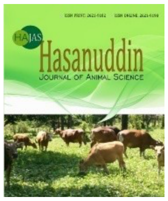

Hasanuddin J. Anim. Sci. Vol. 8, No. 1: 52-62
pISSN 2621-9182 eISSN 2621-9190
DOI: 10.20956/hajas.v8i1.45972

Optimizing Nutrient Supply for Dwarf Elephant Grass in Shaded Pine Forest

A. Irsyammawati*, I. Subagiyo, and V. Afrilia

Animal Science Faculty, Universitas Brawijaya, Indonesia
*Corresponding author: E-mail: artharini_19@ub.ac.id

How to Cite: A. Irsyammawati, I. Subagiyo, and V. Afrilia. 2026. Optimizing Nutrient Supply for Dwarf Elephant Grass in Shaded Pine Forest. Hasanuddin Journal of Animal Science, 8(1):52–62. https://doi.org/10.20956/hajas.v8i1.45972

ARTICLE INFO

Article history:
Submission: July 29, 2025
Accepted: May 03, 2026
Published: May 31, 2026

ABSTRACT

Pine forest undergrowth in tropical regions often remains underutilized despite its potential to alleviate forage deficits for ruminant livestock. This study explored whether moderate NPK fertilization could enhance the growth and quality of dwarf elephant grass (*Pennisetum purpureum cv. Mott*). A Completely Randomized Design were employed to test four fertilization levels 0 (T0), 3 g (T1), 6 g (T2), 9 g (T3) of NPK per cutting in a pine canopy environment, replicating each treatment three times. Key data included stem-to-leaf ratio, Neutral Detergent Fiber (NDF), and Acid Detergent Fiber (ADF). Soil nutrient status and microclimate (light intensity, temperature) were also monitored. Statistical analysis utilized ANOVA followed by multiple range tests. The results show that moderate fertilization (3 g and 6 g) increased leaf growth, yielding significantly lower stem-to-leaf ratios compared to the control and the highest fertilizer treatment (9 g). Moreover, NDF and ADF values rose with escalating fertilizer rates; at 9 g, fiber content was notably elevated, suggesting a decline in forage digestibility. Moderate NPK fertilization effectively leverages pine forest undergrowth for quality forage production by enhancing leaf growth without excessively increasing fiber content.

Keywords: Dwarf elephant grass, fertilizer, forage quality, pine forest

INTRODUCTION

Indonesia, recognized for its extensive archipelagic configuration and natural resource wealth, has long grappled with the sustainability of forested areas amid multiple land-use pressures [1]. Pine forests, totaling approximately 2.566.889 hectares on Java Island alone, are managed primarily by Perum Perhutani, yet sizable tracts of underused land remain beneath the canopy [2]. While these forest stands fulfill critical ecological functions, including carbon sequestration and soil protection, they also present untapped agricultural potential, particularly for forage production. Integrating forage crops under forest canopies aligns with broader agroforestry principles, in which a deliberate blending of trees and agricultural commodities can help reconcile forest conservation with the need for livestock feed [3]. Agroforestry approaches in various regions have shown promise in bolstering rural livelihoods without undermining ecological stability, given careful management of soil fertility, light interception, and plant diversification [4].

Pine stands in Java typically have low light beneath their canopies, which poses a challenge for conventional forage crops that rely on high photosynthetic rates. Nevertheless, shading regimes are known to moderate temperatures and may reduce evapotranspiration, benefiting certain shade-tolerant plant species [5]. Cultivating forages under these conditions addresses a critical gap, as livestock producers often face feed shortages, particularly in tropical areas where pastures can be depleted during dry seasons. Efforts to rehabilitate forest lands in East Java through agroforestry systems have highlighted the viability of integrating robust forage species that can flourish in partial shade [6]. In a global context, shade-grown forages have become a growing area of interest, spurred by the pursuit of farming practices that meet both productivity and environmental conservation targets [7].

Dwarf elephant grass (*Pennisetum purpureum cv. Mott*), also called Odot grass, has emerged as a strong candidate for shaded environments because of its adaptability and high nutritional value [8]. Studies highlight the grass's ability to produce a favorable stem-to-leaf ratio, a critical determinant of palatability and digestibility for ruminants [9]. However, limited light penetration beneath pine canopies can hinder growth and nutrient uptake [10]. Adequate fertilization may mitigate some of these drawbacks, but the question remains how best to calibrate fertilizer application without excessive stem biomass or detrimental increases in fiber content [11]. Under certain conditions, elevated nitrogen inputs can drive lignification, raise Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) concentrations, and thus compromise the forage's nutritive value [12].

