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Research Article

The Study of Seasonal Patterns in Vegetation Diversity and Forage Yield Dynamics

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Abstract: This study examines the seasonal dynamics of vegetation diversity, forage yield, and nutrient quality in Tarabbi Village, Malili District, East Luwu Regency, conducted from July 2023 to July 2024. Using a survey approach and field measurements, data were collected through the Estimated Actual Weight method and Summed Dominance Ratio (SDR), complemented by Geographic Information System (GIS) technology for analysis. Principal Component Analysis (PCA) and cluster heatmaps were utilized to explore forage diversity and productivity across the dry and rainy seasons. Results reveal significant seasonal variations in forage yield and botanical composition in Tarabbi District, East Luwu. The rainy season emerges as a pivotal period for optimizing forage production, particularly in grass-dominated pastures. Despite this dominance, the inclusion of legumes and other plant species is essential for providing balanced and nutrient-rich forage for livestock. To sustain pasture productivity and ecological integrity year-round, adopting effective management strategies, such as adjusting stocking rates and promoting sustainable grazing practices, is imperative. Forage yield parameters, including fresh and dry weight, increased during the rainy season, with grasses showing the highest fresh weight production at 1.30 tons/ha, followed by legumes at 0.72 tons/ha. Nutrient analysis highlighted legumes as the most nutrient-dense, with the highest crude protein (9.35%) and fat content (4.63%), whereas grasses exhibited higher crude fiber (32.46%), important for digestion. These findings underscore the importance of integrated approaches to pasture management in addressing vegetation diversity and forage yield dynamics in seasonal patterns in Indonesia. By understanding these dynamics, sustainable livestock systems can be developed, ensuring ecological balance and improved productivity in the region.

Keywords: Seasonal Variations, Forage Yield, Botanical Composition, Sustainable Pasture Management, Livestock Systems

Introduction

Natural pastures and grasslands are vital ecosystems that support diverse plant and animal species, contribute to soil health, and play a crucial role in global food security (Bernis-Fonteneau *et al.*, 2024; Maestre *et al.*, 2021). The profitability of pastures and the competition between different types of plant vegetation are critical considerations in land management. Pastures cover a significant portion of the world's land area and are primarily used for grazing livestock. The management of these lands involves balancing the productivity of desirable forage species with the control of less desirable or invasive species, often termed weeds. This balance is crucial for maintaining high pasture productivity and profitability (Vlasenko *et al.*, 2022; Syamsu *et al.*, 2019). The competition between different species in pastures can pose significant challenges for pastoral managers. This competition can disrupt the balance of the ecosystem, leading to a decline in the quality and diversity of vegetation. When dominant species outcompete others, it can reduce biodiversity, which is crucial for maintaining ecological functions such as nutrient cycling, soil health, and resistance to pests and diseases (McLachlan and Sindel, 2023; Yan *et al.*, 2024). As a result, the pasture may become less productive and less economically viable for livestock grazing.

Pasture rehabilitation is a common practice in temperate and tropical grazing systems, where grasses dominate the vegetation (Delaby *et al.*, 2020). In tropical climates, natural grass vegetation contributes significantly to pasture composition, with studies reporting 84.42% grass cover in pastures (Sema *et al.*, 2023). In Indonesia, particularly in South Sulawesi, grasslands are 64.04% of the total pasture area (Khaerani *et al.*, 2024). However, forage productivity varies significantly between seasons, affecting grazing capacity. Rinduwati *et al.* (2016) observed that forage production in South Sulawesi fluctuates from 1.39 tons per hectare during the dry season to 5.35 tons per hectare in the rainy season. This seasonal variation also alters the proportion of forage types, with grass accounting for 50% of the dry-season forage, increasing to 69% in the rainy season.

Understanding vegetation diversity and forage yield in natural pastures is crucial for optimizing ecological and economic sustainability in grazing systems. Natural pastures provide essential forage for livestock, particularly in regions where grazing plays a fundamental role in agriculture (Deosaran *et al.*, 2024). Maintaining biodiversity while ensuring forage yield is often challenged by environmental factors, such as climate variability, soil fertility, and grazing pressure (Bybee-Finley *et al.*, 2023; Mahjoub *et al.*, 2023). In this context, understanding the relationship between species composition, seasonal variations, and forage output becomes essential for pastoralists, land managers, and policymakers aiming to enhance the long-term viability of natural pastures.

Tarabbi District and Malili Village serve as representative examples of broader grazing systems in tropical environments, where achieving a balance between biodiversity conservation and optimal forage yield is crucial for sustainable livestock production. Investigating vegetation diversity and forage yields in these natural grasslands, particularly through a case study in Tarabbi Sub-district, Malili Village, East Luwu Regency, is essential for ecological and environmental challenges that impact grassland productivity and sustainability. Despite seasonal forage dynamics' ecological and economic importance, limited research has examined the interplay between vegetation diversity, forage yield, and nutrient composition in tropical grazing systems. Existing studies primarily focus on general forage productivity without integrating advanced analytical techniques to assess spatiotemporal variations. This study addresses this gap by investigating the seasonal patterns of vegetation diversity and forage yield in Tarabbi Village, Malili District, East Luwu Regency, a representative grazing system in tropical Indonesia. This research comprehensively analyses forage dynamics across dry and rainy seasons by employing Geographic Information System (GIS) technology, Principal Component Analysis (PCA), and cluster heatmaps. This study contributes to current knowledge by offering data-driven insights into optimizing sustainable pasture management strategies, ensuring year-round forage availability, and enhancing livestock productivity.

