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SPECIAL SECTION: DEVELOPING FODDER RESOURCES FOR SUB-SAHARAN COUNTRIES

Potential of *Urochloa* grass hybrids as fodder in the Ethiopian highlands

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Abstract

Urochloa grasses have shownpromising results for smallholders to cope with feed shortages in tropical Africa. The objective of this study was to evaluate the performance of two *Urochloa* hybrids, Mulato-I and Mulato-II, in the Ethiopian highlands when managed under different plant spacing and harvesting stages. Treatments included three plant spacings for root splits (0.5 by 0.25 m, 0.5 by 0.5 m, and 0.75 by 0.75 m between rows and plants, respectively) and three harvesting stages: (a) 60 d of growth; (b) 90 d of growth corresponding to 50% bloom, and (c) 120 d of growth (corresponding to full bloom). Experimental plots were laid out in a randomized complete block design with three replications, and observations on the same established stands were made in two consecutive years. Varietal differences were observed in plant height (Mulato-II: 42 cm; Mulato-I: 72 cm), and herbage accumulation (Mulato-II: 3.0 Mg dry matter [DM] ha^{-1}; Mulato-I: 10.6 Mg DM ha^{-1}). Plant spacing also affected the above variables, but year of harvest influenced herbage accumulation. The rate of herbage accumulation tended to be constant, while that of crude protein (CP) declined and fiber concentration increased significantly with advancing maturity. Overall, the decline in quality at full bloom stage appears to be compensated by the greater herbage accumulation, suggesting that farmers can have enough time window to harvest the forages. While Mulato-I was superior in herbage accumulation, Mulato-II was found to be better in forage quality. The two grasses have potential to supply good quality forage provided proper management practices are applied.

1 | INTRODUCTION

Shortageof fodder, both in quantity and quality, for year-round feeding is a major constraint for livestock production in the mixed crop livestock systems of tropical Africa. In the Ethiopian highlands availability of feed becomes critical towards the end of the dry season (Bezabih et al., 2014; Desta & Oba, 2004). Introducing improved forages in such systems is proposed to offer alternative good quality feeds to improve livestock productivity and close yield gaps (Mayberry et al., 2017).

Urochloa grasses are among the potential forages that can be cultivated commercially or under smallholder conditions

Abbreviations: ADL, acid detergent lignin; CP, crude protein; DM, dry matter; HA, herbage accumulation; OM, organic matter; OMA, organic matter accumulation; IVOMD, in vitro organic matter digestibility.

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(Jank et al., 2014; Maina et al., 2020; Midega et al., 2015). The genus *Urochloa* is the source of many tropical grass species that have originated in the African continent and are natural constituents of grasslands (Cheruiyot et al., 2020). Although many species of *Urochloa* are constituents of natural grasslands of tropical Africa, they remain underutilized as a cultivated forage (Cheruiyot et al., 2018; Njarui et al., 2016). On the other hand, species such as Signal grass (*U. decumbens* Stapf), and Palisade grass (*U. brizantha* Hochst ex A. Rich.) R. Webster, have been widely grown as improved pastures over large areas in Latin America and South America and are credited with the transformation of the cattle production sector in that continent (Jank et al., 2014; Muniandy et al., 2019; Peters et al., 2003). In recent years, improved *Urochloa* grasses have been introduced and cultivated by thousands of farmers in eastern Africa, providing alternative good quality feed resources for dairy and beef producers (Cheruiyot et al., 2020; Maina et al., 2020).

In addition to their adaptability to a wide range of agroecology and soil types, *Urochloa* grasses have deep root systems, allowing them to extract nutrients and moisture well and to tolerate dry spells in tropical regions (Ndayisaba et al., 2020; Rao et al., 1998). They can also serve as effective cover crops to control soil erosion and help reclaim degraded lands and to control crop pests through push–pull agricultural pest management (Brandan et al., 2017; Hungria et al., 2016). Hybrid *Urochloa* cultivars (*Urochloa ruziziensis* x *U. decumbens* x *U. brizantha* cultivar Mulato) have shown promising results in improving livestock productivity as they have been bred for quality and biomass production (Brandan et al., 2017; Maina et al., 2020).

Currently, there are ongoing efforts to evaluate the adaptability and performance of the newly released varieties under the climatic conditions of the highlands of Ethiopia. In this regard, participatory variety selection and utilization trials are good learning platforms to demonstrate the suitability of the forages for wider adoption (Njarui et al., 2016).

As seed availability is limited in the smallholder setting, farmers depend on root splits to propagate *Urochloa* grasses in their farms. This experiment was initiated to evaluate the agronomic performance of two hybrid cultivars, namely Mulato-I and Mulato-II, under the highland agro-ecologies of southern Ethiopia. The experiment was specifically aimed at assessing the growth, herbage accumulation, and nutritive value of the two cultivars when subjected to different plant spacings for root splits and harvesting stages. The information generated will help to identify optimal plant spacing and harvesting stages under the subhumid agro-ecological conditions of Ethiopia.

