Tropical Grasslands-Forrajes Tropicales (2024) Vol. 12(3):154–161
doi: 10.17138/TGFT(12)154-161

Research Paper

Agronomic performance and nutritive value of *Urochloa* species, Desho and Rhodes grass grown in sub-humid Central Ethiopia

Desempeño agronómico y valor nutritivo de las especies de Urochloa*, pastos Desho y Rhodes cultivados en en la zona Central subhúmeda de Etiopía*

FANTAHUN DEREJE[1,2], ASHENAFI MENGISTU[2], DIRIBA GELETI[3], DIRIBA DIBA[1], FEKEDE FEYISSA[3], YASIN BERISO[4], BUZUNESH TESFAYE[1] AND MESFIN DEJENE[5]

[1]*Department of Animal Science, Wallaga University, Nekemte, Ethiopia.* wollegauniversity.edu.et
[2]*College of Veterinary Medicine and Agriculture, Addis Ababa University, Addis Ababa, Ethiopia.* aau.edu.et/cvma
[3]*Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.* eiar.gov.et
[4]*Debre Zeit Agricultural Research Center, Bishoftu, Ethiopia.* eiar.gov.et/main-center-debrezeit
[5]*Holetta Agricultural Research Center, Holetta, Ethiopia.* eiar.gov.et/holetta

Abstract

Improved forage grasses with high quality and biomass are a crucial additional feed source for cereal-livestock farming in Ethiopia. This study compared the performance of 4 *Urochloa* species [*U. brizantha* (DZF-13379), *U. humidicola* (DZF-9222), *U. decumbens* 'Basilisk' (DZF-10871) and *U. mutica* (DZF-483)] with other 2 commonly used grasses, Rhodes grass (*Chloris gayana* 'Massaba') and Desho grass (*Pennisetum glaucifolium* local variety Kindu kosha), over 3 years during the main rainy season in Bishoftu in a sub-humid area of Ethiopia. The experiment was conducted using a completely randomized block design. There was significant variation among species for agronomic parameters. The species × year interaction was significant for dry matter yield, plant height, and plot cover but not significant for leaf-to-stem ratio. Nutritional value [ash, acid detergent fiber (ADF), crude protein (CP) and in vitro dry matter digestibility (IVDMD)] was significantly different among species with no differences for neutral detergent fiber (NDF) and acid detergent lignin (ADL). All species showed potential as alternative ruminant feeds with *U. mutica* and *U. brizantha* the highest yielding in the sub-humid environment.

Keywords: Dry matter yield, grass species, leaf-to-stem ratio, plant height, quality.

Resumen

Las gramíneas forrajeras mejoradas con alta calidad y biomasa son una fuente adicional de alimento crucial para la ganadería de cereales en Etiopía. Este estudio comparó el desempeño de 4 especies de *Urochloa* [*U. brizantha* (DZF-13379), *U. humidicola* (DZF-9222), *U. decumbens* 'Basilisk' (DZF-10871) y *U. mutica* (DZF-483)] con otras 2 gramíneas comúnmente utilizadas, la hierba Rhodes (*Chloris gayana* 'Massaba') y la hierba Desho (*Pennisetum glaucifolium* variedad local Kindu kosha), durante 3 años durante la temporada principal de lluvias en Bishoftu, en una zona subhúmeda de Etiopía. El experimento se realizó utilizando un diseño de bloques completos al azar. Hubo una variación significativa entre las especies en cuanto a los parámetros agronómicos. La interacción especie × año fue significativa para el rendimiento de materia seca, altura de la planta y cobertura, pero no fue significativa para la relación hoja/tallo. El valor nutricional [cenizas, fibra detergente ácida (FDA), proteína cruda (PC) y digestibilidad in vitro de la materia

Correspondence: Fantahun Dereje, Department of Animal Science, Wallaga University, Ethiopia and Department of Animal Production Studies, College of Veterinary Medicine and Agriculture, Addis Ababa University, Ethiopia. Email: fantish2010@gmail.com

seca (DIVMS)] fue significativamente diferente entre las especies, sin diferencias para la fibra detergente neutra (FND) y la lignina detergente ácida (LDA). Todas las especies mostraron potencial como alimento alternativo para rumiantes, siendo *U. mutica* y *U. brizantha* las de mayor rendimiento en el ambiente subhúmedo.