Materials and Methods

This research was conducted in Tarabbi Village, Malili District, East Luwu Regency, over a period of one year, from July 2023 to July 2024. Geographically, the study area is located between 2°03'00" - 3°03'25" South Latitude (SL) and 119°28'56" - 121°47'27" East Longitude (EL). The topographical characteristics of the region are predominantly hilly, with an average elevation of 96.36 meters above sea level. The land slope varies across three categories: 15-25, 25-45%, and above 45%. The soil type in this area is classified as latosol.

The annual average temperature in the region ranges from 23°C to 32°C, with humidity levels between 80 and 100%. Monthly rainfall is projected to vary between 160 and 361 mm, with the highest precipitation occurring in December. The peak number of rainy days is recorded in April, with 23 days of rainfall. Meanwhile, the dry season typically occurs from August to September. In terms of administrative boundaries, Tarabbi Village is bordered by Wasuponda District to the north, Manurung Village to the east, Lakawali Village to the south, and Tampinna Village, Tawakua Village and Angkona District to the west. The research sample collection sites are presented in Figure (1) below.

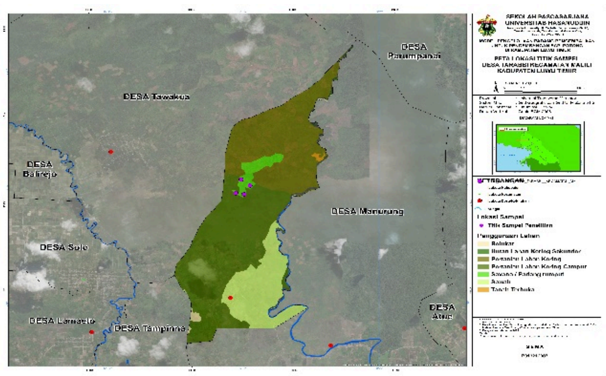

Fig. 1: Research area map

Sampling and Measurement

The method for collecting forage production data involved a survey approach combined with direct field measurements and observations. Forage production was assessed using the "Estimated Actual Weight" method (Paruelo *et al.*, 2000; Tadmor *et al.*, 1975) with a 1 m x 1 m frame. The frame was systematically and randomly placed on the pasture, after which the vegetation within

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the frame was cut and placed into plastic bags for immediate weighing. Quadrants were utilized to define sampling plots, with each quadrant measuring 1 m x 1 m. The quadrant frame was randomly thrown within the observation area to establish the central point. From this point, plots were systematically established in each of the four cardinal directions—east, west, north, and south-resulting in 20 plots per direction. Each plot recorded the type of vegetation, species distribution, and the frequency, density, and dominance of each species by counting the vegetation within each observation plot. The variables measured in this study are plant vegetation and forage production. Botanical composition was calculated in percentage (%) with the following formula (El-Sheseny *et al.*, 2014):

1. Botanical Composition = (Sample dry matter / Total dry matter) ×100%.
2. Meanwhile, the forage dry matter requirement is 3% of body weight (300 kg) and the carrying capacity is calculated based on the following formula (Baron *et al.*, 2006)
3. Carrying capacity = Forage dry matter requirement / Forage dry matter production

Data Collection

The research methodology employed involves a survey approach, followed by field measurements and observations utilizing Geographic Information System (GIS) software technology, encompassing both vector and raster data processing (Chymyrov *et al.*, 2015; Hannaway *et al.*, 2019). The study collects both primary and secondary data; primary data are obtained through direct field measurements, while secondary data are sourced from literature and relevant agencies. The primary data collected focus on forage production and plant vegetation. Based on frequency and density metrics, plant composition data were gathered using direct measurement methods, including the Summed Dominance Ratio (SDR) method.

Data Analysis

The collected data were tabulated and calculated to determine the percentage of botanical composition, the average production of fresh and dry forage material, and carrying capacity. This was followed by analysis using descriptive methods and Multivariate Analysis, principal component analysis, and cluster heatmap using R-studio.

Results

Vegetation Diversity Based on Dry and Rainy Seasons

The analysis of vegetation diversity in Tarabbi District, East Luwu, reveals distinct species abundance patterns across the dry and rainy seasons. The vegetation diversity based on dry and rainy seasons is presented in Table (1).

Table (1) shows the seasonal composition of grasses, legumes, and other plants. Grasses dominate, especially in the rainy season, while legumes and other plants vary between seasons. The data on vegetation diversity in Tarabbi District, East Luwu, reveals notable seasonal variations in the abundance of various legume species between the dry and rainy seasons. In the dry season, the vegetation diversity was dominated by other plants, with 2.28% for *Malasthoma malabatrichum* and *Ipomoea lecunosa L.* Meanwhile, in the rainy season, the vegetation diversity was dominated by grass and legume, with the highest percentage is 4.56% and 5.88% of *Cymbopogon citratus stapf* for grass and *Calopogonium mucoinedes* for legumes respectively.

After assessing the vegetation diversity in Tarabbi District, East Luwu, across dry and rainy seasons, conducting a Principal Component Analysis (PCA) and cluster heatmap can provide deeper insights into the underlying patterns and relationships between different vegetations. The PCA and cluster heatmap are presented in Figs. (2-5).

