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Utilization of Centrosema Legume as a Nutrient-Rich Forage for Sustainable Livestock Systems

Rezki Amalyadi[1*]

[1] Department of Animal Science Faculty of Animal Science, University of Mataram, Indonesia
[*]Corresponding author: rezkiamalyadi@staff.unram.ac.id

Abstract
Livestock production systems in tropical regions face increasing pressure to improve feed quality while maintaining environmental sustainability and reducing dependence on external inputs. Forage legumes offer a viable strategy to address these challenges by enhancing nutritional value and delivering key ecosystem services. This study evaluated the agronomic performance, forage yield, and nutritional characteristics of Centrosema pubescens as a nutrient-rich forage legume within sustainable livestock systems. A field experiment was conducted using a randomized complete block design with three replicates under tropical conditions representative of smallholder production environments. Forage biomass was harvested at the peak vegetative stage and analyzed for dry matter yield, crude protein, fiber fractions, and mineral content using standard laboratory procedures. The results showed that Centrosema produced substantial biomass, exceeding 5 t ha^{-1} of dry matter, indicating strong adaptation and productive capacity under low-input management. Nutritional analysis revealed high crude protein concentrations (18–22%) and moderate fiber levels, supporting its suitability as a protein supplement for ruminant diets dominated by low-quality grasses. Integration of Centrosema into grass-based systems improved overall forage quality and contributed to enhanced soil nitrogen availability through biological nitrogen fixation, thereby reinforcing nutrient cycling and soil health. Conceptual analysis further highlighted the role of grass–legume mixtures in promoting rhizosphere stability and sustaining forage productivity. Overall, the findings confirm that Centrosema pubescens is a promising forage legume for improving feed quality, supporting soil fertility, and advancing the sustainability of tropical livestock production systems. Further studies incorporating animal performance trials are recommended to fully quantify its impact on ruminant productivity.

Keyword: *Centrosema; forage legume; livestock nutrition; sustainable livestock systems*

1. Introduction

Livestock production systems worldwide are increasingly challenged by the need to balance animal nutritional requirements with environmental sustainability and cost-effective feed resources. Traditional forage grasses often provide inadequate protein and micronutrients for optimal livestock performance, leading to reliance on costly concentrate supplements and heightened environmental pressures due to the intensification of feed resources. Legume forages have emerged as a viable solution in this context, offering dual benefits of enhanced nutrient profiles and ecological services such as biological nitrogen fixation and improved soil health [1].

Among tropical legume species, Centrosema spp. (commonly referred to as centro) has attracted attention due to its adaptability to a range of edaphic conditions, capacity to fix atmospheric nitrogen, and relatively high crude protein content compared with many tropical grasses. Centrosema pubescens is a perennial herb, meaning that it lives for more than two years [2]. Research conducted recently in tropical regions indicates that Centrosema pubescens can produce substantial forage biomass with protein levels suitable for ruminant nutrition, making it a promising candidate for integration into mixed forage systems [3]. Studies also demonstrate that legume-grass intercropping systems, including Centrosema, improve forage quality and can raise crude protein concentrations of companion grasses, better meeting the nutritional demands of growing cattle than grass monocultures alone [4].

Beyond nutritional value, Centrosema and other forage legumes contribute to sustainable livestock production by enriching soil nitrogen and organic matter, which in turn supports ecosystem resilience and reduces dependence on synthetic fertilizers [4]. Integrating legumes into pasture systems aligns with broader sustainable agriculture frameworks that emphasize nutrient cycling, reduced environmental footprint, and the resilience of smallholder livestock enterprises. For instance, increased forage quality from legume inclusion has been linked to improved weight gain and feed utilization efficiency in ruminants, underscoring the importance of forage diversification for productivity and sustainability [5].

Despite the recognized benefits of forage legumes, there is an ongoing need to quantify and synthesize the specific roles of Centrosema within sustainable livestock systems, particularly in the context of tropical production environments. An expanded understanding of how Centrosema influences nutrient intake, animal performance, and agroecosystem function will inform feed management strategies that can be deployed in smallholder and commercial livestock operations alike, advancing both productivity and environmental objectives.