Core Ideas

- Two *Urochloa* hybrids, Mulato-I and Mulato-II, were evaluated as forages in Ethiopia.
- Mulato-I had a greater herbage accumulation rate than Mulato-II: 116 vs. 36 kg ha^{-1} d^{-1}.
- Plant spacing and harvesting stages affected rate of herbage accumulation.
- Average crude protein content of the two forages ranged from 180–200 g kg^{-1} dry matter.
- Mulato-I has a potential to provide considerable biomass of good quality forage in the region.

2 | MATERIALS AND METHODS

2.1 | Study site

The experiment was conducted in Damot Gale district of southern Ethiopia located at 6° 57′ 42.6″ N and 37° 49′ 41.52″ E, with an altitude above sea level of 2,005 m (Figure 1). The average temperatures of the area vary between 12 and 24 °C and mean annual rainfall ranges between 400 and 900 mm. The rainfall pattern is bimodal with the main rainy season (*Kiremt*) occurring between June and August and the short rains (*Belg*) from February through April. The dominant soil types in the district are nitosols and cambisols. Mixed crop–livestock farming system is the dominant system in the area. Wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), faba bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), and potato (*Solanum tuberosum* L.) are the main crops grown while cattle, small ruminants, and poultry are reared by farmers. The district is among the most highly populated areas in southern Ethiopia with average landholding per household being <0.5 hectares. The site was purposively selected to align with an ongoing BMZ (Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung), and U.S. Government's Feed the Future initiative projects (Grass2Cash, and Innovation Laboratory for Small Scale Irrigation) aimed at testing and promoting different *Urochloa* cultivars in the area.

2.2 | Experimental design and treatments

The experiment was designed in such a way that observations were made in two consecutive growing rainy seasons (years)