Figure (2) plot illustrates the distribution of forage species during the dry season, highlighting the dominant vegetation groups. The distinct clustering of grasses, legumes, and other plants suggests variations in adaptability and ecological roles under dry conditions. This figure showed that these distinctions are plotted along two primary axes, Dim1 and Dim2, which account for 100% of the variability in the data. Dim1, which explains 65.6% of the total variance, is the most critical factor in differentiating the forages. Along this axis, grass varieties, represented by red circles, are predominantly spread out, indicating that this dimension mainly captures their characteristics. Dim2, which accounts for 34.4% of the variance, further refines the differentiation among forages. Legume varieties, depicted by green triangles, cluster mainly on the negative side of Dim2. This clustering signifies that legumes share similar characteristics that differ from grasses and the other forage types, particularly in the aspects captured by Dim 2.

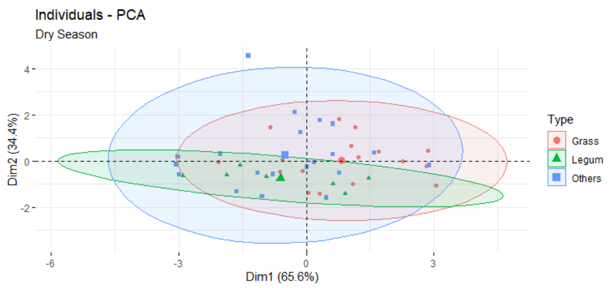

Fig. 2: Principal Component Analysis (PCA) of forage diversity based on dry season

Table 1: Vegetation diversity based on dry and rainy seasons

Vegetation	Dry Season	%	Rainy Season	%
Grasses	*Cynodon plectostachyus*	2.56	*Cynodon plectostachyus*	1.20
	Axonopus compress	1.92	*Axonopus compress*	1.25
	Cynodon dactylon L.	2.88	*Cynodon dactylon L.*	1.29
	Cyperus rotundus	2.88	*Cyperus rotundus*	1.15
	Dactyloctenium Egyptian L	2.56	*Dactyloctenium Egyptian L*	1.68
	Digitaria sanguinalis L.	1.60	*Digitaria sanguinalis L.*	1.06
	Echinocola colona L.	1.28	*Echinocola colona L.*	1.34
	Eleusina Indica	0.96	*Eleusina indica*	1.29
	Epidendrum SPP.	1.92	*Epidendrum SPP.*	1.25
	Mecardonia procumbens	1.60	*Mecardonia procumbens*	1.20
	Panicum maximum	2.24	*Panicum maximum*	0.96
	Paspalum conjugatum L.	1.92	*Paspalum conjugatum L.*	1.01
	Scoparia dulcis L.	2.24	*Dicksonia antartica L.*	1.44
	Crysopogon ariculatus	2.88	*Cymbopogon citratus (DC.) stapf*	4.56
	Schoenoplectus lacustris	1.28	*Zygopetalum maculaum (Kunth)*	1.68
	Spermacoce remota	1.60	*Cymbogon Nardus L.*	1.92
	Imperata cylindrical	0.96	*Scoparia dulcis L.*	1.34
			Stellaria neglecta	1.44
			Crysopogon ariculatus	1.68
			Schoenoplectus lacustris	1.20
			Spermacoce remota	0.96
			Dichantelium clandestinum	1.20
			Imperata cylindrical	1.25
Legumes	*Pyhllantus urinaria*	4.88	*Pyhllantus urinaria*	3.27
	Amaranthus viridis	4.07	*Amaranthus viridis*	2.61
	Cynthillum cenerlum L.	6.50	*Cynthillum cenerlum L.*	1.96
	Calopogonium mucoinedes	2.44	*Calopogonium mucoinedes*	5.88
	Ludwigia palustris	4.88	*Ludwigia palustris*	3.27
	Desmodium triflorum	3.25	*Passiflora foetida*	5.23
	Alycarpus vaginalis L	7.32	*Ipoema hederifolia*	3.92
			Desmodium triflorum	2.61
			Alycarpus vaginalis L	4.58
Other plants	*Chromolaena odorata L.*	2.28	*Chromolaena odorata L.*	3.45
	Gallinsuga quadriradiata	1.42	*Hyptis brevipus*	2.30
	Eclipta prostrata L.	1.71	*Eclipta prostrata L.*	5.75
	Mentha logifolia	1.42	*Mentha logifolia*	4.60
	Veronica arvensis L.	1.99	*Medinilla magnificia lind*	3.45
	Ageratum conyzoides	2.56	*Ageratum conyzoides*	6.90
	Malasthoma malabatrichum	2.28	*Malasthoma malabatrichum*	2.30
	Callisia repens L.	1.14	*Lantana camara*	4.60
	Elephantopus mollis kunth	1.99		
	Crepis pulchara	1.14		
	Crepis bulsifolis	1.99		
	Senna alata	1.42		
	Lantana camara	1.14		
	Erigeron bonariensess	1.99		
	Crassocephalum crepidiodes	1.42		
	Ipomoea lecunosa L	2.28		
	Rubus fruticocus	1.99		
	Ambrosia artemisifolia	1.14		
	Stachytarpheta jamaincensis L.	0.57		
	Nepehthes gracilis korth	1.42		
	Total	100.00		100.00

Figure (3) shows the forage composition during the rainy season. The clustering indicates an increase in grass dominance, while legumes and other plants exhibit different spatial distributions. This figure reveals the distribution of three main types of forages, grasses, legumes, and other varieties, across two primary axes, Dim1 and Dim2. Dim1, which accounts for 83.7% of the total variance, plays a dominant role in distinguishing between these forage types. It captures the most significant differences, particularly in the characteristics of grass and other forages. The grasses, represented by red circles, are primarily spread out along this axis, indicating a variety of traits that are crucial during the rainy season. Legume varieties, shown as green triangles, cluster tightly around the origin of the plot.