Palabras clave: Altura de la planta, calidad, especies de pastos, relación hoja-tallo, rendimiento de materia seca.

Introduction

Feed shortages in quantity and quality are a recurrent challenge to cattle production and productivity in tropical Africa. In Ethiopia's highland crop-livestock mixed farming system, the availability of year-round feed is limited (FAO 2018; Feyissa et al. 2022; Mekonnen et al. 2022). The combination of feed scarcity and low feed quality makes it difficult to meet the maintenance requirements for livestock throughout the year (Feyissa et al. 2022). Currently, pressures from climate change exacerbate these long-standing feed problems (Habte et al. 2022). Introducing improved forages in such systems has been proposed to offer alternative good-quality feeds to improve livestock productivity and close feed gaps (Feyissa et al. 2022).

Urochloa includes many tropical grass species that originated on the African continent and are extensively grown in tropical Latin America and South Asia (Cheruiyot et al. 2020). Although there are over 100 species in this genus, many are underutilized and only a few, such as *Urochloa brizantha* (syn. *Brachiaria brizantha*) (A. Rich.) Stapf (palisade grass), *U. decumbens* (syn. *Brachiaria decumbens*) Stapf (signal grass) and *U. humidicola* (syn. *Brachiaria humidicola*) (Rendle) Schweick (Koronivia grass) are commercially exploited as forage crops (Miles et al. 2004). Recently, improved *Urochloa* grass has been introduced and cultivated by thousands of farmers in eastern Africa to provide alternative high-quality feed resources for livestock producers (Cheruiyot et al. 2020; Maina et al. 2020).

In addition to providing better quality, *Urochloa* grasses show adaptability to a wide range of agroecology and soil types (Cheruiyot et al. 2018). Their deep root systems allow them to extract nutrients and moisture, which helps them tolerate low soil fertility and dry spells in tropical regions (Ndayisaba et al. 2020). They also contribute to carbon sequestration, enhanced nitrogen use efficiency via biological nitrification inhibition (BNI), effective soil erosion control and management of crop pests through push-pull pest management techniques (Arango et al. 2014; Moreta et al. 2014; Rao et al. 2014). *Urochloa* grasses have shown promising results in improving livestock productivity through better quality and higher biomass (Maina et al. 2020).

Currently, there is interest in evaluating the adaptability and performance of *Urochloa* grass species under climatic conditions for the highland smallholder livestock producers of Ethiopia. Comparative yield evaluation of *Urochloa* with other important grass species was identified as the main research approach to demonstrate the suitability of forages for wider adoption in Ethiopia (Feyissa et al. 2022). In the present study, the agronomic performance of four *Urochloa* species [*U. mutica* (DZF-483), *U. decumbens* 'Basilisk' (DZF-10871), *U. brizantha* (DZF-13379), and *U. humidicola* (DZF-9222)], and 2 other grass species [Desho grass (*Pennisetum glaucifolia* Kindu kosha) and Rhodes grass (*Chloris gayana* 'Massaba')] was evaluated to compare the growth, herbage accumulation, and nutritive value in the highlands of central Ethiopia.

Materials and Methods

The experiment was conducted during the main rainy season from 2020 to 2022 at the Debre Zeit Agricultural Research Center (Bishoftu) (08º 44' N, 38º38' E; elevation 1,900 masl) in the sub-humid agroclimatic zone of Central Ethiopia. The center is 47 km East of Addis Ababa, on the road to Adama. The soil type (Tafesse and Esayas 2003) for the experimental plots was Eutric Vertisols.

Four *Urochloa* species [*U. brizantha* (DZF-13379), *U. humidicola* (DZF-9222), *U. decumbens* 'Basilisk' (DZF-10871) and *U. mutica* (DZF-483)] were compared to Desho grass (*Pennisetum glaucifolia* Kindu kosha) and Rhodes grass (*Chloris gayana* 'Massaba'). *Urochloa* species were selected based on their superior performance from earlier trials, while a recently released local variety of Desho grass and Rhodes grass, a popular grass species, were used for comparison.

