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RESEARCH PAPER

Herbage availability predictive modelling using rising plate meter for improved grazing management in Ugandan pasture swards

Jimmy Semakula*[1], Nelson Muwereza, Robert Mwesigwa[1], Moses Matovu[1], Denis Asizua[1], Geoffrey Baihayo[2], Geofrey Nviiri[1], Damalie Akwango[1], Abasi Kigozi, Swidiq Mugerwa[1]

[1]*National Agriculture Research Organization (NARO), National Livestock Resources Research Institute (NaLIRRI), Kampala, Uganda*

[2]*Faculty of Agriculture and Environment, Gulu University, Laroo Division, Gulu City, Uganda*

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Abstract

This study investigated the botanical composition, nutritional quality, and herbage mass availability in mixed native grazing pastures across Mbarara and Nakasongola districts of Uganda during the 2023 seasons. Further, herbage mass prediction equations/models based on the rising plate meter for mixed pasture swards in Uganda were developed. The results revealed that the wet season (Season A) tended to favour a greater diversity of grasses and legumes, enhancing crude protein (CP) content, while the dry season (Season B) resulted in grass-dominated swards, particularly with the invasive *Sporobolus pyramidalis*, and a significant decline in legume prevalence. Nutritional profiles indicated high dry matter (DM) content across seasons; however, CP levels dropped markedly in Nakasongola, with increases in neutral detergent fiber (NDF) during the dry season. Herbage mass availability showed significant seasonal effects, with Season A yielding higher DM across both districts. The rising plate meter method effectively predicted herbage availability, with Model 1 outperforming Model 2 in reliability. However, both models exhibited underestimation bias, needing ongoing calibration and validation. These findings highlight the need for strategic supplementation during the dry season and highlight the importance of local environmental conditions in pasture quality. The developed herbage availability prediction equations could be used to compute available feed for grazing cattle using rising plate meters which could support improved herbage management strategies that enhance livestock productivity and sustainability in Uganda's agricultural sector.

* **Corresponding Author:** Semakula ✉ jynsemakula@yahoo.com

Introduction

Tropical forages are largely characterised as being deficient in nutrients, especially in the dry season (Arthington and Brown, 2005). In Uganda, grazing pastures are characterized by high fibre and lignin content, are low in crude protein (CP) and metabolizable energy (ME) percentages, which do not meet the full nutritional needs of livestock (Dierenfeld *et al.*, 2014; Tibezinda *et al.*, 2016). This inadequacy is exacerbated by the deficiency of supplementary feed resources during the dry season. Several studies (Asizua *et al.*, 2017; Mashiloane and Ntwaeagae, 2009; Mohammed *et al.*, 2020) have shown that ruminant livestock performance can be improved by providing high-quality herbage with the right proportions of grass and legumes. However, pasture quality is influenced by changes in quantity (dry matter availability) and seasonality, both of which can affect intake and animal performance (Ayele *et al.*, 2022; Desta *et al.*, 2023; Nampanzira *et al.*, 2015).

The growing need to increase livestock production has led to changes in farming systems (Otte and Chilonda, 2002). With land scarcity and the decline of traditional practices like transhumance, there has been a shift toward confined grazing systems such as paddocking (Kosmas *et al.*, 2015; Mohammed *et al.*, 2020; Rosales and Livinets, 2005). In these systems, it is crucial to determine the appropriate time to move animals from paddocks with low herbage mass to those with higher dry matter availability to meet their nutritional requirements (Mohammed *et al.*, 2020; Rouquette Jr *et al.*, 2023). Strategic supplementation of animals, especially those with higher physiological demands, and decisions on livestock disposal due to feeding constraints are also necessary (Birhan and Adugna, 2014; Rosales and Livinets, 2005). The need for strategic cattle nutrition has created a demand for a simple and objective method to estimate the herbage mass availability in terms of dry matter (DM) of these pastures. Subjective visual assessment of herbage DM mass or sward height is less accurate than objective measures (Frame *et al.*, 1981) and can lead to either an over or underestimation of the correct value (Hodgson *et al.*, 1999).