On the other hand, the other plant category, represented by blue squares, shows a broader distribution, particularly along Dim1. This spread suggests that this group encompasses a wide variety of forage types with diverse characteristics. The ellipses drawn around each group on the plot represent confidence intervals, providing a visual indication of where the majority of data points for each forage type are located. The elongated red ellipse for grasses along Dim1 suggests that there is considerable variability among grass varieties, while the smaller, more centered green ellipse for legumes reinforces their uniformity. The blue ellipse for other forages covers a larger area, further emphasizing the diversity within this group.

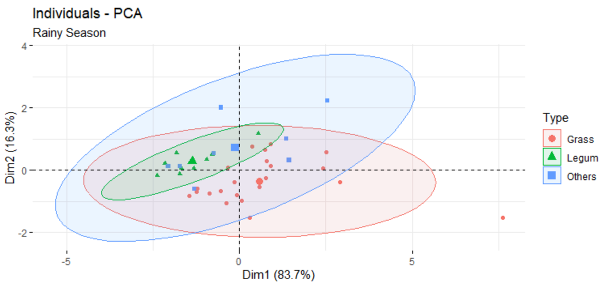

Fig. 3: Principal Component Analysis (PCA) of forage diversity based on the rainy season

Figure (4) Reveals the clustering of forage species during the dry season, highlighting variations in species abundance. Grasses, legumes, and other plants form distinct groups, reflecting their parameters. The vertical cluster illustrates the clustering patterns of various forage species, while the horizontal cluster demonstrates the clustering of yield parameters, including Fresh Weight (FW), Fresh Weight Production (FWP), Dry Weight (DW), and Dry Weight Production (DWP). The clusters can be categorized into four distinct groups: Cluster one in the first row exhibits a trend where Fresh Weight (FW) and Fresh Weight Production (FWP) are positive. At the same time, Dry Weight (DW) and Dry Weight Production (DWP) are negative in the category of other plants.

In contrast, cluster two, predominantly consisting of grasses, shows uniformly positive values across all parameters. Cluster three, dominated by legumes and other plants, displays consistently negative values for all parameters. Lastly, cluster four presents positive and negative values across grasses, legumes, and other plants.

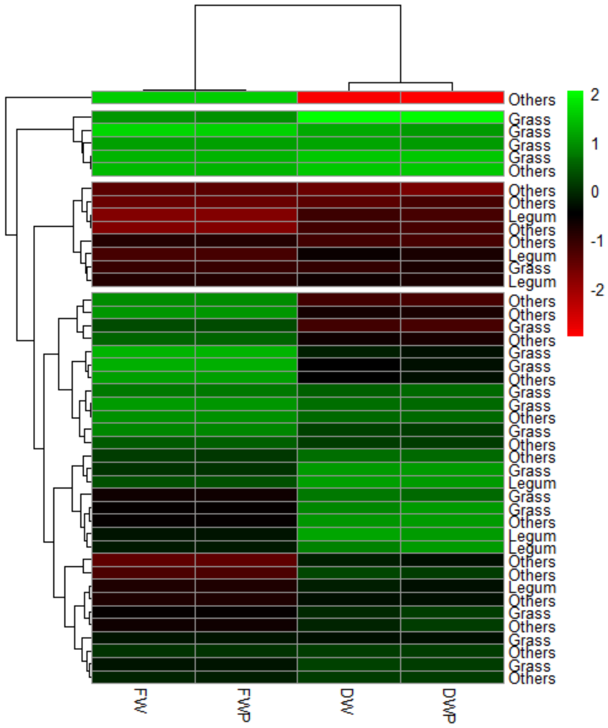

Fig. 4: Cluster heatmap of forage diversity based on dry season

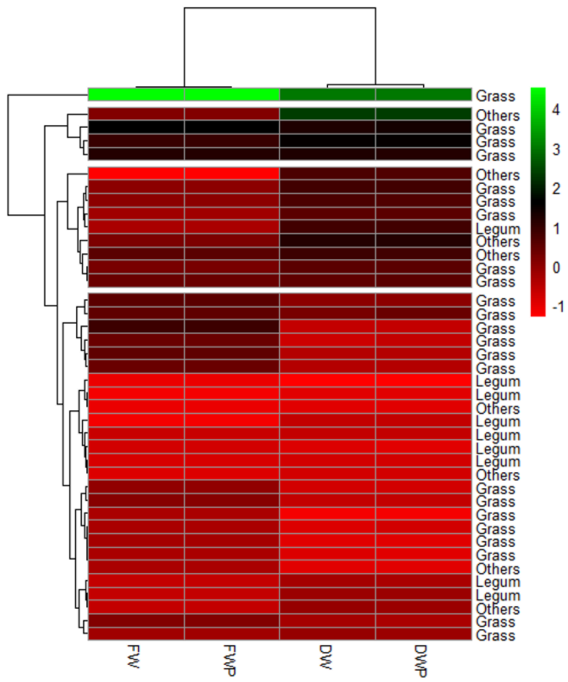

Fig. 5: Cluster heatmap of forage diversity based on the rainy season

Figure (5) illustrates the distribution of forage species during the rainy season. The increased dominance of grasses and shifts in species clustering between columns, representing yield parameters and rows, representing the classification of forages, specifically within the context of the rainy season in Tarabbi District, East Luwu. The vertical cluster illustrates the clustering patterns of various forage species, while the horizontal cluster demonstrates the clustering of yield parameters, including Fresh Weight (FW), Fresh Weight Production (FWP), Dry Weight (DW), and Dry Weight Production (DWP). A similar trend to a cluster of the dry season in Figure (4), the clusters can be categorized into four distinct groups. Cluster one demonstrates that all parameters exhibit positive values within the grass category. In contrast, cluster two shows positive values in the Dry Weight (DW) and Dry Weight Production (DWP) parameters within the other plant categories, while the Fresh Weight (FW) and Fresh Weight Production (FWP) parameters are negative. Clusters three and four reveal a consistent trend where all parameters display negative values across all plant categories, including grasses, legumes, and other plants.

