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Effect of organic manure on growth and yield of dwarf late napiergrass on rocky marginal land

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Abstract. *Wadi A, Akhsan F, Basri. 2025. Effect of organic manure on growth and yield of dwarf late napiergrass on rocky marginal land. Asian J Agric 9: 727-738.* The use of organic manure is a sustainable strategy to improve forage production on low-fertility soils. This study evaluated the effect of different manure application levels on the growth and yield of Dwarf Late napiergrass (DL Napiergrass) cultivated on marginal land under a cut-and-carry system. The field experiment was conducted over two years in Galung Village, Barru District, South Sulawesi, Indonesia, using a randomized block design with four manure treatments: control (0.00), low (1.38), medium (2.88), and high (4.67 g N m^{-2} per application), replicated three times. Manure was applied five times annually, and growth parameters, dry matter yield, nutrient content, and soil characteristics were measured. Data were analyzed using ANOVA and Duncan's Multiple Range Test (DMRT), while regression analysis assessed the relationship between Leaf Area Index (LAI) and Crop Growth Rate (CGR). Results showed that manure application significantly ($P<0.05$) enhanced plant height, tiller number, dry matter yield, and nutrient uptake compared with the control. The highest biomass production was obtained with high-level manure, yielding 33.98 tons/ha/year in the first year and 21.84 tons/ha/year in the second. Soil pH, nitrogen, and phosphorus also improved under manure treatments. LAI and CGR were strongly correlated, while the leaf blade-to-stem ratio remained unchanged. In conclusion, applying 4.67 g N m^{-2} of organic manure per cycle is recommended to optimize DL Napiergrass productivity and soil fertility on marginal land, contributing to sustainable livestock feed production.

Keywords: Dwarf late napiergrass, manure-based fertilization, marginal land

INTRODUCTION

Marginal land areas with limited agricultural value due to poor soil quality, adverse ecological conditions, or geotechnical hazards holds significant potential for forage production. Rocky infertile soils, lacking essential nutrients and organic matter, exemplify such marginal land Previous studies have shown that marginal land can increase livestock production through the development of pastures (Guimarães et al. 2022), mitigate environmental problems through forage cultivation (Zegada-Lizarazu et al. 2022), and support rural economies by producing energy without competing with food production (Ali et al. 2024).

Dwarf Late Napiergrass (DL Napiergrass), a fast-growing perennial forage, enables continuous high-quality feed supply through multiple annual harvests. As a tropical feed crop, DL Napiergrass is widely known for the high biomass yield, with a crude protein content of 10-15% and a digestibility rate of dry matter above 70% (Utamy et al. 2021). It also has good adaptability to winter conditions and better ensilage ability compared to sorghum and sudangrass (Fukagawa et al. 2016). The high leaf-to-stem ratio provides a higher nutritional value, as the leaf contains more digestible nutrients compared to the stem (Rahman et al. 2019). However, DL Napiergrass may be inadequate when used as a sole feed, limiting the production of ruminant livestock (Islam et al. 2024). Despite its limitations, this economical grass requires fewer inputs for high biomass on marginal land and serves as bioenergy feedstock (Sacristán et al. 2021). The strong root system also contributes to improved soil health over time by enhancing the structure and nutrient retention (Bates et al. 2022).

Livestock manure, rich in nutrients and organic matter, enhances soil phosphoric acid content and availability while supporting sustainable grassland ecosystems (Lu et al. 2020). Livestock manure, an eco-friendly organic fertilizer, improves soil physical, chemical, and biological properties while enhancing plant growth, with long-term use significantly increasing nitrogen and phosphorus levels (Kolbe 2022). Livestock manure increases DL Napiergrass dry matter yield proportionally to application rates, outperforming mineral fertilizers by 7.6% in acidic, humid climates (Du et al. 2020). Chicken manure achieves the highest crop productivity, while long-term livestock manure application improves soil organic matter and nutrient availability to sustain high yields (Ning et al. 2022).

