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Quantitative Assessment of Forage Nutritive Value Using a Large Dataset: Implications for Cattle Production in Tennessee

Abstract

Cattle production in the Southeastern United States relies heavily on forages, and hay plays a pivotal role in forage supplementation during times of limited pasture availability. This study analyzed 7,198 forage samples collected across Tennessee, from 2015 to 2023, to evaluate the variability in forage nutritive value across species and its implications for cattle nutrition. Significant variation in forage nutritive values was observed across categories ($P < 0.0001$). Crude protein ranged from 9.8% in native warm-season grasses (NWSG) to 13.4% in orchardgrass. NWSG had the highest fiber content (ADF and NDF), while orchardgrass and annual ryegrass had the highest digestibility (IVTDMD48). Total digestible nutrients (TDN) averaged 58.7%, with the lowest values in NWSG and the highest in bermudagrass and orchardgrass. Relative forage quality (RFQ) ranged from 85 in NWSG to 102 in orchardgrass. The findings reveal significant variability in forage nutritive value across different categories in Tennessee, emphasizing the need for improved forage testing to support more informed decision-making in cattle production. While high-quality forages are often tested, lower-quality forages are underrepresented, leading to potential gaps in understanding.

Abbreviations: CP - Crude Protein, ADF - Acid Detergent Fiber, NDF - Neutral Detergent Fiber, IVTDMD48 - *in-vitro* True Dry Matter Digestibility (48-hour), TDN - Total Digestible Nutrients, RFQ - Relative Forage Quality, NRC - National Research Council, NWSG - Native Warm-Season Grasses, NIRS - Near-Infrared Spectroscopy

Keywords: forage nutritive value, cattle nutritional requirements, forage testing

Introduction

Beef cattle production in the Southeastern US is primarily based on forages, with tall fescue (*Schedonorus arundinaceus* S.) and mixed grass pastures serving as the main feed sources. Tall fescue, though resilient and adaptable, often exhibits inconsistent quality, particularly during periods of dormancy. Tall fescue is a hardy cool-season perennial grass that grows from late February or early March to May, with additional growth occurring late-September to November (Wolf et al. 1979). During dormancy periods, producers typically provide cattle with hay as supplement feed (Short 2001; Boyer et al. 2020). In the region, mixed grass pastures, which vary in species composition but often include tall fescue, orchardgrass (*Dactylis glomerata* L.), bermudagrass (*Cynodon dactylon* L.), crabgrass (*Digitaria sanguinalis* L.), and others, present additional challenges due to their variability in forage nutritive value.

Forage nutritive value is defined as a description of the degree to which forage meets the nutritional requirements of a specific animal (Allen et al., 2011). Forage nutritive value is influenced by a range of factors, including temperature, stage of maturity, ratio of leaves to stems, grass-legume combinations, fertilization, cultivar choice, and harvest methods. Among these, maturity is the most impacted by external conditions, such as plant species and environmental temperature, and it plays a pivotal role in shaping the variables that determine forage nutritive value (Tesk et al., 2018). Thus, harvested hay must meet cattle nutritional needs, which fluctuate based on the stage of production or class of animal, such as when a cow is lactating, or stocker cattle are growing at a desired rate of gain. Forage nutritive value is a key factor in cattle productivity, influencing growth, reproduction, and overall profitability (Henry et al., 2016; Boyer et al., 2020). Although producers are always targeting to reduce the cost of hay production, if nutritive value is also reduced, it will result in lower profits due to limited weight gain or calving rates. Therefore, producers feeding hay must manage their supplemental hay to optimize animal performance while minimizing costs. From this perspective, knowing the hay quality is crucial.

In Tennessee, hay is fed for an average of 143 days per year (Boyer et al., 2020), making it an essential feed source during times of limited pasture growth. However, the quality of harvested forage often does not meet the nutritional requirements of cattle, particularly during critical periods such as lactation and rapid growth. According to the NRC (2016), a 1,300-pound beef cow producing moderate milk requires crude protein levels of 6.8% to 10.9% and total digestible nutrients (TDN) levels of 49% to 60.1%. Meeting these requirements is critical for maintaining cattle health and productivity, yet many forages in Tennessee fall short.