Forage Yield and Botanical Composition in Seasonal Patterns During the Year

The parameters measured include Fresh Weight (FW), Dry Weight (DW), Fresh Weight Production (FWP), and Dry Weight Production (DWP). The data presented in Tables (2-3) highlight the forage yield and botanical composition across different plant categories, grass, legume, and other plants, in seasonal patterns during the year in Tarabbi District, East Luwu.

Table 2: Forage yield in seasonal patterns during the year

Season	Parameter	Grass	Legume	Other plants	Average
Dry	Fresh weight (gr/m2)	76.25	58.23	67.31	67.26
	Dry weight (gr/m2)	17.65	16.92	15.92	16.83
	Fresh weight production (ton/ha)	0.76	0.58	0.67	0.67
	Dry weight production (ton/ha)	0.18	0.17	0.16	0.17
Rainy	Fresh weight (gr/m2)	130.09	72.16	90.19	97.48
	Dry weight (gr/m2)	25.68	21.79	26.78	24.75
	Fresh weight production (ton/ha)	1.3	0.72	0.9	0.97
	Dry weight production (ton/ha)	0.26	0.22	0.27	0.25

Table (2) Compares forage yield between dry and rainy seasons. During the dry season, grass exhibited the highest Fresh Weight, averaging 76.25 grams per square meter (gr/m²), followed by other plants at 67.31 gr/m², with legumes showing the lowest at 58.33 gr/m². The average Fresh Weight across all plant categories during this season was 67.26 gr/m². In terms of Dry Weight, grass again led with 17.65 gr/m², slightly higher than legumes and other plants, which recorded 16.92 gr/m² and 15.92 gr/m², respectively. Fresh Weight Production (FWP) followed a similar pattern, with grass yielding 0.76 tons per hectare (ton/ha), while other plants and legumes produced 0.67 tons/ha and 0.58 tons/ha, respectively. The average FWP across all categories was 0.67 ton/ha. Dry Weight Production (DWP) was highest in grass at 0.18 ton/ha, followed by legumes at 0.17 ton/ha and other plants at 0.16 ton/ha, with an average of 0.17 ton/ha across all categories. The rainy season brought significant increases in forage yield across all categories. Grass showed a dramatic increase in Fresh Weight, reaching 130.09 gr/m², nearly doubling its dry season value. Other plants and legumes also increased, with Fresh Weight reaching 90.19 gr/m² and 72.16 gr/m², respectively. The average Fresh Weight during the rainy season was 97.48 gr/m². Dry Weight values also increased, with other plants leading at 26.78 gr/m², followed by grass at 25.68 gr/m² and legumes at 21.79 gr/m², resulting in an average of 24.75 gr/m². Fresh Weight Production (FWP) also showed improvements, with grass producing 1.30 tons/ha, other plants 0.90 tons/ha, and legumes 0.72 tons/ha, bringing the average FWP to 0.97 tons/ha. Dry Weight Production (DWP) also rose, with other plants slightly outperforming grass at 0.27 ton/ha compared to 0.26 ton/ha, while legumes maintained a steady 0.22 ton/ha, leading to an average of 0.25 ton/ha.

Table (3) shows forage yield and botanical composition during the year, highlighting the total production and the sustainable use of this yield. The matter production of forage in Tarabbi District, East Luwu, is around 12,060 kilograms per hectare annually. However, to ensure the land's long-term productivity, only 45% of this dry matter amounts to 5,427 kilograms per hectare, which is recommended for sustainable use. This sustainable forage is further reflected in the carrying capacity data. The land can support approximately 1.65 AU/year, representing the forage consumption of livestock. On a more detailed scale, the monthly carrying capacity is 0.14 AU/year, allowing for yearly grazing management. These figures underscore the importance of balanced grazing, ensuring that the land remains productive and supporting livestock sustainability needs.

Table 3: Botanical composition in seasonal patterns during the year

Parameter	Value
Dry Matter production (kg/ha)	12.060
Proper Use Factor (PUF 45%)	5.427
Carrying Capacity (AU/year)	1.65
Carrying Capacity (AU/month)	0.14

Nutrient Quality of Forages During the Year

The nutrient quality of forages in Tarabbi District, East Luwu, varies significantly between the dry and rainy seasons, reflecting the impact of seasonal patterns on forage composition. During the rainy season, favorable growing conditions enhance nutrient content across various forage types, including grass, legumes, and other plants. Table (3) presents the nutrient quality of forages throughout the year.

Table (4) Presents the nutrient composition of forages, including protein, fiber, and digestibility. Legumes have higher protein levels, while grasses contain more fiber. Seasonal changes in nutrient quality emphasize the importance of proper forage selection and supplementation for livestock nutrition. Specifically, crude protein levels are highest in legumes at 9.35%, followed by other plants at 8.15% and grass at 7.30%, with an overall average of 8.27%. The increased rainfall during this season supports higher nitrogen uptake by plants, resulting in improved protein content crucial for livestock nutrition.