The experiment was conducted using a completely randomized block design with 3 replicates. Vegetative root splits of 12 month age were transplanted using 2–3 splits per hole at a depth of 10 cm in mid-June

2020 under rainfed conditions without supplementary irrigation in well-prepared 12 m^2 plots with 50 cm between row and 25 cm within row spacing. Nitrogen and phosphorus fertilizers were applied at the rate of 18 kg N/ha and 46 kg P/ha (as DAP), and 46 kg N/ha as urea at transplanting and immediately after each harvest in a band along the planting furrow. Weed management and regular monitoring of disease and insects were performed as appropriate.

Data Collection

Dry matter (DM) yield, plant height, plot cover and leaf-to-stem ratio were measured during the rainy season (June–Sept). The first harvest was carried out 3 months after establishment in the first year (2020) and at intervals of 60 days (2 cuts/rainy season) in 2021 and 2022. Plant height from the soil surface to the uppermost point of the stem was measured on 5 randomly selected plants/plot and expressed as a mean. Visual observation for plot cover was rated on a 1–10 scale (where 1=poor and 10=excellent). The leaf-to-stem ratio was determined by cutting plants from 2 randomly selected consecutive rows and separating by hand into leaf (lamina) and stem (leaf sheath+stem). Samples of each plant part were weighed, homogenized and subsampled and dried in a forced draft oven at 65 °C for 72 h. Fresh herbage yield was sampled by cutting the entire plot at a stubble height of 10 cm by hand using a sickle and weighing immediately. A subsample of 300 g of freshly harvested biomass was cut into small pieces and dried at 65 °C for 72 h in an oven to calculate dry matter yield as:

$$\text{DM yield (t/ha)}=(10\times TFW\times SSDW)/(HA\times SSFW),$$

where:

TFW is the total fresh weight of the harvested area (kg);
SSDW is the subsample dry weight (g);
HA is the harvest area (m^2);
SSFW is the subsample fresh weight (g).

A sample of 400 g from each treatment was collected at harvest and dried under the shade for laboratory analysis. Nutritional analyses of feed samples were performed at the Bishoftu Agricultural Research Center Food and Nutrition Laboratory and Holetta Agricultural Research Center Animal Feed and Nutrition Laboratory. Grass samples were dried at 105 °C overnight and ground to pass through a 1 mm sieve. The total ash content was determined in a furnace at 550 °C for 6 h. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined according to Van Soest and Robertson (1985). Nitrogen (N) was determined using the Kjeldahl method and in vitro dry matter digestibility (IVDMD) was determined using the modified Tilley and Terry method (Tilley and Terry 1963).

Statistical analysis

The Linear mixed-effect model (LME) approach was used to analyze the forage yield and nutritive value data using the 'lme4' package (Bates et al. 2015) in R. Pasture species, year and interaction of pasture and year were considered as fixed effects and the effects of plots within replicated blocks were included as random effects of the model. Harvesting years were included as repeated measures because they were measured from the same plot. Mean comparisons of the effects were performed using the 'lsmeans' package (Lenth 2016) in R for the cultivar across years. Nutritive value was separately analyzed using one-way ANOVA to determine significant differences among the pasture species. The statistical model used was:

$$Y_{ijkx}=\mu+C_j+Y_x+(C_j\times Y_x)+\varepsilon_{ijkx},$$

where:

Y_{ijkx} is the response variable;
μ is the overall mean;
C_j is the effect of jth grass cultivar;
Y_x is the effect of jth year;
$C_j\times Y_x$ is the interaction between cultivar and year;
e_{ijxk} is the random error.

Tukey's honestly significant difference post hoc test was used to separate significant differences between pasture species.

Results

Average annual rainfall for the experimental years (2020–2022) was 814.8 mm with a long-term mean (1990–2020) of 473.2 mm (Table 1). Compared with the long-term climatic data, the trial period had higher rainfall, especially during the Kiremt season (June to September), the main rainy season in Ethiopia.

Effects of species, year and their interaction on agronomic traits.

