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Performance Evaluation of Phalaris Grass Accessions in Northwestern Highlands of Sekela District, Amhara Region, Ethiopia

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ABSTRACT

A field experiment was conducted to assess the adaptability, morphological characteristics, dry matter yield, and chemical composition of four Phalaris grass accessions at Sekela district, Amhara Region of Ethiopia. The treatments were *Phalaris aquatica* grass that was widely used in the area as a control, along with three new accessions (ILRI 6853, ILRI 10552, and ILRI 14353) sourced from Debre Berhan Agricultural Research Center. Root splits were planted for all accessions. The study was carried out using a randomized complete block design (RCBD) with five replications over two consecutive years. All data were collected at a 10% heading at each harvest. Measurements for plant height (PH) and leaf length (LL) were taken from 10 plants in the middle rows, excluding the border rows. Data were analyzed using analysis of variance (ANOVA) following the GLM procedure of SAS software (9.0). Phalaris accessions ILRI 6853 and ILRI 14353 had higher ($P < 0.05$) plant height (PH), number of tillers per plant (NTPP), and dry matter yield (DMY) compared to the control. Additionally, accession ILRI 6853 exhibited lower ($P < 0.05$) neutral detergent fiber (NDF) and acid detergent fiber (ADF) content than the other tested accessions. Based on overall performance, accessions ILRI 6853 and ILRI 14353 were selected for their superior production performance and lower fiber content, making them well-suited to address the critical feed shortages for improved livestock production in the study area. Therefore, Phalaris grass accessions ILRI 6853 and ILRI 14353 are recommended for further demonstration and adoption in the study area and similar agroecologies.

1. INTRODUCTION

The Ethiopian highlands, situated 1500 meters above sea level, receive more than 700 mm of annual rainfall and maintain a mean daily temperature of less than 20°C (Zinash et al., 2001). Ethiopia is home to a vast livestock population, comprising 70.3 million cattle, 42.9 million sheep, 52.5 million goats, 2.15 million horses, 10.8 million donkeys, 0.38 million mules, 8.1 million camels, and 57.0 million poultry (CSA, 2021). The highlands of Ethiopia are characterized by crop-livestock mixed farming systems, where livestock plays an integral role in most agricultural activities across the country.

Livestock not only contributes to the agricultural GDP (45%) and the overall GDP (19%), but also plays a significant role in foreign exchange earnings, accounting for 16-19% (Statista, 2022). Additionally, the livestock sector employs over 30% of the agricultural labor force. It also contributes 15% of export earnings and supports 62.79% of agricultural employment (World Bank, 2023). In addition to its economic contributions, livestock production improves the nutritional status and income of the population by providing meat, milk, eggs, cheese, and butter, as well as by-products such as hides, skins, and live animals for both home consumption and export. Livestock also helps mitigate risks in times of crop failure (CSA, 2021). Despite its importance, the livestock sector struggles to meet the growing demand for animal products due to low productivity per animal (IGAD, 2011). One of the major factors contributing to this low productivity is the persistent feed shortage, both in quality and quantity, which adversely influences livestock production (Ayele et al., 2021).

Improving livestock feeding through the adoption of sown forages can significantly enhance productivity. Among the many perennial forage grasses, Phalaris grass stands out as one of the most promising options for the Ethiopian highlands. Phalaris is well suited to highland areas (Kediret et al., 2007), known for its high yield and ease of propagation and management (ILRI, 2010). Phalaris aquatica, for example, has an average dry matter yield of about 4.75 t/ha (Venkataramanan et al., 2014), and its seed yield ranges from 300-400 kg/ha under optimal conditions (Alemayehu et al., 2017). The grass is typically propagated either vegetatively using root splits or by seed, with the propagation method varying across agroecologies (Getnet and Gezahagn, 2012).

