doi: 10.17138/TGFT(8)72-85

Research Paper

Evaluation of forage quantity and quality in the semi-arid Borana Lowlands, Southern Oromia, Ethiopia

Evaluación de la cantidad y calidad del forraje natural en la zona semi-árida de Borana Lowlands, Southern Oromia, Etiopía

GEMEDO DALLE

Center for Environmental Science, Addis Ababa University, Ethiopia. aau.edu.et

Abstract

This study was conducted with the aim of determining herbaceous biomass during different seasons, plus nutritive value of herbaceous species and forage on selected woody plants and documenting pastoralists' perceptions of the value of various forage species in Borana Zone, Oromia, Ethiopia. Data were collected from a total of 92 main plots of 500 m^2 during rainy and dry seasons located across different functional Land Use Units called Kalo (enclosed areas), Worra (grazed by lactating stock) and Foora (more remote and grazed by dry and non-lactating stock). Total herbage and leaves of woody plants were analyzed for concentrations of crude protein (CP), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and ash. Perceptions of farmers were determined through group discussions. Herbage biomass plus chemical composition of both herbaceous and woody forage species varied significantly across seasons and Land Use Units. Mean herbaceous biomass in all Land Use Units was poor (876–1,469 kg DM/ha). Mean CP, NDF and ADF concentrations of the herbaceous samples were 62, 749 and 444 g/kg DM, respectively. Mean CP% of leaves from woody plants was higher (11%) than from herbage (6%). In both groups, crude protein concentrations were highest during the wet season and lowest during the dry season, whereas fiber concentrations were highest in the dry season. Mean CP% of herbaceous forage species was below the critical level recommended for both beef cattle (7%) and small ruminants (9%) but forage from woody species should provide a reliable supply of supplementary nitrogen. Management of rangelands should be designed to ensure that desirable herbaceous species are preserved, while desirable woody species are also a valuable asset. Determination of management strategies to ensure that the desirable mix of species is maintained is imperative if sustainable production is to continue.

Keywords: Borana pastoralists, herbaceous biomass, nutritive value, pasture management, tropical rangelands.

Resumen

En la zona semi-árida de Borana, Oromia, Etiopía, se midió la biomasa herbácea disponible en pasturas naturales durante diferentes estaciones del año y se determinó el valor nutritivo de las especies herbáceas y del follaje de plantas leñosas seleccionadas. Además se documentó la percepción de los productores pastoriles tradicionales sobre el valor de varias especies forrajeras. Los datos se obtuvieron durante las épocas lluviosas y secas en un total de 92 parcelas de 500 m^2 cada una, ubicadas en diferentes unidades funcionales de uso pastoril: *Kalo* (áreas encerradas), *Worra* (pasturas utilizadas con hembras lactantes) y *Foora* (áreas remotas utilizadas con animales no lactantes). De las plantas herbáceas enteras y del follaje de las especies leñosas se analizaron las concentraciones de proteína cruda (PC), materia orgánica (MO), fibra detergente neutra (FDN), fibra detergente ácida (FDA), lignina detergente ácida y cenizas. Las percepciones de los pastores fueron registradas con base en reuniones grupales. La biomasa disponible y la composición química de las especies herbáceas y del follaje de las leñosas variaron significativamente según las estaciones y las unidades de uso pastoril. En promedio de las unidades de uso pastoril, la biomasa herbácea disponible fue baja (876–1,469 kg MS/ha).

Correspondence: Gemedo Dalle, Center for Environmental Science, Addis Ababa University, P. O. Box 80119, Addis Ababa, Ethiopia.
E-mail: gemedo.dalle@aau.edu.et

Las concentraciones, promedio, de PC, FDN y FDA de las muestras herbáceas fueron de 62, 749 y 444 g/kg de MS, respectivamente. La concentración, promedio, de PC en el follaje de las plantas leñosas fue mayor (11%) que la las herbáceas (6%). En ambos grupos, las concentraciones de PC fueron más altas durante la estación lluviosa y más bajas durante la estación seca, mientras que las concentraciones de fibra fueron más altas en la estación seca. El porcentaje de PC promedio de las especies herbáceas fue menor que el nivel crítico recomendado tanto para ganado bovino (7%) como para pequeños rumiantes (9%), mientras que se espera que el follaje de las especies leñosas proporcione un suministro confiable de nitrógeno complementario. Los resultados demuestran que el manejo de las pasturas naturales debe ser diseñado para asegurar la conservación de las especies herbáceas deseables, considerando que las especies leñosas deseables son un activo valioso. La identificación y aplicación de estrategias de manejo, tendientes a mantener una combinación deseable de especies en las pasturas, son imprescindibles para asegurar una producción ganadera sostenible en la región.

Palabras clave: Biomasa herbácea, manejo pastoril, pasturas naturales tropicales, productores pastoriles, valor nutritivo.

Introduction

The Borana Lowlands occupy 95,000 km^2 (Alemayehu Mengistu 2004) in Ethiopia and are populated by pastoralists who represent a vital part of Ethiopia's population, contributing significantly to the nation's GDP. Review of different studies, e.g. Shapiro et al. (2017), estimated direct contribution of livestock production in lowland pastoral systems of Ethiopia to agricultural GDP and national GDP to be 39 and 17%, respectively. The area supports 480,000 families with an annual population growth rate of 2.5–3% (Homan et al. 2004). Livestock production dominated by the Boran breed has been the major source of livelihood for Borana pastoralists. According to CSA (2008), in 2007 there were 1,771,589 cattle, 1,991,196 goats, 699,887 camels and 52,578 donkeys in the Borana zone. The Boran breed remains one of the most productive breeds as it is fast-growing and fertile with good milk production compared with other indigenous cattle breeds in Ethiopia (Aynalem Haile et al. 2011).

Livestock play a crucial role in the subsistence economy, culture and religion of pastoralists in Ethiopia, and represent both social capital and an insurance against disaster (Herlocker 1999). Borana pastoralists are known for their strong tradition of livestock production through using their indigenous rangeland and water management strategies. The herbage on offer in the rangelands, however, is highly variable, both in quantity and quality. Vázquez-de-Aldana et al. (2000) reported that the botanical composition of available forage was highly variable as was the nutritional quality, which was further exacerbated by topographic relief, soil characteristics, climate, season and management. The semi-sedentary Borana pastoralists have developed strategies to exploit this highly variable resource, and are known for sustainably using the Borana land in southern Ethiopia for livestock production.

Rangeland management markedly affects botanical composition and, consequently, herbage quantity and quality. In order for the grazing system to be sustainable, better understanding of the characteristics of the forage available is needed. However, little or no data are currently available on the quality of plant resources in the study area.

Therefore, this study was conducted in the Borana Lowlands to determine both quality and quantity of forage resources in this semi-arid pastoral production system throughout the year. The specific objectives were to determine herbaceous biomass and nutritive value of forage species and document pastoralists' perceptions on forage species.

Materials and Methods

Study area

The study was conducted in Arero and Yaballo Districts of Borana Zone, Oromia, Ethiopia (Figure 1). This study was part of a larger project of the Borana Lowland Development Program (BLPDP)/Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) aimed at developing a pastoral-oriented self-help concept for sustainable natural resource management under changing ecological and socio-economic conditions. Field data were collected from 2001 to 2003 in different seasons.