Crude fiber content, which is essential for digestion but can affect digestibility if too high, shows the highest values in the grass at 32.46%, with legumes and other plants having lower levels. In the rainy season, plant growth likely reduces fiber content, making the forages more digestible. Conversely, as plants mature and become more fibrous during the dry season, crude fiber content increases, particularly in grass, potentially reducing digestibility. Crude fat content, an important energy source for livestock, is highest in other plants at 4.89% and legumes at 4.63%, with grass having the lowest at 2.67%. The rainy season's active plant metabolism likely contributes to higher fat levels, whereas the dry season may see a slight reduction as plant growth slows.

Neutral Detergent Fiber (NDF) is highest in other plants at 55.00%, followed by legumes and grass. Acid Detergent Fiber (ADF) are indicators of plant cell wall content and indigestibility, respectively. ADF shows a similar pattern, with the highest levels in other plants at 49.72%. During the dry season, these fiber components typically increase, making forages more fibrous and less digestible. In contrast, the rainy season supports lower NDF and ADF levels due to enhancing forage digestibility.

Table 4: Nutrient quality of forages during the year

Parameter	Forages	Average		
	Grass	Legume	Other plants	
Crude protein	7.30	9.35	8.15	8.27
Crude fiber	32.46	30.27	26.47	29.73
Crude fat	2.67	4.63	4.89	4.06
NDF	45.37	49.36	55.00	49.91
ADF	44.72	46.28	49.72	46.91
Dry matter	24.17	26.51	24.08	24.92
Organic matter	83.6	78.42	80.69	80.90

Dry matter content is slightly higher in legumes at 26.51% compared to grass and other plants. The dry season in Tarabbi District, with its reduced moisture levels, results in higher dry matter content, making the forage more concentrated. However, forages have higher moisture content during the rainy season, leading to lower dry matter percentages. Organic matter is highest in the grass at 83.6%. Although organic matter content remains relatively stable across seasons, the rainy season's abundant plant growth likely supports higher levels. In contrast, the dry season may decrease slightly due to the loss of more decomposable organic compounds.

Discussion

The study in Table (1) reveals significant seasonal variations in vegetation diversity and forage yield, impacting pasture productivity and livestock nutrition. Grasses dominate throughout the year, but species composition shifts with seasons. Drought-tolerant grasses like *Cynodon dactylon* (2.88%) thrive in the dry season while moisture-loving species like *Cymbopogon citratus* (4.56%) increase in the rainy season. Legumes, such as *Calopogonium mucoinedes* (5.88%) in the rainy season and *Cynthillum cenerlum* (6.50%) in the dry season, contribute to forage quality, while other plant species, including *Chromolaena odorata* (3.45%), add to botanical diversity. These seasonal patterns influence forage availability, livestock carrying capacity, and the need for adaptive management. In line with data in Table (2), seasonal variations in forage yield in Tarabbi Village highlight the influence of rainfall on pasture productivity. Fresh weight production peaks in the rainy season.

In contrast, dry season yields decline, limiting forage availability. Dry matter content also fluctuates, affecting forage quality and livestock nutrition. While the rainy season provides higher biomass, nutrient dilution can reduce feed quality. Rotational grazing, legume integration, and invasive species control should be implemented to sustain pasture productivity. Forage conservation strategies can help balance the seasonal fluctuations in forage supply.

In the dry and rainy season of the Tarabbi District, East Luwu, a comprehensive analysis was conducted to understand the variability among different forage varieties. This was achieved through a Principal Component Analysis (PCA) (Figs. 2-3); the PCA analysis highlights seasonal variations in forage diversity, with clear clustering of grasses, legumes, and other plants. In the dry season (Figure 2), grasses show higher variability, while legumes form a distinct cluster, indicating shared traits. Other plants display broader distribution, reflecting diverse adaptability to dry conditions. In the rainy season (Figure 3), grasses remain dominant but exhibit greater variability, while legumes show more uniformity. Other plants continue to display a wide range of characteristics, suggesting broad ecological adaptability. This spread along both Dim1 and Dim2 suggests a diverse range of characteristics within this group, making it less uniform compared to grasses and legumes. This analysis holds practical implications for forage management in the Tarabbi District. By understanding the distinct profiles of each forage type, farmers and agricultural planners can make informed decisions about which varieties to cultivate during the dry season. The distinct separation between grasses, legumes, and other forages highlights the potential for selective cultivation. However, if a broader range of traits is needed, the other plant category's diversity could be explored. Moreover, these findings can inform breeding strategies. The variability observed in grasses suggests opportunities for breeding programs to enhance specific traits. In contrast, the diversity in the other plant categories might be tapped to develop new forage varieties better suited to the rainy season conditions in the Tarabbi District.

The Figs. (4-5) reveal a distinct separation between vegetation types across different seasons. Grasses (green clusters) dominate the rainy season, indicating their strong growth response to increased moisture availability. In contrast, other plants (red clusters) show higher variation, suggesting that they include species with broader ecological adaptations. The presence of legumes in specific clusters highlights their seasonal persistence. Additionally, the heatmap's hierarchical clustering emphasizes the association of specific species across seasonal shifts, showing that some vegetation types exhibit consistent patterns. In contrast, others fluctuate significantly between the dry and rainy seasons. These insights support adaptive pasture management, where strategic rotational grazing and species selection can enhance forage sustainability throughout the year.