Marginal land in Indonesia remains underused due to poor soil quality, nutrient deficiencies, and water limitations, necessitating significant attention (Leroy et al. 2022). Manure application on low-yield, nutrient-deficient marginal land is a common practice to improve soil physical, chemical, and biological properties (Selim 2020). In general, productivity is limited in degraded and contaminated marginal land (Ning et al. 2022). Traditional agricultural management on marginal land is often hampered by low nutrient levels and poor soil structure (Jayawardena et al. 2023). Integrated manure and conventional fertilizer application in napiergrass plantations significantly improves soil fertility, nutrient availability, microbial activity, and crop productivity (Dhaliwal et al. 2021).

While DL Napiergrass shows high production potential, meeting rising livestock feed demands on marginal land requires fertilization beyond the 4.67 g N/m² baseline, warranting further research on effective strategies (Pereira et al. 2022). Napiergrass is a type of grass widely used in tropical countries as ruminant animal feed (Tresia et al. 2024). DL Napiergrass, valued for its high biomass and crude protein content, thrives on low-fertility marginal land (Jayawardena et al. 2023). However, the production potential can be optimized with proper maintenance management (Scordia et al. 2022). Low-quality grass production stems from inadequate nutrition, necessitating balanced nutrient management (Scordia et al. 2022).

Livestock manure application is a potential strategy to enhance DL Napiergrass productivity and improve marginal land functionality. However, the approach has not been widely investigated by previous studies. Samara et al. (2020) reported that crop productivity can be increased with livestock manure, but excessive use may also cause nutrient imbalance. The study only focused on corn crops and not marginal land, underscoring the need to determine the appropriate dosage of livestock manure in the cultivation of DL Napiergrass on marginal land. Therefore, this study aims to determine the appropriate dosage of livestock manure used in the maintenance of DL Napiergrass planted on marginal land to increase productivity, Total Nitrogen (T-N), and Total Phosphoric acid (T-P) content. It was assumed that the higher the concentration of manure used, the greater the growth and production of DL Napiergrass.

MATERIALS AND METHODS

Study area

This study was conducted in an experimental field in Galung Village, within the Barru District, South Sulawesi Province, Indonesia. The location was selected as one of the areas with marginal land in Galung Village, and the climate was tropical. The initial condition of marginal land is presented in Table 1.

Procedures

Planting method

This study was conducted for two years under natural environmental conditions. DL Napiergrass was cultivated by transplanting stem cuttings on two plants per square meter in November 2021 until October 2023. The plot was set in a Latin square arrangement for manure application with a size of 3×3 meter. The total plots used are 12 plots.

Study design

The study uses a randomized complete block that is designed based on the year of plant growth and production measurements, characterized by three levels of manure application, each replicated three times. Manure was applied at four different levels, namely 0.00 (control), 1.38 (low), 2.88 (medium), and 4.67 (high) g N m^{-2} $time^{-1}$. Application to DL Napiergrass was consistent over the two years, with five times in the first year and five times in the second year. Fertilization is carried out five times a year to align with the growth cycle of DL Napiergrass, ensuring consistent nutrient availability during critical growth phases. Manure used was compost, and the nutrient content is presented in Table 2.

Plant sampling

Plant sampling was carried out four times during defoliation in both years. For each sampling event, three plants per plot were selected and cut 10 cm above ground level. The same process was carried out for the first, second, third, and fourth cuttings during the first and second years.

Table 1. Fresh weight, water, dry weight, Total Nitrogen (T-N), Total Phosphoric acid (T-P), and pH content of soil

Parameter	Content	Soil fertility index*
T-N Content (%)	0.17	0.21-0.5
T-P Content (%)	3.89	8-10
T-K Content (%)	0.03	0.4-0.5
pH	5.00	5.5-6.5

Note: *: Maro'ah et al. (2022)

Table 2. Changes in fresh weight, water content, dry weight, Total Nitrogen (T-N), Total Phosphoric acid (T-P), Total Potassium (T-K) content, and pH of manure in the first and second years