Phalaris is a key grass species for both forage development and soil conservation in Ethiopia. It boosts excellent forage quality and is best used in combination with other forages to optimize its value as livestock feed. Phalaris thrives at altitudes between 1800 and 3000 meters, is frost and drought-tolerant, and can grow effectively with more than 400 mm of annual rainfall. While it requires fertile soils for strong growth, it can still survive on poorer soils, although its soil conservation value is diminished due to weaker growth. Phalaris is particularly suitable for use in contour forage strips for soil conservation and can also be integrated into backyard forage systems and mixed pastures (Alemayehu et al., 2017). It offers a continuous supply of green forage throughout the year, making it ideal for intensive small-scale farming systems (Alemayehu et al., 2017). However, the yield performance of Phalaris grass varies across different environments (agroecology, soil type, soil fertility), and there is limited information on the performance of various accessions. Therefore, the objective of this study was to evaluate selected Phalaris grass accessions for their yield, chemical composition, and desirable agronomic characteristics.

2. MATERIALS AND METHODS

2.1. Description of Study Area

The study was conducted at the Ambisi kebele, Sekela district, located in the West Gojjam Zone of the Amhara region, Ethiopia. It is geographically located at 10^{O} 96' North and 37^{O} 15' East. Ambisi kebele /study site is 2681 meters above sea level. The soil types in this area are primarily clay loam and black soils. Clay loam soils constitute approximately 25% of the area, while black soils make up about 27%. The dominant soil types in these areas are red-brown to red clayey soils, which are relatively fertile and productive compared to other soil types. These soils are less fertile and may be more susceptible to erosion and fertility decline due to extensive deforestation and cultivation practices. Ambisi Kebele's soils are primarily clay loam and black soils, with varying fertility levels. Soil conservation and fertility management practices are essential to sustain agricultural productivity and prevent further degradation of soil resources.

2.2. Land Preparation and Planting

The study was conducted on a farmer's field under a contractual agreement, with a total experimental land size of 30m x 20m rented from the farmer. After selecting the land, it was plowed using oxen four times, and the seedbed was prepared prior to planting. The root splits were planted in June 2021 on the well-prepared experimental plot. The study spanned two main rainy seasons in 2021 and 2022. Weeding and hoeing were carried out at each growth stage three times per year to support the growth of the grasses.

2.3. Experimental Design and Treatments

The treatments in this study consisted of four Phalaris grass accessions: control, ILRI 6853, ILRI 10552, and ILRI 14353. Root splits of each accession were planted on well-prepared land at the start of the 2021/2022 main rainy season. The treatments were randomly assigned to plots within a block. NPS fertilizer was applied at a rate of 100 kg ha^{-1} at planting, followed by urea application at 50 kg ha^{-1} after establishment and at each cutting interval. The experiment was conducted using a randomized complete block design (RCBD) with five replications. The plot size was 3m x 4m (12m^2), with a row spacing of 50 cm, a plant spacing of 30 cm, and a 1m gap between plots and blocks.

2.4. Data Collection

Data were collected at 10% heading at each harvest of the two main rainy seasons. Morphological parameters, including plant height (PH) and leaf length (LL), were measured from ten plants in the middle rows, excluding the border rows. Additionally, the number of tillers per plant (NTPP) was counted from ten plants in the middle rows, excluding the border rows. The leaf-to-stem ratio (LSR) was determined by separating the leaves and stems, drying, and weighing each component, with the ratio calculated by dividing the dry weight of the leaves by the dry weight of the stems. Dry matter yield (DMY) was calculated by multiplying the fresh biomass collected from the sampling area by the dry matter percentage (DM%) for each accession in each harvesting year.

2.5. Chemical Composition Analysis

Chemical analyses of forage samples were conducted by taking representative samples for each plot across two year and componsite samples were used for analsyis. The forage samples were dried in a forced air-draft oven at 60°C for 72 hours to determine dry matter (DM) percentage. After drying, the samples were milled using a laboratory mill and passed through a 1 mm sieve. The analyses for dry matter (DM) content, ash, neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) were performed at the Andassa Livestock Research Center's nutrition laboratory. The procedures for analyzing NDF, ADF, and ADL followed the methods outlined by Van Soest et al (1991).