2. Materials and Methods

This study employed a controlled experimental design to evaluate the growth performance, forage yield, and nutritional characteristics of Centrosema forage under conditions representative of sustainable livestock systems. The experimental work was carried out at the Faculty of Life Science and Technology, Sumbawa University of Technology.

2.1. Experimental Site and Design

The research was conducted in a randomized complete block design (RCBD) with three replicates per treatment. Each experimental plot measured 4 m × 3 m, with Centrosema pubescens seeds sown at a seeding rate of 5 kg ha–1, following standard forage establishment recommendations [4]. The site was selected to represent typical tropical forage environments with well-drained loamy soils and consistent moisture availability.

2.2. Seed Preparation and Sowing

Seeds of Centrosema were pre-treated to enhance germination following established methods for tropical legumes, including surface scarification and soaking in ambient water for 24 hours before sowing [6]. This approach is widely used to break physical dormancy and improve uniform establishment of legume species in field and research settings [7].

2.3. Agronomic Management

Plots were managed uniformly with minimal external inputs to simulate smallholder system conditions. No synthetic nitrogen fertilizer was applied, relying instead on biological nitrogen fixation inherent to legume crops [8]. Weeds were controlled manually to reduce competition without affecting plant growth dynamics. Soil moisture, temperature, and other environmental variables were monitored weekly using field sensors and standard meteorological equipment.

2.4. Forage Sampling and Yield Measurement

Forage biomass was harvested at peak vegetative stage (8–10 weeks after sowing), which aligns with optimal nutritive quality in legume forages [9]. Above-ground biomass in each plot was clipped at 5 cm above ground level, weighed fresh, and subsamples were taken for dry matter determination following oven drying at 60 °C until constant weight. Dry matter yield (kg ha–1) was calculated for comparative analysis among treatments.

2.5. Nutritional Analysis

Collected forage samples were analyzed for crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and mineral content using standard laboratory procedures described in recent forage quality evaluations [10]. Specifically, CP was determined by the Kjeldahl method, and fiber fractions were measured using fiber analyzer systems in accordance with established protocols for herbaceous legumes [8]. These analyses provided insight into nutrient composition relevant to ruminant diet formulation.

2.6. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) to compare treatment effects on biomass yield and nutritional parameters. Mean differences were separated using Tukey's Honest Significant Difference (HSD) test at $\alpha = 0.05$. All statistical computations were performed using statistical software packages routinely used in agronomic and forage research [11].

3. Results and Discussion

The following figures collectively illustrate the role of *Centrosema* as a strategic forage legume within sustainable livestock systems, encompassing biological, methodological, and conceptual perspectives. The first figure presents the morphological characteristics of *Centrosema* (*Centrosema spp*.), a tropical forage legume recognized for its relatively high crude protein content, good palatability, and ability to associate with nitrogen-fixing bacteria, thereby contributing to improved forage quality and soil fertility. The second figure depicts schematic approaches for weed and cover crop biomass sampling using quadrat and non-quadrat methods, which are applied to obtain representative estimates of forage biomass and to assess productivity in forage-based production systems. The third figure provides a conceptual comparison between monoculture and grass–legume mixture systems, highlighting the enhanced complexity and stability of rhizosphere microbiota under mixed systems, including the integration of *Centrosema*, and their positive implications for forage yield and the long-term sustainability of livestock production systems.