Uganda's grazing systems are typically based on natural pastures with mixed species; therefore, the quality and quantity of herbage can vary over time and across different areas (Nampanzira *et al.*, 2015). Herbage availability and quality serve as critical determinants in sustaining livestock productivity, acting as a primary source of nutrition (Ayele *et al.*, 2022). The complex interplay of various factors, including temporal-spatial dynamics and botanical composition, significantly influences the quality and quantity of forage (Birhan and Adugna, 2014; Koidou *et al.*, 2019). This often calls for supplementary feeding and to make the right feeding decisions, farmers need to know how much dry matter is available in the pasture. The extent to which these temporal-spatial variations in pasture quality, quantity and botanical composition exist warrants research.

The standard method for determining DM is quadrat cutting, involving cutting, and washing, drying, and weighing samples (Hodgson *et al.*, 1999; Sanderson *et al.*, 2001). The method involves cutting pasture, washing, and oven drying, and weighing the samples. This method is destructive, labour-intensive, time-consuming, and expensive from a farmer's perspective and thus, not used on a farm (Webby and Pengelly, 1986). Consequently, there are clear benefits from alternative non-destructive, objective measures of pasture. To address this, alternative, non-destructive, real-time methods based on pasture sward height including the rising plate meter and sward sticks have been developed (Hodgson *et al.*, 1999; Somasiri *et al.*, 2014). The rising plate meter gives a measurement (kg DM/ha) based on the pasture sward height, density, and the species present in the sward (Fulkerson *et al.*, 1998; Hodgson *et al.*, 1999). The sward stick estimates the height (cm) of the pasture sward (Frame *et al.*, 1981; Stewart *et al.*, 2001). The calibration equations for both the plate meter and sward stick in perennial grass-legume mixes such as ryegrass/white clover pastures in template countries are well documented (Hodgson *et al.*, 1999). These methods use linear regression models to estimate herbage DM from sward height, originally calibrated for perennial ryegrass/white clover swards. However, it remains unclear how well these models apply to other grass, and grass-legume mixtures, different seasons, or varied locations in Uganda. Whereas both methods are simple to use, the plate meter provided compressed height which gives a more reliable sward height reading compared to the sward stick and is thus, expected to give more accurate herbage availability (DM Kg/ha) estimates (Murphy *et al.*, 2021; O'Donovan *et al.*, 2002). In this study, we aimed to study the dynamics shaping herbage availability in Uganda, with a specific focus on Mbarara and Nakasongola districts. Further, we investigated the dynamic shifts in botanical composition, acknowledging its pivotal role in understanding forage variations. Additionally, we studied the relationship between quadrant cut estimated dry matter and on estimated using the rising plate meter technique. Specifically, this research had three objectives in respect to the natural pasture sward mixes; 1. Determine the effect of season and location on herbage quality and availability in the natural grazing pasture, 2. Determine the relationship between herbage DM mass measured by quadrat cut method and plate meter readings and 3. Determine if the above relationship is consistent across two seasons (A: wet and B: dry).

Materials and methods

Study location

The research was conducted on natural grazing pastures across selected farms in two districts of Uganda, Mbarara and Nakasongola, from January to June 2023, encompassing two distinct seasons: the wet season (A) and the dry season (B). In Mbarara, the study focused on three farms Mbarara ZARDI Farm (0° 36′ 09′′ S; 30° 36′ 35′′E), Mungonya's Farm (0° 34′ 02′′ S; 30° 36′ 53′′E), and Rukidi's Farm (0° 35′ 23′′ S; 30° 35′ 51′′E), each located within 10 km of one another. Mbarara district is situated approximately 270 km southwest of Kampala, at an elevation of 1,454.57 meters (4,772.21 feet) above sea level. The district experiences an average annual temperature of 22.01°C (71.62°F) and receives about 357.72 millimeters (14.08 inches) of precipitation per year. In contrast, the Nakasongola district included Kitangala Farm (1° 6' 33.34" N; 32° 32' 52.62" E), Lubbobbo Farm (1° 02′ 48′′ N; 32° 32′ 56′′E), and Green Farm (1° 05′ 02′′ N; 32° 25′ 06′′E), all located within 10 km of each other. Nakasongola lies 118 km north of Kampala, at an elevation of 1,105.25 meters (3,626.15 feet) above sea level. This district has a higher average annual temperature of 24.71°C (76.48°F) but receives significantly less precipitation, approximately 160.7 millimeters (6.33 inches) annually.