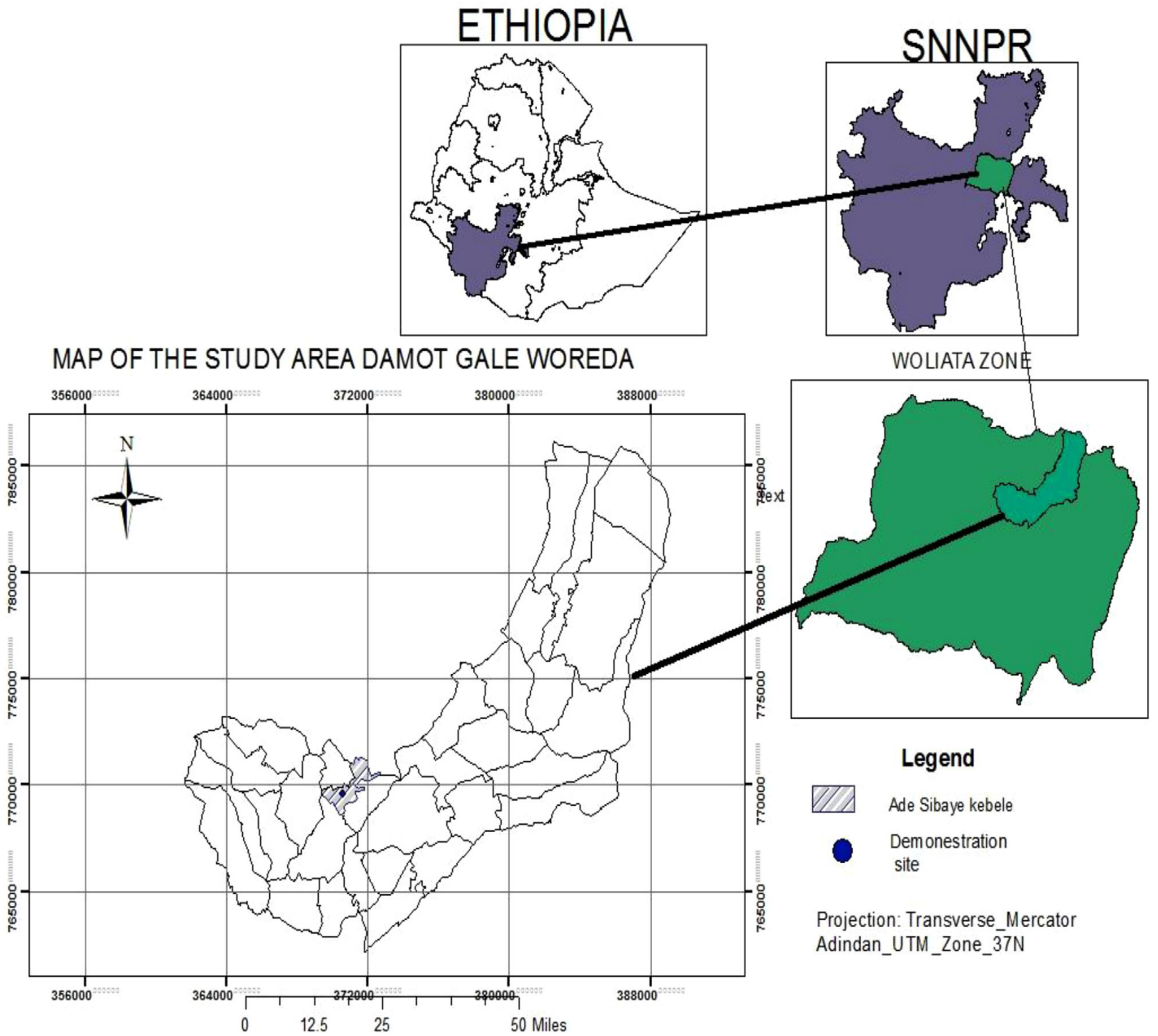

FIGURE 1 Map of the study location

on the same experimental plots. The experiment was laid out in a randomized complete block design with three replications. Slope gradient of the experimental plot was used as a blocking factor. The treatments included two *Urochloa* hybrid cultivars (Mulato-I and Mulato-II), three plant spacings for root splits of these grasses and three harvesting stages. The plant spacings were: (S1) 50 cm between rows and 25 cm between plants; (S2) 50 cm between rows and 50 cm between plants; (S3) 75 cm between rows and 25 cm between plants. The harvesting stages were: 60 d of growth (H1); 90 d of growth corresponding to 50% bloom (H2), and after 120 d of growth corresponding to full bloom. The treatments were combined in a 2×3×3 factorial arrangement. Three blocks, each containing 18 plots of 6 m^2 (2 by 3 m) were used for the experiment. A 1-m space was maintained between adjacent plots and between blocks.

After the forages were established as per the design in May 2019, the same establishment was used to observe the agronomic performances of the varieties during the 2019 and 2020 growing seasons. Upon completing the first season of observation, the plots were maintained until the next year with uniform management and supplemental irrigation to make sure that the root system remained intact during the long dry spell. Before the onset of the 2nd year observation, the plots were uniformly cut at 5-cm stubble height.

2.3 | Land preparation and management

The experimental field was plowed twice and smoothened to make sure that it was uniformly aerated. The field was then blocked into three and each block was split into 18 experimental plots. The treatment combinations were randomly assigned to the plots within a block. Before planting root splits, experimental plots were irrigated every other day in the evening with 20 L of water per 6 m^2 for 7 d. Root splits of the two cultivars, which were sourced from the International Livestock Research Institute herbage seed unit, were planted after preparing a pit of 15-cm depth as per the spacing specifications. The root splits were obtained from forage plots established from direct seeding of the two grasses. Each root split had on average four tillers. At planting, inorganic fertilizers, N and P were applied across the plots uniformly at a rate of 64 kg ha^{-1} for N, and 20 kg ha^{-1} for P in the form of urea and diammonium phosphate (DAP) (i.e., 100 kg ha^{-1} urea and 100 kg ha^{-1} DAP). Forty days into the growth of the forages, additional N was applied at a rate of 46 kg ha^{-1} in the form of urea (i.e., 100 kg ha^{-1} urea). To ensure uniform establishment, watering of the experimental plots (20 L of water $plot^{-1}$) was applied every other day until 30 d of growth. Handheld water cans were used for the irrigation. At the start of the 2nd year's observation, the same rate of fertilizer and procedure of application was followed as in Year 1. The 2nd year observation commenced at the start of the main rainy season in June 2020, and the forage growth was totally rainfed.

Soil samples were collected before commencing the trial using a soil auger at two soil depths: the upper layer at 0- to 10-cm depth and lower layer at 11- to 20-cm depth. Samples were collected from five positions located randomly along criss-crossed diagonal lines on the experimental field. At the end of the second season's observation period, soil samples were collected from each plot at the time of forage harvest and bulked by treatment.

2.4 | Agronomic data collection

During the observation periods, the trial plots were regularly monitored and data on growth performance including plant height, tiller count, leaf/stem ratio, and herbage accumulation were measured. Plant height was measured by taking 10 random plants at each growth stage (60, 90, and 120 d of growth). Plant height was measured from the base of the stem to the top-most leaf using a meter ruler. Similarly, tiller count (number of plants per tussock) was conducted on five randomly laid quadrats of 0.25m^2 per plot. Days to 50% and full bloom were recorded through regular visual observation of the entire plot. When plots reached the time of harvest according to the treatment stages, the entire grass in each plot was cut at a height of 5 cm above the ground by a hand sickle, and the fresh forage weight taken on the spot and a sample of 500 g was taken. The sample was immediately placed in a draft oven at 65 ˚C for 48 h for dry matter (DM) determination and subsequent chemical composition analysis. Herbage accumulation (HA) was calculated by multiplying fresh forage biomass by the respective DM concentration of the samples. Organic matter accumulation (OMA) was calculated by multiplying HA by the organic matter concentration (determined after laboratory analysis).

Rate of herbage accumulation (RHA) was calculated as follows:

$$\text{RHA}\left(\text{DMha}^{-1}\text{d}^{-1}\right) = HA\ ha^{-1}\text{at}\ harvest/days\ of\ forage\ growth,$$

where days of forage growth refers to the 60, 90 and 120 d of growth for the respective harvesting stage treatments.

Rate of OMA (OM ha^{-1} day^{-1}) was calculated as: OMA ha^{-1}/days of forage growth, where OM is organic matter.

Rate of crude protein (CP) accumulation (CP ha^{-1} day^{-1}) was calculated as: HA × CP concentration in the forages/days of forage growth.

