Research in Ecology
https://journals.bilpubgroup.com/index.php/re

ARTICLE

Forage Nutrient Fluctuations During the Dry Season: A Case Study of Tropical Grazing Land in East Nusa Tenggara, Indonesia

Grace Maranatha [1], *Putri Pandarangga* [2], *Yohanis Umbu Laiya Sobang* [1], *Fredeicus Dedy Samba* [1*]

[1] *Faculty of Animal Science, Marine and Fisheries, Nusa Cendana University, Kupang 85228, Indonesia*

[2] *Faculty of Veterinary Medicine, Nusa Cendana University, Kupang 85228, Indonesia*

ABSTRACT

Natural grazing land plays a crucial role in extensive ruminant livestock systems, especially in semi-arid tropical regions such as East Nusa Tenggara (ENT), Indonesia. The availability and quality of forage during the dry season present significant challenges. This study aimed to identify variations in grass species composition and fluctuations in forage nutritional content in natural grazing lands of ENT during the dry season (July–October 2024). Sampling was conducted in four sub-districts: two representing lowland zones and two representing highland zones. In each sub-district, four grazing fields were selected, and ten plots were sampled per grazing field, totaling 160 sampling plots. Species identification and nutrient analysis included crude protein, crude fiber, energy content, and protein-energy ratio. Statistical analyses using ANOVA and Tukey's multiple comparison test were performed to evaluate significant differences in nutritional parameters across months and zones. Dominant species identified were *Themeda arguens*, *Heteropogon contortus*, *Brachiaria decumbens*, *Ischaemum timorense*, *Cynodon dactylon*, and *Pennisetum clandestinum*. Results showed significant monthly fluctuations in crude protein and fiber contents ($p < 0.05$), with protein levels decreasing from July (9.31 ± 2.66%) to October (7.53 ± 3.10%). Energy content and protein-energy ratio

*CORRESPONDING AUTHOR:
Fredeicus Dedy Samba, Faculty of Animal Science, Marine and Fisheries, Nusa Cendana University, Kupang 85228, Indonesia; Email: dedysamba011292@gmail.com

ARTICLE INFO
Received: 15 May 2025 | Revised: 26 May 2025 | Accepted: 4 June 2025 | Published Online: 3 September 2025
DOI: https://doi.org/10.30564/re.v7i4.9954

CITATION
Maranatha, G., Pandarangga, P., Sobang, Y.U.L., et al., 2025. Forage Nutrient Fluctuations During the Dry Season: A Case Study of Tropical Grazing Land in East Nusa Tenggara, Indonesia. Research in Ecology. 7(4): 71-84. DOI: https://doi.org/10.30564/re.v7i4.9954

also varied significantly across the dry season. A monthly shift in dominant grass species composition was observed, influenced by environmental conditions and species adaptability. The protein-energy ratio of forage remained below optimal levels throughout the dry season, potentially limiting livestock productivity. These findings provide important scientific insights for developing climate-resilient feeding strategies and support policy formulation for sustainable tropical livestock farming in semi-arid regions.

Keywords: Dry Season; Forage; Nutrient Fluctuations; Tropical Grazing Land; East Nusa Tenggara

1. Introduction

Natural grazing land plays an important role in extensive livestock systems, especially in semi-arid tropical areas such as East Nusa Tenggara (ENT), Indonesia. In this region, ruminant livestock such as cattle and goats generally rely on pasture as the main source of forage throughout the year. However, ENT is classified as a dry tropical climate area characterized by low and short rainfall and high temperatures, which potentially and negatively impact biomass production, forage quality, and quantity through changes in rainfall patterns, temperature, and extreme weather events [1], as well as plant distribution and abundance [2].

The availability and quality of forage during the dry season pose a major challenge. During this period, vegetation growth begins to decline, triggered by drought, while overgrazing pressure further worsens the productivity and sustainability of natural grasslands [3]. Climate change exacerbates this nutritional imbalance. Increasing temperatures and drought frequency cause forage plants to experience physiological stress, such as impaired nitrogen metabolism and decreased photosynthetic activity, which affect the quality of the biomass produced [4,5]. Studies have shown that pastures in dry areas experience a crude protein concentration decrease of more than 30% during the dry season compared to the rainy season [6].

This condition directly affects livestock performance. Declining availability and quality of forage result in imbalanced nutrient intake, contributing to reduced weight gain, digestive efficiency, and overall livestock productivity [7]. This has implications for the decreasing cattle population in ENT, one of the national cattle producers, from 1,175,615 heads in 2022 to 593,636 heads in 2024 (Data from the Central Statistics Agency of Indonesia 2025). Ruminant livestock face significant challenges, with nutritional stress being one of the most critical factors affecting animal health and productivity [8]. Forage is an essential component of the beef and dairy industries, playing a vital role in the livelihoods of local farmers and national food security. Therefore, a deep understanding of forage nutrient fluctuation patterns during the dry season is needed as a basis for formulating adaptive and sustainable pasture management strategies.

This research was conducted as a case study to identify variations in the nutrient content of natural forage during the dry season in ENT grazing land. The findings of this study are expected to provide a scientific basis for developing feed systems resilient to climate change as well as policy recommendations supporting sustainable tropical livestock farming.

2. Materials And Methods

2.1. Study Area

This study was conducted at four natural grazing locations in South Central Timor Regency, East Nusa Tenggara (ENT) Province, representing two agroecological zones: lowlands at 65–238 meters above sea level (masl) and highlands at 1456–1489 masl, determined using Global Position System (GPS) aids [9]. The locations were purposively selected based on the largest cattle population, the largest grazing area, the condition of grazing vegetation actively used during the dry season, and the representation of agroclimatic zones based on secondary data from the Meteorology, Climatology, and Geophysics Agency of Indonesia [9].

Within each agroecological zone (lowlands and highlands), two subdistricts were selected as sampling sites. In each subdistrict, sampling was conducted in four grazing fields, with ten observation plots of 1 m² in each grazing field, using a 1×1 m² quadrant tool. Thus, a total of 160 plots were observed (4 subdistricts × 4 grazing fields × 10 plots). The initial plot locations were determined by stratified random sampling to capture vegetation heterogeneity. Subsequent plots were placed following wind directions (north, south, east, west) using GPS tools [9]. Each plot was intensively observed for the forage species consumed by livestock (cattle and goats) through direct observation, consumption traces, and interviews with local farmers.

The study was conducted during the dry season from July to October 2024. Climate data from BMKG indicated that the highland areas have an average temperature of 22–25°C with rainfall less than 30 mm/month, while lowland areas have an average temperature of 31–34°C and rainfall less than 20 mm/month **(Table 1)** and the Geographical Location of the Research Area **(Figure 1)**.

Table 1. Geographical conditions of research locations in South Central Timor Regency, ENT Province.