Study design

The study was conducted in two phases including one on assessing on-farm herbage nutritional profile and availability and a second phase of establishing the relationship between herbage availability dry matter mass and the different methods of measurement. In the second phase, herbage availability prediction equations were developed and validated.

Phase 1: Herbage botanical composition, nutritional profile, and availability measurement

To evaluate herbage botanical composition, nutritional profile, and availability, a thorough sampling and analysis approach was adopted across farms in Mbarara and Nakasongola districts in Uganda, in two seasons, in 2023. Each farm utilized three paddocks as replicates, with livestock rotated among them based on farm management decisions.

Botanical composition was assessed by collecting composite herbage samples from strips around each quadrat cut. Four composite samples per farm were sorted into predominant species (grasses, legumes, and dead matter), oven-dried, and weighed to determine botanical composition. The remaining sample was frozen, ground, and sieved (1 mm) for nutritional quality analysis. Key measures included dry matter digestibility (DMD) and digestible organic matter digestibility (DOMD) using in vitro methods

(Roughan *et al.*, 1977), percentage crude protein (CP) via the Dumas combustion method (AOAC method 968.06), and percentage acid detergent fibre (ADF) using a Tecator Fibretec System (Robertson, 1981). Metabolizable energy (ME) content was calculated from organic matter digestibility using the equation DOMD × 0.16 MJ/kg DM (Roughan *et al.*, 1977).

Pre- and post-grazing herbage dry matter (DM) masses were measured using quadrat cuts (0.15 m^2 per cut) from four random quadrats in each paddock during every grazing rotation. The cuts were taken in a way ensuring that at least three separate cutting incidences per season were done leading to a total of 432 cuts. Herbage samples were collected using an electric shearing hand-piece and then washed and oven-dried at 70°C for a minimum of 48 hours to determine the DM content. In addition to the quadrat cuts, herbage height and mass were also estimated using a rising plate meter reading (JENQUIP, Fielding, New Zealand). Four readings were taken with a plate meter before each quadrat cut, and the initial and final readings were used to calculate the average sward height, across the three paddocks on each farm.

Phase 2: Establishing the relationship between herbage availability, dry matter mass, and different measurement methods

An assessment was conducted to evaluate the relationship between herbage dry matter (DM) mass determined using the quadrat cut (the benchmark for estimating herbage biomass) method and the plate meter. By measuring the compressed pasture sward heights with the plate meter, regression models were developed to predict herbage biomass based on these heights. The predictor equations were constructed by regressing sward heights measured using the rising plate meter against the DM mass estimates derived from quadrat cuts.

Statistical analysis

The relationships between herbage DM mass and plate meter readings were analyzed within seasons and across seasons for each herbage mix individually, and when mixed herbage swards were combined via a Linear Mixed Effect Model in R program version 3.4.4 (R Core Team, 2016). The model was fitted with season and location and their interaction as fixed effects while farm was considered as random effect. Seasonal effect had a significant effect ($P<0.01$) but not location or their interaction in the model and thus, individual (season-based) herbage mass availability prediction equations were developed for the different seasons (A: Wet; B: dry seasons). Season A comprised the wet months, spanning from March to May and October to December, while Season B included the drier months, covering June to August and December to February.