Rate of digestible organic matter (DOM) accumulation was estimated as: rate of OMA (ha^{-1} day^{-1}) × IVOMD, where IVOMD is in vitro organic matter digestibility of the forages.

2.5 | Laboratory analysis

Analysis of herbage samples was conducted at the nutrition laboratory of the International Livestock Research Institute in Addis Ababa. Herbage samples were dried at 65 ˚C for 72 h and then ground to pass through 1-mm sieve. Near infrared reflectance spectroscopy (NIRS) was used for the forage analysis using equations developed for *Urochloa* grasses from conventional analysis of proximate chemical fractions (AOAC, 1990; Van Soest et al., 1991). The NIRS instrument used was Foss 5000 forage analyzer with software package WinISI II. Predicted traits were organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), metabolizable energy (ME) and in vitro digestible organic matter (IVDOM).

The soil samples were analyzed in the Horticoop-Ethiopia soil laboratory. Soil pH was measured according to ES ISO 10390: 2014 (1:2.5), soil texture by Bouyoucos hydrometer method, organic carbon by Walkley and Black method (Soon & Abboud, 1991), total nitrogen by ES ISO 11261:2015 (Kjeldahl method), phosphorus by ES ISO 11263: 2015 (Olsens method), and sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), and sulfur (S) by Mehlich-3 method, respectively.

2.6 | Statistical data analysis

The collected data were analyzed using the general linear model (GLM) procedure of SAS version 9.2. A probability

TABLE 1 Pre- and post-trial soil physicochemical analysis results of the experimental site soil

Parameters	Pre-trial soil test		Post-trial soil test			
			Mulato-I plots		Mulato-II plots	
	0–10 cm	11–20 cm	0–10 cm	11–20 cm	0–10 cm	11–20 cm
Sand, %	23	23.6	23.9	26	22.7	24.5
Clay, %	31	30.8	31.8	28	32	29.5
Silt, %	46	45.6	44.2	46	45.3	46
Textural class	Clay-loam	Clay-loam	Clay-loam	Clay-loam	Clay-Loam	Clay-Loam
pH	5.51	5.94	5.58	6.1	5.24	5.71
Ca, cmol kg^{-1}	3.12	3.80	3.2	4.03	2.42	3.58
Mg, cmol kg^{-1}	0.50	0.60	0.47	0.58	0.37	0.54
K, cmol kg^{-1}	0.80	0.94	0.62	0.80	0.53	0.76
Na, cmol kg^{-1}	0.39	0.44	0.35	0.45	0.28	0.33
Available P, mg kg^{-1}	1.89	0.82	2.55	0.90	2.85	0.92
S, mg kg^{-1}	27.6	16.5	18.4	14.6	21.9	16.8
OC, g kg^{-1}	15.3	12.4	14.3	8.5	14.0	12.1
TN, g kg^{-1}	1.3	1.2	1.2	0.8	1.3	1.2
C/N Ratio	11.61	10.43	11.72	10.28	10.70	10.1

level of $P < .05$ was used to declare significance. The following model was used for the analysis:

$$Yijk = \mu + Bi + Vj + SPk + DHh + YHn + Vj \times SPk + Vj \times DHh + Vj \times YHn \times DHh + eijk,$$

where

$$Yijk = \text{the dependent variable}$$

$$\mu = \text{overall mean}$$

$$B_i = \text{the ith block effect}$$

$$V_j = \text{the j}^{\text{th}}\text{Variety effect (j = 1Mulato} - \text{I}, 2 = \text{Mulato} - \text{II)}$$

$$SP_k = \text{the k}^{\text{th}}\text{spacing effect(k = 50 cm x 25 cm, } 50\ cm\ x\ 50\ cm\ and\ 75\ cm\ x\ 25\ cm)$$

$$DH_h = \text{the h}^{\text{th}}\text{ days to harvesting (h = 60, 90, and120 d)}$$

$$YH_n = \text{the n}^{\text{th}}\text{ year of harvest (n = 1 first year, 2 = year harvest)}$$

$$V_j \times SP_k = \text{the interaction effect of j}^{\text{th}}\text{ variety and k}^{\text{th}}\text{spacing}$$

$$V_j \times DH_h = \text{the interaction effect of j}^{\text{th}}\text{variety and h}^{\text{th}}\text{days } to\ harvest$$

$$V_j \times YH_n \times DH_h = \text{the three way interaction of j}^{\text{th}}\text{variety, h}^{\text{th}}\text{days to harvest, andn}^{\text{th}}\text{year of harvest.}$$

3 | RESULTS

3.1 | Soil physicochemical properties

The soil textural composition indicated that the experimental site is dominated by clay-loam soil type (Table 1). The soil reaction was slightly acidic, ranging from 5.5 to 6.0. The topsoil layer (0–10-cm depth) tended to be more acidic than the deeper layer (11–20-cm depth). There was an increasing trend for soil Ca (3.12–3.80 cmol kg^{-1}), Mg (0.50–0.60), K (0.80–0.94 cmol kg^{-1}), and Na (0.39–0.44 cmol kg^{-1}) with increasing soil depth. On the other hand, soil available P (1.89 to 0.82 cmol kg^{-1}) tended to decrease with increasing soil depth. Looking at the before- and after trial soil nutrients, Mg, K, and Na concentrations indicated a decreasing trend, while available P showed an increasing trend in both grass plots. Total nitrogen showed a declining trend in the Mulato-I plots at the