This study used Principal Component Analysis (PCA) and cluster heatmaps to analyze seasonal variations in vegetation diversity and forage yield due to their ability to simplify complex data and highlight key patterns. PCA was chosen to reduce dimensionality and identify the main factors influencing seasonal changes. Unlike Non-metric Multidimensional Scaling (NMDS), which is more suitable for nonlinear relationships, PCA provides clear eigenvalues and loadings, making it easier to interpret dominant trends. Meanwhile, cluster heatmaps effectively visualized species associations and seasonal groupings, offering a more intuitive representation. They also provided clearer insights than traditional diversity indices by displaying species clustering based on environmental factors. The use of PCA helped identify key environmental drivers of seasonal shifts, while the heatmaps confirmed distinct vegetation patterns over time. These methods revealed seasonal trends that would have been less apparent using conventional statistical approaches. Their combined use provided a clearer, data-driven understanding of biodiversity changes in Tarabbi Village, offering valuable insights for sustainable forage management.

The botanical composition of the forages in Table (3), particularly the proportion of grass, legumes, and other plants, also varies with the seasons. During the rainy season, the growth of grass is most pronounced, likely due to its competitive advantage in utilizing available moisture and nutrients. This results in grass being the dominant species in the forage mix, which is beneficial for grazing systems that rely heavily on grass as the primary forage source. The increased grass yield during the rainy season ensures that livestock have access to abundant forage, which supports higher stocking rates and better overall livestock productivity. The higher grass yield during the rainy season plays a vital role in boosting livestock productivity by supplying ample forage, enabling increased stocking rates. This seasonal surplus is essential for sustaining livestock health and productivity, as it ensures improved nutritional intake and facilitates effective grazing management (Ribeiro and Barbero, 2022). Legumes play a vital role in enhancing the nutritional quality of forage, particularly through their high protein content, which ranges from 20-45% (Niderkorn *et al.*, 2024). Although contributing less to the overall yield compared to grass, it plays a crucial role in enhancing the nutritional quality of the forage, particularly in terms of protein content. It also produces nitrogen through biological nitrogen fixation. Hasan *et al.* (2019) revealed that Biological Nitrogen Fixation (BNF) played a crucial role in enhancing forage growth and production in arid and degraded pasturelands. Their growth, however, is more sensitive to seasonal variations, with a relatively modest increase in yield during the rainy season. The presence of legumes in the forage mix is advantageous during the rainy season when their higher protein content can complement the increased biomass from grasses, thereby improving the overall nutritional value of the forage available to livestock (Stutz *et al.*, 2023; Watuwaya *et al.*, 2020). Other plants, which represent a diverse group of species, also show increased yields during the rainy season. These plants contribute to the botanical diversity of the forage. They may provide additional benefits, such as resilience to grazing pressure and the ability to thrive in specific microenvironments within the pasture (Utamy *et al.*, 2025). They can also be effectively utilized as a basic material for producing liquid fertilizers, such as those derived from Chromolaena odorata (Hasan *et al.*, 2019). However, their contribution to the overall forage yield is generally lower than that of grasses and legumes and their nutritional value can vary widely depending on the species composition (Tozer *et al.*, 2016)

The carrying capacity of the land, which reflects the number of Animal Units (AU) that can be sustainably supported per hectare, is directly influenced by the seasonal variations in forage yield. The data in Table 3 indicates that during the rainy season, the carrying capacity increases due to the higher forage availability, allowing for a higher stocking rate. This period of abundance must be managed carefully to avoid overgrazing, which can lead to long-term pasture degradation (Meshesha *et al.*, 2019). During the dry season, the reduced forage yield lowers the carrying capacity, necessitating decreased stocking rates or the introduction of supplemental feeding to maintain livestock health and productivity. The Proper Use Factor (PUF), which suggests that only 45% of the total dry matter production should be used to ensure sustainable grazing, is critical in preventing overutilization of the forage resources. Adhering to this guideline helps maintain the ecological balance of the pasture and ensures its long-term productivity (Slayi and Jaja, 2024).

The declining pasture productivity in Tarabbi Village, Malili District, East Luwu Regency. This decline is attributed to the predominance of natural grazing areas dominated by weeds with minimal legume presence, resulting in low forage quality. The presence of allelopathic substances in weeds further inhibits plant growth, whereas legumes, known for their superior nutritional content compared to grasses, also contribute to nitrogen fixation, a critical component for sustainable pasture management (Rusdy, 2020). According to Watuwaya *et al.* (2022) and Sema *et al.* (2021), the ideal composition of grazing land is 60% grasses and 40% legumes. However, Vlasenko *et al.* (2021) identified slightly alkaline soil conditions as a key factor in reducing legume prevalence due to their limited ability to absorb soil nutrient ions under such conditions.

The seasonal dynamics of vegetation diversity and forage yield observed in Tarabbi Village, Indonesia, align with findings from other regions in Southeast Asia. For instance, a study conducted in the seasonally dry forests of Huai Kha Khaeng Wildlife Sanctuary, Thailand, reported significant fluctuations in forage availability throughout the year. The highest forage availability was recorded in June, following prescribed burns, with values ranging from 156.2 to 252.6 kg/ha, while the lowest availability occurred in February, prior to burning, with values between 16.8 and 39.8 kg/ha. Environmental factors such as canopy cover, tree density, soil pH, and topography influence these variations, underscoring the complex interplay between biotic and abiotic factors in determining forage dynamics (Chankhao *et al.*, 2022). Similarly, research on seasonal and interannual changes in vegetation activity of tropical forests in Southeast Asia has demonstrated that forest vegetation is positively correlated with precipitation during the dry season. This indicates that water availability is a critical driver of vegetation dynamics in these ecosystems (Zhang *et al.*, 2016). In the Greater Mekong Subregion, studies on rubber plantations have revealed that plant diversity patterns are significantly influenced by environmental variables such as temperature and latitude. Higher plant diversity is observed in areas with greater environmental heterogeneity, suggesting that diverse microclimates and topographies can support a wider range of plant species (Lan *et al.*, 2022). These studies collectively highlight the importance of environmental factors, including climate variability and habitat management practices, in shaping vegetation diversity and forage availability across Southeast Asia. The findings from Tarabbi Village contribute to this broader understanding by providing localized insights into how seasonal patterns affect forage yield and botanical composition in Indonesian grasslands.