This study evaluated the forage nutritive value from eight common forage categories in Tennessee, aiming to help producers understand the variation between and within these categories, and to highlight the importance of this information for cattle production.

Methods

The University of Tennessee Extension's Soil, Plant, and Pest Center (Nashville, TN) is the reference laboratory to the University of Tennessee Extension System, which has an office in each of the 95 counties in the state. From 2015 to 2023, a total of 7,198 forage samples were submitted by producers and analyzed to determine forage nutritive value. The number of samples analyzed varied across categories, ranging from 65 to 3,803 (Table 1). Self-reported forage category identification by producers was normalized to align with laboratory categories. The species were self-identified by the producer when submitting a sample and may contain legumes and other species, however, this factor is a known issue in self-identification in sample submissions. Legume, corn silage, and under-represented samples were not included in this data set, allowing more of a focus on the predominant grass species grown in Tennessee. Although these forage samples were classified as hay, haylage, baleage, and silage, these classifications were excluded as factors. These data do not indicate when the forage was harvested but only when the sample was analyzed, which could be near harvest or at feeding; therefore, only forage categories were compared for nutritive value. The classified samples included: annual ryegrass (*Lolium multiflorum* L.); bermudagrass; mixed grass forage (*exact species unknown*); native warm-season grasses (NWSG) [i.e., switchgrass (*Panicum virgatum* L.), big bluestem (*Andropogon gerardii* V.), indiangrass (*Sorghastrum nutans* L.), Eastern gammagrass (*Tripsacum dactyloides* L.) and little bluestem (*Schizachyrium scoparium* M.); orchardgrass; tall fescue; small grains [i.e., cereal rye (*Secale cereale* L.), triticale (*Triticosecale rimpaui* C.), and oats (*Avena sativa* L.)]; and, warm-season annuals [i.e., crabgrass, sorghum (*Sorghum bicolor* L.), teff (*Eragrostis tef* Z.), sudex (*Sorghum bicolor var. bicolor* × *bicolor var. sudanense*), pearl millet (*Pennisetum glaucum* L.), and sudangrass (*Sorghum bicolor* L.)]. There may be hybrids and other species within the categorized forages, however, that was not known at the time of analysis. It should be noted that the forage samples used in this analysis may not fully represent all forage production systems.

The samples were tested for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), *in-vitro* true dry matter digestibility (IVTDMD48), total digestible nutrients (TDN), and relative forage quality (RFQ). Calculated parameters of TDN and RFQ are adapted for best use and reliability to the region. The TDN calculation is [TDN=98.625-(ADF*1.048)] and the RFQ [RFQ=(DMI, % of BW)×(TDN, % of DM)÷1.23]. This laboratory has been certified for all years by the National Forage Testing Association (NFTA, Stuart, FL). Analytical results were obtained by using near-infrared spectroscopy (NIRS) instrumentation with calibrations provided through the NIRS Forage and Feed Consortium (Berea, KY) and tested in partnership with The University of Tennessee Beef & Forage Center’s NIRS Forage and Feed Nutritional Analysis Laboratory (Knoxville, TN). The analysis procedures followed the recommendations and methods outlined by McIntosh et al. (2022), and all data utilized the calibrations from the NIRSC throughout the entire data set period, however, calibration updates did occur annually.

These data were statistically analyzed using univariate analysis with PROC GLM in SAS 9.4 M8 (SAS Institute, Cary, NC). Forage categories were analyzed as the fixed effect, and laboratory samples as random. A Kolmogorov-Smirnov normality test for LSD determined mean separations across forage species, with a P-value less than 0.05 indicating statistical significance.