TABLE 2 Growth performance of Mulato-I and Mulato-II grasses established under different planting space, and harvested at three growth stages and observed over 2 yr

Variety	Plant height	Tillers count/plant	Herbage dry matter accumulation
	cm		Mg ha^{-1}
Mulato-I			
Spacing			
50 by 25 cm spacing	77	7.2	11.8
50 by 50 cm spacing	72	7.3	12.3
75 by 25 cm spacing	66	6.5	7.9
Harvesting stage			
60 d of growth	43	5.8	7.4
90 d of growth	64	5.7	8.9
120 d of growth	107	9.6	15.4
Year of harvest			
First	71	6.0	11.8
Second	72	7.0	9.5
Mean	72 ± 27.1	6.9 ± 2.31	10.6 ± 4.51
Mulato-II			
Spacing			
50 by 25 cm spacing	44	6.2	4.0
50 by 50 cm spacing	39	5.0	2.7
75 by 25 cm spacing	41	5.7	3.3
Harvesting stage			
60 d of growth	33	4.3	2.1
90 d of growth	37	4.7	2.8
120 d of growth	55	7.9	3.1
Year of harvest			
First	41	5.4	3.7
Second	41	5.8	2.9
Mean	42 ± 11.4	5.6 ± 1.70	3.0 ± 1.33
P values			
Variety	.031	.157	<.001
Spacing	.054	.622	.001
Harvesting stage	.008	<.001	.027
Year of harvest	.911	.141	.047
Variety × spacing	.124	.311	.231
Variety × harvesting stage	.115	.095	.109
Variety × year × harvesting stage	.121	.243	.110

soil depth of 10–20 cm, while it remained the same in Mulato-II plots.

3.2 | Growth and yield performances

Mulato-I showed significantly higher upright growth and herbage accumulation than Mulato-II (Table 2). The average biomass accumulation over the three harvest stages shows that Mulato-I had more than three times greater herbage accumulation than Mulato-II (10.6 vs. 3.0 Mg DM ha^{-1}). The effect of spacing was significant on plant height and herbage accumulation. Accordingly, higher upright growth (Mulato-I, 77 cm; Mulato-II, 44 cm) and herbage accumulation (Mulato-I, 11.8 Mg DM ha^{-1}; Mulato-II, 4.0 Mg DM ha^{-1}) were obtained when the root splits were planted 50 cm between rows and 25 cm between plants. As expected, harvesting stage strongly affected plant height, tiller count, and herbage accumulation