Topography	Altitude (MASL)	Coordinate	Temperature (°C)	Humidity (%)
Lowlands	65-238	10°01’42”S 124°13’37”E 10°10’00”S 124°23’42”E	22–25°C	48-31
Highlands	1456-1489	9°41’37”S 124°14’09”E 9°43’09”S 124°12’31”E	31–34°C	79-68

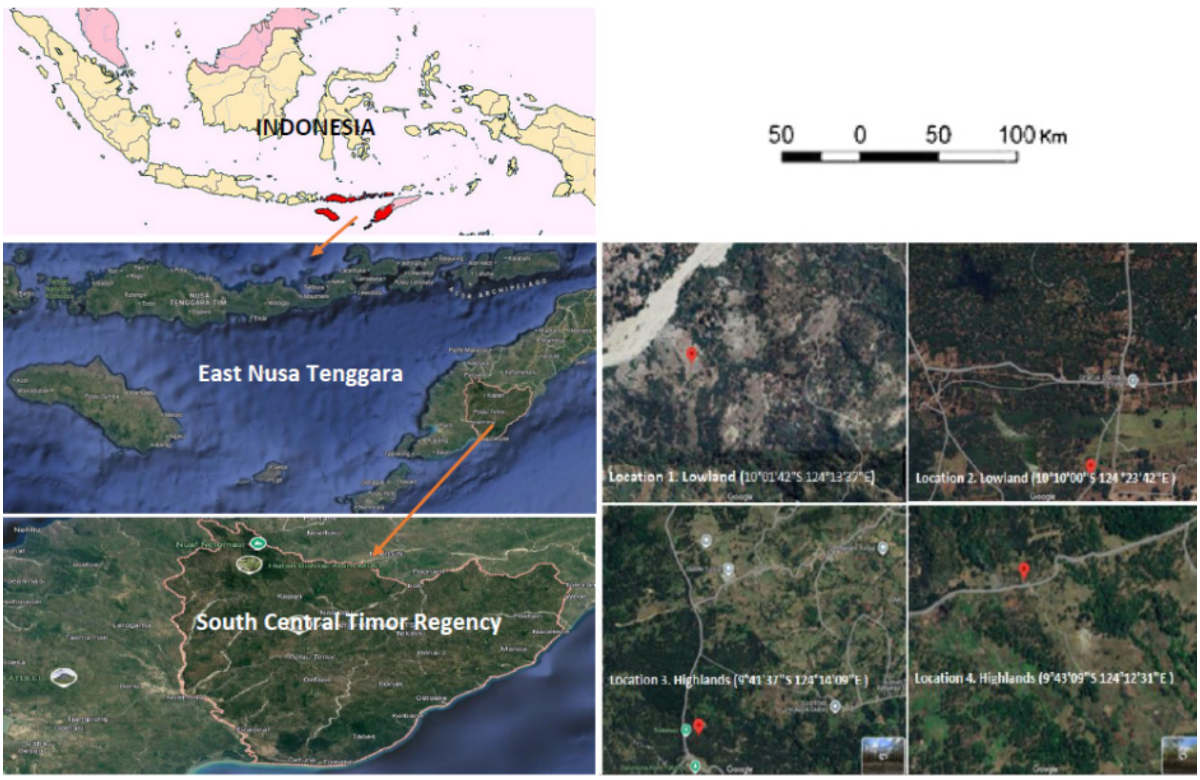

Figure 1. Geographical location of the research area.

2.2. Forage Sampling Procedure

Forage sampling was conducted in each observation plot measuring 1×1 m², representing areas with actively growing natural vegetation, free from erosion or bare soil patches. The following standardized procedure was applied across all sampling locations:

1. Plot establishment: Sampling plots (1×1 m²) were demarcated in the field using measuring tape and wooden stakes placed at ground level.
2. Vegetation inventory: All grass species present within each plot were identified and recorded using a standardized botanical key to support species-level classification.
3. Forage harvesting: The aboveground biomass within each plot was clipped using plant shears at approximately 3 cm above the soil surface. The harvested forage was then sorted by species (with emphasis on natural grasses) and weighed to determine fresh biomass yield.
4. Sample labeling and processing: Forage samples from each plot were labeled with unique identification codes and placed into pre-labeled paper or plastic bags. Samples were initially air-dried at ambient room temperature to obtain air-dry weight. Subsequently, samples were oven-dried at 105°C for 7 days to achieve a constant dry weight. These dried samples were used for proximate chemical analyses.

2.3. Identification and Sample Analysis

Dominant forage species in each plot were identified based on local taxonomy and relevant scientific literature [10]. After identification, forage samples were collected and weighed to determine fresh biomass weight, then air-dried at room temperature to determine air dry weight, followed by oven drying at 60°C for 48 hours to obtain constant dry weight [11]. From each plot, a representative sample of 100 g was taken for nutrient content analysis.

Nutrient analysis included dry matter (DM %), organic matter (OM %), crude protein (CP %), crude fiber (CF %), total digestible nutrients (TDN %), and energy (kcal/kg DM), following the procedures of the Association of Official Analytical Chemists (AOAC) [12]. The forage protein-energy ratio was also calculated according to standard protocols [13].

2.4. Statistical Analysis

Nutrient measurement data were analyzed using analysis of variance (ANOVA) to test for significant differences among months and agroecological zones. Tukey's post hoc test was applied to identify specific group differences. All analyses were conducted at a significance level of 5% ($p < 0.05$). Results were presented as means and standard deviations and interpreted to understand seasonal nutrient fluctuation patterns in forage during the dry season.

3. Results And Discussion

3.1. Results

3.1.1. Changes in Grass Species Composition and Availability

This study revealed significant differences in grass species availability between months and agro-ecological zones. In the lowland areas, the dominant grass species were *Themeda arguens* and *Heteropogon contortus*, both showing a significant increasing trend in their proportions from July to October ($p < 0.05$). *Themeda arguens* reached its peak availability in October. Conversely, species such as *Brachiaria decumbens*, *Ischaemun timorense*, and *Cynodon dactylon* exhibited a significant decline over the same period (ANOVA, $p < 0.05$), indicating their lower tolerance to prolonged drought conditions.

In the highlands, *Pennisetum clandestinum* and *Cynodon dactylon* were the most dominant and stable species throughout the dry season, showing no significant monthly fluctuations ($p > 0.05$). *Themeda arguens* and *Heteropogon contortus* had lower overall availability but displayed different trends; *Heteropogon contortus* showed a gradual increase towards the end of the dry season ($p < 0.05$), while *Themeda arguens* fluctuated without a clear trend.

These results suggest a clear shift in species dominance driven by environmental conditions, with drought-tolerant species dominating in lowlands, and a relatively stable composition observed in highlands. The spatial heterogeneity and adaptability of species to microclimatic variations were captured by stratified random sampling as described in the methods [9], and the monthly shift trends are presented in the following graph **(Figure 2** and **3)**.

