Similarly, in his study in the central highlands of Ethiopia, Zerihun (1985) reported that species richness in quadrats vary from 5 to 24 with an average of 12 species richness. Likewise, study by Muluberhan *et al.* (2006) in northern Ethiopia reported 4.3 and 3 herbaceous species richness in the enclosed and grazed areas of 1 m^2, respectively. On their part, Oba *et al.* (2001) found 5.3 to 8.3 species richness per 1 m^2 in enclosed areas when compared to 5.1 to 7.5 species in 1 m^2 in open plots. The differences in species richness within farming systems and grazing management types were statistically significant ($P \leq 0.05$). There was also a significant variation of species richness when farming system and grazing management systems are analyzed together. Gross *et al.* (2000), Virtanen *et al.* (2000), Oba *et al.* (2001) reached a similar conclusion when they reported that the difference may occur when a range of different habitats are analyzed together.

Table 8. Interaction of ffect of farming system by grazing management on mean (± SE) species richness per quadrat (m^2) in montane grassland at Kokosa District.

	Grazing management					
Farming system*	Communal	Enclosure	Stream bank	Benchmark	Mean	CV (%)
Dominant livestock-*enset*	4.1±0.10b	4.6±0.39a	4.3±0.14.00b	3.0±0.39c	4.0	12.50
Enset-livestock	4.3±0.17ab	4.6±0.21a	3.8±0.04c	4.0±0.08b	4.2	5.80
Enset-livestock-cereal	4.7±0.05b	5.5±0.15a	4.4±0.20b	4.3±0.08b	4.7	4.95
Mean	4.3	4.9	4.2	3.4	4.2	

**Means within a row followed by the same letter are not significantly different at $P \leq 0.05$. SE = Standard error; CV = Coefficient of variation*

3.3. Relationship between Biomass Production and Plant Species Richness

The current study indicated the existence of differences in the mean biomass accumulated between the enclosed and open grazing areas. The study showed that the highest species richness occurred in the enclosed grazing areas with an intermediate biomass production. Grime (1997) and Oba *et al.* (2001) reported similar findings. As can be seen in Figures 2 and 3, the species richness first raised and then declined following the constant increase in the biomass. In contrast, the study suggested that an increase in the biomass in the benchmark was not related to an increase in species richness (Figure 2). Similarly, Oba *et al.* (2001) reported that the optimum richness corresponds to a given biomass level and age of enclosures.

This might be due to an increase in the competition intensity at the increased rate of the biomass production that became the cause for the elimination of the less competitive species from the community at peak biomass production (Grime, 1973; Huston, 1994; Bonser and Reader, 1995). The study, therefore, implied that the less competent species and the newly emerging seedlings might have been eliminated in the benchmark sites. This tendency may in turn cause decline in the richness of the species. Similar findings were reported by Kamau (2004), Oba *et al.* (2001), Huston (1994) and Guo (1996) that the long term grazing exclusion did not increase the richness of species although there was a substantial increase in the aboveground biomass.