2.6. Data Analysis

The data were analyzed using analysis of variance (ANOVA) with SAS software (SAS, 2002). Significant differences between treatment means were determined using the least significant difference (LSD) test, and significance was declared when $P < 0.05$. The statistical model for the analysis of data was:

$$Y_{ijk} = \mu + v_i + + E_{ijk}$$

Where: $Y_{ijk=}$ all dependent variables,
μ = Overall mean,
$v_{i\,=}$ effect of accessions (four accessions),
E_{ijk} = residual error

3. RESULTS AND DISCUSSIONS

3.1. Growth Characteristics of Various Phalaris Grass Accessions

Phalaris accessions exhibited significant variation in growth characteristics and biomass yield ($P < 0.05$). Accession ILRI 14353 had the highest plant height, the control, and accession number ILRI 6853 and accession number ILRI 10552 had intermediate values. While ILRI 6853 showed the best leaf length and number of tillers per plant. ILRI 6853 also had the highest dry matter yield (DMY) in both years, supporting its potential for high biomass production. In general, accessions ILRI 6853 and ILRI 14353 outperformed the control in growth and yield. Plant height is a key factor influencing biomass yield in forage crops and serves as a critical indicator of growth achieved during the growing season (Wang et al., 2025). The growth traits, including plant height (PH), leaf length (LL), number of tillers per plant (NTPP), and dry matter yield (DMY), exhibited consistent patterns (P>0.05) across two production years. This consistency offers an opportunity to select accessions with similar growth habits and yields for further evaluation. Among the Phalaris accessions, ILRI 14353 demonstrated significantly greater plant height (P<0.05) compared to accession ILRI 6853 and the control, although no significant difference was observed when compared to accession ILRI 10552.

Table 1. Growth and dry matter yield parameters of Phalaris grass

Treatments	Year 1 (2021)					Year 2 (2022)				
	PH (Cm)	LL (Cm)	NTPP (Count)	LSR	DMY (t ha^{-1})	PH (Cm)	LL (Cm)	NTPP (Count)	LSR	DMY (t ha^{-1})
Control	75.94^{b}	30.74^{c}	52.71^{b}	1.26^{d}	4.39^{b}	78.36^{b}	33.45^{c}	56.08^{b}	1.33^{d}	5.48^{b}
ILRI 6853	72.25^{b}	46.75^{a}	63.51^{a}	1.45^{a}	5.18^{a}	76.22^{b}	48.95^{a}	68.35^{a}	1.78^{a}	6.67^{a}
ILRI 10552	77.22^{ab}	39.52^{b}	56.58^{ab}	1.39^{b}	4.59^{b}	80.16^{ab}	42.56^{b}	59.76^{b}	1.59^{b}	5.79^{b}
ILRI 14353	82.94^{a}	36.23^{b}	62.70^{a}	1.32^{c}	5.06^{a}	84.45^{a}	39.3^{b}	68.74^{a}	1.45^{c}	6.71^{a}
Mean	77.10	38.31	58.88	1.35	4.80	79.80	41.07	63.23	1.54	6.16
SEM	2.459	1.563	2.474	0.007	0.251	2.561	1.63	2.65	0.009	0.267
P–value	0.0204	0.0475	0.0426	<.0001	0.0309	0.0031	0.0451	0.002	<.0001	0.034

PH= plant height, LL= leaf length, NTPP= number of tillers per plant, LSR= leaf to steam ratio, DMY/t/ha= Dry matter yield ton per hectare

In contrast to plant height, Phalaris accession ILRI 6853 exhibited significantly ($P<0.05$) higher leaf length (LL) compared to the other accessions in both production years. The number of tillers per plant (NTPP) is a key agronomic trait as it directly influences the biomass yield of forage grasses (Gezahegn et al., 2024). Among the tested Phalaris accessions, the control accession had significantly ($P<0.05$) fewer tillers per plant than the other three accessions in both years. This may be attributed to genetic deterioration of the control accession and the prolonged effects of its introduction into the environment.