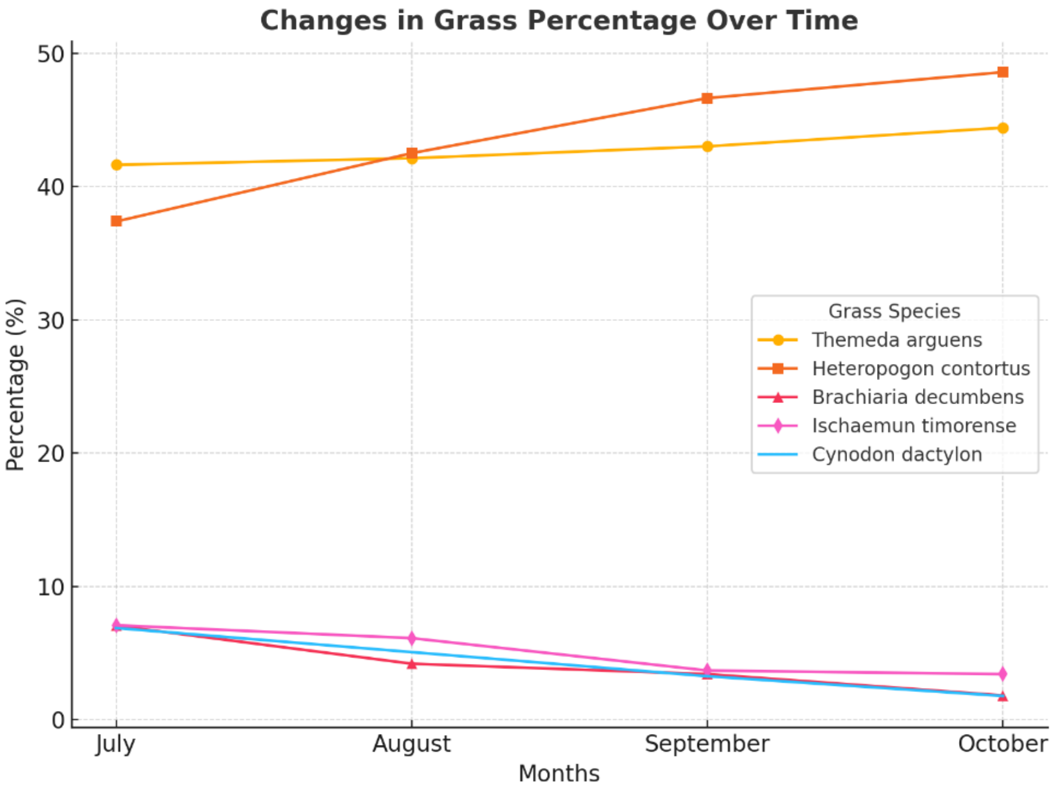

Figure 2. Graph of shifts in the dominance of grass species in lowland pastures during the dry season.

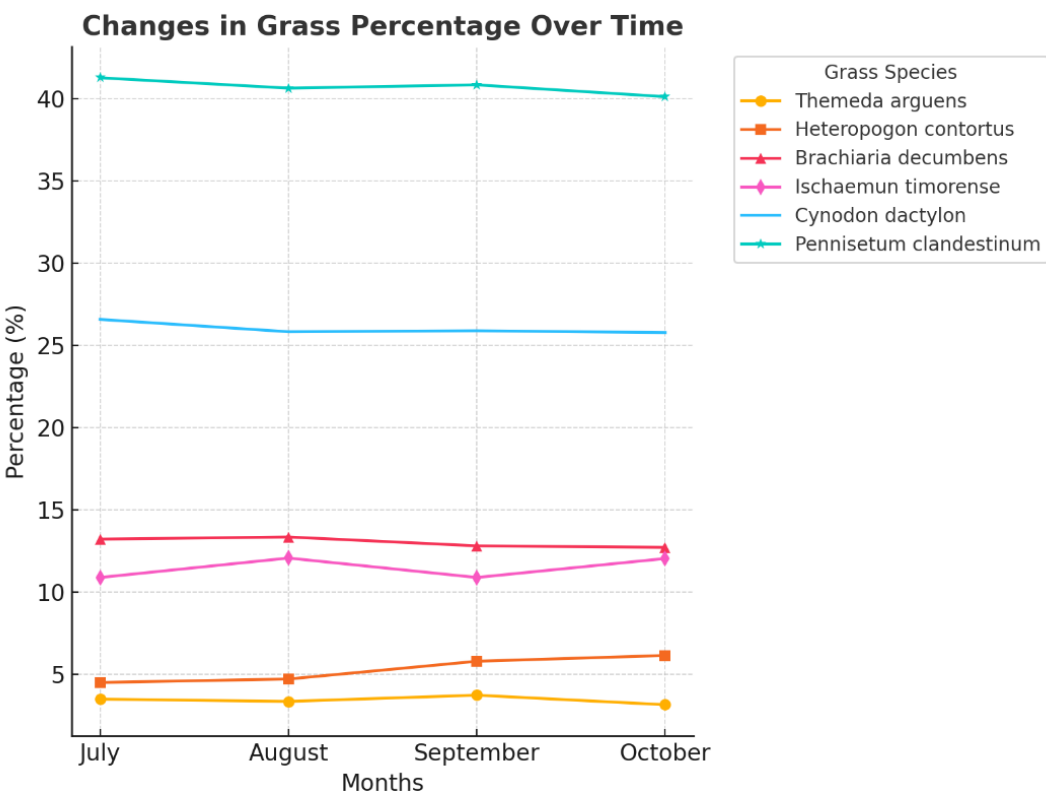

Figure 3. Graph of shifts in the dominance of grass types in highland grazing fields during the dry season.

3.1.2. Fluctuations in Nutrient Availability during the Dry Season

The nutritional composition of forage exhibited a statistically significant decline over the course of the dry season across both agro-ecological zones, as confirmed by one-way ANOVA ($p < 0.05$). Forage samples collected in July recorded the highest nutritional values, which gradually declined through to October (**Table 2**). This downward trend was particularly evident in the levels of crude protein (CP), total digestible nutrients (TDN), and metabolizable energy (kcal/kg DM). The reduction aligns with common dry-season phenomena such as increased lignification, cell wall thickening, and nitrogen depletion, consistent with previous findings and AOAC analytical protocols [12].

Table 2. Nutritional value and protein-energy ratio of forage available in natural grazing pastures.