Soil fertility in pine forests typically requires targeted interventions. In some shaded forest ecosystems, soils have high organic carbon but marginal levels of phosphorus and potassium, conditions that can limit plant growth if not properly managed [13]. These biochemical profiles underscore the importance of fertilizer regimes containing nitrogen, phosphorus, and potassium (NPK), as each macronutrient plays distinct and vital roles in plant metabolism [14] [15]. Indeed, nitrogen primarily supports leaf development and chlorophyll synthesis, phosphorus promotes root growth and energy transfer, and potassium enhances stress tolerance and overall physiological function. Yet an excess of these nutrients, especially under restricted light, can lead to imbalances in vegetative growth, with more biomass diverted to stems at the expense of leaves [16].

Numerous studies highlight the need for context-specific strategies. In Indonesia, the development of productive agroforestry frameworks is strongly shaped by soil type, land history, and climatic variability [17]. For example, soils with elevated carbon content can support high microbial biomass, although microbial nitrogen competition may limit plant availability [18]. Similar complexities arise in comparative analyses of suboptimal drylands, where the interplay between carbon cycling and nutrient dynamics shapes plant growth [17]. Meanwhile, empirical work in the eastern Brazilian Amazon underscores that shade-tolerant forest species can be strategically positioned within agricultural mosaics to maximize ecological services and feed production [5]. Experimental evidence from tropical forage legumes further shows that moderate shading can enhance nutrient concentration, although excessive shade often suppresses biomass [19]. Biostimulant applications under shade conditions have also shown promise for mitigating some of the negative effects of limited light [20]. These findings collectively suggest that partial shade regimes, if paired with well-tailored fertility programs, can sustain or even improve forage quality compared with conventional open-field systems [7].

Despite these encouraging insights, there remains a notable lack of data on how incremental variations in NPK affect the morphological and biochemical properties of Dwarf Elephant grass when grown under pine canopies [21]. While modest nitrogen inputs are likely to increase protein content and leaf production, higher doses may raise fiber fractions beyond acceptable thresholds for optimal rumen function [9]. Therefore, an optimal NPK threshold may exist, one that supports shoot expansion without triggering excessive stem elongation or lignification [11].

Previous studies on land rehabilitation in East Java suggest that carefully monitored agroforestry solutions can revitalize forest lands, generate economic benefits for local communities, and preserve ecological integrity [6]. Agroforestry's future role in restoring soil fertility and bolstering rural livelihoods depends on place-based research that refines management protocols [3]. In the central Himalayas, research shows that tree fostering can enhance microbial biomass and promote soil health, suggesting parallels with tropical pine systems, which also have similarly high organic matter [4]. Carbon accumulation in biomass and soil is also a top concern, given Indonesia's vulnerability to land degradation and the international emphasis on mitigating deforestation and greenhouse gas emissions [1] [17]. Thus, improvements in forage cultivation under pines could align with broader carbon conservation objectives by reducing the incentive to clear new land for grazing.

Balanced fertilization that accounts for local soil conditions, particularly in areas with low phosphorus and potassium, can be transformative for plant development without compromising environmental quality [12]. A body of research on best practices for nitrogen dosing, especially in partially shaded environments, consistently highlights the need to avoid exceeding the nitrogen threshold that triggers disproportionate proliferation of stem cell walls [14]. Meanwhile, potassium remains central to improving tolerance to abiotic stressors such as fluctuating shade levels and moisture availability [15].

Given this intricate web of environmental, agronomic, and socioeconomic considerations, investigating how varying rates of NPK fertilization shape the morphological and nutritional characteristics of dwarf elephant grass under pine canopies is an urgent priority. The current study builds on prior findings supporting the viability of dwarf elephant grass in shaded settings [8] and aims to clarify the relationship between fertilizer rates and fiber content and forage digestibility [21]. Identifying an optimal fertilization threshold will not only address feed shortages among ruminant livestock producers but also offer insights into how agroforestry practices can be integrated more systematically in forested regions. Such knowledge may amplify the conservation potential of shade-tolerant species while meeting local livelihood needs [5].