The main study sites were Dida Hara Pastoral Association (PA) in Yaballo and Web PA in Arero. In addition, a government ranch called Dida Tuyura and Foora (an area used for dry or non-lactating livestock) were selected randomly for the forage resource assessment. The government ranch was reputed to be in relatively good rangeland condition and was included as a benchmark for comparing the other Land Use Units. Yaballo town is 570 km south of Addis Ababa (9°0'19" N, 38°45'49" E; 2,355 masl). Dida Hara and Web are located about 30 km northeast and 85 km southeast of Yaballo town, respectively. Foora is located in Dida Hara PA, about 48 km southeast of Yaballo town. Dida Tuyura Ranch is in Dida Yaballo PA (Yaballo district), about 25 km northeast of Yaballo town.

Livestock populations in the Borana Lowlands are predominantly cattle, while small ruminants and camels are also important in the production system. Rearing dromedaries has expanded since the 1990s. Estimates have shown that herd composition in Tropical Livestock Units (TLU) was 90% cattle, 5% small ruminants and 4% dromedaries (Homann 2004). Borana cattle are a *Bos indicus* breed that belong to the Large East African Zebu breed group (Homann 2004).

Figure 1. Location of Borana Zone, in Oromia, Southern Ethiopia. (Source: Google Earth).

Climatic characteristics

The elevation of the study area ranges from 750 to about 2,000 m above sea level. Rainfall is bimodal, with the long rains during March–May and short rains during October–November (Haugen 1992; Coppock 1994). Mean annual rainfall is 412 mm in Web (Web weather station; data from Southern Range Development Unit) and 566 mm in Dida Hara (Yaballo town as the nearest station; data from the National Meteorological Services Agency of Ethiopia). While mean annual temperature varies from 19 to 24 °C (Alemayehu Mengistu 1998), the mean maximum temperatures for Yaballo stations ranged from 24.4 to 26.4 °C and minimums from 13.8 to 14.8 °C (1989–2001 raw data from the National Meteorological Services Agency of Ethiopia). In general, December–February is the hot dry season, March–May is the long rainy season, June–August is the cool dry season and September–November is the short rainy season. The difference between the long rains and short rains is the amount of rain that the area receives.

Soil characteristics

The soils in the study area are granitic and volcanic soils and their mixtures (Coppock 1994). Valley bottomlands of the Borana rangelands are dominated by vertisols. Review of studies that described upland rangeland soils in the study area showed that the soils vary in color (yellow, brown, grey or red) and have almost equal proportions of sand, silt and clay (Alemayehu Mengistu 2004). In general, Dida Hara soils are the lightest, containing the highest proportion of sand, whereas Web has soils with higher levels of available P, Ca, Mg, CEC and pH. Mean available P ranged from 2.0 ppm in Foora to 30 ppm in Web Worra. Concentrations of P and Ca and CEC are highly variable in both Dida Hara and Web (Gemedo Dalle 2004).

Sampling strategy

Borana pastoralists classify their grazing lands into enclosed grazing lands for calves (Kalo), grazing lands for lactating livestock (Worra) and grazing lands for dry livestock (Foora). Based on suitability for different classes of livestock (i.e. availability of forage and watering points), the pastoralists establish their villages (pastoral camps) locally called Olla. Classification and demarcation of the grazing land into Kalo, Worra and Foora is based on distance from the villages and accessibility of watering points: Kalo is adjacent to the villages, Worra the next removed and Foora the most remote. Similarly, Kalo and Worra are located within walking distance (distance from water covered by grazing livestock in a single day, which is about 12 km) from watering points, whereas Foora are remote from the watering points (having no permanent watering point within the grazing area) and dry livestock utilizing this area depend on surface rainwater or must walk long distances to access watering points. Kalo was fenced and protected from grazing from early wet season to hot dry season, and was accessible for grazing only during the hot dry season. Worra and Foora were open to livestock throughout the year. A stratification sampling technique was used to collect samples from these functional Land Use Units. Within each Land Use Unit, the initial sampling point was established randomly, but subsequent units were established at 200 m intervals on a linear transect.

Samples of both herbaceous and woody forage species were gathered from different Land Use Units. Herbaceous samples were collected during cool dry (June–August), short rains (September–November) and long rains (March–May) seasons, whereas woody samples were taken during short rains, hot dry (December–February) and long rains seasons. Within the various districts, an effort was made to sample from different sites in all seasons, in an attempt to ensure that the samples were representative for the specific study sites.

Forage sampling

Forage samples were collected from a total of 92 main plots of 50 × 10 m (500 m^2) each (Table 1). Within each 500 m^2 plot, 5 subplots of 0.5 × 0.5 m (0.25 m^2), 4 at the corners and 1 in the center, were established and herbaceous samples were collected for both biomass and forage nutritive value determination. Samples from the 5 subplots were pooled and assumed to represent the main plot. To demarcate these subplots, a 3-sided frame of welded metal (0.5 × 0.5 m), left open at one side as recommended by Whalley and Hardy (2000), was used. All grasses, herbaceous forbs and sedges rooted within the marked area of 0.25 m^2 were cut at 2 cm above ground following the method of Vázquez-de-Aldana et al. (2000). Immediately after harvesting, the material sampled in each plot was sorted manually into species and weighed in the field using a portable digital balance to determine contributions of individual species to total fresh biomass. Because of logistical issues sorted samples could not be dried individually and were pooled again, dried at 60 °C for about 48 hours in a well-ventilated oven (Adesogan et al. 2000) and weighed to determine both total herbaceous biomass and the contribution of individual species to total dry biomass.

For woody plants, samples of green leaves (including young and old) of each plant and each species were collected at random. For *Vachellia tortilis* (syn. *Acacia tortilis*), fruits (pods) were also collected as they were preferred by animals. A total of 75 samples (25 samples for each of the 3 seasons) were collected and analyzed. An effort was made to sample from the same species in all 3 seasons. However, during the hot dry season, some species had shed leaves, so samples were taken from other drought-resistant forage species as indicated by the pastoralists. In each season, only 1 sample per species was taken from the first site where the identified woody plant was encountered. In other words, only a single sample of each browse species was collected and only from a single tree/shrub.

Nomenclature of plant species follows published volumes of Flora of Ethiopia and Eritrea (Hedberg and Edwards 1995; Edwards et al. 1995, 1997) and was updated according to the taxonomy of the Genetic Resources Information Network GRIN (npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearch.aspx).

Chemical analyses

After oven-drying of samples at 105 °C, dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), ash, ADF-Ash and in vitro digestibility of dry matter (IVDMD) were determined in the laboratory of the International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia. IVDMD was analyzed only during the cool dry season.

CP was determined using the Kjeldahl method (N × 6.25), IVDMD by the in vitro rumen digestibility procedure (Van Soest and Robertson 1985) and NDF, ADF and ADL by the detergent system of analysis (Van Soest and Robertson 1985). Ash was determined by igniting samples at 500 °C (AOAC 1990).

Pastoralists' perceptions

Eight community-level group discussions were held in 4 places: Dikale (DIK), Dambala Abba Chana (DAC) (both in Dida Hara), Tesso Qallo (TSQ) and Dhibu Kolocho (DBK) (both in Web PA). One hundred and eight pastoralists (52 men and 56 women) participated in the group discussion. Pair-wise preference ranking was used to identify the most preferred forage species. According to their palatability to livestock, grass species were classified as highly desirable (decreasers), intermediate (increasers) and least desirable (pioneers), based on pastoralists' perceptions and field observations. Decreasers were defined as desirable grass species that are likely to decrease with heavy grazing pressure (Baars et al. 1996).