A combined analysis of variance for DM yield, plant height, plot cover and leaf-to-stem ratio on dry matter basis of the four *Urochloa* species, Rhodes grass and Desho grass showed there was significant variation among species (P<0.01) for DM yield, plant height, plot cover and leaf-to-stem ratio (Table 2). Significant (P<0.05) species × year interactions were observed for all the parameters except for leaf-to-stem ratio dry basis.

The combined analysis indicated significant differences in forage dry matter yield among species (Table 3). *U. mutica* followed by Desho grass had the highest DM yield, but they did not differ significantly from other species, except for *U. humidicola*. Variation among species in experimental periods was also significant except for 2021. Low dry matter yields were observed during the establishment year compared to 2021 and 2022.

Table 1. Mean rainfall and temperature variation over the trial years and long-term (1990-2020).

Months of the year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall, trial years (mm)	5.9	4.8	28.3	39.2	71.4	117.5	217.9	213.9	96.0	19.4	0.0	0.4
Rainfall, long-term mean (mm)	7.5	10.7	34.6	29.6	29.4	65.3	129.9	107.4	42.5	8.2	3.5	4.6
Mean daily min temperature trial years (°C)	7.2	8.5	10.3	11.7	11.1	11.5	11.5	11.1	10.4	7.0	5.2	5.1
Mean daily max temperature trial years (°C)	26.6	27.7	29.2	29.4	28.1	26.4	21.3	22.3	23.2	24.3	24.3	24.6
Mean daily min temperature long-term (°C)	9.3	10.4	11.8	13.2	12.9	12.6	13.5	13.5	12.5	9.3	7.8	7.5
Mean daily max, temperature long-term (°C)	26.7	28.0	28.9	28.9	29.2	27.9	25.0	24.4	25.4	29.2	26.2	25.8

Table 2. Species, year and their interaction effects on agronomic traits in Bishoftu.

Parameters	Species	Year	Species × Year
DM yield (t/ha)	**	***	**
Plant height (cm)	***	**	***
Plot cover	***	**	***
Leaf-to-stem ratio dry basis	**	ns	ns

ns=non-significant; *=P<0.05; **=P<0.01; ***=P<0.001.

Table 3. Dry matter yield of grass species tested for 3 years at Bishoftu.

Species	Dry matter yield (t/ha)			
	2020	2021	2022	Combined analysis
U. brizantha (DZF-13379)	2.61[b]	14.53	17.23[a]	11.46[ab]
U. humidicola (DZF-9222)	2.13[b]	11.6	11.98[ab]	8.57[b]
U. decumbens (DZF-10871)	4.38[ab]	15.75	13.44[ab]	11.19[ab]
U. mutica (DZF-483)	6.72[ab]	17.02	16.96[a]	13.57[a]
Rhodes grass ('Massaba')	8.52[a]	14.97	9.84[b]	11.11[ab]
Desho grass (Kindu kosha)	8.66[a]	17.2	12.97[ab]	12.94[a]
Mean	5.03	15.18	13.74	11.47
SEM	1.38	1.38	1.38	0.83

Means with different letters are significantly different. SEM=standard error of the mean.

The combined analysis indicated that *U. mutica* was the tallest (P<0.05) followed by Rhodes grass and *U. brizantha* (Table 4). Species varied significantly across all the experimental periods. Low plant height was observed in *U. humidicola* throughout the experimental period.

The combined analysis indicated that *U. mutica*, Desho, *U. brizantha*, and *U. decumbens* had higher plot cover than *U. humidicola* and Rhodes grass (Table 5). There was also significant variation in plot cover among the species across the experimental period.

Nutritional Value

Ash, ADF, CP and IVDMD were significantly different (P<0.05) among species, while NDF and ADL were not significantly different (Table 6).

Table 4. Plant height (cm) of grass species tested for 3 years at Bishoftu.

Species	Plant height (cm)			
	2020	2021	2022	Combined analysis
U. brizantha (DZF-13379)	96[bc]	99[b]	94.5[a]	96.5[b]
U. humidicola (DZF-9222)	75[d]	83.5[c]	79.2[b]	79.8[d]
U. decumbens (DZF-10871)	92[bcd]	100.7[b]	80.5[b]	91.1[bc]
U. mutica (DZF-483)	132.7[a]	116.5[a]	99.3[a]	116.2[a]
Rhodes grass ('Massaba')	107[b]	99[b]	88.5[ab]	98.2[b]
Desho grass (Kindu kosha)	84.7[cd]	81.8[c]	90.8[ab]	85.8[cd]
Mean	97.9	96.75	88.8	94.6
SEM	4.68	4.68	4.68	2.28

Means with different letters are significantly different. SEM=standard error of the mean.