Year	Manure application level	Fresh weight (g)	Water content (%)	Dry weight (g)	T-N content (%)	T-P content (%)	T-K content (%)	pH
First	L	500.00±0.00^a	26.50±10.81^a	367.51±54.14^c	0.12±0.04^a	2.68±0.79^a	0.09±0.05^a	9.07±0.15^a
	M	1000.00±0.00^a	26.79±10.43^a	732.06±104.45^b	0.12±0.04^a	2.21±0.87^a	0.18±0.09^a	9.17±0.21^a
	H	1500.00±0.00^a	26.59±10.69^a	1101.21±160.75^a	0.16±0.05^a	2.05±0.89^a	0.26±0.14^a	9.21±0.23^a
Second	L	500.00±0.46^a	9.08±0.22^a	90.74±0.38^a	0.18±0.04^a	2.32±0.22^a	0.08±0.00^a	8.26±0.54^a
	M	1000.00±0.46^a	9.06±0.24^a	90.74±0.32^a	0.16±0.05^a	1.36±0.23^a	0.16±0.01^a	8.22±0.08^a
	H	1500.00±0.37^a	9.06±0.19^a	90.68±0.33^a	0.16±0.05^a	1.28±0.25^a	0.24±0.02^a	8.25±0.63^a

Note: Treatment: L: Low, M: Medium, and H: High manure level. ^{abc}: Different superscripts in the same column show noticeable differences (P<0.05)

Each section of the plant, namely the Leaf Blade (LB), the stem including the Leaf Sheath (ST), and the Dead portions (D), was carefully separated from the harvested plants. These parts were dried at 72°C to determine the dry matter weight, then growth traits, including plant height, length, and tiller count, were recorded during each sampling period. Furthermore, the leaf area was determined at each sampling interval using a handheld laser leaf area meter, specifically the CI-202 model (PT. Daya Teknik Meterindo, Indonesia).

Sampling of soil

Soil samples were collected from the border area between blocks 0-15 cm below the surface. Sampling was conducted with three replications, occurring three times in the first year and twice in the second year.

Chemical analysis of soil

During the experimental period from June to October, the soil pH was monitored monthly using compact pH meters (model pH-22, HORIBA Co. Ltd.). Furthermore, the chemical characteristics of the soil water, such as the levels of anions and cations, were examined using an ion analyzer (Model: IA-300, Toa-DKK Co. Ltd.).

Chemical analysis of plant

The nitrogen (N) content and total phosphoric acid (P) in each plant organ (leaves and stems) were measured over two years using a CN analyzer (Model: NC-220F; Sumigraph). The temperature used to turn fresh ingredients into dry ingredients is 70°C for 3×24 hours, then ground and continued at 105°C for 6 hours according to the AOAC procedure.

Data analysis

Data were tested with Analysis of Variance (ANOVA) using Microsoft Excel 2016 to determine the effect of treatment on the variables measured. Duncan Multiple Range Test (DMRT) was further used to determine the difference between treatments.

To test the relationship between Leaf Area Index (LAI) and Crop Growth Rate (CGR), a simple linear regression analysis was used. Simple linear regression analysis is used to predict a single dependent variable based on a single independent variable.

The regression equation relationship expresses simple regression analysis:

$$\hat{Y} = \alpha + bX$$

Where:

$\hat{Y}$: Subject in the predicted dependent variable

α: Y Value when X value = 0 (constant value)

b: Direction number or regression coefficient, which shows the increase or decrease of the dependent variable based on the change of the independent variable. Positive (+) when the direction of the line rises, and negative (-) when the direction of the line descends.

X: Subject on an independent variable that has a certain value.

RESULTS AND DISCUSSION

Soil conditions on marginal land

Soil conditions on marginal land were better with the use of manure in the first and second years. Fresh materials, water content, soil dry matter, total nitrogen, and total phosphoric tended to be the same in all treatments except for fresh weight in the first year. The statistical analysis showed that the treatment using manure dosage in the maintenance of DL Napiergrass had a significant effect ($P<0.05$) on fresh weight in the first-year measurement. All other observed parameters had no significant effect ($P>0.05$). Further test using Duncan showed that the medium and high concentrations were significantly different from the low and control concentrations. With higher concentrations, the weight of fresh DL Napiergrass tended to increase. The higher the level of manure, the more neutral the soil pH condition, as presented in Table 3.