Table 1. Descriptions of Land Use Units and sampling details in the Borana Lowlands, Ethiopia.

Land Use Unit	Explanation	Sampling intensity		
		No. of samples	No. of seasons	Total
Dida Hara Kalo (DHK)	Dida Hara grazing land for calves	21	3	63
Dida Hara Worra (DHW)	Dida Hara grazing land for lactating livestock	14	3	42
Web Kalo (WBK)	Web grazing land for calves	19	3	57
Web Worra (WBW)	Web grazing land for lactating livestock	14	3	42
Dida Tuyura Ranch (DTR)	Government ranch used for conserving Borana breeds	10	2	20
Foora (FOR)	Grazing land for dry livestock between Dida Hara and Web	14	3	42

Data analysis

Descriptive statistics were used in organizing, summarizing and describing the data. Comparison of mean values was performed using two-tailed t-test following Fowler and Cohen (1996). ANOVA was applied to investigate variability across Land Use Units and seasons. Effects of season × land use interactions were determined using GLM (General Linear Model).

Results

Rainfall

Rainfall data for Dida Hara were taken from Yaballo town, which was the nearest station to Dida Hara and that of Web was from Web station, which was collected by Southern Range Development Unit. The mean annual rainfall in Dida Hara (Yaballo) and Web is presented in Table 2.

While mean monthly rainfall ranged from 5.9 to 144.1 mm in Dida Hara and 2.0 to 113.9 mm in Web (Table 2), variation within individual months was great as observed from the CV%.

Two rainfall peaks are conspicuous, demonstrating the bimodal nature of rainfall in the Borana Lowlands. Annual totals were highly variable, ranging from 188 to 803 mm with mean of 545 mm in Dida Hara, and from 211 to 638 mm with mean of 412 mm in Web. This difference in annual rainfall between the two sites was statistically significant (t = 2.196, df = 22 at P=0.05), indicating that Web is more arid than Dida Hara.

Herbaceous biomass

The above-ground herbaceous presentation yields (standing crop) were highly variable both spatially and temporally (Tables 3 and 4), with significant differences across seasons (P = 0.026) and Land Use Units (P = 0.000). Presentation yields for Dida Hara Kalo and Dida Tuyura Ranch, which were relatively protected sites, were higher than those in other Land Use Units, which were communally grazed, during the main rainy season.

Mean herbage biomass over all Land Use Units ranged from 921 kg DM/ha in the early wet season to 1,241 kg DM/ha in the cool dry season following the long rains. Available herbage biomass during the cool dry season was higher than in the other seasons.

Biomass contribution of herbaceous species

The contribution to available biomass by various herbaceous species varied among sites and seasons. After short rains, *Chrysopogon aucheri*, *Digitaria milanjiana* and *Eragrostis papposa* were the main contributors in Dida Hara, *C. aucheri* alone contributing almost half of the herbaceous biomass. In Web, most of the contribution

Table 2. Mean monthly rainfall in mm (1988–2001) and the coefficient of variation at the main study sites in the Borana lowlands, Ethiopia (raw data for Yaballo were taken from the National Meteorological Services Agency of Ethiopia).

Month	Dida Hara		Web	
	Mean	CV (%)	Mean	CV (%)
January	24.5	125.7	17.1	193.6
February	33.6	129.5	9.2	208.7
March	56.4	76.4	68.6	66.9
April	144.1	49.2	113.9	60.9
May	77.1	69.8	57.9	68.6
June	14.5	65.5	3.2	146.9
July	12.0	106.7	3.1	151.6
August	5.9	105.1	2.0	170
September	35.2	98.3	15.7	135.0
October	87.4	59.3	58.6	93.7
November	37.1	83.6	51.7	98.1
December	17.4	69.5	11.6	171.5
Overall total	545		413	
SD	40.2		35.3	

Table 3. Effects of season on mean herbaceous presentation yields (kg/ha) on different Land Use Units in the Borana Lowlands, Ethiopia.

Land Use Unit	Cool dry (Jun-Jul 2001)		Short rains (Nov-Dec 2001)		Long rains (Mar-Apr 2002)	
	Mean	SD	Mean	SD	Mean	SD
Dida Hara Kalo	1,285	119	1,841	676	1,093	540
Dida Hara Worra	1,220	68	680	297	850	320
Web Kalo	1,269	93	1,393	662	712	210
Web Worra	1,162	174	983	496	576	658
Dida Tuyura Ranch	-[1]	-	1,542	251	1,396	740
Foora	1,270	129	458	152	901	635
Mean	1,241		1,150		921	

[1]Logistical issues prevented data collection at Dida Tuyura Ranch in June-July 2001.

Table 4. Herbaceous biomass contribution by each species (% DM basis) on different Land Use Units in the short and long rainy seasons, and their forage value (FV) as perceived by pastoralists in the Borana Lowlands, Ethiopia.