Table 5. Plot cover and 3 year mean leaf-to-stem ratio on a dry matter basis of grass species tested for 3 years at Bishoftu.

Species	Plot cover				Three year mean leaf-to-stem ratio[1]
	2020	2021	2022	Combined analysis	
U. brizantha (DZF-13379)	6[b]	8[ab]	9[a]	7.67[a]	0.92[a]
U. humidicola (DZF-9222)	6[b]	7[a]	7.3[bc]	6.78[b]	0.91[a]
U. decumbens (DZF-10871)	6[b]	8.7[a]	8[abc]	7.56[a]	0.96[a]
U. mutica (DZF-483)	7.7[a]	8.3[a]	8.3[ab]	8.11[a]	0.87[a]
Desho grass (Kindu kosha)	7[ab]	8.7[a]	7.7[bc]	7.78[a]	0.87[a]
Rhodes grass ('Massaba')	7[ab]	8.3[a]	7[c]	7.44[b]	0.72[b]
Mean	6.6	8.2	7.9	7.6	0.83
SEM	0.32	0.32	0.32	0.27	0.07

[1]Leaf-to-stem ratio presented as 3 year mean (no species × year interaction); Means with different letters are significantly different; SEM=standard error of the mean.

Table 6. Nutritional value of perennial forage grass species evaluated in Bishoftu.

Species	Ash%	NDF%	ADF%	ADL%	CP%	IVDMD%
U. brizantha (DZF-13379)	7.96[b]	73.4	43.9[ab]	10.58	12.73[a]	54.2[b]
U. decumbens (DZF-10871)	9.66[ab]	73.1	43.4[ab]	10.01	10.23[ab]	51.4[bc]
U. humidicola (DZF-9222)	11.98[a]	70.6	41.1[ab]	9.18	12.93[a]	57.8[a]
U. mutica (DZF-483)	9.04[ab]	76	38[b]	8.6	12.43[a]	52.6[b]
Desho grass (Kindu kosha)	8.91[ab]	73.7	43.9[ab]	9.79	8.27[b]	54.6[ab]
Rhodes grass ('Massaba')	8.69[b]	77.1	48.3[a]	9.79	9.43[ab]	48.6[c]
Mean	9.37	73.98	43.1	9.66	11	53.2
SEM	1.14	2.53	1.88	2.06	0.78	1.27

NDF=neutral detergent fiber; ADF=acid detergent fiber; ADL=acid detergent lignin; CP=crude protein; IVDMD=In vitro dry matter digestibility. Means with different letters are significantly different. SEM=standard error of the mean.

Discussion

The occurrence of species × year interactions for agronomic traits was expected because of climatic variation between the test years. There was a change in the ranking order of grass species over the years owing to the nonuniformity of growing conditions (rainfall, temperature) during the experimental period. These results agree with those of Wassie et al. (2018), who reported significant species × accession × year interactions. All species were able to persist throughout the dry season from year to year.

Given the feed supply challenges faced by smallholders in mixed crop-livestock systems, cultivating *Urochloa* grasses can alleviate feed shortages (Midega et al. 2018). This study showed they are capable of producing a similar herbage yield to the naturally occurring pasture Desho grass and higher yield than the commonly used Rhodes grass. They can be easily integrated into cropping systems, providing additional benefits such as soil conservation and land rehabilitation (Cheruiyot et al. 2018a; Horrocks et al. 2019; Damene et al. 2020). *Urochloa* grasses are adaptable to rainfed conditions, enabling farmers to produce surplus feed during the growing season that can be stored for use during periods of scarcity (Cezário et al. 2015).