By increasing manure concentration, the N and P content in the soil decreased due to the ability of plants to absorb these elements in the soil. In contrast to the pH value, the tendency to increase was observed with higher manure concentrations.

Total Nitrogen (T-N) and Total Phosphoric acid (T-P) in dwarf late napiergrass

The nutrient content of DL Napiergrass in each part appeared to be better with the use of manure. Based on the results, the Total Nitrogen content (T-N) and Total Phosphoric acid (T-P) tended to increase, followed by the elevated level of organic fertilizer use, as shown in Table 4. The trend of higher T-N and T-P occurred as manure concentrations increased. T-N showed the highest value on the leaf blade, while T-P was highest on the stem.

Plant growth with manure application at different levels

The higher use of manure on marginal land increased the growth rate of DL Napiergrass. Plant height, plant length, tiller number, and mean tiller weight increased with higher levels of manure, as shown in Figure 1. Plant height, plant length, tiller number, and mean tiller weight showed an increasing trend along with higher manure levels. More specifically, plant height and length showed a significant difference ($P<0.05$), specifically in the first three years of cutting. However, between medium and low manure concentrations did not provide a significant difference ($P>0.05$). The tiller number showed a significant difference ($P<0.05$) between all treatments. The higher the concentration, the greater the tiller number. The mean tiller number showed an increase ($P<0.05$) with higher manure concentration, specifically in the first cut of the first year.

Plant production with manure application at different levels

The production of dry matter per part of DL Napiergrass increased significantly ($P<0,05$) with a higher amount of manure use (Figure 2). Higher levels of manure increased leaf blade, stem, dead, and total dry matter weight compared to the treatment without manure. These parameters show an increasing trend along with higher concentrations of manure application. Leaf blade, stem, and dead, and total dry matter weight showed a significant difference (P<0.05) in all treatments except for dead dry matter weight. The second-year measurements showed almost the same trend for all treatments.

The total dry matter production on each part of DL Napiergrass is shown in Table 5. Leaf blade, stem, dead, and total dry matter weight increased with higher levels of manure concentrations in the first and second years (Figure 3). The total dry matter weight at high manure concentrations was significantly different compared to other treatments in the first and second years. The total dry matter weight had the highest value in the high-level manure application, at 33.98 tons/ha/year in the first year and 21.84 tons/ha/year in the second year.

Relationship between LAI and CGR

The higher the use of manure, the greater the LAI and the CGR. Meanwhile, the specific leaf area showed the same data for all treatments. Graphs of LAI, CGR, the ratio of leaf blade to stem, and specific leaf area calculations are presented in Figure 4. The LAI and CGR showed different results between all treatments. Based on the results, the LAI and CGR increased (P<0.05) along with higher concentrations of manure. The ratio of leaf blade to stem, and specific leaf area showed the same data for all treatments, specifically evident in the specific leaf area in the second-year measurement. LAI and CGR first and second years showed a very close relationship for all treatments. R2 is close to the number 1, which shows a very strong relationship. The relationship between LAI and CGR is presented in Figure 5.

Table 3. Variations were observed in the fresh weight, water content, dry weight, total nitrogen (T-N), total phosphoric acid (T-P) content, and soil pH levels of the soil in the first and second years