Nutritional Components	July	August	September	October	MSE	*p*-value
Dry Matter (%)	26.23 ± 1.25^{a}	27.80 ± 1.80^{ab}	29.60 ± 1.70b^{c}	30.05 ± 1.75^{c}	0.89	0.013*
Organic Matter (%)	88.20 ± 2.40^{a}	85.40 ± 4.20^{ab}	84.20 ± 3.10^{b}	83.20 ± 3.00^{b}	2.75	0.041*
Crude Protein (%)	9.30 ± 2.50^{a}	9.05 ± 3.00^{a}	7.80 ± 3.25^{b}	7.55 ± 3.05^{b}	1.90	0.032*
Crude Fiber (%)	25.05 ± 2.40^{b}	25.20 ± 2.00^{b}	28.50 ± 1.00^{a}	28.35 ± 1.15^{a}	0.85	0.005*
Energy (kcal/kg DM)	4199.35 ± 102^{a}	4065.25 ± 174^{b}	3986.80 ± 200^{b}	3929.20 ± 190^{b}	2100.50	0.022*
TDN (%)	38.90 ± 7.90^{a}	35.25 ± 8.70^{ab}	30.95 ± 4.00^{b}	30.60 ± 4.30^{b}	5.50	0.028*
P/E Ratio	1 : 4.65^{a}	1 : 4.54^{a}	1 : 4.81^{a}	1 : 4.79^{a}	0.01	0.112

*Note: *Significant difference (p < 0.05), Superscript values a,b,c indicate significant differences between months based on post-hoc tests (Tukey HSD), MSE = Mean Square Error of one-way ANOVA, p-value is based on the results of one-way ANOVA.*

In contrast, crude fiber (CF) content increased significantly ($p < 0.05$) throughout the season, reflecting the typical shift toward more fibrous, less digestible forage under prolonged drought stress. Such changes have well-documented implications feed intake, digestion, and nutrient utilization in ruminants.

Interestingly, the protein-to-energy (P:E) ratio remained relatively stable ($p > 0.05$) across months. This suggests that despite the overall decline in nutrient concentrations, the relative balance between protein and energy availability in the forage was preserved to a certain extent. This condition, however, may still fall short of meeting the nutritional requirements of growing or lactating animals without supplementation.

Variability observed between months and between ecological zones could be attributed to a combination of factors, including shifts in dominant forage species, differences in soil fertility, and microclimatic variations. These findings highlight the urgent need for climate-adaptive forage management practices such as silvopastoral integration, forage conservation (hay/silage), and strategic water resource management to mitigate the impacts of seasonal nutrient deficits on livestock productivity [11,13].

3.2. Discussion

3.2.1. Availability of Grass Species

This study revealed a statistically significant shift ($p < 0.05$) in the composition of grass species during the dry season across different altitudes. In lowland areas, drought-tolerant species such as *Themeda arguens* and *Heteropogon contortus* became more dominant. This shift reflects their high adaptability to arid microclimates and decreased rainfall, supporting their capacity to sustain growth when water becomes limited. In contrast, other less drought-resilient species declined, reducing the overall forage diversity and quality available to livestock.

These compositional changes underscore the importance of topographical and microclimatic factors in shaping pasture vegetation. Environmental conditions, particularly soil moisture and temperature, are primary determinants of grassland productivity, typically favoring species diversity and biomass under wetter and nutrient-rich conditions [14,15]. Although grazing intensity also influences species composition [16], its effects are modulated by climatic and edaphic contexts. For example, rotational grazing tends to be more effective in areas with higher rainfall [17], whereas grazing exclusion in arid environments may reduce vegetation cover and biodiversity.

Our data also suggest that pasture efficiency was generally higher in highland regions, supported by lower temperatures and higher humidity, which favor optimal growth phases of both tropical and subtropical grasses. This finding aligns with previous studies that link modified climate and hydrology in mountainous zones with shifts in pasture dynamics [18]. For instance, global warming may shift alpine grasslands to higher elevations, reducing pasture availability in lower areas and causing ecosystem fragmentation [19–21].

Understanding the dominant species across topographies enables the formulation of adaptive grazing strategies, including rotational systems and forage conservation planning. The seasonal pattern of species availability is especially critical for designing supplementary feeding systems during forage-scarce periods. Moreover, this study highlights the urgent need for climate-resilient pasture and livestock management practices in tropical regions like East Nusa Tenggara (ENT). The findings can inform regional policies aimed at sustainable grassland use and improved livestock productivity in the face of increasing climatic variability.

3.2.2. Nutritional Content of Forage in Pastures

Protein Content

Statistical analysis using ANOVA ($p < 0.05$) demonstrated significant temporal variation in crude protein content from July to October. The highest protein levels were recorded in July, likely due to favorable environmental conditions moderate temperatures and residual soil moisture that promote the growth of young, protein-rich forage.

In August, protein content slightly declined, a response to advancing drought conditions and reduced rainfall, which slow vegetative growth and initiate the reproductive phase in grasses. This trend continued into September, when protein levels dropped more sharply, coinciding with the maturation and senescence of forages. As grasses transition into flowering and seeding stages, nutrient allocation shifts from leaf development to reproduction, reducing crude protein availability.

By October, protein values were at their lowest. This is attributed to the prevalence of standing hay mature, fibrous, and desiccated forage characterized by higher lignin and cellulose content but lower protein concentration. This seasonal decline reflects strong climatic controls on forage quality, especially under heat and water stress conditions [22,23]. Protein and lipid profiles, including amino acid composition, directly affect feed quality and animal performance [24,25]. Insufficient protein or amino acid imbalance can impair livestock growth, reproduction, and feed conversion efficiency.

Environmental stressors such as heat and drought have been shown to disrupt nitrogen metabolism in plants, decreasing protein synthesis and stability [4,5]. This study reinforces the hypothesis that prolonged dry seasons reduce the nutritional value of forages, with implications for ruminant productivity [26,27]. Furthermore, warming and moisture stress can reduce plant fitness and shift species composition, compounding the nutritional challenges [7].

Although moderate drought may maintain forage quality in certain cases, prolonged deficits cause a buildup of structural carbohydrates and fiber, decreasing digestibility and intake efficiency [28,29]. Rising atmospheric CO_2 may alter forage quality by increasing non-structural carbohydrates and reducing nitrogen concentration, although this response can vary with altitude and species [30]. In highland regions, some forages may retain higher nitrogen content due to changes in species composition or plant physiology.

Overall, the protein content of forage followed a declining trajectory across the dry season. Early dry months

(July–August) offered relatively nutritious forage, but quality deteriorated sharply in September and October. These results corroborate the general principle that seasonal rainfall patterns shape forage protein dynamics, with greater leaf:stem ratios and protein synthesis occurring under favorable moisture conditions [31,32]. However, even during the rainy season, anti-nutritional factors like tannins and lignin can limit digestibility and animal performance if not properly managed [33].

Crude Fiber Content

The crude fiber content of forage in July was recorded to be the lowest compared to other months, at 20.15 ± 1.45%. This indicates that the forage during this month was still young and fresh, with a lower proportion of crude fiber. Young forage typically has better nutritional value, including high protein content and lower crude fiber. In this regard, in inadequately managed pasture grass with rotational grazing, the supply of forage is nutritionally beneficial because the grass does not reach physiological maturity, resulting in a lower fibrous fraction [34]. This phenomenon generally occurs in grazing fields, although other factors such as climate and high temperatures also influence forage quality.