Results

All analyzed parameters differed across forage categories ($P < 0.0001$), where a significant variability in forage nutritive value was observed (Table 1). The CP values ranged from 9.8% in NWSG to 13.4% in orchardgrass, with an average of 11.5%. The highest ADF and NDF values were observed in NWSG, while the lowest ADF values were found in bermudagrass and the lowest NDF values in annual ryegrass. The average ADF and NDF values were 38.1% and 64.4%, respectively. The IVTDMD48 averaged 69.2%, with the lowest value in NWSG (64.1%) and the highest values in annual ryegrass (73.9%) and orchardgrass (73.2%). The lowest calculated TDN values were observed in the NWSG at 55.8%, while the highest values were recorded in bermudagrass (61.6%) and orchardgrass (61%). On average, the forage categories had a TDN value of 58.7%. The calculated RFQ values varied considerably, with orchardgrass achieving an RFQ of 102, while NWSG averaged just 85. Overall, the average RFQ across all forage categories was 91. Mean distribution by nutritive value analyte can be found in the Appendix (Figures 1-6) representing the distribution that represents the mean value for each forage classification with standard error of mean (SEM) and caps highlighting the error range.

Table 1. Forage nutritive content analytes by forage classification.

Classifcation	*n*	CP		ADF		NDF		IVTDMD48		TDN		RFQ	
Annual Ryegrass	256	11.5	cd	37.6	d	59.7	e	73.9	a	59.4	b	102.0	a
Bermudagrass	569	12.6	b	35.3	e	65.6	b	68.4	cd	61.6	a	92.7	c
Mixed Grass Forage	3803	11.2	d	38.8	c	64.1	c	68.1	d	58.1	d	90.7	d
Native Warm-Season Grasses	399	9.8	f	40.9	a	69.0	a	64.1	e	55.8	e	83.0	f
Orchardgrass	501	13.4	a	36.0	e	61.6	d	73.2	a	61.0	a	99.0	b
Small Grains	65	10.6	e	37.3	d	61.7	d	72.0	b	59.7	b	97.6	b
Tall Fescue	1186	11.2	d	38.8	c	64.0	c	68.9	d	58.1	c	90.6	d
Warm-Season Annuals	419	11.6	c	40.1	b	65.0	b	69.4	d	56.8	d	87.7	e
	mean	11.5		38.2		64.4		69.2		58.7		91.6	
	min	9.8		35.3		61.6		64.1		55.8		83.0	
	max	13.4		40.9		69.0		73.2		61.6		99.0	
	stdev	1.2		2.1		2.6		3.0		2.1		5.5	
	P=Value	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	
	LSD	0.4		0.6		0.8		1.0		0.7		2.4	

Analytes: crude protein (CP); acid detergent fiber (ADF); neutral detergent fiber (NDF); *in-vitro* true dry matter digestibility 48-hour (IVTDMD48); relative forage quality (RFQ); and total digestible nutrients (TDN).

Note: All data represented at 100% Dry Matter (DM).

Note: Letters within a column signify differences among species at the 0.05 probability level.

Discussion

Overall, the NWSG presented the poorest values across all parameters analyzed, while orchardgrass and annual ryegrass presented the most favorable results in forage nutritive value. Under the assumption that the minimum CP recommended for proper dietary maintenance of a rumen is 7% (NRC, 2001), all forage categories analyzed can match this requirement. However, a moderate milk-producing (18 lb peak) 1,300-pound beef cattle cow, which is common in Tennessee, would need up to 10.9% CP on a DM basis and TDN between 49 to 60.1% DM, depending on the stage of production (NRC, 2016). Therefore, on average, a producer feeding NWSG and small grain hay would need to supplement protein to meet the nutritional requirements of their cows. In contrast, orchardgrass and bermudagrass hay, with their high CP content, are more likely to meet most of the protein needs in a cow-calf system, which is common in Tennessee.

Orchardgrass, bermudagrass, and annual ryegrass had lower fiber contents, contributing to their higher digestibility. This aligns with findings that species with lower fiber levels are generally more suitable for livestock feeding (Undersander et al., 2002). Species with higher digestibility (e.g., annual ryegrass and orchardgrass) also tended to have higher TDN, supporting their use in energy-intensive feeding systems. Using the RFQ index, Hancock (2011) reported that most beef cows need fair quality forage (90-109) for non-lactating cows but good quality forage when nursing (110-139). Except for the NWSG and warm-season annuals, all other forage categories analyzed had RFQ values ranging from 90.6 to 102. This highlights the importance of assessing hay quality in advance to avoid unexpected declines in animal performance later in the cattle production cycle.