By bridging these facets of soil fertility, nutrient dynamics, plant physiology, and sustainable land management, this research has broader implications for forest land rehabilitation and integrated livestock systems [6] [7]. The anticipated outcomes could solidify agroforestry's position as a key mechanism for optimizing the use of underutilized forest areas, reconciling economic productivity with ecosystem health, and contributing to national agendas for reforestation and climate change adaptation [3]. As emerging research underscores, the viability of shaded forage cultivation depends on context, highlighting the importance of localized experimentation and carefully tailored fertilization regimes [19] [20]. Ultimately, the findings from this study aim to inform stakeholders, ranging from forest managers to livestock producers, about practical strategies for harnessing the benefits of partial-shade environments in ways that are both productive and environmentally sound.

MATERIALS AND METHODS

Experimental site and design

This study was conducted in the Universitas Brawijaya Forest in Donowarih Village, Karangploso Subdistrict, Malang Regency, Indonesia. The site features 21-year-old stands of pine (*Pinus merkusii*) spaced 3.5 × 6.0 m apart, creating a partially shaded environment suitable for forage cultivation trials. A Completely Randomized Design (CRD) was used to assess the effects of NPK fertilization on dwarf elephant grass *(Pennisetum purpureum cv. Mott*) grown under shade. Four fertilization treatments were replicated three times across 12 plots. Each experimental plot measured 4.80 × 0.40 m, with 0.50 m spacing between plots and 1.00 m between blocks. These buffer zones minimized the risk of nutrient seepage or plant interference across treatment boundaries [22].

Planting material and field preparation

Stem cuttings of dwarf elephant grass, each with at least two nodes, were selected for uniform size and vigor [8]. Before planting, the experimental area was cleared of weeds and tilled to a depth of about 20 cm. Planting density was standardized at 40 × 40 cm, with each cutting planted at a 45° angle to optimize root establishment. Two nodes were buried at a depth of 15 cm, leaving one node slightly above the soil surface. This configuration is widely accepted to promote rapid tillering in tropical forage species across a range of environmental conditions [15].

Fertilizer treatments

Four NPK levels (16% N, 16% P, 16% K) were tested: (i) no NPK application (T0/control), (ii) 3 g NPK per cutting (T1), (iii) 6 g NPK per cutting (T2), and (iv) 9 g NPK per cutting (T3). Fertilizer was applied on days 14, 24, and 34 after planting by incorporating granules into the soil around each plant. Hand-weeding was performed regularly to minimize competition. Watering was provided as needed to maintain adequate moisture, while avoiding excessive irrigation to prevent nutrient leaching. Throughout the trial, light intensity was measured daily at 08:00, 12:00, and 15:30 using a lux meter to capture diurnal variations under the pine canopy [10].

Data collection and analysis

1. Stem-to-leaf ratio

To quantify morphological responses, the stem-to-leaf ratio was measured at each harvest. Grass samples were cut 5 cm above ground level and then carefully separated into stems and leaves. The fresh weight of each fraction was recorded immediately to minimize bias from dehydration. The ratio was calculated as stem weight divided by leaf weight per sample [18]; [22].

2. Fiber content (NDF and ADF)

Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) analyses were conducted using the Van Soest method [23]. A 1-g sample of oven-dried, ground grass (1-mm sieve) was treated with the corresponding detergent solutions, following established fiber extraction protocols [20]. Post-filtration residues were dried at 105°C for eight hours, and NDF and ADF percentages were calculated by comparing residue weights to initial sample weights [11]. Elevated fiber levels typically reflect higher lignin and cellulose content, reducing overall digestibility [9].

Statistical analysis

Data were analyzed using Analysis of Variance (ANOVA) to assess the significance of differences among treatments [24] [25]. When significant effects were detected ($p<0.05$), Duncan's Multiple Range Test (DMRT) was used to compare treatment means [11].

RESULTS AND DISCUSSIONS

Initial soil analyses revealed high organic carbon (3.55%) and moderate total nitrogen (0.27%), yielding a C/N ratio of 13. The results of soil analyses from the Chemical Soil Laboratory, Agriculture Faculty, Universitas Brawijaya, are stated in Table 1.

Table 1. Result of soil analysis

Parameter	**Plant Nutrient**					
	Organic Carbon (%)	**N. Total (%)**	**C/N**	**Organic matter (%)**	**P (mg kg-1)**	**K (me/100g)**
Content	3.55% (High)	0.27% (Moderate)	13 (High)	6.15% (High)	3.06 (Very Low)	0.07 (Very Low)

Such values confirm the presence of relatively high organic matter but moderate nitrogen availability, consistent with typical conditions in partially disturbed pine forest ecosystems [13]; [26]. Phosphorus and potassium were found to be low, at 3.06 mg/kg and 0.07 me/100g, respectively. Low P and K levels suggest the potential need for external fertilization to bolster forage productivity [27].