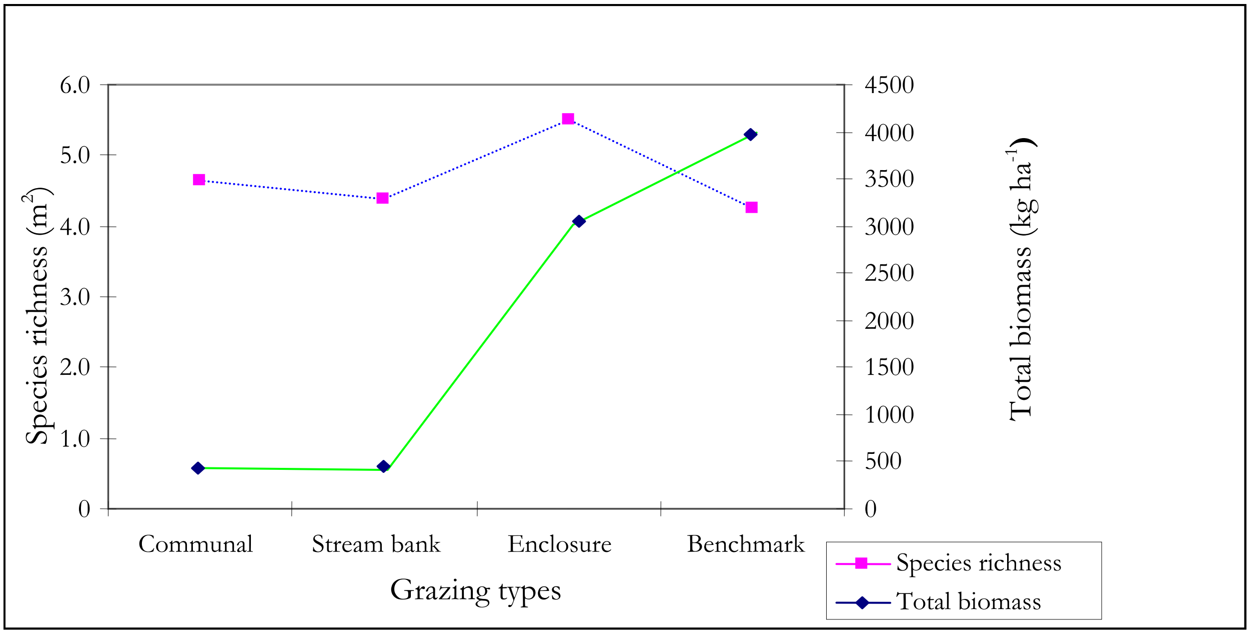

Figure 2. The relationship between biomass and plant species richness.

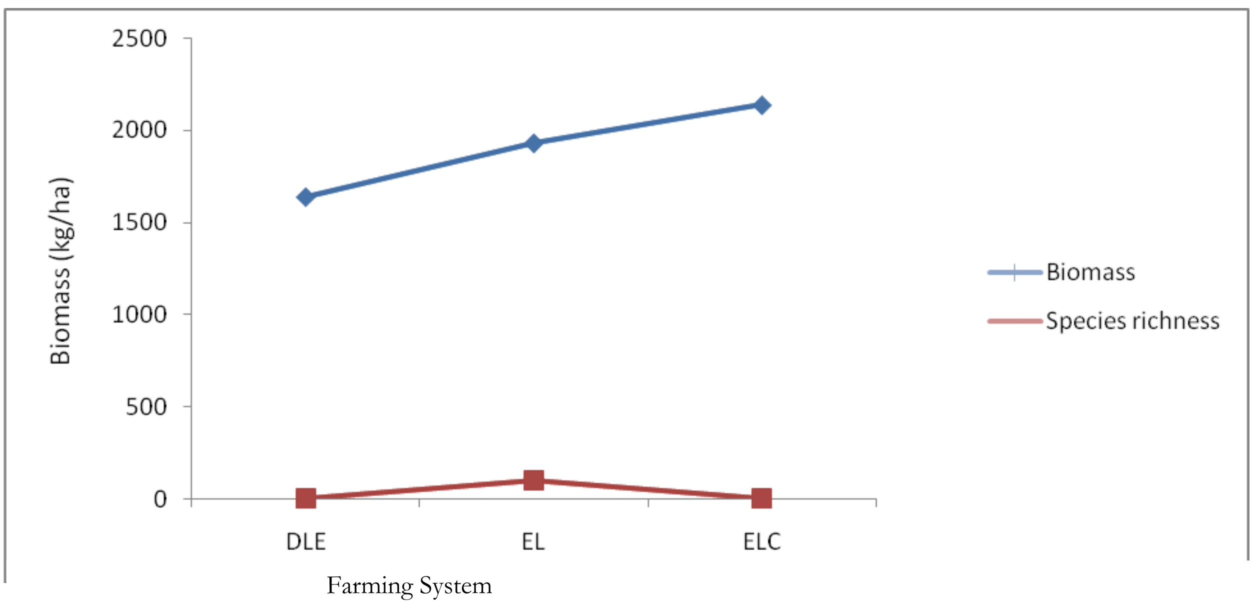

Figure 3. Relationship between mean biomass and plant species richness in different farming systems.

4. Conclusions

The study revealed that the aboveground biomass of the plant species was significantly ($P \leq 0.05$) different depending on the extent of the grazing pressure. The study suggested that light disturbance could help reduce the cover of dead shoot and facilitate the seed soil contact and foster the re-growth of plants. Grass dry biomass and total dry biomass were found to be significantly high in the *enset*-livestock-cereal farming system having lower dry matter biomass of forbs. The dominant livestock-*enset* farming system which had a high number of livestock and was characterized as lower condition class had a lower total dry matter biomass.

The species richness in a sample quadrat of 1 m^2 of the study areas varied slightly across the grazing types and the farming systems. A significantly higher ($P \leq 0.01$) richness occurred in the enclosure grazing areas and the *enset*-livestock farming system (where biomass is intermediate) while the least richness was observed in the benchmark sites and in the *enset*-livestock-cereal farming system, the highest biomass was recorded. The reason behind this might be the competitive elimination of the less competitor species from the community at peak biomass production

The current study suggested that the species richness is positively associated with the intermediate grazing pressure implying that livestock grazing management plays a crucial role in maintaining species richness in grassland communities. Although the environmental factors are considered much more important in the area, the importance of internal interaction should not also be overlooked in the biomass–species relationship. However, this still needs verification in further studies.

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