The crude fiber content increased slightly in August to 25.25 ± 2.09%. This increase is likely due to the initial process of forage aging, where changes in environmental conditions cause forage to enter the growth phase characterized by a higher crude fiber content due to increasing lignin and structural fiber proportions. As plants progress toward maturity, their relative protein content tends to decrease while their structural fiber content, indicated by fractions such as ADF and NDF, tends to increase [35]. This observation aligns with the general phenological decline in forage quality towards the end of the growing season [36].

In September, crude fiber content increased significantly to 28.53 ± 0.98%. Statistical analysis using one-way ANOVA confirmed that the increase in crude fiber from July to September was significant ($p < 0.05$), with post-hoc Tukey's test revealing that September's crude fiber content was significantly higher than July and August. This increase indicates that most forage had entered the generative phase or was starting to experience drought stress. The high crude fiber content in this phase results from increased lignification in plant cells, a typical response to hot and dry conditions. The smaller standard deviation compared to August suggests more homogeneity in forage quality during September.

Warming generally advances plant phenology, leading to earlier leaf and flower emergence [37–39]. In some cases, leaves also senesce earlier [40]. Drought stress and elevated temperatures accelerate leaf senescence [41] and reduce reproductive success [30,42], causing plants to age more quickly and increasing crude fiber content.

In October, crude fiber content decreased slightly to 28.38 ± 1.20%, though still at a high level. This decrease, not statistically significant compared to September ($p > 0.05$), likely resulted from plant conditions that began to dry completely, causing slight fiber degradation. Nonetheless, the high crude fiber content remained a key characteristic, indicating a decline in overall forage quality.

Overall, the data show a significant increasing trend in crude fiber content from July to September ($p < 0.05$), followed by a slight, non-significant decrease in October. This pattern reflects natural forage aging and seasonal influences on plant structure. Increasing crude fiber over time is accompanied by decreasing protein content and forage quality. These changes are closely linked to temperature and air-availability effects on plant metabolism, where the optimal temperature for leaf photosynthesis is lower than the temperature at which leaf respiration peaks [43].

Energy Content

Forage energy content in July was the highest among the months, recorded at 4199.37 ± 102.35 kcal/kg. This high energy content is likely influenced by the presence of young, fresh forage rich in easily digestible components. This typically occurs at the onset of the rainy season when plants receive sufficient air and nutrients for optimal growth and quality.

In August, energy content decreased to 4065.31 ± 173.84 kcal/kg, coinciding with the dry season's onset. This decline is due to plant maturation and senescence, increasing crude fiber and lignin contents that reduce digestibility and available energy. Key nutritional indicators such as Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF), and Dry Matter Digestibility (DMD) correspond with these energy fluctuations [44].

Energy content further decreased in September to 3986.83 ± 200.55 kcal/kg, reflecting dry season effects.

The greater standard deviation suggests increased variability in forage quality across the pasture. In October, energy content reached its lowest at 3929.28 ± 191.41 kcal/kg. One-way ANOVA analysis indicated that energy content decreased significantly from July to October ($p < 0.05$). Regression analysis showed a strong negative correlation between crude fiber content and energy content ($p < 0.01$), highlighting that increasing fiber lowers forage energy.

The decline in energy reflects drought impacts where plants invest more energy in flowering and seed formation rather than vegetative growth, which typically contains higher energy [45]. Changes in plant community composition and functional groups also contribute to shifts in palatability and nutritional value. The forage energy content demonstrated a significant downward trend from July to October, corresponding with natural aging and drying processes in pasture plants. While forage quantity is easier to measure, quality assessment requires detailed nutritional evaluation as conducted here [46,47].

3.2.3. Total Digestible Nutrients (TDN)

The TDN content of forage in July was recorded as 38.90 ± 7.93%, representing the highest value during the observation period. This elevated TDN level indicates that forage quality was relatively high, characterized by greater digestibility and a higher proportion of nutrients available for absorption by ruminants. These conditions are likely attributable to the presence of young, fresh plant material at the onset of the rainy season, which tends to be rich in protein and energy while relatively low in crude fiber.

In August, TDN content declined to 35.20±8.73%. This reduction may be associated with environmental shifts and plant physiological changes as the region transitions into the dry season. During this period, forages advance in maturity, accumulate more structural carbohydrates such as lignin, and exhibit reduced digestibility. The increase in standard deviation also reflects a greater heterogeneity in forage quality across grazing areas. Forages with TDN content above 50% are generally considered adequate to meet the energy requirements of grazing ruminants [48], that high TDN values contribute to favorable rumen microbial activity, enhancing fermentation efficiency [49]. Additionally, that elevated atmospheric CO_2 concentrations can enhance forage digestibility by approximately 7% [50].

As the dry season intensifies, the TDN content continued declining in September, reaching 30.91 ± 4.04%. This trend reflects increased lignification and reduced nutrient bioavailability, particularly as forages enter a more senescent state. Although the standard deviation was lower, indicating more uniform quality, the overall digestibility had substantially declined. By October, the TDN content further dropped to 30.57 ± 4.33%, suggesting that the majority of available forage had reached an advanced maturity stage with high fiber and lignin contents, and consequently, diminished nutritional value. TDN serves as a proxy for overall forage digestibility [51].

Interestingly, no significant difference ($p > 0.05$) in TDN percentage between seasons during their trial period, with an average of 51.38 ± 5.83% in the rainy season and 38.36 ± 6.45% in the dry season [49]. Similar values were in *Brachiaria*-dominated grasslands during peak rainfall, a period marked by increased photoassimilate production which supports higher metabolic efficiency in grazing animals [52,50].

Overall, the data demonstrate a consistent decline in TDN content from July to October, paralleling a progressive reduction in forage quality due to plant aging and water stress during the dry season. While moderate drought stress can sometimes delay plant maturation and temporarily preserve digestibility [53,54], the prolonged dry conditions observed in this study led to reductions in the apparent digestibility of organic matter (OM), dry matter (DM), and crude protein (CP) [55]. These reductions are often exacerbated by nitrogen deficiency, which compromises rumen metabolism, microbial activity, and ultimately the efficiency of nutrient utilization.

3.2.4. Protein-Energy Ratio (P:E)

The protein-energy (P:E) ratio is a crucial indicator reflecting the nutritional balance of forage for ruminants, representing the proportion between available crude protein and metabolizable energy. This ratio is influenced by forage digestibility, degradation rates of plant components, and the synchronization of ruminal fermentation. A low P:E ratio indicates an energy-rich diet, whereas a high ratio suggests a relatively higher protein availability. However, this balance may be disrupted when protein is poorly degradable in the rumen or when energy is limited, ultimately reducing nutrient utilization efficiency.