These findings align with broader research highlighting soil constraints in pine-dominated landscapes, where the accumulation of acidic organic matter can limit nutrient availability [28] [29]. Consequently, the low phosphorus and potassium levels observed here are not unexpected under pine stands, which often require targeted fertilization to sustain agricultural crops [30].

Interestingly, plots receiving the maximum fertilizer dose (9 g per cutting) showed the greatest nutrient accumulation but also exhibited slight acidification, as reflected by a decrease in pH from 5.1 to 4.9. Previous work under pine stands has similarly reported that increased nitrogen inputs can accelerate soil acidification [31] [32]. Persistent acidification can reduce the availability of essential nutrients and potentially harm soil microbial communities [33] [34]. Although no severe pH drop was observed here, ongoing monitoring would be warranted if high fertilization rates were used over multiple growing cycles [30].

Light intensities recorded under the pine canopy averaged 6,128 lux, about 43.52% of open-field sunlight. Morning measurements ranged from 4,200–4,500 lux, peaked at midday (6,500–6,600 lux), and declined in the late afternoon (3,900–4,100 lux). This reduction in irradiance is typical of pine stands of moderate density [5] [7]. Shade-induced variations in light regimes affect photosynthetic potential, thereby influencing the morphological and biochemical adaptations of forages [19].

Past research indicates that reduced light availability can intensify competition among plant shoots for resources, particularly when nutrient levels are elevated [32]. For instance, some plant species respond to reduced light by redirecting assimilates from leaves to stems to elevate their canopy position [35]. The interplay between available nutrients and diminished radiation often drives distinct outcomes in plant morphology [36] [37].

Diurnal temperature readings showed mild fluctuations, with an average morning temperature near 21.8°C, rising to about 25.0°C at midday, and settling at approximately 23.1°C in the evening. These temperatures are relatively moderate for tropical lowland conditions and do not appear to pose a major stressor for grass growth [38]. The slight midday peak is consistent with partial shading, in which canopy cover mitigates extreme temperature surges, potentially benefiting plant development [39].

Stem-to-leaf ratio

The stem-to-leaf ratio is a reliable indicator of forage quality because leaves generally provide more digestible nutrients than stems [37]. Analysis of variance (ANOVA) showed highly significant differences ($p < 0.01$) among treatments in the stem-to-leaf ratio (Table 2).

Table 2. Average stem to leaf ratio

Treatment	Parameters		
	Leaf (%)	Stem (%)	Stem to leaf ratio
T0	55.65±2.20^{ab}	44.35±2.20^{ab}	0.80±0.07^{ab}
T1 (3 g NPK/cutting)	64.49±4.67^{b}	35.51±4.67^{a}	0.55±0.12^{a}
T2 (6 g NPK/cutting)	61.68±4.38^{b}	38.32±4.38^{a}	0.63±0.11^{a}
T3 (9 g NPK/cutting)	51.31±0.77^{a}	48.69±0.77^{b}	0.95±0.03^{b}

The 3 g (T1) and 6 g (T2) fertilization treatments resulted in lower ratios of 0.55±0.12 and 0.63±0.11, respectively, indicating a more balanced distribution of leaf and stem material [16]. Meanwhile, the control (no NPK) exhibited a ratio of 0.80±0.07, whereas the highest fertilization rate (9 g) yielded the highest ratio at 0.95±0.03.

These findings confirm that moderate NPK application effectively promotes leaf proliferation while curbing stem overextension, a pattern echoed by prior studies on forage management [40]. By contrast, excessive fertilization appears to accelerate stem elongation, resulting in proportionally fewer leaves [12] [32]. Plant physiological mechanisms likely involve nitrogen-driven upregulation of cell division in stem internodes when resource availability exceeds photosynthetic capacity [35]. This morphological shift can be detrimental to overall forage palatability, underscoring the need to calibrate fertilizer inputs [9].

Under suboptimal light conditions, an elevated stem-to-leaf ratio may reflect the plant's adaptive response to shade, such as seeking better light capture by elongating stems [19] [32]. Although dwarf elephant grass can tolerate moderate shading, excessive NPK inputs appear to exacerbate the elongation response, resulting in a disproportionate increase in the stem fraction [15]. This interaction highlights that fertilization under pine canopies requires a refined balance to avoid undue stimulation of vertical growth, which would undermine the forage's nutritive value [3].