Plant family	Species	Land Use Unit[1] (%)						FV[2]
		DHK	DHW	WBK	WBW	FOR	DTR	
		Short rains (November)						
Acanthaceae	*Barleria spinisepala*	0.8	0.2	0.0	0.0	0.1	0.5	H
Asparagaceae	*Chlorophytum gallabatense*	6.0	0.5	0.1	0.0	0.0	1.8	H
Commelinaceae	*Commelina africana*	1.8	1.0	0.1	0.0	0.2	0.3	H
Cyperaceae	*Cyperus bulbosus*	0.0	0.3	0.0	0.0	1.9	0.0	I
	Cyperus sp.	2.7	1.6	0.2	0.4	0.4	0.4	I
Fabaceae	*Indigofera volkensii*	0.3	0.0	0.0	1.4	0.0	0.0	I
Poaceae	*Cenchrus ciliaris*	0.0	0.0	6.2	2.4	0.0	0.0	H
	Tetrapogon roxburghiana (syn. *Chloris roxburghiana*)	0.0	1.4	5.5	4.4	13.4	0.0	I
	Chrysopogon aucheri	41.3	50.2	4.5	2.5	57.1	37.5	I
	Cynodon dactylon	0.0	0.0	10.9	0.0	0.0	0.0	H
	Digitaria milanjiana	12.5	10.7	0.0	0.0	16.1	1.7	H
	Eleusine intermedia	3.1	0.0	0.0	0.0	0.0	0.9	L
	Eragrostis papposa	13.1	21.1	0.3	1.0	10.2	2.1	I
	Harpachne schimperi	4.4	1.0	0.0	0.0	0.6	0.7	I
	Heteropogon contortus	2.4	7.3	0.0	0.0	0.0	33.0	I
	Ischaemum afrum	0.0	0.0	5.3	0.0	0.0	0.0	L
	Leptothrium senegalense	0.0	0.0	0.1	0.7	0.0	0.0	I
	Megathyrsus maximus (syn. *Panicum maximum*)	1.5	0.0	0.0	5.9	0.0	0.0	H
	Cenchrus mezianus (syn. *Pennisetum mezianum*)	4.7	0.0	66.9	81.6	0.0	0.0	L
	Themeda triandra	4.1	3.2	0.0	0.0	0.0	21.0	I
Velloziaceae	*Xerophyta humilis*	0.8	1.2	0.0	0.0	0.0	0.2	I
		Long rains (April)						
Acanthaceae	*Barleria spinisepala*	0.0	0.0	0.0	0.0	0.7	0.0	H
Asparagaceae	*Chlorophytum gallabatense*	3.4	0.8	0.0	0.0	0.3	0.1	H
Commelinaceae	*Commelina africana*	3.1	1.2	0.4	3.9	1.5	0.0	H
Cyperaceae	*Cyperus bulbosus*	0.0	0.0	2.7	0.4	0.0	0.0	I
	Cyperus sp.	5.9	0.8	4.9	1.8	0.0	0.4	I
Poaceae	*Andropogon chinensis*	0.0	0.0	0.0	0.0	0.0	29.7	L
	Bothriochloa radicans	0.0	0.0	0.0	0.0	0.0	3.2	L
	Cenchrus ciliaris	0.0	2.4	42.8	26.1	0.0	0.0	H
	Tetrapogon roxburghiana (syn. *Chloris roxburghiana*)	1.3	0.0	0.4	8.2	0.0	0.4	I
	Chrysopogon aucheri	40.4	52.1	8.5	13.4	57.8	14.2	I
	Digitaria milanjiana	11.7	14.3	19.5	7.6	7.5	0.0	H
	Digitaria neghellensis	0.0	0.0	0.0	0.8	0.0	0.0	H
	Eleusine intermedia	3.3	0.0	0.0	0.0	0.0	0.0	L
	Eragrostis papposa	11.3	12.1	0.0	0.0	1.6	0.0	I
	Harpachne schimperi	0.0	0.0	0.0	0.0	0.0	0.4	I
	Heteropogon contortus	10.4	5.6	0.0	0.0	0.0	34.9	I
	Leptothrium senegalense	0.0	3.4	0.0	0.0	0.0	0.0	I
	Megathyrsus maximus (syn. *Panicum maximum*)	0.0	0.0	0.0	6.2	0.0	0.0	H
	Cenchrus mezianus (syn. *Pennisetum mezianum*)	3.2	1.6	0.0	18.9	30.6	0.0	L
	Setaria verticillata	0.0	0.0	0.2	0.1	0.0	0.0	H
	Sporobolus pellucidus	0.0	0.0	20.3	12.7	0.0	0.0	I
	Themeda triandra	6.1	0.8	0.0	0.0	0.0	16.7	I
Velloziaceae	*Xerophyta humilis*	0.0	4.7	0.0	0.0	0.0	0.0	I

[1]Land Use Unit: DHK = Dida Hara Kalo; DHW = Dida Hara Worra; WBK = Web Kalo; WBW = Web Worra; FOR = Foora; and DTR = Dida Tuyura Ranch; [2]Forage value: H = highly palatable; I = intermediate; and L = least palatable, as assessed by pastoralists from the main study sites, Dida Hara and Web.

to biomass (74%) was from the least palatable grass, *Cenchrus mezianus* (syn. *Pennisetum mezianum*). In Foora, most of the biomass (57%) was from a single species *C. aucheri*, although *Tetrapogon roxburghiana* (syn. *Chloris roxburghiana*) (13%), *D. milanjiana* (16%) and *E. papposa* (10%) made marked contributions. On Dida Tuyura Ranch, *C. aucheri* (37%), *Heteropogon contortus* (33%) and *Themeda triandra* (21%) were major contributors (Table 4).

In the early wet season (Long rains; Table 4), *C. aucheri* contributed nearly half (46%) to available herbaceous biomass at Dida Hara, and about 58% at Foora sites. *C. mezianus* made a large contribution (31%) at Foora site. In Web, *Cenchrus ciliaris* contributed the highest proportion (34%), while at Dida Tuyura Ranch, the dominant contributor was *H. contortus* (35%). Overall, *C. aucheri* was the main contributor to herbaceous biomass at most sites during both seasons. At Web sites, the dominant species were *C. mezianus* in November (short rains) and *C. ciliaris* in April (long rains).

Estimation of contributions to available biomass by highly desirable, intermediate and least desirable forage grasses showed that intermediate grasses were most prominent in Dida Hara, Dida Tuyura and Foora areas but not in Web zones (Table 5).

Nutritive quality of herbaceous species

Chemical composition of herbaceous samples was compared across both Land Use Units and seasons (Table 6). In general, there was a strong trend for an increase in CP% from the cool dry season to the long rainy season. Mean CP% was 48 g/kg DM in cool dry season, 62 g/kg DM after short rains and 76 g/kg DM during the long rainy season. There was variation in CP% across the seasons ($P = 0.000$) and Land Use Units ($P = 0.013$).

However, there were no differences in CP levels across various Land Use Units during the cool dry season. During the short rains, Dida Hara and Foora sites had higher CP than Web sites and Dida Tuyura Ranch. During the long rains, Web sites showed higher CP levels than Dida Hara sites with Dida Tuyura Ranch showing lowest levels (Table 6).

Nutritive value of woody plants

Mean chemical composition of leaves from woody plants is summarized in Table 7. CP concentration ranged from 47 to 168 g/kg DM. *Senegalia brevispica* (syn. *Acacia brevispica*), *Balanites aegyptiaca, Chionothrix latifolia, Combretum hereroense, Cordia sinensis* (syn. *Cordia gharaf*), *Dalbergia microphylla, Ficus sycomorus, Maerua triphylla* and *Ziziphus* sp. were the top species with higher CP%. CP% for most species reported in Table 6 was an average for 3 seasons. However, *C. hereroense, C. sinensis, D. microphylla, F. sycomorus* and *Ziziphus* sp. were sampled only during the hot dry season when other highly ranked species had shed their leaves. *Salvadora persica, Kirkia burgeri, F. sycomorus, Commiphora kataf* (syn. *Commiphora erythraea*) and *Terminalia prunioides* had high amounts of ADF, NDF and ADL.

CP% in woody plants was highest in the wet season (169 g/kg DM) and lowest in the dry season (139 g/kg DM; Table 8).

Table 5. Mean contribution (% DM basis) to available biomass by highly desirable, intermediate and least desirable species in the Borana Lowlands, Ethiopia for the various Land Use Units.

	Land Use Unit[1]					
	DHK	DHW	WBK	WBW	DTR	FOR
	Short rains (November)					
Grasses						
Highly desirable	14.0	10.7	17.1	8.3	1.7	16.1
Intermediate	65.3	84.2	10.4	8.6	94.3	81.3
Least desirable	7.8	0.0	72.2	81.6	0.9	0.0
Sedges	2.7	2.0	0.2	0.4	0.4	2.3
Forbs	10.2	3.0	0.2	1.4	2.8	0.3
	Long rains (April)					
Grasses						
Highly desirable	11.7	16.9	62.5	40.8	0.0	7.5
Intermediate	69.5	74.1	29.2	34.3	66.6	59.5
Least desirable	6.5	1.6	0.0	18.9	32.9	30.6
Sedges	5.9	0.8	7.6	2.2	0.4	0.0
Forbs	6.5	6.7	0.5	3.9	0.1	2.5
	Mean of the two seasons					
Grasses						
Highly desirable	12.8	13.8	39.8	24.5	0.8	11.8
Intermediate	67.4	79.1	19.8	21.4	80.4	70.4
Least desirable	7.2	0.8	36.1	50.2	16.9	15.3
Sedges	4.3	1.4	3.9	1.3	0.4	1.1
Forbs	8.3	4.9	0.4	2.6	1.5	1.4

[1]Land Use Units: DHK = Dida Hara Kalo; DHW = Dida Hara Worra; WBK = Web Kalo; WBW = Web Worra; FOR = Foora; and DTR = Dida Tuyura Ranch.