Despite these differences, neither higher quality nor lower quality forages consistently met the nutritional requirements for cattle, as outlined by the NRC (2016). While high-quality forages, such as orchardgrass and annual ryegrass, are more commonly available on the market with a forage test report, lower-quality species like NWSG are less likely to undergo testing. This creates potential challenges for producers in meeting cattle nutritional requirements, as these lower-quality forages may inadvertently be fed without supplementation, leading to limited animal performance and reduced economic returns (Boyer et al., 2020; NRC, 2016).

Located in the heart of the tall fescue belt, Tennessee was expected to have tall fescue as the most tested forage classification. With 1,186 samples analyzed, tall fescue exhibited medium forage nutritive value. While it was not as high-quality as orchardgrass and annual ryegrass, it also did not fall into the lower-quality range of NWSG and warm-season annuals. This is also true for the mixed grass forage classification, which primarily consists of tall fescue hayfields that have been overseeded with orchardgrass or, over time, have incorporated warm-season forages such as crabgrass. Crabgrass has values like those of pure tall fescue, except for IVTDMD48, which was 0.7% lower.

These results emphasize the need for better forage species selection and management in Tennessee to meet cattle nutritional needs; and can be combined with enterprise budgets to determine the most cost-effective hay options with the highest quality. Most cow-calf operations in this region follow a spring calving season (i.e., January-March) meaning peak nutritional demands occur during these months, which are also months when producers are feeding hay. While species like orchardgrass and annual ryegrass are of higher quality, they may not be sufficient to meet the full nutritional requirements of cattle in Tennessee. Lower-quality forages, such as tall fescue and mixed grass forage, although being the most tested categories, are still underrepresented in testing overall. This underrepresentation contributes to a skewed understanding of forage nutritive value in the state. It is still quite common to find hay available on the market without any forage test report to verify its quality. Therefore, there is a clear need for a broader focus on testing forages that are commonly found in Tennessee's pastures.

Without comprehensive testing of forages, producers may be unaware of nutritional deficiencies in their forage supplies. This could lead to improper supplementation and reduced cattle performance. Even when high-quality forages are tested, they still fail to consistently meet the NRC recommended TDN and CP levels for high-requirement cattle, such as lactating cows. To bridge the gap between actual forage nutritive value and cattle nutritional requirements, improved management practices are essential, including soil testing, weed control, and proper harvest management (e.g., maintaining appropriate stubble height and harvest frequency). These practices could include increasing the proportion of high-quality species, such as orchardgrass, annual ryegrass, and small grains, in forage production and improving the frequency of testing for all forages. Additionally, strategic harvesting and targeted supplementation during nutritional deficits can help mitigate the negative effects of limited-quality forage on cattle performance.

Another useful way to provide producers with information on forage nutritive value is through laboratories that analyze forage samples. Forage samples provide a wealth of data on nutritive value across various forage types. These data can demonstrate to producers the potential variation in nutritive value and can be combined with enterprise budgets to determine the highest quality forage at the lowest cost. This approach pools samples from various producers to demonstrate seasonal and species variation among forages, which could be useful in managing nutritive value and profitability.

The results further highlight a critical gap in forage testing and its significant impact on cattle production and profitability. As such, educational programs should focus on the economic and nutritional advantages of improved forage management. Broadening forage testing would provide a more comprehensive view of forage nutritive value and availability in Tennessee, enabling more accurate ration balancing and the strategic use of supplements to meet livestock nutritional needs. Future analyses should also consider integrating legumes and alternative forages into mixed grass pastures to improve forage nutritive value. Enhancing producer education on the importance of testing diverse forage types, along with providing cost-effective testing services, could help bridge this gap.