Fiber content (NDF and ADF)

Neutral Detergent Fiber (NDF), which encompasses cellulose, hemicellulose, and lignin, increased with fertilizer application. As shown in Table 3, NDF values were lowest in the control plots (56.79±0.21%) and highest in the 9 g fertilization plots (62.41±0.75%). The 3 g and 6 g treatments produced intermediate values (57.11±0.60% and 60.44±0.35%, respectively). Statistical analysis confirmed that these differences were significant ($p < 0.01$).

This pattern supports the hypothesis that elevated nitrogen inputs favor structural carbohydrate deposition, consistent with earlier findings in tropical grasses [11] [36]. NDF increases reduce forage digestibility, suggesting that the net nutritional gains from fertilization may plateau or even reverse beyond certain thresholds [40] [32].

Table 3. NDF and ADF for all the treatments

Treatment	NDF (%)	ADF (%)
T0 (Control)	56.79 ± 0.21^{a}	35.26 ± 0.11^{a}
T1 (3 g NPK/cutting)	57.11 ± 0.60^{a}	36.22 ± 0.28^{b}
T2 (6 g NPK/cutting)	60.44 ± 0.35^{b}	38.55 ± 0.83^{c}
T3 (9 g NPK/cutting)	62.41 ± 0.75^{c}	41.84 ± 1.08^{d}

Note: Different superscript letters within a column denote significant differences ($p< 0.01$).

In parallel, Acid Detergent Fiber (ADF), comprising cellulose and lignin but excluding hemicellulose, also increased with fertilization intensity. The T3 (9 g treatment) produced the highest ADF content (41.84±1.08%), notably greater than the control's 35.26±0.11% ($p<0.01$). The surge in ADF with increased NPK supply aligns with previous reports linking elevated lignin to excessive nitrogen levels [12] [41]. Additionally, the synergy between nitrogen and shading conditions can exacerbate lignification, underscoring the nuanced interplay of environmental and nutritional factors [32] [42]. In practical terms, higher ADF reduces forage digestibility and can lead to declines in voluntary feed intake by ruminants [9]. With each incremental rise in NPK rate, the potential advantage in total biomass can be partially offset by less favorable fiber attributes [37] [40]. Consequently, these findings highlight the need to moderate fertilizer inputs to maintain an acceptable balance between yield and quality [43].

CONCLUSIONS

Moderate fertilizer applications (3 g and 6 g per cutting) significantly enhanced leaf production and maintained comparatively lower fiber levels (NDF and ADF), thereby improving palatability and digestibility. Conversely, excessive fertilization (9 g per cutting) increased biomass but also proportionately elevated stem elongation and fiber content, potentially undermining forage utility for ruminants.

ACKNOWLEDGEMENT

The authors would like to thank Brawijaya University for facilitating this experiment.

AUTHORS' CONTRIBUTIONS

All authors contributed to this experiment.

COMPETING INTERESTS

The authors declared that there is no conflict of interest

ETHICAL CLEARANCE

This research does not require ethical clearance because it does not involve the use of animals.

REFERENCES

[1] K. Austin, A. Schwantes, Y. Gu, and P. Kasibhatla, „What causes deforestation in Indonesia?", Environmental Research Letters, Vol. 14, No. 2, pp. 024007, 2019. DOI https://doi.org/10.1088/1748-9326/aaf6db

[2] Wikipedia, "Perhutani", 2025. https://id.wikipedia.org/wiki/Perhutani

[3] P. Paris, F. Camilli, A. Rosati, A. Mantino, G. Mezzalira, C.D. Valle, A. Franca. G. Seddaiu, A. Pisanelli, M. Lauteri, A. Brunori, G.A. Re, F. Sanna, G. Pagaglini, M. Mele, V. Ferrario, and P.J. Burgess, "What is the future for agroforestry in Italy?", Agroforestry Systems, Vol. 93, No. 6, pp. 2243-2256, 2019. https://doi.org/10.1007/s10457-019-00346-y

[4] S. Bargali, and K. Padalia, "Effects of tree fostering on soil health and microbial biomass under different land use systems in the central Himalayas", Land Degradation and Development, Vol. 30, No. 16, pp. 1984-1998, 2019. DOI https://doi.org/10.1002/ldr.3394