Pastoralists' perceptions

Ranking of the forage value of plant species was performed through group discussions with pastoralists. According to the perceptions of Borana pastoralists, *Cenchrus ciliaris* and *Digitaria milanjiana* were grasses with the highest nutritive value (Tables 4 and 9). Similarly, *Senegalia brevispica, Grewia tembensis* and *Maeroa triphylla* were the most highly appreciated woody species (Table 8). Some forbs, such as *Commelina africana*, have high nutritional quality. All sedges (*Cyperus* spp.) were perceived to have intermediate nutritional value (Table 4).

Table 6. Mean chemical composition of the herbaceous biomass sampled in three seasons across different Land Use Units (LUU) in the Borana Lowlands, Ethiopia.

LUU[1]	Ash (%)	OM (%)	NDF (g/kg)	ADF (g/kg)	ADL (g/kg)	ADF-Ash (g/kg)	CP (g/kg)	IVDMD (%)
	Cool dry season (June-July)							
DHK	11	89	761	429	91	68	45	38
DHW	13	87	742	434	89	82	45	32
WBK	11	90	754	439	144	59	52	37
WBW	9	91	780	491	277	42	47	33
DTR[2]	-	-	-	-	-	-	-	-
FOR	10	90	768	468	95	67	49	36
	Short rains (November-December)							
DHK	10	90	768	481	101	51	67	
DHW	11	89	763	418	87	69	79	
WBK	9	91	798	504	111	52	49	
WBW	9	91	803	508	126	52	52	
DTR	9	91	768	479	89	51	50	
FOR	11	89	730	407	80	68	76	
	Long rains (March-April)							
DHK	12	88	717	413	91	57	78	
DHW	15	86	696	383	78	77	84	
WBK	21	79	638	368	78	134	96	
WBW	23	77	653	375	112	143	101	
DTR	9	91	779	468	90	46	40	
FOR	11	89	778	450	114	65	58	

[1]Land Use Units: DHK = Dida Hara Kalo; DHW = Dida Hara Worra; WBK = Web Kalo; WBW = Web Worra; FOR = Foora; and DTR = Dida Tuyura Ranch.
[2]During the cool dry season, samples were not collected from DTR.
OM = organic matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; CP = crude protein; IVDMD = in vitro dry matter digestibility.

Table 7. Mean nutritive values of leaves from woody plants across 3 seasons and frequency of appreciation (FAP) of the forage species by pastoralists in the Borana Lowlands, Ethiopia.

Family	Species	DM (%)	Ash (%)	NDF (g/kg)	ADF (g/kg)	ADL (g/kg)	CP (g/kg)	FAP (%)
Amaranthaceae	*Chionothrix latifolia*[1]	91	19	378	251	36	136	38[3]
Anacardiaceae	*Rhus natalensis*[1]	91	10	538	422	246	90	75
Asteraceae	*Vernonia phillipsiae*	91	12	480	328	119	76	50
Apocynaceae	*Cynanchum viminale* (syn. *Sarcostemma viminale*)[1]	89	11	498	482	93	47	38
Burseraceae	*Commiphora kataf* (syn. *Commiphora erythraea*)	88	10	307	296	127	93	13
	Commiphora habessinica	89	14	473	484	291	114	25
Capparaceae	*Boscia mossambicensis*[1,3]	92	8	616	414	143	100	63[3]
	Cadaba farinosa[1]	91	24	379	290	156	113	25
	Maerua triphylla[1]	92	14	451	294	107	141	63
Combretaceae	*Combretum hereroense*[2]	91	11	314	268	72	140	13
	Terminalia prunioides[1]	89	9	290	286	68	100	25
Convolvulaceae	*Cladostigma hildebrandtioides*	92	9	546	390	79	117	25[3]
Cordiaceae	*Cordia sinensis* (syn. *Cordia gharaf*)[1,2]	91	18	365	407	89	141	13
Ebenaceae	*Euclea divinorum*[1,2]	92	8	245	329	151	80	38[3]
Fabaceae	*Senegalia brevispica* (syn. *Acacia brevispica*)[1]	91	7	421	278	132	154	88
	Senegalia goetzei (syn. *Acacia goetzei*)[1]	91	7	511	458	250	109	13[3]
	Vachellia tortilis (syn. *Acacia tortilis*)[1]	91	7	490	440	208	113	63[3]
	Dalbergia microphylla[1,2]	92	8	293	217	65	150	25

Continued

Family	Species	DM (%)	Ash (%)	NDF (g/kg)	ADF (g/kg)	ADL (g/kg)	CP (g/kg)	FAP (%)
Kirkiaceae	*Kirkia burger*	88	8	280	217	68	109	13
Lamiaceae	*Plectranthus igniarius*	90	18	502	540	250	116	38
Malvaceae	*Grewia damine* (syn. *Grewia bicolor*)[1,3]	91	9	484	367	128	104	100[3]
	Grewia tembensis[1]	90	13	407	303	67	130	88
Moraceae	*Ficus sycomorus*[1,2]	89	15	250	234	54	134	13[3]
Oleaceae	*Olea europaea* subsp. *cuspidata*[1]	93	6	384	297	127	73	38[3]
	Schrebera alata[1,2]	92	6	306	301	79	97	-
Phyllanthaceae	*Phyllanthus sepialis*	91	12	432	298	97	99	38[3]
Rhamnaceae	*Ziziphus* sp.[2]	92	5	177	153	41	168	-
Rutaceae	*Vepris glomerata*[1]	93	10	465	380	173	144	38
Salvadoraceae	*Salvadora persica*[1]	88	36	252	162	39	89	13
Sapindaceae	*Haplocoelum foliolosum*[1]	93	7	473	359	153	77	25[3]
	Pappea capensis[1,3]	92	6	526	423	163	83	75[3]
Zygophyllaceae	*Balanites aegyptiaca*[1,3]	92	11	408	287	132	120	38

[1]Drought-resistant forage species (according to the pastoralists' perceptions).
[2]Species sampled only once during hot dry season (December–February) but were not appreciated as highly desirable forage species by the pastoralists (Gemedo Dalle 2004).
[3]Woody forage species appreciated by the pastoralists for grazers (cattle).
DM = dry matter; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; CP = crude protein; FAP = frequency of appreciation.

Table 8. Mean seasonal chemical composition of forage from woody plants in the Borana Lowlands, Ethiopia.

Season	Ash (%)	NDF (g/kg)	ADF (g/kg)	ADL (g/kg)	CP (g/kg)
Hot dry (Jan-Feb)	10.9	326	300	96	139
Short rains (Nov-Dec)	12.5	506	391	161	167
Long rains (Mar-Apr)	11.6	444	332	138	169

NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin; CP = crude protein.

Table 9. Preference ranking (1 = highest rank) of the top 5 grass and woody forage species by men (M) and women (W) pastoralists (number of participants in parenthesis) during group discussions in the Borana Lowlands, Ethiopia.