The results confirmed the high forage yield of *U. mutica* (DZF-483) in sub-humid environments, as reported previously by Assefa et al. (2016) and Bantihun et al. (2022). Dry matter yield of *U. mutica* (DZF-483) obtained for 2022 (16.96 t/ha) was higher than the 13.3 t/ha reported during variety registration (Assefa et al. 2016) and also higher than 11.8 t/ha reported in the northwest highlands of Ethiopia by Bantihun et al. (2022). *U. decumbens* 'Basilisk' dry matter yields (11.26 t/ha) were comparable with the results of Faji et al. (2022), who reported 11.40 t/ha in Holetta, Ethiopia. *U. brizantha* (DZF-13379) displayed increasing forage dry matter yield each year, indicating the potential and importance of this cultivar as a candidate variety for registration (unpublished data). Dry matter yield of *U. brizantha* of 11.2 t/ha was higher than yields of 5.09 t/ha reported for other *U. brizantha* ecotypes grown in Northwestern Ethiopia (Wassie et al. 2018). *U. humidicola* had the lowest yield but has additional advantages such as restoration ability when established on degraded lands (Damene et al. 2020).

Dry matter yield of Desho grass was lower than those reported in other studies at higher altitudes in Ethiopia (Asmare et al. 2017; Faji et al. 2022). This is supported by Mengistu et al. (2024), who indicated that the origin of Desho grass was highland and mid-elevation areas and that highland environments were better for the growth and development of Desho grass. Rhodes grass ('Massaba') dry matter yields were much lower than those reported by Faji et al. (2022) under supplementary irrigation in Holetta. This difference could be due to weather, soil type and irrigation.

All species had CP concentrations greater than 7%, meeting the minimum crude protein requirements for the synthesis of microbial proteins in the rumen needed to support the maintenance requirements of ruminants (Van Soest 1994). *U. humidicola*, *U. brizantha* and *U. mutica* were classified as medium protein feed sources and the remaining species were categorized as low-protein feed sources using the classification of Lonsdale (1989). CP concentrations of *U. mutica*, *U. decumbens*, Desho, and Rhodes grass were higher than those reported by Bantihun et al. (2022) and Faji et al. (2022).

Ash ranged from 8–12%, which is in agreement with the report of Wassie et al. (2018). NDF was higher than the values (65%) for tropical grasses reported by (Van Soest 1994), classifying them as a low-quality roughage. The variable ADF reported may be due to the different grass genotypes and species. Faji et al. (2022) reported that the nutritive value can vary with genotype, harvesting stage and environment. *U. humidicola* is more digestible than the other perennial grass species evaluated, although IVDMD showed a decline with an increase in NDF, ADF and ADL. This could be attributed to lignin deposition in the cell wall and an increased proportion of stem in the forage with ageing. Results for nutritive value of *U. decumbens*, Desho grass and Rhodes grass in the current study were higher than those reported by Faji et al. (2022). Differences between these results and those of other studies are probably due to the differences in the edaphic, climatic, and biotic conditions of the study environment as well as the maturity stage at harvest, management and supplementary irrigation.

Conclusions

The *Urochloa* grasses compared well with other grasses evaluated in this study with the potential to produce forage with good nutritive value and serve as alternative options for smallholders in rainfed sub-humid environments in Central Ethiopia. These grasses demonstrated optimal organic matter digestibility and remarkably high crude protein (CP) concentration, making them excellent forage supplements in systems where crop residues are the primary feed resource. *U. mutica*, followed by *U. brizantha*, may be particularly recommended due to their higher biomass production and adequate forage nutritive value. Further studies should be conducted on the performance of animals fed these grasses as a basal diet to make feeding recommendations to livestock producers in the area.

Acknowledgments

The authors thank the Ethiopian Institute of Agricultural Research for its financial support. The authors are also grateful to the technical and field assistants of the Forage and Pasture Research Program, Debre Zeit Agricultural Research Center for their support during the fieldwork and Debre Zeit and Holetta laboratory technicians and researchers working in animal nutrition for their support during laboratory analysis.

References

(Note of the editors: All hyperlinks were verified 10 September 2024).