[5] I.D. Vale, I.S. Miranda, D. Mitja, A.M. Santos, G.G.A.D. Santos, F.M. Leão, M.G. Oliveira, and L.G.D.S. Costa, "Conservation potential of shade-tolerant forest species in agricultural mosaics in the eastern Brazilian Amazon", Acta Amazonica, Vol. 50, No. 2, pp. 124-132, 2020. DOI https://doi.org/10.1590/1809-4392201902772

[6] I.R. Puspitawati and A. Susanto, "Potential plants developed with agroforestry system for forest land rehabilitation in East Java", International Journal of Science and Environment (IJSE), Vol. 2, No. 1, pp. 40-46, 2020. DOI https://doi.org/10.51601/ijse.v2i1.15

[7] J.R.M. Pezzopane, A.C.D.C Bernardi, M.V. Azenha, P.P.A. Oliveira, C. Bosi, A.D.F. Pedroso, and S.N. Esteves, "Production and nutritive value of pastures in integrated livestock production systems: shading and management effects", Scientia Agricola, Vol. 77, No. 2, p. E20180150, 2020. DOI https://doi.org/10.1590/1678-992x-2018-0150

[8] H. Purwawangsa dan B.W. Putera, "Pemanfaatan lahan tidur untuk penggemukan sapi", Risalah Kebijakan Pertanian dan Lingkungan, Vol. 1, No. 2, pp. 92-96, 2014. DOI: 10.20957/jkebijakan.v1i2.10299

[9] R. Polakitan, and B. Kairupan, "Pertumbuhan dan produktivitas Rumput Gajah Dwarf (*Pennisetum purpureum* cv.Mott) pada umur potong berbeda", Jurnal Zootek, Vol. 34, No. 2, pp. 124-129, 2010.

[10] A. Kurniawati, K.L. Darusman, R.Y. Rachmawaty, ”Indian Pennywort (*Centella asiatica L.* (Urban)) growth, yield, and triterpenoid content as medicinal substance on various levels of shadin”, Bul. Agron, Vol. 33, pp. 62-67, 2005. DOI: https://doi.org/10.24831/jai.v33i3.1267

[11] R. Muhakka, N. Yani, and A. Abdullah, “Pengaruh pemberian pupuk cair terhadap kandungan NDF, ADF, kalium, dan magnesium pada rumput gajah Taiwan”, Jurnal Peternakan Sriwijaya, Vol. 3, No. 1, pp. 47-54, 2014.

[12] A. Budiman, L. Nurhayati, and E. Fatchiyah, ”Total non-structural carbohydrate (TNC) of three cultivars of Napier Grass (*Pennisetum purpureum* Schum) at vegetative and generative phase”, Journal of the Indonesian Tropical Animal Agriculture, Vol. 36, No. 2, pp. 126-130, 2012. DOI: https://doi.org/10.14710/jitaa.36.2.126-130

[13] B. Bachtiar. “Ilmu tanah”. Fakultas Pertanian, Universitas Sumatra Utara, Medan, Indonesia, 2006.

[14] E. Kurniawan, ”Kandungan protein kasar dan serat kasar Rumput Gajah Mini *(Pennisetum purpureum cv. Mott)* yang dipupuk dengan pupuk organik cair”, [Skripsi] Fakultas Peternakan, Universitas Hasanuddin, Makassar, Indonesia, 2016.

[15] S. Murni, D. Suslam, and A. Latifa, ”Pengaruh level pupuk N,P,K terhadap komponen tanaman *Brachiaria humidicola Cv.Tully* dan *Pennisetum purpureum cv.Mott* di areal pertanaman kelapa”, Jurnal Zootek, Vol. 34, No. 2, pp. 124-129, 2002.

[16] I. Supardi, ”Pengaruh pemberian cendawan Mikoriza arbuskula (Cma) dan pupuk terhadap pertumbuhan dan produksi rumput *Brachiaria decumbens Stapf*”, [Skripsi] Fakultas Peternakan Institut Pertanian Bogor, Bogor, Indonesia, 2001.

[17] S. Sufardi, S. Syafruddin, T. Arabia, K. Khairullah, and H. Umar, “Comparison of carbon content in soil and biomass in various types of sub-optimal dryland use in Aceh Besar, Indonesia”, IOP Conf. Ser.: Earth Environ. Sci., Vol. 1116, p. 012049, 2022. DOI https://doi.org/10.1088/1755-1315/1116/1/012049

[18] Sufriyanto, H.S. Hastuti, D. Prabowo, S.J.A. Setyawati, E. Yuwono, J. Andriyani, and Pudjiarti, “Optimalisasi pupuk cair urine sapi bunting dan slurry biogas metode nanometer untuk meningkatkan produktivitas Rumput Gajah”, Prosiding Seminar Nasional, Pengembangan Sumber Daya Pedesaan dan Kearifan Lokal Berkelanjutan II, p. 204-208, 2012.