Model evaluation (building and validation)

To ensure robust validation of the models, 70% of the data was used in the model-building phase, while the remaining 30% of unseen data was used for validation as described in Semakula *et al.* (2021). The predictive models fitting pasture sward height as a predictor for herbage biomass were developed by season using 70% of the data (training data) selected using the caret package. The performance of these models was evaluated using various accuracy metrics as described by (Semakula *et al.*, 2020b). Model performance evaluation was conducted on the training dataset using two metrics (Botchkarev, 2019; Theil, 1958) adjusted coefficient of determination (adj. R2) and the root mean square error (RMSE).

Using the unseen testing datasets (30% of the data), each herbage mass prediction model validation was conducted, with each replicated 1000-fold through bootstrapping technique. Each season-based prediction model was evaluated on unseen test data from their corresponding season, another season and combined data from both seasons to assess their reliability, generalizability and robustness. The quality and predictive capacity of the prediction models was assessed using the coefficient of determination (r2), mean bias, root mean squared error (RMSE), residual prediction deviation (RPD), the ratio of performance to interquartile distance (RPIQ), and percent error (RPE) (McDowell *et al.*, 2012).

Results

Botanical composition, nutritional quality, and herbage mass dry matter (DM)

The botanical composition of grazing pastures across different seasons indicated the diversity and distribution of plant species contributing to forage quality in Mbarara and Nakasongola districts during 2023 (Fig. 1 and 2). In Mbarara, the botanical composition varied between seasons ($p<0.05$). During the wet season (Season A), there was a higher proportion of grasses and legumes, contributing to better nutritional quality, particularly with regard to crude protein (CP) content. Nakasongola showed a similar pattern to Mbarara, with a more balanced mix of grasses and legumes during the wet season, supporting better CP content and overall forage quality. However, in both locations, the dry season showed a significant shift towards grass-dominated swards especially the non-palatable invasive *Sporobolus pyramidalis*, with a corresponding reduction in legumes.

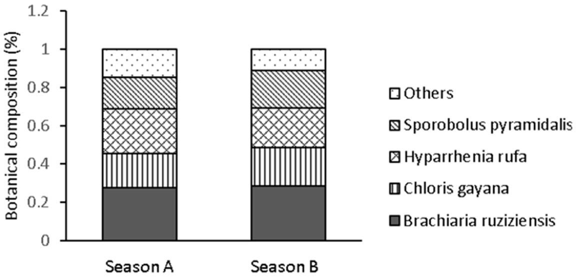

Fig. 1. The botanical composition of grazing pastures by season for Mbarara district in 2023

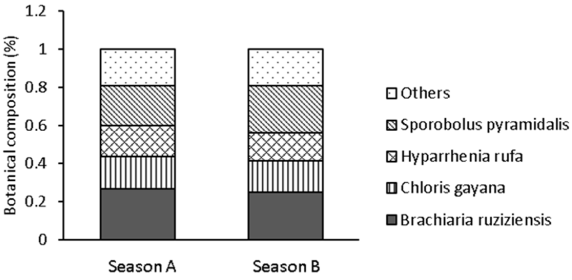

Fig. 2. The botanical composition of grazing pastures by season for Nakasongola district in 2023

Nutritional profile

The nutritional profile of the pasture in the study areas did not vary by season or location ($p>0.05$), except for NDF in Mbarara, and CP in Nakasaonola ($p < 0.05$) (Table 1). The DM content in both Mbarara and Nakasongola was consistently high across both seasons, indicating minimal variability between the wet (Season A) and dry (Season B) periods. There was a decline in crude protein content during the dry season (Season B) in both districts, more evident in Nakasongola, where the CP content decreased significantly in Season B ($p=0.018$). In Mbarara, on the other hand was a non-significant CP reduction ($p=0.176$). Both districts ' ME values were relatively stable across seasons ($p>0.05$). In both districts, there was an increase in NDF during the dry season. The increase in NDF was approximately 3% which was statistically significant for Mbarara ($p=0.015$), and 5.8% for Nakasongola, although this increase was not statistically significant ($p>0.05$).