Conclusions

These results underscore the need for improved forage management practices and the development of educational programs to enhance forage nutritive value and cattle productivity in Tennessee. The variability in forage nutritive value across Tennessee highlights the challenges producers face in meeting cattle nutritional requirements, emphasizing the need for improved forage testing to support more informed decision-making in cattle production. While better quality forages are more likely to be tested, both high and low-quality forages fall short of meeting NRC recommended requirements, particularly during periods of high nutritional demand, such as lactation. Lower-quality forages, which are underrepresented in forage testing, contribute to a skewed understanding of the true state of forage nutritive value in Tennessee. By expanding forage testing, producers can make more accurate decisions regarding ration balancing and supplementation, ultimately improving cattle performance and profitability. Educational programs that emphasize the benefits of forage testing, along with cost-effective testing services, can help address this critical gap and promote more sustainable and efficient forage management practices.

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Appendix

Figure 1. Crude Protein (%CP) distribution that represents the mean value for each forage classification with standard error of mean (SEM) and caps highlighting the error range.

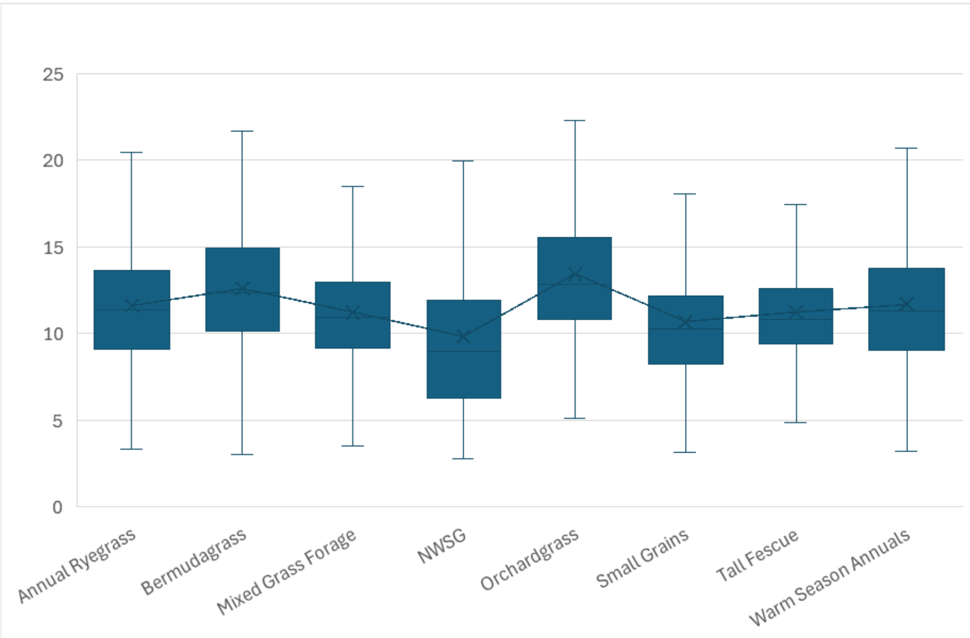

Figure 2. Acid Detergent Fiber (%ADF) distribution that represents the mean value for each forage classification with standard error of mean (SEM) and caps highlighting the error range.