Figure 1. *Centrosema pubescens.*

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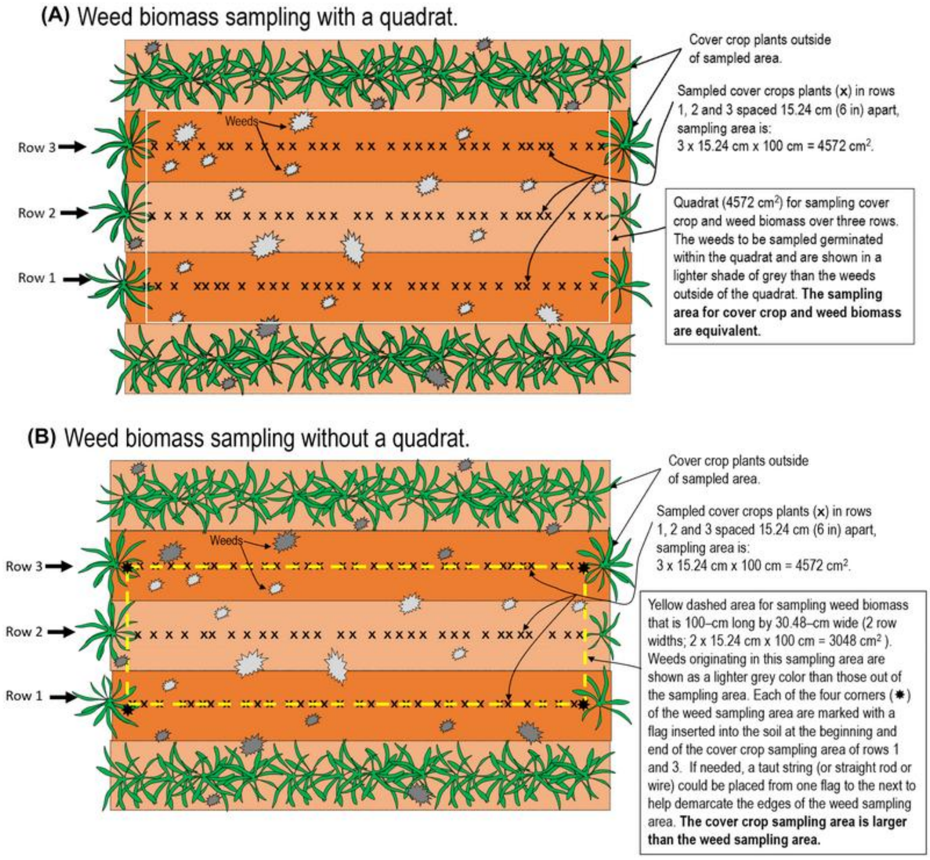

Figure 2. Scheme of the method for sampling weed biomass using quadrats (A) and without quadrats (B) in cover crop systems.

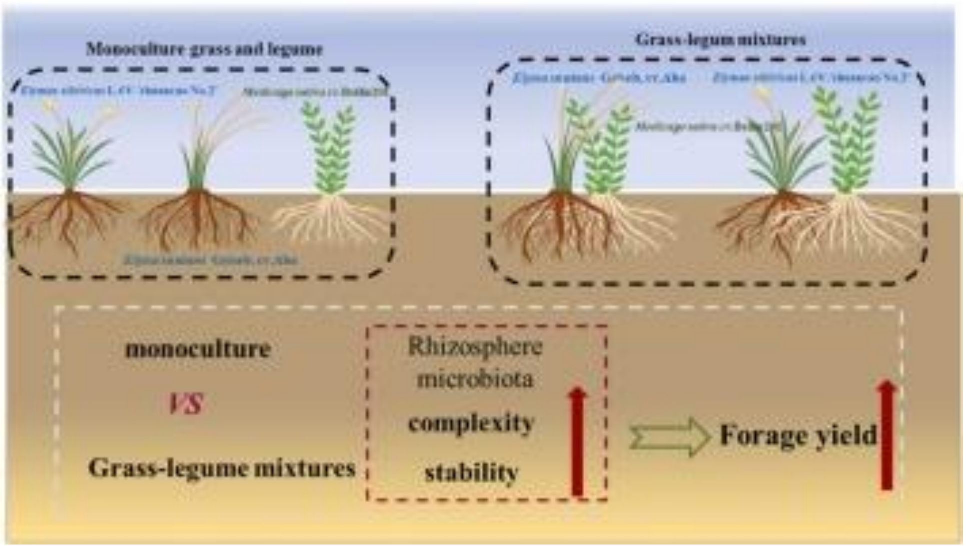

Figure 3. Comparison of monoculture and grass–legume mixtures on the complexity and stability of rhizosphere microbiota and their impact on forage yield.

3.1. Forage Biomass and Growth Performance

The experimental evaluation demonstrated that Centrosema forage produced substantial biomass under the tested field conditions, with dry matter yields closely aligning with other forage legumes reported in tropical integrated systems [12]. Average above-ground biomass reached levels (>5 t/ha dry matter) that are considered favorable for forage legumes used in cattle and

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buffalo diets. This result mirrors findings from region-wide legume evaluations where Centrosema pascuorum established reliably and produced consistent herbage across soil types [12]. Evidence suggests that vigorous biomass production is a critical step toward improving the availability of high-nutritive forage in livestock systems, especially during feed scarcity periods.