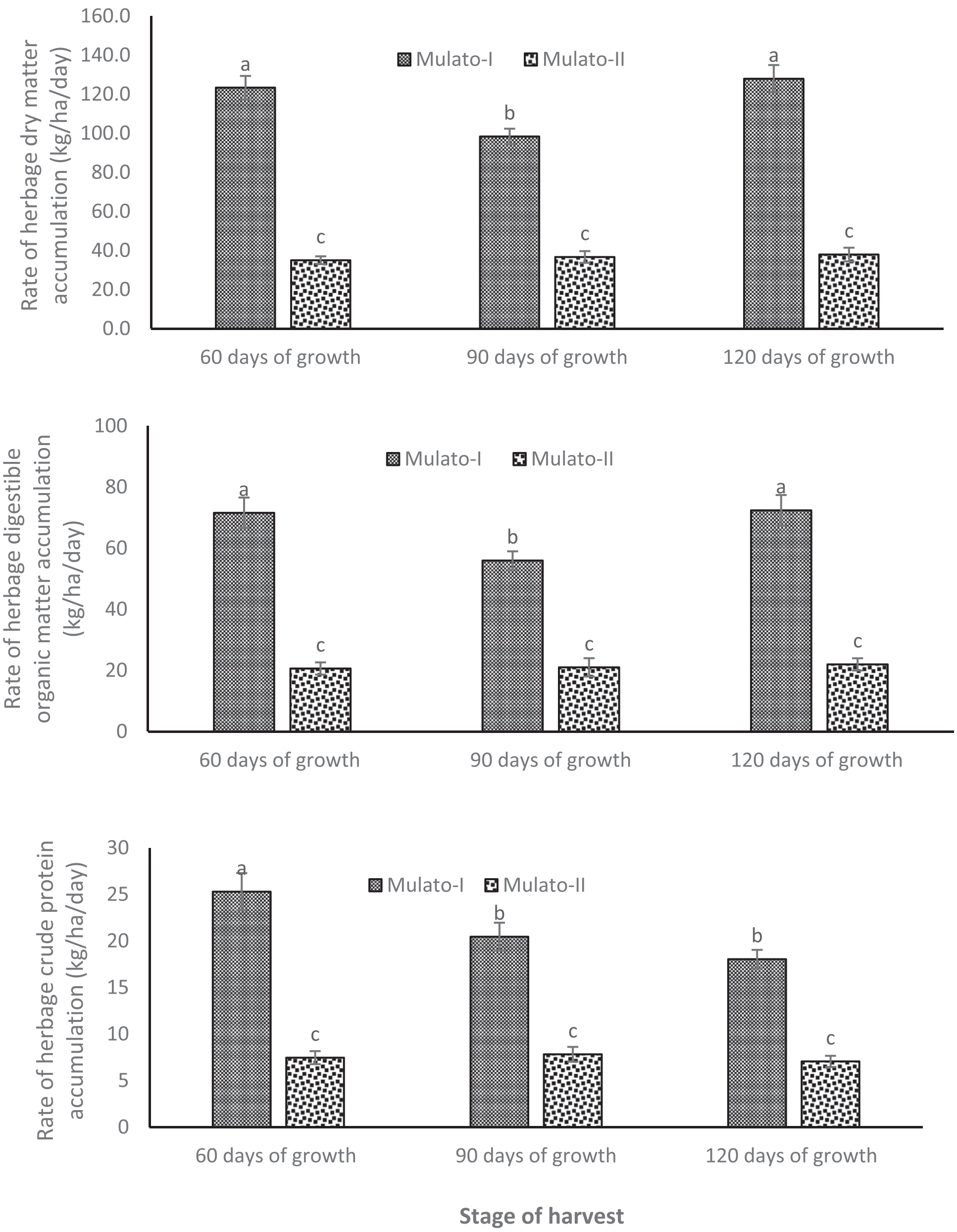

FIGURE 2 Rate of herbage dry matter, digestible organic matter and crude protein accumulation

at harvest. The total herbage accumulation increased linearly as the stage of harvest increased from 60 to 120 d (Table 2).

The average rate of herbage accumulation for Mulato-I varied for the different harvest stages, being 123 kg ha^{-1} day^{-1} for the 60-d harvest, 98 kg ha^{-1} day^{-1} for the 90-d harvest, and 128 kg ha^{-1} day^{-1} for the 120-d harvest (Figure 2). On the other hand, the average rate of herbage accumulation for Mulato-II remained similar across the different harvest stages ranging from 35 to 38 kg ha^{-1} day^{-1}. The average daily digestible organic matter accumulation followed the same trend as the rate of herbage accumulation for both varieties (Figure 2). The daily crude protein accumulation declined with advancing maturity for Mulato-I but remained unchanged for Mulato-II at the different harvesting stages (Figure 2). The effect of year was significant only for herbage accumulation, with the 1st year yielding higher biomass than the 2nd year for both varieties (Mulato-I: 11.8 Mg ha^{-1} vs. 9.5 Mg ha^{-1}; Mulato-II: 3.7 Mg ha^{-1} vs. 2.9 Mg ha^{-1}). Two-way and three-way interaction effects were not significant.

The chemical composition of the two grass varieties harvested at different stages of growth is shown in Table 3. The data for both years were combined, as there was no year effect. The nutritive value of the two varieties differed in all proximate compositions analyzed. Mulato-II had greater CP (200 vs. 180 g kg^{-1} DM), IVOMD (580 vs. 570 g kg^{-1} DM), and ME (7.6 vs. 7.4 MJ kg^{-1} DM), and lesser NDF (640 vs. 660 g kg^{-1} DM) and ADF (350 vs. 380 g kg^{-1} DM)

TABLE 3 The average nutritive value of Mulato-I and Mulato-II grasses managed under different plant spacing and harvest days and observed over 2 yr

Treatment[a]	Composition Ash	CP	NDF	ADF	ADL	IVOMD	ME
	g kg^{-1} DM						MJ kg^{-1} DM
Mulato-I							
Spacing							
50 by 25 cm spacing	139	183	671	403	53	562	7.3
50 by 50 cm spacing	141	191	662	373	48	571	7.4
75 by 25 cm spacing	140	190	660	372	50	570	7.3
Harvesting stage							
60 d	138	211	638	350	43	582	7.5
90 d	140	208	652	352	47	571	7.5
120 d	141	141	703	444	61	550	7.2
Mean ± SD	140 ± 10.3	180 ± 36	66 ± 34	380 ± 47	50 ± 9	57 ± 17	7.4 ± 2.1
Mulato-II							
Spacing							
50 by 25 cm spacing	142	202	648	370	48	57	7.6
50 by 50 cm spacing	158	209	630	341	46	58	7.7
75 by 25 cm spacing	160	201	633	339	44	58	7.8
Harvesting stage							
60 d	140	212	627	327	38	59	7.5
90 d	152	208	641	351	45	58	7.5
120 d	171	190	644	370	52	57	7.6
Mean ± SD	150 ± 15	200 ± 20	640 ± 22	350 ± 3.0	45 ± 8	58 ± 12	7.6 ± 0.16
P value							
Variety	.008	.020	.001	.005	.026	.004	.002
Harvesting stage	.003	<.001	.005	<.001	<.001	.003	.227
Spacing	.064	.098	.082	.093	.095	.526	.753
Variety×Harvesting	.140	.001	<.001	.001	.034	<.001	.404

Note. CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; IVOMD, in vitro organic matter digestibility; ME, metabolizable energy.