Based on ANOVA results, the P:E ratio in July was 1:4.65 ($p > 0.05$), indicating a relatively high energy concentration compared to protein, which reflects the early vegetative stage of forage with higher digestibility and nutrient availability. In August, the ratio slightly declined to 1:4.54 ($p > 0.05$), suggesting a relative reduction in protein as plants transitioned to later growth stages and forage quality began to decline due to prolonged drought. This trend coincided with the accumulation of structural carbohydrates, which reduce digestibility and increase the animal's energy requirements.

In September, the P:E ratio increased significantly to 1:4.81 ($p < 0.05$), the highest value observed during the study period. This shift implies that although energy content declined due to rising crude fiber levels (CF increased significantly from 25.06% in July to 28.53% in September ($p < 0.05$), protein levels remained relatively stable. However, this elevated ratio is more indicative of a nutritional imbalance caused by energy deficiency rather than an improvement in feed quality. In October, the ratio slightly decreased to 1:4.79 ($p > 0.05$), indicating further deterioration in forage quality as lignification intensified during plant senescence.

Phenological changes in forage plants, particularly flowering and seed development between September and October, accelerated the decline in nutritional value, as shown by increased fiber content and decreased protein and energy concentrations. The accumulation of dry straw and plant litter in November further led to a dramatic reduction in forage nutritional quality.

Overall, the P:E ratio remained relatively stable throughout the observation period, with minor fluctuations that aligned with seasonal changes and forage quality dynamics. The lowest ratio in July (1:4.65) corresponded to the period of optimal forage quality, whereas the highest ratio in September (1:4.81) coincided with increased fiber and reduced energy content. Although the October decrease was not statistically significant ($p > 0.05$), the trend reflected an ongoing energy limitation that could constrain ruminant productivity.

According to the literature, the ideal P:E ratio for optimal ruminant performance is approximately 1:5.1[13]. Deviations from this ratio may impair feed utilization efficiency. Structural characteristics of forage such as the leaf-to-stem ratio and crude fiber content are highly season-dependent and influence protein-energy balance [56].

To counter the decline in forage quality, particularly during the dry season, targeted nutritional supplementation strategies are essential. Low-dose nitrogen fertilization may serve as a sustainable intensification measure to enhance pasture productivity, forage quality, and reduce both grazing pressure and greenhouse gas emissions [57]. Nitrogen deficiency, especially in low-protein diets, limits rumen microbial activity, protein synthesis, and fiber degradation, reducing feed conversion efficiency and increasing reliance on body reserves, often leading to significant weight loss in ruminants during drought periods.

4. Conclusions and Recommendations

This study demonstrates significant monthly fluctuations in forage nutritional quality during the dry season in tropical grazing areas of East Nusa Tenggara, Indonesia. Using one-way ANOVA, the research confirmed that dry matter, organic matter, crude fiber, TDN, energy, and protein-energy ratio all showed statistically significant variations ($p < 0.05$) from July to October. Forage quality consistently declined over time, with a marked increase in dry matter and crude fiber, and a notable decrease in energy and digestibility (TDN), which could compromise livestock productivity.

Additionally, changes in dominant grass species were observed monthly in both lowland and highland zones, shaped by environmental conditions and species adaptability. These findings underline the urgent need for climate-adaptive forage management strategies, including early harvesting, forage conservation (e.g., silage/hay), and potential rotational grazing systems to prevent nutritional stress in ruminants during prolonged dry seasons.

Further research incorporating the rainy season and broader ecological indicators is recommended to optimize sustainable pasture-based livestock systems in semi-arid tropical regions.

Novelty Statement

Studies on nutrient fluctuations and vegetation of forage in natural pastures during the dry season have not yet been conducted.

Author Contributions

G.M. was the lead researcher who played a role in conceptualizing the research framework and methods and contributed to research supervision, ensuring the integrity of the data representation and robustness of the research results, Y.U.L.S. contributed to the depth of the research findings, providing important insights that significantly influenced the final results, P.P. played an important role in leading data collection, writing the article and refining the manuscript for publication, F.D.S. played an important role in data collection and analysis as well as the corresponding author. All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia through the Directorate of Research, Technology, and Community Service under the Primary Contract Number: 073/E5/PG.02.00.PL/2024 and the Secondary Contract Number: 432/UN15.22/SP2H/PL/2024.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. All relevant data are included in the manuscript.

Acknowledgment

The author would like to express sincere gratitude to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia through the Directorate of Research, Technology, and Community Service for the support and funding provided for the implementation of this research. Appreciation is also extended to the Institute for Research and Community Service of the University of Nusa Cendana, as well as the Government of Timor Tengah Selatan Regency, East Nusa Tenggara Province, Indonesia, for their cooperation and contributions in supporting the successful completion of this research activity.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Cheng, M., McCarl, B., Fei, C., 2022. Climate change and livestock production: A literature review. Atmosphere. 13(1), 140. DOI: https://doi.org/10.3390/atmos13010140

[2] Kelly, A.E., Goulden, M.L., 2008. Rapid shifts in plant distribution with recent climate change. Proceedings of the National Academy of Sciences of the United States of America. 105(33), 11823–11826. DOI: https://doi.org/10.1073/pnas.0802891105

[3] Viciedo, D.O., Prado, R. de M., Martínez, C.A., et al., 2019. Short-term warming and water stress affect Panicum maximum Jacq. stoichiometric homeostasis and biomass production. Science of The Total Environment. 681, 267–274. DOI: https://doi.org/10.1016/j.scitotenv.2019.05.108

[4] Bita, C.E., Gerats, T., 2013. Plant tolerance to high temperature in a changing environment: Scientific fundamentals and production of heat stress-tolerant crops. Frontiers in Plant Science. 4, 273. DOI: https://doi.org/10.3389/fpls.2013.00273

[5] Feller, U., Vaseva, I.I., 2014. Extreme climatic events: Impacts of drought and high temperature on physiological processes in agronomically important plants. Frontiers in Environmental Science. 2, 39. DOI: https://doi.org/10.3389/fenvs.2014.00039

[6] Noguerol, R.M., Pérez, A.J.M., Pedroche, J., et al., 2023. Climate change alters pasture productivity and quality: Impact on fatty acids and amino acids

in Mediterranean silvopastoral ecosystems. Agriculture, Ecosystems & Environment. 358, 108703. DOI: https://doi.org/10.1016/j.agee.2023.108703

[7] Calcerrada, J.R., Chano, V., Matías, L., et al., 2022. Three years of warming and rainfall reduction alter leaf physiology but not relative abundance of an annual species in a Mediterranean savanna. Journal of Plant Physiology. 275, 153761. DOI: https://doi.org/10.1016/j.jplph.2022.153761

[8] Muzzo, B.I., Ramsey, R.D., Villalba, J.J., 2025. Changes in climate and their implications for cattle nutrition and management. Climate. 13(1), 1. DOI: https://doi.org/10.3390/cli13010001

[9] Lourenço, M., Van Ranst, G., De Smet, S., et al., 2007. Effect of grazing pastures with different botanical composition by lambs on rumen fatty acid metabolism and fatty acid pattern of longissimus muscle and subcutaneous fat. Animal. 1(4), 537–545. DOI: https://doi.org/10.1017/S1751731107703531

[10] Wintle, B., Moore, G., Nichols, P., 2009. Identifying sub-tropical grass seedlings. Bulletin 4775. Available from: https://library.dpird.wa.gov.au/bulletins/199 (cited 15 May 2025).