[19] F. Lista, B. Deminicis, J. Almeida, S. Araújo, and P. Zanella, “Forage production and quality of tropical forage legumes submitted to shading”, Cienc. Rural, Vol. 49, No. 7, p. E20170726, 2019. DOI https://doi.org/10.1590/0103-8478cr20170726

[20] M. Lopes, M. Dias-Filho, T. Castro, E. Gurgel, and G. Silva, “Efficiency of biostimulants for alleviating shade effects on forage grass”, Journal of Agricultural Studies, Vol. 9, No. 3, pp.14-30, 2021. DOI https://doi.org/10.5296/jas.v9i3.18833

[21] M. Zainuddin, “Pengaruh pemberian bokashi kotoran sapi terhadap pertumbuhan dan produksi Rumput Gajah Mini (*Pennisetum purpureum* cv. Mott)”, [Skripsi] Fakultas Peternakan, Universitas Hasanuddin, Makassar, Indonesia, 2015.

[22] P. Rodrigues, “Productive traits and nutritional value of Urochloa ruziziensis submitted to different planting densities and defoliation intensities”, Arquivo Brasileiro De Medicina Veterinária E Zootecnia, Vol. 75, No. 5, pp. 1005-1015, 2023. DOI https://doi.org/10.1590/1678-4162-12976

[23] P.J.V. Soest, “Nutritional ecology of the ruminant”, Commstock Publishing Associates, A Division of Cornell University Press, Ithaca and London, 1982.

[24] A. Filho, D. Silveira, M. Loregian, L. Osmari, and V. Ortiz, “Experimental design and precision in trials with black oat, common vetch, and forage turnip intercropping”, Revista Brasileira De Ciências Agrárias - Brazilian Journal of Agricultural Sciences, Vol. 17, No. 2, pp. 1-8, 2022. DOI https://doi.org/10.5039/agraria.v17i2a129

[25] D. Kim, G. Kim, S. Lee, J. Park, and W. Lee, ”Optimization of growth conditions for forage production in a fresh forage growing system”, Emirates Journal of Food and Agriculture, Vol. 31, No. 10, pp. 759-769, 2019. DOI https://doi.org/10.9755/ejfa.2019.v31.i10.2016

[26] U. Abdullah, “Soil quality index analysis of pine forest land use types on dryland in Aceh Besar regency”, Jurnal Penelitian Pendidikan IPA, Vol. 10, No. 6, pp. 2971-2977, 2024. DOI https://doi.org/10.29303/jppipa.v10i6.7228

[27] A.O. Adekiya, W.S. Ejue, A. Olayanju, O. Dunsin, C.M. Aboyeji, C. Aremu, K. Adegbite, and O. Akinpelu, “Different organic manure sources and NPK fertilizer on soil chemical properties, growth, yield, and quality of Okra”, Scientific Reports, Vol. 10, p. 16083, 2020. DOI https://doi.org/10.1038/s41598-020-73291-x

[28] A. Klimek, S. Rolbiecki, R. Rolbiecki, G. Gackowski, P. Stachowski, and B. Jagosz, “The use of wood chips for revitalization of degraded forest soil on young scots pine plantation”, Forests, Vol. 11, No. 6, p. 683, 2020. DOI https://doi.org/10.3390/f11060683

[29] V. Manral, S. Bargali, and C. Shahi, “Changes in soil biochemical properties following replacement of banj oak forest with chir pine in central Himalaya, India”, Ecol. Process, Vol. 9, p. 30, 2020. DOI https://doi.org/10.1186/s13717-020-00235-8

[30] Y. Fan, L. Liu, C. Wu, G. Yu, Z. Wang, J. Fan, and C. Tu, “The effect of regulating soil pH on the control of pine wilt disease in a black pine forest”, Forests, Vol. 14, No. 8, p. 1583, 2023. https://doi.org/10.3390/f14081583