The dry matter yield (DMY) over two harvest years ranged from 4.39 to 5.19 t/ha in the first year and 5.48 to 6.71 t/ha in the second year (Table 1). In our study, two Phalaris grass accessions (14353 and 6853) exhibited similar patterns in terms of their number of tillers per plant (NTPP) and DMY, with accessions that had higher NTPP producing better dry matter yields. This aligns with findings by Bimrew et al. (2017) and Misganaw et al. (2022), who also reported higher dry matter yields associated with greater NTPP in desho grass under similar agro-ecological conditions. Additionally, Laidlaw (2005) highlighted the importance of tiller mass in grasses, noting that it enhances survival chances and increases the available forage, a finding consistent with our results.

However, the relationship between plant height (PH) and dry matter yield was not consistent in our study. While accession ILRI 14353 showed better DMY at a higher PH, accession ILRI 6853 achieved higher DMY despite having a relatively shorter plant height. This contrasts with other grass species, such as desho grass, where higher PH typically correlates with increased DMY (Bimrew et al., 2017; Misganaw et al., 2022). Furthermore, Phalaris grass accession ILRI 6853 exhibited a higher leaf-to-stem ratio (LSR) than the other tested accessions, which is a critical factor affecting digestibility and the overall nutritive value of the grass, as leaves contain more nutrients and less fiber than stems (Gezahegn et al., 2024). Conversely, the control accession had a significantly lower ($P<0.05$) LSR compared to the other accessions in both experimental years, likely due to genetic deterioration and the prolonged effects of its introduction to the environment.

3.2. Combined Growth Properties and Dry Matter Yield of Phalaris Grass

In a similar pattern across both production years, the growth characteristics such as plant height (PH), leaf length (LL), number of tillers per plant (NTPP), and dry matter yield (DMY) exhibited consistent trends when analysed over the combined years. Phalaris grass accession 14353 showed significantly higher ($P<0.05$) PH compared to accession 6853, although no significant difference was observed between accession ILRI 14353, ILRI 10552, and the control. In contrast to PH, accessions ILRI 6853 and ILRI 14353 had higher NTPP than accession ILRI 10552 and the control in the combined year analysis. Consistent with the growth characteristics, both accession ILRI 6853 and ILRI 14353 recorded significantly higher ($P<0.01$) DMY than the other tested accessions. Additionally, the leaf-to-stem ratio (LSR) of accession ILRI 6853 was significantly ($P<0.05$) higher than that of the other Phalaris accessions, indicating better nutritional quality. Conversely, the control treatment showed the lowest LSR, which likely reflects the genetic deterioration of the control Phalaris grass and the long-term effects of its introduction to the environment.

Table 2. Combined analysis of dry matter yield and related parameters of Phalaris grass across years

Treatments	Parameters				
	PH (cm)	LL (cm)	NTPP(count)	LSR	DMY ($t^{-1}yr^{-1}$)
Control	77.15[ab]	32.10[c]	54.39[b]	1.30[d]	4.93[b]
ILRI 6853	74.24[b]	47.85[a]	65.93[a]	1.61[a]	5.92[a]
ILRI 10552	78.69[ab]	41.04[ab]	58.17[b]	1.49[b]	5.19[b]
ILRI 14353	83.70[a]	37.77[bc]	65.72[a]	1.39[c]	5.89[a]
Mean	78.44	39.69	61.05	1.45	5.48
SEM	2.01	1.13	2.32	0.0045	0.235
P-value	0.0301	0.0452	0.0312	<.0001	0.0305

PH= plant height, LL= leaf length, NTPP= number of tillers per plant, LSR= leaf to steam ratio, DMY $t^{-1}yr^{-1}$= *Dry matter yield ton per hectare*

3.3. Chemical Composition of Phalaris Grass Accessions

The chemical composition of the various Phalaris grass accessions is presented in Table 3. The dry matter (DM) percentage of Phalaris grass accession ILRI 6853 was higher than the control, although no significant differences were observed between accession ILRI 14353, ILRI 10552, and the control. However, Ash content did not differ significantly among the accessions.