[11] Elejalde, D., Nabinger, C., Cadenazzi, M., et al., 2012. Quality of the forage apparently consumed by beef calves in natural grassland under fertilization and oversown with cool season forage species. Brazilian Journal of Animal Science. 41, 1360–1368. DOI: https://doi.org/10.1590/S1516-35982012000600007

[12] AOAC, 2010. Official Methods of Analysis of AOAC International, 18th ed. AOAC International: Gaithersburg, MD, USA.

[13] Hogan, J., 1996. Principles of supplementary feeding. In: Bakrie, B., Hogan, J., Liang, J.B., et al. (eds.). Ruminant Nutrition and Production in the Tropics and Subtropics. Australian Centre for International Agricultural Research: Canberra, Australia. pp. 66–73.

[14] Carrascosa, A., Moreno, G., Rodrigo, S., et al., 2024. Unravelling the contribution of soil, climate and management to the productivity of ecologically intensified Mediterranean wood pastures. Science of The Total Environment. 957, 177575. DOI: https://doi.org/10.1016/j.scitotenv.2024.177575

[15] Fang, Y., Wan, L., Tong, J., et al., 2025. Hydrothermal conditions dominated sensitivity and lag effect of grassland productivity in Yunnan Province, China: Implications for climate change. Agricultural Water Management. 308, 109293. DOI: https://doi.org/10.1016/j.agwat.2025.109293

[16] Maestre, F.T., Bagousse-Pinguet, Y.L., Delgado-Baquerizo, M., et al., 2022. Grazing and ecosystem service delivery in global drylands. Science. 378, 915–920. DOI: https://doi.org/10.1126/science.abq4062

[17] Venter, Z.S., Cramer, M.D., Hawkins, H.J., 2019. Rotational grazing management has little effect on remotely-sensed vegetation characteristics across farm fence-line contrasts. Agriculture, Ecosystems & Environment. 282, 40–48. DOI: https://doi.org/10.1016/j.agee.2019.05.019

[18] Casale, F., Bocchiola, D., 2022. Climate change effects upon pasture in the Alps: The case of Valtellina Valley, Italy. Climate. 10, 173. DOI: https://doi.org/10.3390/cli10110173

[19] Huber, R., Briner, S., Peringer, A., et al., 2013. Modeling social-ecological feedback effects in the implementation of payments for environmental services in pasture-woodlands. Ecology and Society. 18, 41. DOI: https://doi.org/10.5751/ES-05487-180241

[20] Briner, S., Elkin, C., Huber, R., 2013. Evaluating the relative impact of climate and economic changes on forest and agricultural ecosystem services in mountain regions. Journal of Environmental Management. 129, 414–422. DOI: https://doi.org/10.1016/j.jenvman.2013.07.018

[21] Dibari, C., Costafreda-Aumedes, S., Argenti, G., et al., 2020. Expected changes to alpine pastures in extent and composition under future climate conditions. Agronomy. 10, 926. DOI: https://doi.org/10.3390/agronomy10070926

[22] Elgersma, A., Tamminga, S., Ellen, G., 2006. Modifying milk composition through forage. Animal Feed Science and Technology. 131, 207–225. DOI: https://doi.org/10.1016/j.anifeedsci.2006.06.012

[23] Glasser, F., Doreau, M., Maxin, G., et al., 2013. Fat and fatty acid content and composition of forages: A meta-analysis. Animal Feed Science and Technology. 185, 19–34. DOI: https://doi.org/10.1016/j.anifeedsci.2013.06.010

[24] Su, M., Chen, D., Zhou, J., et al., 2022. Effects of different dietary carbohydrate sources on the meat quality and flavor substances of Xiangxi Yellow Cattle. Animals. 12, 1136. DOI: https://doi.org/10.3390/ani12091136

[25] Wu, G., Bazer, F.W., Dai, Z., et al., 2014. Amino acid nutrition in animals: Protein synthesis and beyond. Annual Review of Animal Biosciences. 2, 387–417. DOI: https://doi.org/10.1146/annurev-animal-022513-114113

[26] Habermann, E., Oliveira, D.E.A., Delvecchio, G., et al., 2021. How does leaf physiological acclimation impact forage production and quality of a warmed

managed pasture of Stylosanthes capitata under different conditions of soil water availability? Science of The Total Environment. 759, 143505. DOI: https://doi.org/10.1016/j.scitotenv.2020.143505

[27] Hart, E.H., Christofides, S.R., Davies, T.E., et al., 2022. Forage grass growth under future climate change scenarios affects fermentation and ruminant efficiency. Scientific Reports. 12, 4454. DOI: https://doi.org/10.1038/s41598-022-08309-7

[28] Deak, A., Hall, M.H., Sanderson, M.A., et al., 2007. Production and nutritive value of grazed simple and complex forage mixtures. Agronomy Journal. 99, 814–821. DOI: https://doi.org/10.2134/agronj2006.0166

[29] Li, C., Peng, F., Xue, X., et al., 2018. Productivity and quality of alpine grassland vary with soil water availability under experimental warming. Frontiers in Plant Science. 9, 1790. DOI: https://doi.org/10.3389/fpls.2018.01790

[30] Dumont, B., Andueza, D., Niderkorn, V., et al., 2015. A meta-analysis of climate change effects on forage quality in grasslands: Specificities of mountain and Mediterranean areas. Grass and Forage Science. 70, 239–254. DOI: https://doi.org/10.1111/gfs.12169

[31] Silva, J., Cabral, L., Sousa, D., et al., 2017. Supplementation levels for non-lactating cows grazing during the rainy season. Semina Ciências Agrárias. 38(2), 885–894. DOI: https://doi.org/10.5433/1679-0359.2017v38n2p885

[32] Silva, M., Silva, D., Magalhães, A., et al., 2017. Influence of the period of year on the chemical composition and digestibility of pasture and fodder selected by goats in caatinga. Revista Brasileira de Saúde e Produção Animal. 18, 402–416. DOI: https://doi.org/10.1590/S1519-99402017000300001