Table 1. Dry matter (DM), crude protein (CP), Neutral detergent fibre (NDF), dry matter digestibility (DMD) and metabolisable energy content (ME) of herbages of grazing pastures during the wet and dry seasons by district in 2023 (least-squares mean with SEM in parentheses)

District	Nutrient	Season A (n=18)	Season B (n=18)	SE	p-value
Mbarara	DM	92.4(1.2)	93.9(1.55)	0.46	0.930
	CP	10.2(0.78)	9.8(1.39)	0.48	0.176
	ME	10.2(0.49)	10.5(0.54)		
	NDF	61.0(4.69)	63.9(8.31)	2.87	0.015
Nakasongola		(n=18)	(n=18)		
	DM	92.9(0.63)	94.3(0.91)		
	CP	9.5(0.69)	8.0(1.01)	0.7	0.018*
	ME	10.3(0.39)	10.0(0.2)	0.92	0.106ns
	NDF	56.7(3.74)	62.5(6.28)	4.43	0.219ns

Season A (Months March to May; October to December); Season B (Months June to August; December to February)

Herbage availability

There were significant seasonal effects on herbage mass availability (p < 0.05), but neither location nor the interaction between season, and location had a statistically significant effect (p>0.05). Season A consistently showed significantly greater herbage DM availability compared to Season B, across both Mbarara and Nakasongola districts (Fig. 3).

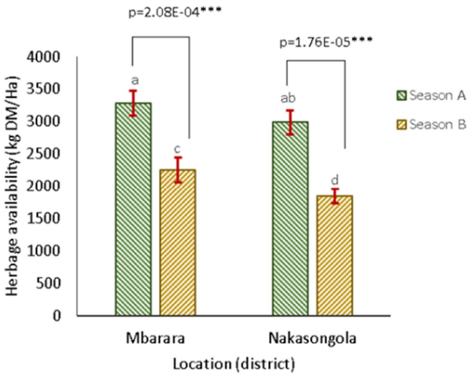

Fig. 3. Mean herbage dry matter availability (Kg DM/ha) across seasons in Mbarara and Nakasongola districts

Estimation of herbage dry matter availability based on the rising plate meter

Model building

In both districts, the herbage DM availability was greater (P<0.05) in Season A compared to Season B. The Plate Meter provided estimates that closely aligned with the quadrat cuts, particularly in Season A when pasture growth was abundant. Due to significant (P<0.05) season effects on the slope of the prediction equations, two separate herbage availability prediction equations were developed (Table 2; Fig. 4). The plate meter was less accurate in Season B, likely due to its limitations in accounting for thinner and sparser pastures.

Table 2. Model parameters and goodness of fit indicators

Parameter	Model 1	Model 2
Intercept	542	568.5
Slope	136.4	196.7
R^2	0.809	0.741
RMSE	399.2	578.06
MAE	277.3	443.63

Models (1: Herbage availability prediction model based on wet season (A); 2: model based on dry season (B) data)

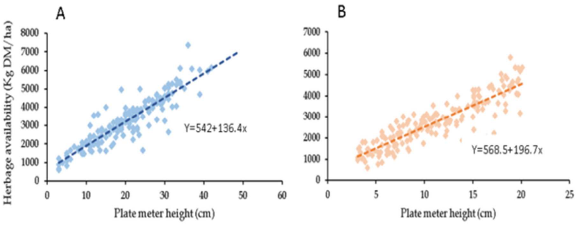

Fig. 4. Herbage availability by method of measurement. A and B, respectively, are for seasons A and B

Model validation

The analysis of the model performance metrics obtained from unseen test datasets for seasons A and B reveals several critical insights into the effectiveness of the developed herbage mass prediction equations based on the rising plate meter method. The two models, Model 1 and Model 2, were constructed using 70% of the datasets from seasons A and B, respectively, and were subsequently evaluated on the remaining 30% of unseen data. Model 1 consistently outperformed Model 2 across the datasets for both seasons, as indicated by higher R2 values (Table 3). Specifically, Model 1 achieved R2 values of 0.652 for season A and 0.604 for season B, compared to Model 2's R2 of 0.528 for season A and 0.688 for season B. In combined datasets, Model 1 produced an R2 of 0.597, while Model 2 produced a lower R2 of 0.575, indicating that Model 1 provided a more reliable fit for predicting herbage mass.