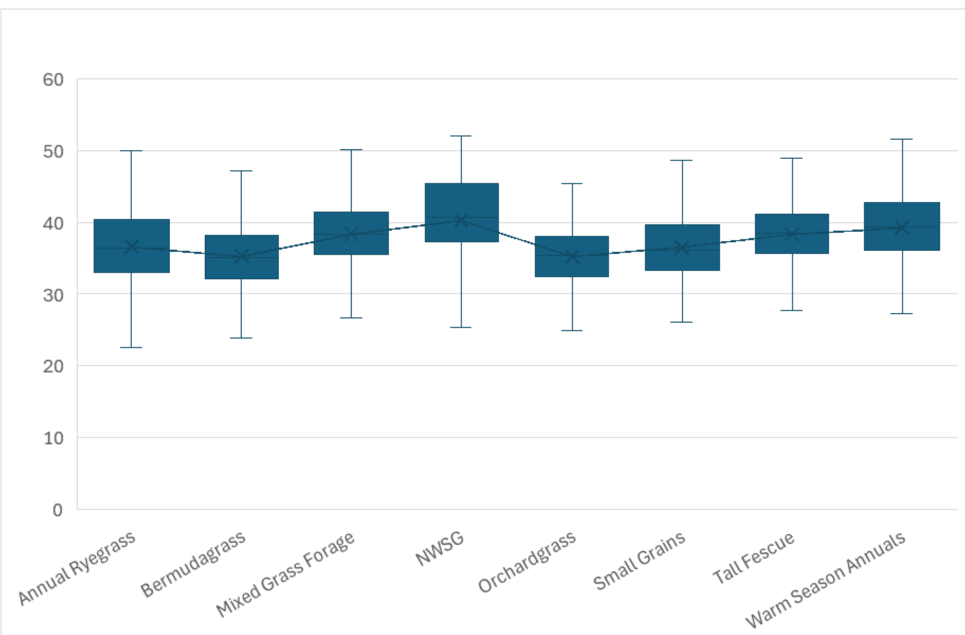

Figure 3. Neutral Detergent Fiber (%NDF) distribution that represents the mean value for each forage classification with standard error of mean (SEM) and caps highlighting the error range.

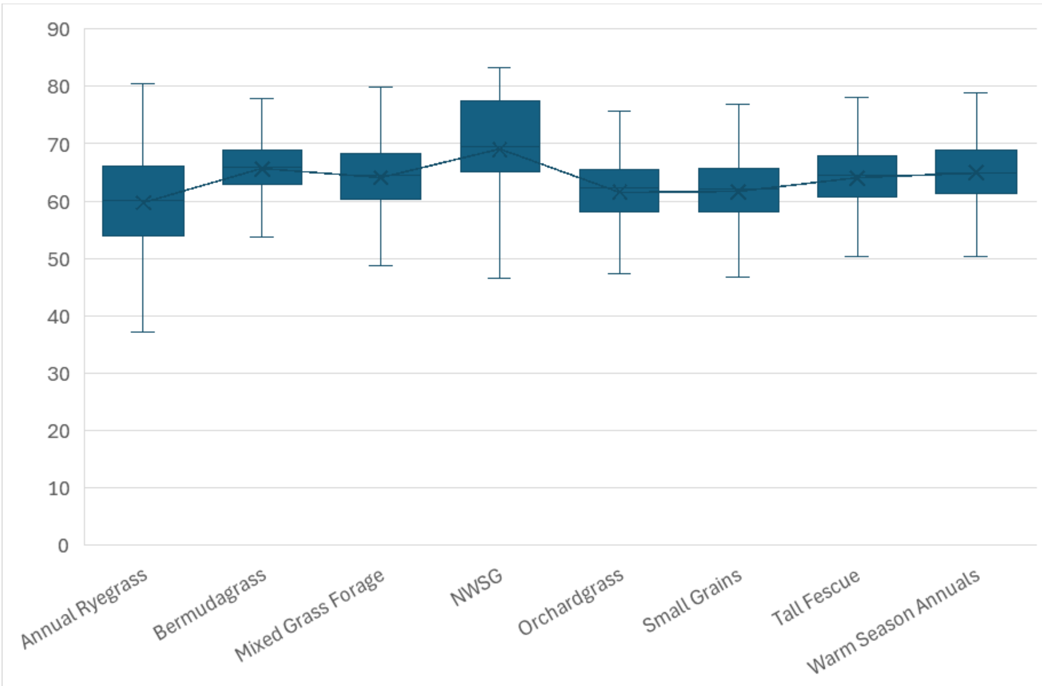

Figure 4. *In-vitro* True Dry Matter Digestibility 48 hour (%IVTDMD48) distribution that represents the mean value for each forage classification with standard error of mean (SEM) and caps highlighting the error range.