	Site[1] and gender group							
	DIK		DAC		TSQ		DBK	
	M (11)	W(13)	M (13)	W (10)	M (13)	W(21)	M (15)	W (12)
Forage grasses								
Cenchrus ciliaris	1	2	1	2	1	2	1	2
Chrysopogon aucheri	4	4	3	3	-	4	3	5
Digitaria milanjiana	2	1	2	1	3	1	2	4
Digitaria neghellensis	3	-[2]	-	-	2	-	-	-
Eleusine intermedia	-	-	5	-	-	-	5	-
Halchisoo (botanical name not determined)	-	-	-	-	4	-	-	1
Megathyrsus maximus (syn. *Panicum maximum*)	-	-	4	5	-	-	4	-
Cenchrus mezianus (syn. *Pennisetum mezianum*)	5	3				3		3
Themeda triandra	-	5	-	4	5	5	-	-
Woody plants for browsers								
Senegalia brevispica (syn. *Acacia brevispica*)	1	-	1	1	2	-	2	1
Vachellia nilotica subsp. *nilotica* (syn. *Acacia nilotica*)	-	5	-	-	-	-	-	-
Vachellia tortilis (syn. *Acacia tortilis*)	4	-	-	-	-	-	-	-
Balanites aegyptiaca	-	4	2	-	-	-	-	-
Blepharispermum pubescens[3]	-	-	-	-	-	2	-	-
Cadaba farinosa	-	-	-	-	4	1	-	-

Continued

	Site[1] and gender group							
	DIK		DAC		TSQ		DBK	
	M (11)	W(13)	M (13)	W (10)	M (13)	W(21)	M (15)	W (12)
Commiphora kataf (syn. *Commiphora erythraea*)	-	-	-	-	-	-	3	-
Dalbergia microphylla	-	-	-	-	-	-	-	5
Grewia damine (syn. *Grewia bicolor*)	-	-	-	-	-	5	-	-
Grewia tembensis	5	2	3	3	1	-	1	4
Kirkia burgeri	-	-	-	-	-	-	4	-
Maerua triphylla	3	-	5	4	-	4	-	3
Phyllanthus sepialis	-	-	4	-	-	-	-	-
Plectranthus barbatus (syn. *Plectranthus comosus*)[3]	-	-	-	-	5	-	-	-
Rhus natalensis						3		2
Cynanchum viminale (syn. *Sarcostemma viminale*)	2	1	-	2	-	-	-	-
Vepris glomerata	-	-	-	-	3	-	5	-
Vernonia phillipsiae		3		5				

[1]DIK = Dikale, DAC = Dambala Abba Chana, TSQ = Tesso Qallo and DBK = Dhibu Kolocho.
[2]Empty cell (-) means the species was ranked below rank 5.
[3]Species not listed in Table 7 (Table 7 contains species that were sampled, whereas this table contains species mentioned by local communities during free listing).

Discussion

Herbaceous standing crop

The greater availability of forage on the government ranch and Kalos (enclosures) than on open-grazed areas such as the Worra and Foora showed the importance of exclosures for conserving and sustainably using forage resources during the dry season. This was in agreement with previous reports (Oba et al. 2001; Ayana Angassa et al. 2010). The pattern for highest mean herbaceous biomass to occur in the cool dry season (Jun-Jul) and lowest in the main rainy season (Mar-Apr), after the hot dry season, was according to expectations. In the cool dry season growth of vegetation has been stimulated by the long rains and herbage is mature. It is traditional for Borana pastoralists to protect Kalos from grazing during the wet season and open them for general grazing in the hot dry season (Dec-Jan), when there is relatively high accumulation of herbage mass. Grazing land management practices may be the main reasons for the significant differences in presentation yields of herbaceous biomass across the Land Use Units in this study rather than the actual productive ability of these areas. The different presentation yields of forage on the government ranch from those on the communal grazing lands may reflect grazing management imposed. There were only few Borana cattle on the government ranch during the study years and it was therefore subjected to only low stocking pressure during all seasons. Old growth accumulated and rank grass dominated the new growth of desirable species. Furthermore, the ranch was highly encroached by woody species that might have contributed to low forage quality. Although the author of this manuscript agrees with protection of the ranch area, proper management following standard range management techniques should be followed. It should serve as a demonstration farm and learning laboratory for surrounding pastoralists. Ayana Angassa et al. (2010) also reported that there was variation as a result of rangeland management that affected biomass of most herbaceous species, plus grass basal cover and herbaceous species richness and diversity.

Quantifying the contributions of various species to forage mass allows useful comparisons of the productivity of different species and different management practices, and provides a basis for appropriate stocking rates to be developed (Sollenberger and Cherney 1995). Rainfall (precipitation), soil moisture, radiation, temperature, soil nitrogen and phosphorus are important environmental factors that affect herbage production (Gutman et al. 1990). The maximum presentation yield of herbage recorded in this study was 1,840 kg DM/ha during the short rains, while studies in similar semi-arid ecosystems reported much higher values. In similar arid areas of northern Kenya, mean herbaceous biomass inside exclosures was 4,180 kg DM/ha and that of continuously grazed open rangelands 1,802 kg DM/ha (Oba et al. 2001). Our results for herbaceous biomass yields from all sites in the Borana Lowlands fall within the category of poor, and such low herbaceous yields would directly affect livestock production and ecosystem stability.

Unlike the study of Ayana Angassa and Baars (2000), very low percentages of highly palatable grasses were found. Grasses considered of intermediate nutritive value by pastoralists were dominant at most sites, while highly palatable species were present at much lower levels, in agreement with the rangeland condition assessment report by Gemedo Dalle et al. (2006). This aspect is discussed further in a subsequent section.

Seasonal changes in forage value

Both herbage biomass and chemical composition of the herbaceous forage samples varied significantly across the seasons. Physiological age of forage species, time of grazing, species and botanical fraction are some of the factors that cause variability in chemical composition of forages (Adesogan et al. 2000). The decline in CP% in herbaceous forage from 7.6% in the wet season to 4.8% in the dry season, and that of woody plants from 16.9 to 13.9%, respectively, is in agreement with previous findings (Pérez Corona et al. 1998; Hussain and Durrani 2009; Habtamu Teka et al. 2013; Zhai et al. 2018). According to the report by Habtamu Teka et al. (2013), chemical composition of all grass species showed significant ($P<0.05$) variation between sites, seasons and species in agreement with our results.

In contrast, nutrient concentrations of browse from woody plants is subject to relatively less seasonal variation (Crowder and Chheda 1982) and this particularly enhances their value as dry season feeds for livestock (Dicko and Sikena 1992). About three-quarters of the woody forage plants studied were perceived as drought-resistant species by pastoralists. Several studies from arid ecosystems, e.g. Dicko and Sikena (1992), have shown that perennial shrubs retained high CP% for a longer period than herbaceous species, with a range of 7% in winter to 14% in spring. During the hot dry season when herbaceous species were almost dry and in limited supply for livestock, mean CP% in leaf material on woody plants was 13.9%, which would provide a valuable N supply to rumen microflora provided the nitrogenous components were digestible. Mean in vitro dry matter digestibility of the herbaceous forage was very low (35%) with a range from 32 to 38% indicating its limited potential to contribute energy. Conservation of these drought-resistant species is an important strategy for sustaining livestock production, especially during dry periods.