[a]For Mulato-I and Mulato-II grasses harvested at different stages of growth (mean ± SEM).

(Table 3). As the stage of harvest increased from 60 to 120 d of growth, there was a decline in the concentration of CP and in vitro digestible organic matter, and an increase in NDF, ADF, and ADL (Table 3). There was variety × harvesting stage interaction for CP, NDF, and IVOMD. The CP concentration of Mulato-I had a sharp decline at the 120 d of harvesting stage compared to 60-d harvest (from 210 to 140 g kg^{-1} DM) while that of Mulato-II had a moderate decline (from 210 to 190 g kg^{-1} DM). While the NDF concentration of Mulato-II remained similar at the different harvest stages (630–640 g kg^{-1} DM), that of Mulato-I increased significantly (640 to 700 g kg^{-1} DM). Spacing had no effect on the chemical composition of the two grass varieties.

4 | DISCUSSION

4.1 | Performance of *Urochloa* varieties

In view of the feed supply challenge that smallholders face in the mixed crop–livestock system, cultivation of *Urochloa* grasses can contribute to mitigating feed shortages (Midega et al., 2018). The grasses can produce higher herbage mass than naturally grown pastures, with the potential to be easily integrated in the cropping systems to serve multiple functions including soil conservation and land rehabilitation (Cheruiyot et al., 2018; Horrocks et al., 2019). The grasses are suitable both for rainfed and irrigated cultivation, allowing farmers to produce excess in the growing seasons that can be conserved and used in times of scarcity (Cezário et al., 2015). In the present study, the performance of the two hybrid cultivars, Mulato-I and Mulato-II, under the highland agro-ecological conditions of Ethiopia, indicates their potential to improve the feed resource base of livestock producers.

The clay-loam soil of the study site with a pH of 5.5–6.0 appears to be non-limiting for the two cultivars, as this pH range is generally considered suitable for the growth of grasses (Brady & Weil, 2008). It is also reported that *Urochloa* grasses can cope in highly weathered soils with a pH as low as 3.0, which makes them potential candidates to integrate into land reclamation efforts (Brandan et al., 2017; Dube et al., 2018).

Looking at the agronomic data, it was apparent that Mulato-I was superior to Mulato-II in upright growth and herbage accumulation during both years. The initial establishment and regrowth were found to be faster for Mulato-I, which seem to have contributed to the high yield performance. As land is in short supply and farmers are keen to optimize biomass yield per unit of area (Bezabih et al., 2016), the high herbage accumulation observed from Mulato-I may attract the attention of smallholders more than Mulato-II. An important feature of *Urochloa* grasses is that they can grow well on less fertile and degraded lands with a gradual positive effect on soil health (Horrocks et al., 2019). This makes them suitable in reclaiming degraded watersheds (Brandan et al., 2017). Therefore, although the herbage biomass accumulation of the two grasses may be lower than local checks such as Desho grass, and recently introduced Napier cultivars (Bezabih et al., 2019), they provide alternative options for farmers to produce forage and maintain their land resources.

Generally, Mulato-II had better nutritive value than Mulato-I with greater CP and IVOMD. This may be partly explained by the high leaf/stem ratio of Mulato-II (Mutimura & Everson, 2012). The low CP and IVOMD concentration in Mulato-I is compensated by its greater herbage accumulation (Figure 2). An important feature observed in both grasses was that the CP concentrations (180–210 g kg^{-1} DM) were exceptionally high. These levels of protein are typical of legume forages that are used for protein supplements (Melaku, 2004). This characteristic is interesting and highly valuable given the fact that cereal crop residues, with crude protein concentration of <50 g kg^{-1}, are the dominant basic feeds in the smallholder system of the Ethiopian highlands and that nitrogen is a limiting nutrient under such settings (Mengesha et al., 2017). It is well known that a minimum of 70 g kg^{-1} crude protein in the diet of ruminants is required to meet maintenance requirements for rumen microbial growth and fiber digestion (Van Soest, 1994). Under smallholder conditions, to obtain acceptable productivity in small ruminants the protein concentration of the diet consumed should be well above 100 g kg^{-1} (Mengesha et al., 2017). In this regard, mixing crop residues with legume forages has been recommended as a feasible method to improve the quality of the basal diet and meet production requirements (Bezabih et al et al., 2016; Manaye et al., 2009). From the current study, it can be observed that the two *Urochloa* grasses can be both a source of good quality feed and N in the diet of ruminants. Looking at the average CP concentration of the two forages and herbage accumulation per hectare, it can be calculated that the N recovery in one harvest season for Mulato-I was 305 kg N ha^{-1} and that for Mulato-II was 96 kg N ha^{-1}. The total amount of N fertilizer applied in one observation season was 110 kg ha^{-1}. From this it is interesting to note that much more N was recovered from the soil system than was applied in the case of Mulato-I, whereas comparable amount of N was recovered to what was applied in the case of Mulato-II. The high N recovery in Mulato-I may suggest a depletion of the soil N stock. To some degree the forage may also benefit from the presence of non-symbiotic N_2 fixation activity in the soil system (Villegas et al., 2020). The results of pre- and post-trial soil N concentrations (Table 1) confirms the idea that there was soil N depletion as the soil N in the 10-to-20-cm soil depth declined from 1.3 g kg^{-1} soil DM pre-trial to 0.8 g kg^{-1} soil DM post-trial for Mulato-I. The soil N test in the case of Mulato-II is in line with the observed N recovery, as there was no depletion over the observation period. The seasonal difference in herbage accumulation may also be partly explained by N depletions, which indicates that proper fertility management is essential to maintain the soil nutrient dynamics for a sustainable forage production. In this respect, benefiting from symbiotic N_2 fixations through grass–legume intercropping strategy is very important. Earlier studies using ^{15}N tracers indicated that more than 30% of the N accumulated by *Urochloa* brizantha grass could be derived from N fixed by the intercropped legume (Viera-Vargas et al., 1995).