The bias observed in the models highlights a tendency for both to underestimate herbage mass. Model 1 showed a bias of -12.9 for season A and -196.51 for season B, while Model 2 exhibited a more significant underestimation with bias values of -151.7 and -17.7 for seasons A and B, respectively. The Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) values reveal the degree of deviation in predictions. Model 1 had RMSE values of 534.8 and 679.89 for seasons A and B, respectively, while Model 2 recorded significantly higher RMSE values of 1143.1 and 655. The Relative Prediction Error (RPE), Relative Percent Difference (RPD), and Relative Prediction Index (RPIQ) further elucidate the models' performance.

Table 3. Performance metrics (Coefficient of determination r², Bias, RMSE, RPE, RPD, and RPIQ) for predicting herbage dry matter (DM kg/ha) availability using plate meter compressed height readings across seasons

Model	Season test dataset	r^2	BIAS	RMSE	MAE	RPE	RPD	RPIQ
1	A	0.652	-12.9	534.8	349.1	0.106	3.43	3.05
1	B	0.604	-196.51	679.89	539.74	0.239	1.36	2.39
1	Combined	0.597	45.42	781.73	591.62	0.21	1.17	2.11
2	A	0.528	-151.7	1143.1	779.34	0.51	1.61	1.43
2	B	0.688	-17.7	655	349.24	0.12	1.41	2.48
2	Combined	0.575	-98	1226.87	883.53	0.32	0.74	1.35

Models (1: Herbage availability prediction model based on season A; 2: a model based on season B data). Test datasets (Data from season A: wet season; Season B: dry season; Combined: data from both seasons A and B).

Model 1 achieved RPD values of 3.43 (A) and 1.36 (B), indicating good predictive performance in season A but moderate performance in season B. In contrast, Model 2's RPD values of 1.61 (A) and 1.41 (B) suggest a poorer predictive capability, particularly for season A. Notably, RPIQ values indicated Model 1's superior robustness, with scores of 3.05 (A) and 2.39 (B) compared to Model 2's RPIQ values of 1.43 (A) and 2.48 (B).

Discussion

Botanical composition, nutritional quality, and herbage mass dry matter (DM)

The study showed no significant ($P>0.05$) temporal and spatial variability in pasture composition and nutritional profiles except for NDF ($P<0.05$) across the seasons and regions of Mbarara and Nakasongola. During the dry season, the increased prevalence of grasses was likely responsible for the elevated Neutral Detergent Fiber (NDF) content observed in the nutritional analysis. The higher NDF levels indicate a shift towards more fibrous pasture, which is often associated with a reduction in overall digestibility and nutritional value (Bell *et al.*, 2021; Finch *et al.*, 2014). Simultaneously, the decline in legume populations during the dry season appears to have significantly impacted the Crude Protein (CP) levels in the pastures. These results contrast those by Dierenfeld *et al.* (2014) who in their preliminary studies also reported no significant seasonal difference in all nutritional parameters in natural grazing pastures of Kayunga district in Uganda. In Mbarara, where CP levels remained more stable, it suggests a greater resilience of pasture quality, likely due to more favorable conditions for legume persistence. In contrast, Nakasongola experienced a sharper decline in CP levels during the dry season, potentially indicating a greater reliance on legumes for protein content, which could adversely affect animal performance if supplementation is not provided (Lamidi *et al.*, 2014; Moog, 1991; Mwangi *et al.*, 2021).