Comparing pastoralists' perceptions and scientific knowledge on forage nutritive value

The pastoralists identified *Cenchrus ciliaris*, *Digitaria milanjiana*, *Megathyrsus maximus* and *Themeda triandra* as highly palatable grasses. Similar perceptions of Borana pastoralists were reported by Habtamu Teka et al. (2013) and in an earlier report by Skerman and Riveros (1989). Furthermore, the pastoralists identified *Chrysopogon aucheri* and *Digitaria milanjiana* as drought-resistant forage grasses, concurring with the report by Skerman and Riveros (1989). Among the woody species *Vachellia tortilis*, *Boscia mossambicensis*, *Chionothrix latifolia*, *Grewia damine* and *Pappea capensis* for grazers (cattle) and *Senegalia brevispica*, *Grewia tembensis* and *Maerua triphylla* for browsers, e.g. camels and goats, were ranked as the top forage species. Le Houérou and Corra (1980) also reported that most of the woody plants identified during this study were considered palatable for animals, being preferred over other species.

Comparing pastoralists' indigenous knowledge with laboratory results showed that Borana pastoralists have an accurate perception of the nutritive value of the various forage species. In general, the pastoralists' knowledge of forage species growth and quality indicated that they know which species should be retained in the pasture and which were least useful to ensure sustainable animal production in the area.

Comparison of the Land Use Units

The high fluctuation of species composition on Web sites might be due to presence of permanent watering points (Web deep wells or Ela) in the area, which allowed high numbers of livestock to remain in the area resulting in overgrazing and consumption of desirable species. During the long rains, most livestock are taken away from the deep wells as water is more readily available and highly desirable species get the opportunity to regrow during this time.

When comparing Land Use Units, CP% varied across the Land Use Units as reported by Habtamu Teka et al. (2013). Overall, forage on the Dida Tuyura Ranch had the lowest CP levels and the highest concentrations of NDF and ADF reflecting the under-utilization of this area and accumulation of a bulk of mature fibrous material. This suggests that 'over-protection' of rangelands is not necessarily a desirable management strategy and significant defoliation by grazing animals at certain times might be needed to stimulate pastures and ensure a sustainable system.

Status of forage nutritive value in relation to livestock production

Herbaceous species had lower forage quality than the woody browse species in agreement with previous reports (Hussain and Durrani 2009; Gete Zewudu and Gemedo Dalle 2019). CP concentrations in standing forage exceeded the threshold level of 7% (Humphreys 1991; Pérez Corona et al. 1998; Ganskopp and Bohnert 2001) only during the long rains. This and other studies, e.g. Habtamu Teka et al. (2013), showed that quality of standing herbaceous forage in the Borana Lowlands was largely below the threshold level for good livestock production. The minimum recommended CP concentration in diets for small ruminants is even higher (9%) (Araújo Filho et al. 1998). While animals would select a higher quality diet from herbaceous forage than the whole plant data indicate, as the seasons progressed CP concentrations in the selected diet would decline. Access to some browse from woody species would alleviate this N deficiency as time progressed, while feeding of N supplements would also increase intake of the low quality forage. The study highlighted the importance of restoring degraded rangelands and also the need to improve forage quality through focused interventions aimed at increasing CP concentration in the herbaceous forage.

Tree leaves are nutritionally desirable, mainly as a source of CP (Forwood and Owensby 1985). The mean CP concentration in foliage of woody plants determined by this study was 11%. This was significantly higher than the CP concentration in herbaceous forage in agreement with reports from other areas, e.g. Musco et al. (2016). Furthermore, NDF, ADF and ADL concentrations in forage from woody plants were lower than those of herbaceous species. Trees and shrubs represent an integral part of diets for domestic ruminants in Africa and may constitute an important source of proteins, minerals and vitamins, especially during the dry season (Dicko and Sikena 1992). Borana pastoralists recognized the importance of woody species with higher CP concentration in this semi-arid environment. For long-term sustainability of the system, grazing management must be designed to retain the desirable woody plants, while restricting encroachment by undesirable trees and shrubs.

In conclusion, this study provides additional information on quantity (herbaceous) and nutritive value (both herbaceous and woody plants) of available forage in different seasons across different functional Land Use Units in a semi-arid rangeland of the Borana Lowlands, Ethiopia, where the main production system is livestock production, predominantly cattle breeding. Mean nutritive value of available forage from herbaceous species was below the critical level recommended for maintenance of both beef cattle and small ruminants for much of the time, while forage from woody species contained moderate levels of crude protein. This indicates the importance of maintaining a mixture of herbaceous species and desirable woody species in these rangelands. In the Dida Hara rangelands, very few highly desirable herbaceous species were present, even in areas where grazing was restricted. There is an urgent need to restore these rangelands to a condition where desirable species are more prevalent. Surprisingly, in Web areas desirable species were dominant during the long rains. Further studies are warranted to determine why these differences occurred between the Land Use Units and whether strategies can be developed to improve the situation in the Dida Hara area. It seems that 'over-protection' as has been practiced on the Dida Tuyura Farm is not the solution and more intensive study of the Web sites may yield possible solutions for testing. Furthermore, herd diversification for effective utilization of browse species was recommended as a result of this study.

Acknowledgments

I thank the Borana pastoralists for their hospitality, patience and unreserved willingness to share their knowledge, and am grateful for the support from local administration.

I sincerely acknowledge the in-depth and professional review by anonymous reviewers. Their contributions have improved the quality of this manuscript.

References

(Note of the editors: All hyperlinks were verified 15 April 2020.)

Adesogan AT; Givens DI; Owen E. 2000. Measuring chemical composition and nutritive value in forages. In: Mannetje L't; Jones RM, eds. Field and laboratory methods for grassland and animal production research. CAB International, Wallingford, UK. p. 263–278. doi: 10.1079/9780851993515.0263

Alemayehu Mengistu. 1998. The Borana and the 1991–92 drought. A rangeland and livestock resource study. Institute for Sustainable Development and French Catholic Committee against Hunger and for Development, Addis Ababa, Ethiopia.

Alemayehu Mengistu. 2004. Rangelands biodiversity: Concepts, approaches and the way forward. Addis Ababa University, Addis Ababa, Ethiopia.

Ayana Angassa; Baars RMT. 2000. Ecological condition of encroached and non-encroached rangelands in Borana, Ethiopia. African Journal of Ecology 38:321–328. doi: 10.1046/j.1365-2028.2000.00250.x

Ayana Angassa ; Oba G; Treydte AC; Weladji RB. 2010. Role of traditional enclosures on the diversity of herbaceous vegetation in a semi-arid rangeland, southern Ethiopia. Livestock Research for Rural Development 22, Article #163. lrrd.org/lrrd22/9/anga22163.htm

AOAC (Association of Official Analytical Chemists). 1990. Official methods of analysis. 15th Edn. AOAC, Arlington, VA, USA.

Araújo Filho JA de; Leite ER; Silva NL da. 1998. Contribution of woody species to the diet composition of goat and sheep in Caatinga vegetation. Pasturas Tropicales 20(2):41–45. bit.ly/3eNCXnB

Aynalem Haile; Workneh Ayalew; Noah Kebede; Tadelle Dessie; Azage Tegegne. 2011. Breeding strategy to improve Ethiopian Boran cattle for meat and milk production. Improving Productivity and Market Success of Ethiopian Farmers Project Working Paper No. 26. ILRI, Nairobi, Kenya. hdl.handle.net/10568/3141

Baars RMT; Chileshe EC; Kalokoni DM. 1996. Rangeland condition in high cattle density areas. In: Baars RMT, ed. Condition and management of the rangelands in the western province of Zambia. Ph.D. Thesis. Wageningen Agricultural University, Wageningen, The Netherlands. p. 71–82. edepot.wur.nl/493462

Crowder LV; Chheda HR. 1982. Tropical grassland husbandry. Longman, London, UK.