Arango J; Moreta D; Núñez J; Hartmann K; Domínguez M; Ishitani M; Miles J; Subbarao G; Peters M; Rao I. 2014. Developing methods to evaluate phenotypic variability in biological nitrification inhibition (BNI) capacity of *Brachiaria* grasses. Tropical Grasslands-Forrajes Tropicales 2(1):6–8. doi: 10.17138/tgft(2)6-8

Asmare B; Demeke S; Tolemariam T; Tegegne F; Haile A; Wamatu J. 2017. Effects of altitude and harvesting dates on morphological characteristics, yield and nutritive value of desho grass (*Pennisetum pedicellatum* Trin.) in Ethiopia. Agriculture and Natural Resources 51(3):148–153. doi: 10.1016/j.anres.2016.11.001

Assefa G; Mengistu S; Feyissa F; Bediye S. 2016. Animal feed resources research in Ethiopia: Achievements, challenges and future directions. Ethiopian Journal of Agricultural Sciences special issue:141–155.

Bantihun A; Asmare B; Mekuriaw Y. 2022. Comparative evaluation of selected grass species for agronomic performance, forage yield, and chemical composition in the highlands of Ethiopia. Advances in Agriculture 2022(1):6974681. doi: 10.1155/2022/6974681

Bates D; Mächler M; Bolker B; Walker S. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67(1):1–48. doi: 10.18637/jss.v067.i01

Cezário AS; Ribeiro KG; Santos SA; Valadares Filho SC; Pereira OG. 2015. Silages of Brachiaria brizantha cv. Marandu harvested at two regrowth ages: Microbial inoculant responses in silage fermentation, ruminant digestion and beef cattle performance. Animal Feed Science and Technology 208:33–43. doi: 10.1016/j.anifeedsci.2015.06.025

Cheruiyot D; Midega CAO; Pittchar JO; Pickett JA; Khan ZR. 2020. Farmers' perception and evaluation of *Brachiaria* grass (*Brachiaria* spp.) genotypes for smallholder cereal-livestock production in East Africa. Agriculture 10(7):268. doi: 10.3390/agriculture10070268

Cheruiyot D; Midega CAO; Ueckermann EA; Van den Berg J; Pickett JA; Khan ZR. 2018. Genotypic response of brachiaria (*Urochloa* spp.) to spider mite (*Oligonychus trichardti*) (Acari: Tetranychidae) and adaptability to different environments. Field Crops Research 225:163–169. doi: 10.1016/j.fcr.2018.06.011

Damene S; Bahir A; Villamor GB. 2020. The role of Chomo grass (*Brachiaria humidicola*) and enclosures in restoring soil organic matter, total nitrogen, and associated functions in degraded lands in Ethiopia. Regional Environmental Change 20(3):92. doi: 10.1007/s10113-020-01680-z

Faji M; Kebede G; Feyissa F; Mohammed K; Mengistu G. 2022. Yield, yield components, and nutritive value of perennial forage grass grown under supplementary irrigation. Advances in Agriculture 2022(1):5471533. doi: 10.1155/2022/5471533

FAO (Food and Agriculture Organization of the United Nations). 2018. Ethiopia: Report on feed inventory and feed balance. Rome, Italy. 160 pages. openknowledge.fao.org

Feyissa F; Kebede G; Geleti D; Assefa G; Mengistu A. 2022. Improved forage crops research and development in Ethiopia: Major achievements, challenges and the way forward. OMO International Journal of Sciences 5(2):36–69. doi: 10.59122/135BE51

Habte M; Eshetu M; Maryo M; Andualem D; Legesse A. 2022. Effects of climate variability on livestock productivity and pastoralists perception: The case of drought resilience in Southeastern Ethiopia. Veterinary and Animal Science 16:100240. doi: 10.1016/j.vas.2022.100240

Horrocks CA; Arango J; Arevalo A; Nuñez J; Cardoso JA; Dungait JAJ. 2019. Smart forage selection could significantly improve soil health in the tropics. Science of The Total Environment 688:609–621. doi: 10.1016/j.scitotenv.2019.06.152

Lenth RV. 2016. Least-Squares Means: The R Package lsmeans. Journal of Statistical Software 69(1):1–33. doi: 10.18637/jss.v069.i01

Lonsdale C. 1989. Straights: Raw materials for animal feed compounders and farmers. Chalcombe Publications, Great Britain. p. 17–47. ISBN 10: 0948617152