The differences in legume abundance and CP levels between the two regions underscore the importance of local environmental conditions in determining pasture quality. Notably, the dry season's reduced moisture content affects various soluble nutritional parameters, resulting in less succulent and more fibrous forage (Ihediwa *et al.*, 2022; Oladejo *et al.*, 2023). This agrees with findings that highlight the seasonal dynamics of forage quality, where drier conditions typically lead to a decline in nutritional value (Dumont *et al.*, 2014; Safari *et al.*, 2011). Despite these variations, pasture dry matter (DM) content remained relatively stable across seasons, suggesting that herbage in both regions is well-suited for grazing even under changing environmental conditions. The stability of Metabolizable Energy (ME) across seasons further indicates that the energy supply from pastures is consistent, allowing livestock to maintain energy intake throughout the year. These findings contrast those reported by Tibezinda *et al.* (2016) in western Uganda. The increased NDF content during the dry season may necessitate dietary adjustments to ensure livestock meet their nutritional requirements, emphasizing the need for strategic supplementation (Duguma and Janssens, 2021; Lamidi *et al.*, 2014; Makkar, 2002).

Prediction of herbage availability using a rising plate meter

The study's findings illustrate the efficacy of the rising plate meter technique in predicting herbage availability in mixed native grazing pastures in Uganda. The superior performance of Model 1, as indicated by its higher R2 values compared to Model 2, suggests that the tools, model architecture, and training processes utilized were more effective at capturing the variability in herbage mass data. This discovery aligns with prior research emphasizing the reliability of the rising plate meter as a tool for estimating pasture biomass (Chapa *et al.*, 2023; Gargiulo *et al.*, 2020; Somasiri *et al.*, 2014). The higher R2 values demonstrate Model 1's capacity to account for a larger proportion of variance in the unseen test data, highlighting its practical relevance for pasture management in Uganda.

Nonetheless, the underestimation bias observed in both models is consistent and has important implications for future research or model improvements. The pronounced bias in Model 2, especially for season A, highlights the importance of ongoing calibration and validation across a broader array of datasets. These attempts are expected to enhance prediction precision and reproducibility across diverse environments (Moore and Doherty, 2005; Viney *et al.*, 2009). Finally, the discrepancies between Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) prove the need for enhanced predictive capacity. The conduct of additional studies may improve model application results by including a wide range of grazing scenarios and seasonal differences that can contribute to enhancing the skills.

The significance of evaluating comparative performance measures like Relative Prediction Error (RPE), Relative Percent Difference (RPD), and Relative Prediction Index (RPIQ) cannot be overstated. The strong RPIQ values of Model 1 indicate its dependability in various conditions, which is critical for farmers and land managers who depend on precise herbage mass forecasts for effective grazing management The strong RPIQ values of Model 1 indicate its dependability in various conditions, which is critical for farmers and land managers who depend on precise herbage mass forecasts for effective grazing management (Beukes *et al.*, 2019; Hodgson *et al.*, 1999; Sollenberger *et al.*, 2020). In summary, although the rising plate meter method shows potential in predicting herbage mass, further improvements in model development are necessary to minimize prediction bias and improve accuracy. Ongoing exploration of alternative modeling techniques is imperative. These coupled with the incorporation of a broader range of environmental factors, will assist in establishing calibration protocols that address the unique grazing dynamics in Ugandan pastures.

Conclusion

This study highlights the significant impact of seasonal and regional variations on pasture composition, nutritional profiles, and herbage availability in Uganda's mixed native grazing pastures, with increased NDF and reduced CP levels during the dry season, particularly in Nakasongola. The rising plate meter method effectively predicts herbage availability, with Model 1 outperforming Model 2; however, both models exhibited underestimation bias, necessitating continuing calibration and validation. To enhance pasture management and prediction accuracy, it is recommended to incorporate a broader range of environmental variables in model development, implement supplementation strategies to counter low CP levels during the dry season, and provide farmers with training on effective pasture assessment tools. Further research should also explore alternative modeling techniques and the interaction of grazing systems with pasture quality, contributing to improved livestock productivity and sustainability in Uganda's agricultural sector.

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