[31] Z. Yang, X. Wu, L. Huang, W. Xie, Y. Chen, Y. El-Kassaby, and J. Feng, “Soil bacteria to regulate Phoebe bournei seedling growth and sustainable soil utilization under NPK fertilization”, Plants, Vol. 10, No. 9, p. 1868, 2021. DOI https://doi.org/10.3390/plants10091868

[32] Y. Liang, C. Cossani, V. Sadras, Q. Yang, and Z. Wang, “The interaction between nitrogen supply and light quality modulates plant growth and resource allocation”, Front. Plant Sci., Vol. 13, p. 864090, 2022. DOI https://doi.org/10.3389/fpls.2022.864090

[33] W. Jiang, L. Gong, L. Yang, S. He, and X. Liu, “Dynamics in c, n, and p stoichiometry and microbial biomass following soil depth and vegetation types in low mountain and hill region of China”, Sci. Rep., Vol. 11, p. 19631, 2021. DOI. https://doi.org/10.1038/s41598-021-99075-5

[34] M. Spohn and J. Stendahl, “Carbon, nitrogen, and phosphorus stoichiometry of organic matter in Swedish forest soils and its relationship with climate, tree species, and soil texture”, Biogeosciences, Vol. 19, No. 8, pp. 2171-2186, 2022. DOI https://doi.org/10.5194/bg-19-2171-2022

[35] S. Chai, J. Chen, X. Yue, C. Li, Q. Zhang, V.R.D. Dios, Y. Yao, and W. Tan, “Interaction of bes1 and lbd37 transcription factors modulates brassinosteroid-regulated root forging response under low nitrogen in Arabidopsis”, Front. Plant Sci., Vol. 13, p. 998961, 2022. DOI https://doi.org/10.3389/fpls.2022.998961

[36] M. Lopes, M. Cândido, R. Pompeu, R. Silva, C. Lacerda, and F. Bezerra, "Yield and chemical composition of massai grass fertilized with nitrogen", International Journal of Agriculture and Natural Resources, Vol. 47, No. 2, pp. 69-78, 2020. DOI https://doi.org/10.7764/ijanr.v47i2.2068

[37] V. Neville, "You are how you eat: foraging behavior as a potential novel marker of rat affective state", Affective Science, Vol. 5, No. 3, pp. 232-245, 2024. DOI https://doi.org/10.1007/s42761-024-00242-4

[38] M. Ferreira, R. Esser, G. Santos, and R. Tavares, "Agronomic performance of *Urochloa brizantha cv. marandu* cultivated in clayey and sandy soil submitted to water and nutritional management", Revista Engenharia Na Agricultura-Reveng, Vol. 29, pp. 179-191, 2021. DOI https://doi.org/10.13083/reveng.v29i1.12468

[39] M. Lopes, M. Cândido, R. Pompeu, R. Silva, M. Carneiro, L. Neto, and T. Carvalho, "Biomass components and structure of massai grass fertilized with nitrogen and grazed by sheep", Arquivo Brasileiro De Medicina Veterinária E Zootecnia, Vol. 71, No. 4, pp. 1411-1420, 2019. DOI https://doi.org/10.1590/1678-4162-10051

[40] H. Rusch, "Nitrogen fertilization and genotype jointly drive bermudagrass (*cynodon spp.*) productivity but are not associated with differences in soc", Agrosystems Geosciences & Environment, Vol. 6, No. 3, p. e20412, 2023. DOI https://doi.org/10.1002/agg2.20412

[41] K. Hemida, A. Eloufey, G. Hassan, and M. Rady, "Integrative soil and leafy application of NPK fertilizers improves growth, yield, antioxidant, and nutrient status of *Capsicum annuum l. 2.* under loamy soil conditions", Fayoum Journal of Agricultural Research and Development, Vol. 34, No. 2, pp. 31-45, 2020. DOI https://doi.org/10.21608/fjard.2020.189852

[42] D. Astuti, B. Suhartanto, N. Umami, and A. Irawan, "Productivity, nutrient composition, and hydrocyanic acid concentration of super-2 forage sorghum at different NPK levels and planting spaces", Tropical Animal Science Journal, Vol. 42, No. 3, pp. 189-195, 2019. DOI https://doi.org/10.5398/tasj.2019.42.3.189

[43] M. Ghosh, W. Ashiq, H. Vasava, D. Gamage, P. Patra, and A. Biswas, "Short-term carbon sequestration and changes of soil organic carbon pools in rice under integrated nutrient management in India", Agriculture, Vol. 11, No. 4, p. 348, 2021. DOI https://doi.org/10.3390/agriculture11040348