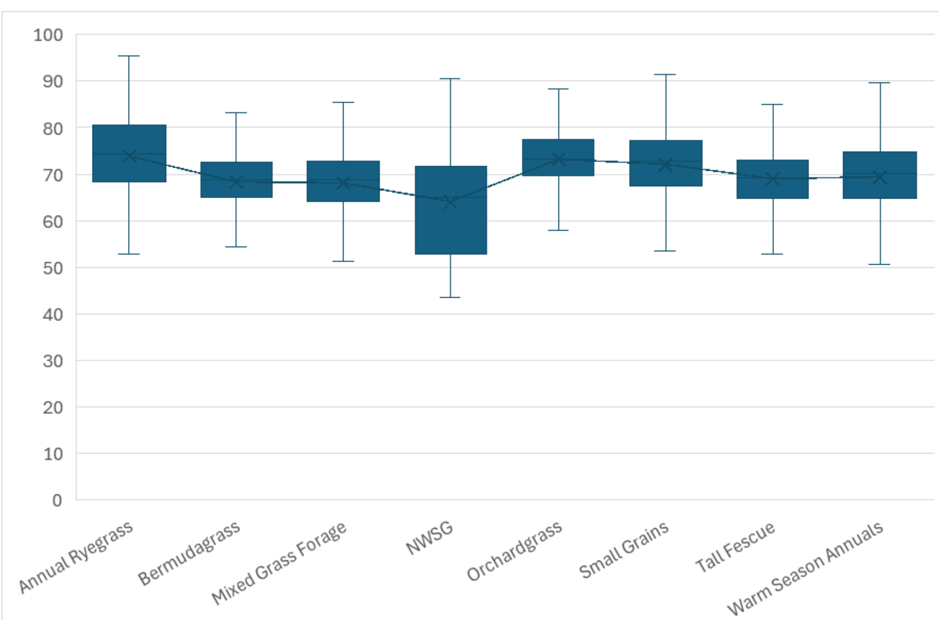

Figure 5. Total Digestible Nutrients (%TDN) distribution that represents the mean value for each forage classification with standard error of mean (SEM) and caps highlighting the error range.

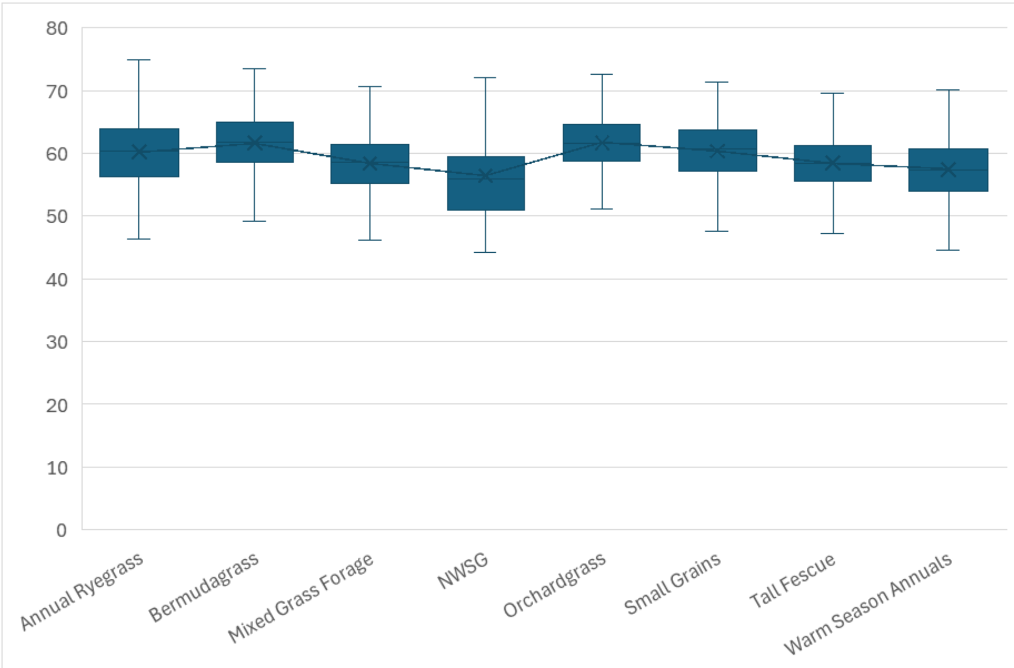

Figure 6. Relative Forage Quality (Index) distribution that represents the mean value for each forage classification with standard error of mean (SEM) and caps highlighting the error range.