Rusdy (2020) emphasized that the optimal proportion of forage in pastures includes 60% grasses and 40% legumes. However, variations in this balance can arise from differences in water availability, soil topography, and climatic factors. Climatic elements such as temperature, humidity, rainfall, light intensity, and altitude significantly influence forage nutritional value and production. For example, rainfall increases forage plants' nitrogen, phosphorus, and crude fat content. However, in Wajo District, the proportion of legumes remains low compared to weeds and grasses (Table 3), primarily due to heightened interspecies competition. Salugin *et al.* (2019) noted that competing plants limit nutrient availability and suppress legume growth, particularly when legumes constitute less than 20% of the initial sown proportion.

Several studies highlight the significant impact of environmental factors such as rainfall, drought, and salinity on the growth phases of grasses and legumes (Khaerani *et al.*, 2018; Mykhalkiv *et al.*, 2023; Pirnajmedin *et al.*, 2024). Adequate rainfall ensures sufficient water for physiological processes, while temperature regulates transpiration and photosynthesis rates. Excessive temperatures reduce photosynthetic efficiency, ultimately impacting forage production and quality. Alternating wet and dry seasons exacerbate this issue by adversely affecting the quality and quantity of available forage in natural grasslands. During the rainy season, forage production is abundant but of lower quality compared to the dry season (Kust *et al.*, 2020; Salugin *et al.*, 2019). The findings reveal that vegetation in natural grasslands is dominated by weeds (55%), grasses (30%), and legumes (15%), with fresh weight production recorded at 42.25 tonnes/ha and dry weight at 5.20 tonnes/ha. These data indicate a decline in vegetation diversity and forage production in Tarabbi Sub-district, Malili Village, East Luwu Regency, highlighting the need for improved pasture management strategies.

This study provides insights into how seasonal changes affect vegetation diversity and forage yield, key ecological sustainability components. The findings highlight the relationship between plant diversity and ecosystem stability. While the study effectively connects vegetation diversity to ecological sustainability within Tarabbi Village, South Sulawesi, Indonesia, its implications for broader tropical regions need further exploration. Similar seasonal patterns occur in many tropical ecosystems, where shifts in vegetation influence agricultural productivity and biodiversity. By applying the study's findings to other regions with comparable climates, land-use practices, and environmental challenges, it can contribute to broader discussions on sustainable land management.

The nutrient composition of forages, as presented in Table (4), indicates differences in crude protein, fiber, fat, and digestibility components across different plant groups. Legumes generally had higher crude protein (9.35%) and crude fat (4.63%), making them a valuable source of nutrition for livestock, while grasses contained higher levels of crude fiber (32.46%), which can affect digestibility. The Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) levels suggest variations in cell wall components that influence forage digestibility and intake. For instance, higher NDF and ADF values in other plants indicate lower digestibility, which may impact livestock performance if forage selection is limited. These seasonal fluctuations in forage quality may influence grazing behavior, feed intake, and overall livestock growth and reproduction. During periods when forage crude protein levels decline, supplementation may be necessary to maintain optimal livestock performance (Ako *et al.*, 2019). The results highlight the need for adaptive management strategies, such as rotational grazing, strategic forage selection, and supplementation, to ensure consistent nutritional intake for livestock throughout the year. However, we acknowledge certain limitations in our study. These include potential constraints related to seasonal variability in data collection, which may not fully capture year-to-year fluctuations in vegetation diversity and forage yield.

Additionally, the specific environmental conditions of the study area, such as soil fertility, precipitation levels, and grazing pressures, may limit the generalizability of our findings to other regions with different ecological characteristics. While our study has certain limitations, it provides meaningful insights into how seasonal changes influence vegetation diversity and forage yield, offering valuable guidance for sustainable pasture management. A more extended observation period, broader geographic coverage, and refined sampling methods in future research will help address these constraints and strengthen the reliability of our findings. Future studies can develop more effective strategies to enhance forage productivity, support livestock nutrition, and foster ecological sustainability in diverse grazing systems.

Conclusion

This study highlights the substantial influence of seasonal variations on forage yield and botanical composition in Tarabbi District, East Luwu. The rainy season is critical for optimizing forage production, particularly grass-dominated pastures. Despite this dominance, including legumes and other plant species, is essential for providing a balanced and nutrient-rich forage for livestock. To sustain pasture productivity and ecological integrity year-round, adopting effective management strategies, such as adjusting stocking rates and promoting sustainable grazing practices, is imperative. These findings underscore the importance of integrated approaches to pasture management in addressing vegetation diversity and forage yield dynamics in seasonal patterns in Indonesia,

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Author's Contributions

Sema: Conceptualization, data collection, drafting the manuscript, and final revision.

Jasmal Ahmari Syamsu: Conceptualization, data collection, and tabulation, drafting the manuscript, and final revision.

Ambo Ako: Conceptualization, drafting of the manuscript, and final revision.

Rinduwati: Conceptualization, data collection, and tabulation, and final revision.

Ethics

This study was carried out with the permission of the local authorities and in accordance with institutional research ethics guidelines. Field surveys and data collection in Tarabbi Village were conducted with prior informed consent from landowners and community members. No endangered or protected plant species were collected or harmed during the study. The research did not involve any experimentation on humans or animals.

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