Regarding fiber fractions, Phalaris grass accession ILRI 14353 exhibited significantly higher (P<0.05) neutral detergent fiber (NDF) content compared to accession ILRI 6853, while no significant variation was found between accession ILRI 10552 and the control. Additionally, Phalaris grass accessions ILRI 14353 and ILRI 10552 had significantly higher (P<0.05) acid detergent fiber (ADF) content than accession 6853 and the control. The NDF content in both Phalaris grass accessions in this study was lower than the values reported by Misganaw et al. (2022) for Napier and desho grasses under various fertilizer treatments in similar agroecologies. On the other hand, the acid detergent lignin (ADL) content in the Phalaris accessions was higher than the values reported by Bimrew et al. (2017), though similar to those reported by Misganaw et al. (2022) for desho grass. The differences between our findings and previous studies may be attributed to genetic variation, soil conditions, and environmental factors that can influence the chemical composition of grasses. Roughage diets with an NDF content ranging from 45-65% are generally considered medium-quality feeds, while those with NDF content below 45% are classified as high-quality feeds (Singh and Oosting,1992). In this study, the NDF content of all Phalaris grass accessions was below 65%, classifying them as medium-quality feeds. The NDF content ranged below the 66.2% average value reported for tropical grasses (Van Soest, 1994). Therefore, the Phalaris grass accessions tested in this study could serve as suitable ruminant feed in the study area and similar agroecologies in other regions.

Table 3. Chemical Composition of Phalaris grass grown under rain-fed conditions

Treatments	Chemical composition parameters (% DM)					
	DM	ASH	OM	NDF	ADF	ADL
Control	89.70[b]	6.92	93.08	60.09[ab]	33.32	11.28[b]
ILRI 6853	90.60[a]	8.41	91.59	58.68[b]	32.26	11.06[b]
ILRI 10552	90.30[ab]	8.15	91.86	60.51[ab]	32.58	15.12[a]
ILRI 14353	90.13[ab]	8.31	91.69	62.04[a]	32.76	16.48[a]
Mean	90.18	7.95	92.05	60.33	32.73	13.49
CV (%)	5.1	12.6	1.1	3.2	6.8	13.6
SEM	0.131	0.272	0.272	0.532	0.507	0.735
P-Value	0.0453	0.1829	0.1829	0.01631	0.9197	0.0023

ADF= acid detergent fiber; ADL= acid detergent lignin; DM= dry matter; NDF= neutral detergent fiber; OM= organic matter

3.4. Correlation of agronomic parameters with dry matter yield and chemical composition

Simple linear bivariate correlation analysis between agronomic traits, dry matter yield (DMY), and chemical composition of Phalaris accessions is summarized in Table 4. Plant height showed a strong positive correlation with fiber components such as neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) ($P > 0.05$), while exhibiting a strong negative correlation with dry matter (DM) content. The taller forage grasses tend to have higher fiber content but lower DM percentages, possibly due to increased structural biomass. The number of tillers per plant showed a positive correlation with DMY ($P > 0.05$), indicating that tillering is a key yield component in perennial grasses. However, tiller number was negatively correlated ($P > 0.05$) with organic matter (OM) content, ADF, and with each other, suggesting a possible trade-off between tiller density and certain compositional qualities. Leaf-to-stem ratio (LSR) was negatively correlated with fiber fractions, but positively correlated with DMY, DM content, and ash content. This indicates that accessions with a higher proportion of leaves may yield more digestible and nutrient-rich forage. Furthermore, DMY showed a positive correlation with NDF, ADL, and DM content, which is partially in agreement with studies such as (Koech et al., 2016) who noted that higher-yielding accessions may accumulate more structural carbohydrates as part of their biomass.

Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) ($P > 0.05$). This finding aligns with studies on other forage grasses, which report that taller plants often accumulate more structural carbohydrates, leading to higher fiber content. For instance, a study on alfalfa found that plant height was positively correlated with internode length and stem diameter, which are associated with increased fiber content. Similarly, plant height significantly influenced forage yield, with taller plants exhibiting higher yields (Jing et al, 2023). The number of tillers per plant showed a positive correlation with DMY ($P > 0.05$), consistent with findings by Opiyo et al. (2011), who observed increased leaf numbers and biomass yield in *Eragrostis superba* under favorable conditions. However, tiller number was negatively correlated with organic matter (OM) content, ADF, and with each other, suggesting a trade-off between tiller density and certain compositional qualities. This aligns with studies indicating that higher tiller numbers can lead to increased biomass but may dilute the concentration of nutrients like OM and fiber components (Koech et al., 2016).

The LSR was negatively correlated with fiber contents but positively correlated with DMY, DM content, and ash content. This suggests that accessions with a higher proportion of leaves may yield more digestible and nutrient-rich forage. This finding is supported by research indicating that a higher leaf-to-stem ratio is associated with better forage quality due to higher concentrations of crude protein and lower fiber content. However, the relationship between LSR and forage quality can vary among species and growth stages, as the leaf's structural components can influence its digestibility (Mganga et al., 2021). DMY showed a positive correlation with NDF, ADL, and DM content, which is partially in agreement with studies noting that higher-yielding accessions may accumulate more structural carbohydrates as part of their biomass. For example, research on forage grasses under irrigation found that age and cutting intervals significantly affect the leaf-to-stem ratio and, consequently, the nutritional composition, with older plants having higher fiber content and lower crude protein (Silva et al., 2012).

Table 4. Correlation of agronomic parameters with dry matter yield and chemical composition

	PH	LL	NTPP	LSR	DMY	DM	ASH	OM	NDF	ADF	ADL
PH	1.00	-0.43	0.175	-0.49	0.159	-0.98	0.16	-0.16	0.99*	0.65*	0.89*
LL		1.00	0.68	0.99**	-0.66	0.99*	0.81	-0.81	-0.53	-0.97*	-0.12
NTPP			1.00	0.6	0.99*	0.18	0.85	-0.86	0.04	-0.74	0.25
LSR				1.00	0.58	0.99	0.77	-0.77	-0.58	-0.96*	-0.16
DMY					1.00	0.19	0.82	-0.83	0.03	-0.71	0.22
DM						1.00	0.52	-0.51	-0.99	-1.00*	-0.99
ASH							1.00	-0.99***	0.05	-0.91	0.45
OM								1.00	-0.05	0.91	-0.45
NDF									1.00	0.36	0.87
ADF										1.00	-0.86
ADL											1.00

PH= plant height at harvest, LL= leaf length, NTPP= number of plant per plant, LSR= leaf to steam ratio, DM= dry matter content, OM= organic matter, NDF= neutral detergent fiber, ADF= acid detergent fiber, ADL= acid detergent lignin

4. CONCLUSION AND RECOMMENDATIONS

In terms of most morphological characteristics and dry matter yield, Phalaris grass accession ILRI 6853 demonstrated the highest performance in both years, followed by accession ILRI 14353. Additionally, accession ILRI 6853 recorded the lowest fiber contents (NDF, ADF, and ADL). Based on the current observations, both of the Phalaris accessions have been supported to be frost-tolerant perennials in the study district. Accessions ILRI 6853 and ILRI 14353 were selected for their superior production performance and lower fiber content, making them well-suited to address critical feed shortages and support enhanced livestock production in the region. Therefore, these two accessions, ILRI (6853 and 14353), are recommended for further demonstration and evaluation in the study area and similar agroecologies.

Limitations of the Study

The limitation of this study is that the percentage crude protein content was not analyzed due to the unavailability of chemicals during our study period in our center and budget shortage to send other nutrition laboratories, as well as security problems in the region to travel a long distance.

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