[33] Lazzarini, I., Detmann, E., Valadares, S., et al., 2016. Nutritional performance of cattle grazing during rainy season with nitrogen and starch supplementation. Asian-Australasian Journal of Animal Sciences. 29, 1120–1128. DOI: https://doi.org/10.5713/ajas.15.0514

[34] Thompson, L.R., Rowntree, J.E., 2020. Invited review: Methane sources, quantification, and mitigation in grazing beef systems. Applied Animal Science. 36, 556–573. DOI: https://doi.org/10.15232/aas.2019-01951

[35] Serrano, J., Shahidian, S., Da Silva, J.M., 2018. Monitoring seasonal pasture quality degradation in the Mediterranean Montado ecosystem: Proximal versus remote sensing. Water. 10, 1422. DOI: https://doi.org/10.3390/w10101422

[36] Adar, S., Sternberg, M., Argaman, E., et al., 2023. Testing a novel pasture quality index using remote sensing tools in semiarid and Mediterranean grasslands. Agriculture, Ecosystems & Environment. 357, 108674. DOI: https://doi.org/10.1016/j.agee.2023.108674

[37] Whittington, H.R., Tilman, D., Wragg, P.D., et al., 2015. Phenological responses of prairie plants vary among species and year in a three-year experimental warming study. Ecosphere. 6, 1–15. DOI: https://doi.org/10.1890/ES15-00070.1

[38] Valencia, E., Mendez, M., Saavedra, N., et al., 2016. Plant size and leaf area influence phenological and reproductive responses to warming in a semiarid Mediterranean species. Perspectives in Plant Ecology, Evolution and Systematics. 21, 31–40. DOI: https://doi.org/10.1016/j.ppees.2016.05.003

[39] Guo, L., Liu X., Alatalo, J.M., Wang, C., et al., 2023. Climatic drivers and ecological implications of variation in the time interval between leaf-out and flowering. Current Biology. 33, 3338-3349. https://doi.org/10.1016/j.cub.2023.06.064

[40] Jochum, G.M., Mudge, K.W., Thomas, R.B., 2007. Elevated temperatures increase leaf senescence and root secondary metabolite concentrations in the understory herb Panax quinquefolius (Araliaceae). American Journal of Botany. 94, 819–826. DOI: https://doi.org/10.3732/ajb.94.5.819

[41] Feller, U., 2016. Drought stress and carbon assimilation in a warming climate: Reversible and irreversible impacts. Journal of Plant Physiology. 203, 84–94. DOI: https://doi.org/10.1016/j.jplph.2016.04.002

[42] Zeiter, M., Schärer, S., Zweifel, R., et al., 2016. Timing of extreme drought modifies reproductive output in semi-natural grassland. Journal of Vegetation Science. 27, 238–248. DOI: https://doi.org/10.1111/jvs.12362

[43] Scafaro, A.P., Fan, Y., Posch, B.C., et al., 2021. Responses of leaf respiration to heatwaves. Plant, Cell & Environment. 44, 2090–2101. DOI: https://doi.org/10.1111/pce.14018

[44] Avci, M., Hatipoglu, R., Çinar, S., et al., 2017. Assessment of yield and quality characteristics of alfalfa (Medicago sativa L.) cultivars with different fall dormancy rating. Legume Research. 41(3), 369–373. DOI: http://dx.doi.org/10.18805/LR-364

[45] Lee, M.A., 2018. A global comparison of the nutritive values of forage plants grown in contrasting environments. Journal of Plant Research. 131, 641–654. DOI: https://doi.org/10.1007/s10265-018-1024-y

[46] Peeters, A., 2009. Importance, evolution, environmental impact and future challenges of grasslands

and grassland-based systems in Europe. Grassland Science. 55, 113–125. DOI: https://doi.org/10.1111/j.1744-697X.2009.00154.x

[47] Henkin, Z., Ungar, E.D., Dvash, L., et al., 2011. Effects of cattle grazing on herbage quality in a herbaceous Mediterranean rangeland. Grass and Forage Science. 66, 516–525. DOI: https://doi.org/10.1111/j.1365-2494.2011.00808.x

[48] Miao, F., Guo, Z., Xue, R., et al., 2015. Effects of grazing and precipitation on herbage biomass, herbage nutritive value, and yak performance in an alpine meadow on the Qinghai-Tibetan Plateau. PLoS ONE. 10, e0127275. DOI: https://doi.org/10.1371/journal.pone.0127275

[49] Tuturoong, R.A.V., Malalantang, S.S., Moningkey, S.A.E., 2020. Assessment of the nutritive value of corn stover and king grass in complete feed on Ongole steer calves productivity. Veterinary World. 13, 801–806. DOI: https://doi.org/10.14202/vetworld.2020.801-806

[50] Guerra, G., Becquer, T., Vendrame, P., et al., 2019. Nutritional evaluation of Brachiaria brizantha cv. Marandu cultivated in soils developed from basalt and sandstone in the state of Paraná. Semina Ciências Agrárias. 40, 469–484. DOI: https://doi.org/10.5433/1679-0359.2019v40n1p469

[51] Weiss, W., Tebbe, A., 2019. Estimating digestible energy values of feed and diets and integrating those values into net energy systems. Translational Animal Science. 3(3), 953–961. DOI: https://doi.org/10.1093/tas/txy119

[52] Costa, P., Junqueira, S., Leonel, F., et al., 2012. Intercropping of corn, Brachiaria grass and leguminous plants: Productivity, quality and composition of silages. Brazilian Journal of Animal Science. 41, 2144–2149. DOI: https://doi.org/10.1590/S1516-35982012001000002

[53] Reddy, B.V.S., Reddy, P.S., Bidinger, F., et al., 2003. Crop management factors influencing yield and quality of crop residues. Field Crops Research. 84, 57–77. DOI: https://doi.org/10.1016/S0378-4290(03)00141-2

[54] Fariaszewska, A., Aper, J., Van Huylenbroeck, J., et al., 2017. Mild drought stress-induced changes in yield, physiological processes and chemical composition in Festuca, Lolium and Festulolium. Journal of Agronomy and Crop Science. 203, 103–116. DOI: https://doi.org/10.1111/jac.12168

[55] Xu, Z., Heuschele, D.J., Lamb, J.F.S., et al., 2023. Improved forage quality in alfalfa (Medicago sativa L.) via selection for increased stem fiber digestibility. Agronomy. 13, 770. DOI: https://doi.org/10.3390/agronomy13030770

[56] Poppi, D.P., Quigley, S., Da STACC., et al., 2018. Challenges of beef cattle production from tropical pastures. Revista Brasileira de Zootecnia. 47. DOI: https://doi.org/10.1590/rbz4720160419

[57] Delevatti, L.M., Cardoso, A.S., Barbero, R.P., et al., 2019. Effect of nitrogen application rate on yield, forage quality, and animal performance in a tropical pasture. Scientific Reports. 9, 7596. DOI: https://doi.org/10.1038/s41598-019-44138-x