Maina KW; Ritho CN; Lukuyu BA; Rao EJO. 2020. Socio-economic determinants and impact of adopting climate-smart *Brachiaria* grass among dairy farmers in Eastern and Western regions of Kenya. Heliyon 6(6):e04335. doi: 10.1016/j.heliyon.2020.e04335

Mekonnen K; Bezabih M; Thorne P; Gebreyes MG; Hammond J; Adie A. 2022. Feed and forage development in mixed crop–livestock systems of the Ethiopian highlands: Africa RISING project research experience. Agronomy Journal 114(1):46–62. doi: 10.1002/agj2.20853

Mengistu G; Faji M; Mohammed K; Workiye M; Kebede G; Terefe G; Dejene M; Feyissa F. 2024. Forage yield and nutritive value of Desho grass (*Pennisetum glaucifolium* Trin.) as affected by cutting heights in the central highlands of Ethiopia. Heliyon 10(7):e28757. doi: 10.1016/j.heliyon.2024.e28757

Midega CAO; Pittchar JO; Pickett JA; Hailu GW; Khan ZR. 2018. A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (J E Smith), in maize in East Africa. Crop Protection 105:10–15. doi: 10.1016/j.cropro.2017.11.003

Miles JW; Do Valle CB; Rao IM; Euclides VPB. 2004. *Brachiaria* grasses. In: Moser LE; Burson BL; Sollenberger LE, eds. Warm-Season (C4) Grasses. Agronomy Monograph 45 American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI. p. 745–783. doi: 10.2134/agronmonogr45.c22

Moreta DE; Arango J; Sotelo M; Vergara D; Rincón A; Ishitani M; Castro A; Miles J; Peters M; Tohme J; Subbarao GV; Rao IM. 2014. Biological nitrification inhibition (BNI) in *Brachiaria* pastures: A novel strategy to improve eco-efficiency of crop-livestock systems and to mitigate climate change. Tropical Grasslands-Forrajes Tropicales 2(1):88–91. doi: 10.17138/TGFT(2)88-91

Ndayisaba PC; Kuyah S; Midega CAO; Mwangi PN; Khan ZR. 2020. Push-pull technology improves maize grain yield and total aboveground biomass in maize-based systems in Western Kenya. Field Crops Research 256:107911. doi: 10.1016/j.fcr.2020.107911

Rao I; Ishitani M; Miles J; Peters M; Tohme J; Arango J; Moreta DE; Lopez H; Castro A; Van der Hoek R; Martens S; Hyman G; Tapasco J; Duitama J; Suárez H; Borrero G; Núñez J; Hartmann K; Domínguez M; Sotelo M; Vergara D; Lavelle P; Subbarao GV; Rincon A; Plazas C; Mendoza R; Rathjen L; Karwat H; Cadisch G. 2014. Climate-smart crop-livestock systems for smallholders in the tropics: Integration of new forage hybrids to intensify agriculture and to mitigate climate change through regulation of nitrification in soil. Tropical Grasslands-Forrajes Tropicales 2(1):130–132. doi: 10.17138/TGFT(2)130-132

Tafesse D; Esayas A. 2003. Soils of Debre Zeit Agricultural Research Center and its sub-centers Technical Paper No 79. Ethiopian Agricultural Research Organization, Ethiopia. bit.ly/4gmIxwY

Tilley JMA; Terry RA. 1963. A two-stage technique for the in vitro digestion of forage crops. Grass and Forage Science 18(2):104–111. doi: 10.1111/j.1365-2494.1963.tb00335.x

Van Soest PJ. 1994. Nutritional ecology of the ruminant. 2nd Edition. Cornell University Press, Cornell, USA. 476 p.

Van Soest PJ; Robertson JB. 1985. Analysis of forages and fibrous foods. CRC-Press.

Wassie WA; Tsegay BA; Wolde AT; Limeneh BA. 2018. Evaluation of morphological characteristics, yield and nutritive value of *Brachiaria* grass ecotypes in northwestern Ethiopia. Agriculture and Food Security 7(1):89. doi: 10.1186/s40066-018-0239-4

(Received for publication 11 August 2023; accepted 29 August 2024; published 30 September 2024)