Coppock DL. 1994. The Borana Plateau of Southern Ethiopia: Synthesis of pastoral research, development and change, 1980–1991. ILCA, Addis Ababa, Ethiopia. hdl.handle.net/10568/4660

CSA (Central Statistical Authority). 2008. Ethiopian Statistical Abstract. CSA, Addis Ababa, Ethiopia. bit.ly/3eJgKXZ

Dicko MS; Sikena LK. 1992. Feeding behavior, quantitative and qualitative intake of browse by domestic ruminants. In: Speedy A; Pugliese PL, eds. Legume trees and other fodder trees as protein sources for livestock. FAO Animal Production and Health Paper 102:129–144. bit.ly/2RGI1Aq

Edwards S; Mesfin Taddese; Hedberg I. 1995. Flora of Ethiopia and Eritrea Vol. 2, Part 2. Uppsala University, Uppsala, Sweden.

Edwards S; Sebsebe Demissew; Hedberg I. 1997. Flora of Ethiopia and Eritrea. Vol. 6. Uppsala University, Uppsala, Sweden.

Forwood JR; Owensby CE. 1985. Nutritive value of tree leaves in the Kansas Flint Hills. Journal of Range Management 38:61–64. bit.ly/3bdqrM6

Fowler J; Cohen L. 1996. Practical statistics for field biology. John Wiley and Sons, Chichester, UK.

Ganskopp D; Bohnert D. 2001. Nutritional dynamics of seven northern Great Basin grasses. Journal of Range Management 54:640–647. doi: 10.2458/azu_jrm_v54i6_ganskopp

Gemedo Dalle 2004. Vegetation ecology, rangeland condition and forage resources evaluation in the Borana Lowlands, Southern Oromia, Ethiopia. Ph.D. Thesis. Georg-August Universität Göttingen, Germany. bit.ly/3eoCdFy

Gemedo Dalle; Maass BL; Isselstein J. 2006. Rangeland condition and trend in the semi-arid Borana Lowlands, Southern Oromia, Ethiopia. African Journal of Range and Forage Science 23:49–58. doi: 10.2989/10220110609485886

Gete Zewudu; Gemedo Dalle. 2019. Evaluation of nutritive value of some native forage species in Tikur Incinni District, Oromia, Ethiopia. Forage Research 45:103–110. bit.ly/34D5MP3

Gutman M; Seligman NG; Noy-Meir I. 1990. Herbage production of Mediterranean grassland under seasonal and yearlong grazing systems. Journal of Range Management 43:64–68. bit.ly/2XDcSle

Habtamu Teka; Madakadze IC; Ayana Angassa; Hassen A. 2013. Nutritive value of grasses in semi-arid rangelands of Ethiopia: Local experience based herbage preference evaluation versus laboratory analysis. Asian-Australasian Journal of Animal Science 26:366–377. doi: 10.5713/ajas.2012.12551

Haugen T. 1992. Woody vegetation of Borana, south Ethiopia. A study on the main vegetation types of the area. SINET: Ethiopian Journal of Science 15:117–130.

Hedberg I; Edwards S. 1995. Flora of Ethiopia and Eritrea. Volume 7. Uppsala University, Uppsala, Sweden.

Herlocker DJ. 1999. Rangeland ecology and resource development in eastern Africa. GTZ, Nairobi, Kenya.

Homann S. 2004. Indigenous knowledge of Borana pastoralists in natural resource management: A case study from Southern Ethiopia. Ph.D. Thesis. Justus Liebig University, Giessen, Germany. core.ac.uk/display/56347787?recSetID=

Humphreys LR. 1991. Tropical pasture utilisation. Cambridge University Press, Cambridge, UK. doi: 10.1017/CBO9780511525810

Hussain F; Durrani MJ. 2009. Nutritional evaluation of some forage plants from Harboi rangeland, Kalat, Pakistan. Pakistan Journal of Botany 41(3):1137–1154. bit.ly/3eikcse

Le Houérou HN; Corra M. 1980. Some browse plants of Ethiopia. In: Le Houérou HN, ed. Browse in Africa. The current state of knowledge. Proceedings of the International Symposium on Browse in Africa, Addis Ababa, 8–12 April 1980. p. 109–114. hdl.handle.net/10568/67392

Musco N; Koura IB; Tudisco R; Awadjihè G; Adjolohoun S; Cutrignelli MI; Mollica MP; Houinato M; Infascelli F; Calabrò S. 2016. Nutritional characteristics of forage grown in South of Benin. Asian-Australasian Journal of Animal Sciences 29:51–61. doi: 10.5713/ajas.15.0200

Oba G; Vetaas OR; Stenseth NC. 2001. Relationships between biomass and plant species richness in arid-zone grazing lands. Journal of Applied Ecology 38:836–845. doi: 10.1046/j.1365-2664.2001.00638.x

Pérez Corona ME; Vázquez de Aldana BR; García Criado B; García Ciudad A. 1998. Variations in nutritional quality and biomass production of semi-arid grasslands. Journal of Range Management 51:570–576. bit.ly/2ykYLWR

Shapiro BI; Gebru G; Desta S; Negassa A; Nigussie K; Aboset G; Mechale H. 2017. Ethiopian livestock sector analysis: A 15 year livestock sector strategy. ILRI Project Report. ILRI, Nairobi, Kenya. hdl.handle.net/10568/92057

Skerman PJ; Riveros F. 1989. Tropical grasses. FAO Plant Production and Protection Series No. 23. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. bit.ly/3cfqUxk

Sollenberger LE; Cherney DJR. 1995. Evaluating forage production and quality. In: Barnes RF; Miller DA; Nelson CJ, eds. Forages. Volume II: The science of grassland agriculture. 5th Edn. Iowa State University Press, Ames, IA, USA. p. 97–120.

Van Soest PJ; Robertson JB. 1985. Analysis of forage and fibrous foods. Laboratory manual. Volume 613. Cornell University, Ithaca, NY, USA.

Vázquez-de-Aldana BR; García-Ciudad B; Pérez-Corona ME; García-Criado A. 2000. Nutritional quality of semi-arid grassland in western Spain over a 10-year period: Changes in chemical composition of grasses, legumes and forbs. Grass and Forage Science 55:209–220. doi: [10.1046/j.1365-2494.2000.00217.x](https://doi.org/10.1046/j.1365-2494.2000.00217.x)

Whalley RDB; Hardy MB. 2000. Measuring botanical composition of grasslands. In: Mannetje L't; Jones RM, eds. Field and laboratory methods for grassland and animal production research. CAB International, Wallingford, UK. p. 263–278. doi: [10.1079/9780851993515.0067](https://doi.org/10.1079/9780851993515.0067)

Zhai X; Zhang Y; Wang K; Chen Q; Li S; Huang D. 2018. Grazing effects on the nutritive value of dominant species in steppe grasslands of northern China. BMC Ecology 18:30. doi: [10.1186/s12898-018-0186-8](https://doi.org/10.1186/s12898-018-0186-8)

(Received for publication 27 December 2019; accepted 6 April 2020; published 31 May 2020)