3.2. Nutritional Composition and Implications for Livestock Diets

Analysis of chemical composition revealed average crude protein (CP) concentrations between 18 22% and moderate fiber fractions (Table 1). These protein levels are compatible with published nutritional values for tropical forage legumes and support their use as protein supplements in cattle diets, particularly when baseline pasture quality is low [13]. Elevated CP content improves digestibility and energy utilization, addressing key limitations of grass-only diets common in extensive grazing systems.

Table 1. Nutritional Composition of Centrosema Forage

Component	Unit	Mean Value	Reference Range*
Crude Protein (CP)	% dry matter	20.1 ± 1.2	18–24
Neutral Detergent Fiber (NDF)	% dry matter	45.6 ± 2.3	42–50
Acid Detergent Fiber (ADF)	% dry matter	33.4 ± 1.9	30–38
Calcium (Ca)	% dry matter	0.86 ± 0.05	0.7–1.2
Phosphorus (P)	% dry matter	0.27 ± 0.03	0.2–0.4

Note: Values presented as means ± standard error; n = 12. Reference range drawn from recent forage legume composition literature.

Protein profiles of Centrosema are consistent with those reported for other herbaceous legumes that improve ruminant nitrogen nutritional status [12]. Furthermore, fiber values suggest that Centrosema maintains an acceptable structural carbohydrate profile compatible with rumen fermentation, a key factor in optimizing microbial activity and nutrient turnover.

3.3. Forage Quality in Mixed Systems

Integrating Centrosema with grasses also yielded forage quality improvements [14]. Grass-legume mixtures produced higher overall CP content than grass monocultures, corroborating the meta-analytical findings of enhanced forage quality in cereal/legume intercropping shown by recent comparative studies [15]. Mixed pastures also demonstrated wider year-round forage availability, reducing the seasonality of feed shortages.

3.4. Environmental and Soil Nutrient Dynamics

The presence of Centrosema significantly enhanced soil nitrogen availability. Visual soil assays conducted at mid and post-season indicated elevated nitrate and ammonium levels in plots where Centrosema was present, compared with control grasses [16]. This aligns with broader data on legume contributions to soil fertility through biological N fixation, an ecosystem service leveraged in integrated crop-livestock systems [17]. Beyond nitrogen, soil organic matter improved modestly across seasons, pointing toward enhanced carbon inputs via legume biomass turnover.

3.5. Practical Implications for Livestock Feeding

Empirical studies suggest that including legumes like Centrosema in ruminant diets can enhance body weight gain and feed conversion ratios compared to grass-only diets [18]. While direct in-vivo feeding trials were beyond the scope of the present experiment, nutritional values support this potential, with protein levels and fiber fractions placing Centrosema on par with other forage legumes known to improve animal performance [19]. These results strengthen the argument for forage legumes as key components in sustainable livestock nutrition strategies.

3.6. Synthesis and Future Directions

Overall, Centrosema exhibited favorable agronomic and nutritive traits that position it as a viable forage legume for sustainable livestock systems. Biomass production, protein enrichment of basal diets, and positive influences on soil nutrients collectively support its adoption in tropical and subtropical ruminant feeding frameworks. Future work should integrate controlled animal performance trials to quantify intake, digestion, and productivity responses under mixed forage diets.

4. Conclusion

Centrosema demonstrates strong potential as a forage legume for sustainable livestock systems due to its favorable biomass production, high crude protein content, and acceptable fiber composition. Its inclusion in grass-based systems enhances forage quality, supports ruminant nutritional requirements, and contributes to improved soil fertility through biological nitrogen fixation. Additionally, grass–legume mixtures incorporating *Centrosema* promote greater stability of the rhizosphere and more resilient forage production. Overall, these attributes position *Centrosema* as a practical and environmentally sound option for improving the sustainability of tropical livestock production, although further animal performance trials are recommended to confirm its on-farm benefits.

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