However, high susceptibility to pests has been reported by farmers who have started producing the grasses on-farm (personal communication, 2019). This may negatively affect wider adoption of these grasses. Red spider mite (*Tetranychus urticae*) infestationhas been reported as the main pest for these grasses, which may be due to the succulent physical structure of the leaf (Cheruiyot et al., 2018). Red spider mite infestation has mainly been reported during the dry period when the forages are stressed with water deficiency. Irrigating these forages during the dry period using sprinkler irrigation techniques do provide an opportunity to minimize pest infestation and at the same time produce good amounts of forage. In general, as this pest has also a potential to attach other food crops, it is important to make sure that the forages would not serve as reservoirs. Adopting effective pest management practices and further improvement of the varieties for resistance would thus be imperative for wider cultivation of the forages (Uzayisenga et al., 2020).

4.2 | Effect of harvesting stage on herbage accumulation and nutritive value

Harvesting forages at the right time is important to optimize productivity and nutritive value, as there is commonly a trade-off with advancing maturity of grass forages. In the present study, rate of biomass accumulation remained fairly constant for Mulato-II across the different harvesting stages, while Mulato-I tended to show a lower rate of herbage accumulation at the 90-d harvest than the other harvest stages. This generally suggests that the 60-d harvest would provide an optimal production, especially if continuous production is ensured through extended rainfall season or with irrigation. In this study, two consecutive harvests at 60 d of growth were not compared with, for instance, one time harvest at 120 d. It would be important to further evaluate these practices in future experiments.

The nutritive value of the forages at the 60- and 90-d harvest were in the same range. At the 120-d harvest, the two varieties showed different responses. For instance, the CP concentration of Mulato-I declined by approximately 33%, while that of Mulato-II declined by 10%. This appears to show that advancing maturity has more effect on the feed chemical composition of Mulato-I than Mulato-II, suggesting that it would be highly advisable to harvest Mulato-I at an earlier growth stage if nutritive value is the goal. However, although the forage nutritive value of Mulato-I declined at 120 d of harvest, it was compensated well by the greater herbage accumulation obtained at this stage (Figure 2). Overall, after the 60 d of growth, the forages can be harvested and used in a relatively wide time window, especially in rainfed conditions where immediate regrowth is not expected.

4.3 | Effect of plant spacing

Accessibility of forage seeds in the smallholder system is a major challenge for adoption of forages (Maina et al., 2020; Peters et al., 2003). As a result, smallholders mainly depend on root splits to establish and expand their grass forage plots. As root splits are bulky to transport, it is important to have a good knowledge of plant spacing that can minimize costs associated with labor for planting, purchase, and transportation of planting materials. Among the plant-spacing options evaluated, the optimal spacing for Mulato-I appeared to be 50 cm between rows and plants, while for Mulato-II it was 50 cm between rows and 25 cm between plants. A wider planting space for Mulato-I indicates its ability to establish faster with a good tillering capacity to fill open spaces between rows and plants.

5 | CONCLUSION

The hybrid *Urochloa* grasses evaluated in the present study have potential to produce forage with good nutritive value and can be considered as alternative options for smallholders. The two grasses had optimal organic matter digestibility and exceptionally high CP concentration, which makes them good forage supplements in the smallholder system where crop residues constitute basic feed resources. The hybrid Mulato-I may be preferentially recommended given its greater biomass production and acceptable forage nutritive value. Harvesting the grasses after 60 d of growth may be recommended if a regrowth can be supported through extended rainfall or irrigation. Optimal spacing requirements for root splits of these grasses appear to be cultivar dependent.

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AUTHOR CONTRIBUTIONS

Mesfin Worku: Formal analysis; Investigation; Writing-original draft. Habtamu Lemma: Conceptualization; Methodology; Writing-original draft. Kassa Shawle: Data curation; Supervision, Validation. Aberra Adie: Investigation. Alan J. Duncan: Validation; Writing-review & editing. Chris S. Jones: Supervision; Writing-review & editing. Kindu Mekonnen: Supervision; Visualization; Writing-review & editing. An Notenbaert: Funding acquisition; Validation; Writing-original draft. Melkamu Bezabih: Conceptualization; Formal analysis; Writing-original draft; Writing-originaldraft

CONFLICT OF INTEREST

Authors declare no conflict of interest in relation to this publication.

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