Year	Manure application level	Fresh weight (g)	Water content (%)	Dry weight (g)	T-N content (%)	T-P content (%)	pH
First	C	460.6±23.67^{b}	19.33±3.99^{a}	371.37±22.92^{a}	0.132±0.04^{a}	2.71±0.76^{a}	5.68±0.39^{a}
	L	464.6±22.78^{b}	19.32±4.09^{a}	374.87±26.07^{a}	0.127±0.04^{a}	2.61±0.73^{a}	5.92±0.52^{a}
	M	497.0±7.18^{a}	19.81±3.95^{a}	398.72±24.72^{a}	0.117±0.00^{a}	2.21±0.83^{a}	6.10±0.56^{a}
	H	493.2±15.32^{a}	19.21±4.35^{a}	398.74±29.97^{a}	0.108±0.00^{a}	2.07±0.88^{a}	6.33±0.69^{a}
Second	C	100.0±0.38^{a}	4.28±0.19^{a}	95.8±0.23^{a}	1.08±0.29^{a}	2.79±1.48^{a}	5.48±0.28^{a}
	L	100.0±0.32^{a}	4.30±0.29^{a}	95.7±0.10^{a}	1.06±0.27^{a}	2.72±1.49^{a}	5.42±0.19^{a}
	M	99.7±0.35^{a}	4.20±0.19^{a}	95.5±0.19^{a}	1.04±0.30^{a}	2.71±1.49^{a}	5.65±0.48^{a}
	H	99.9±0.47^{a}	4.24±0.27^{a}	95.7±0.33^{a}	1.00±0.32^{a}	2.69±1.35^{a}	5.59±0.52^{a}

Note: Treatment: C: No-manure, L: Low, M: Medium, and H: High manure level. ^{abc}: Different superscripts in the same column show noticeable differences (P<0.05)

Table 4. Variations in the Total Nitrogen (T-N) and Total Phosphoric acid (T-P) content of DL napiergrass were observed under different manure application rates in the first year

Plant part	T-N (%)				T-P (%)			
	October							
	Control	Low	Medium	High	Control	Low	Medium	High
Leaf blade	0.46±0.07^{b}	0.54±0.11^{ab}	0.58±0.03^{ab}	0.62±0.07^{a}	0.16±0.02^{a}	0.16±0.00^{a}	0.16±0.00^{a}	0.18±0.00^{b}
Stem	0.21±0.01^{d}	0.26±0.02^{c}	0.31±0.03^{b}	0.39±0.02^{a}	0.28±0.00^{c}	0.29±0.01^{c}	0.33±0.01^{c}	0.35±0.02^{c}
Dead	0.87±0.01^{c}	0.11±0.03^{bc}	0.14±0.00^{ab}	0.17±0.02^{a}	0.05±0.01^{b}	0.05±0.01^{b}	0.06±0.00^{b}	0.08±0.00^{a}

Note: ^{abc}: Different superscripts in the same column show noticeable differences (P<0.05)

Table 5. Changes in leaf blade dry matter weight, stem dry matter weight, dead dry matter weight, and total dry matter weight in DL Napiergrass under different treatments in the first and second year

Year	Manure application level	Leaf blade dry matter weight	Stem dry matter weight	Dead dry matter weight	Total dry matter weight
		ton/ha/year			
First	C	2.29±0.40^{d}	0.94±0.19^{c}	0.19±0.05^{c}	3.42±0.57^{d}
	L	4.93±0.59^{c}	2.23±0.34^{c}	0.54±0.21^{b}	7.69±0.92^{c}
	M	9.97±1.18^{b}	5.15±1.25^{b}	0.79±0.18^{b}	15.91±2.18^{b}
	H	18.69±2.21^{a}	13.90±5.02^{a}	1.39±0.54^{a}	33.98±6.69^{a}
Second	C	1.67±0.24^{d}	0.43±0.12^{d}	0.157±0.08^{c}	2.27±0.37^{d}
	L	4.61±0.73^{c}	1.65±0.28^{c}	0.38±0.20^{bc}	6.63±1.11^{c}
	M	8.20±0.97^{b}	3.04±0.61^{b}	0.64±0.29^{b}	11.90±1.60^{b}
	H	14.36±2.19^{a}	6.46±1.22^{a}	1.03±0.49^{a}	21.84±3.06^{a}

Note: Treatment: C: No-manure, L: Low, M: Medium, and H: High manure level. ^{abc}: Different superscripts in the same column show noticeable differences (P<0.05)

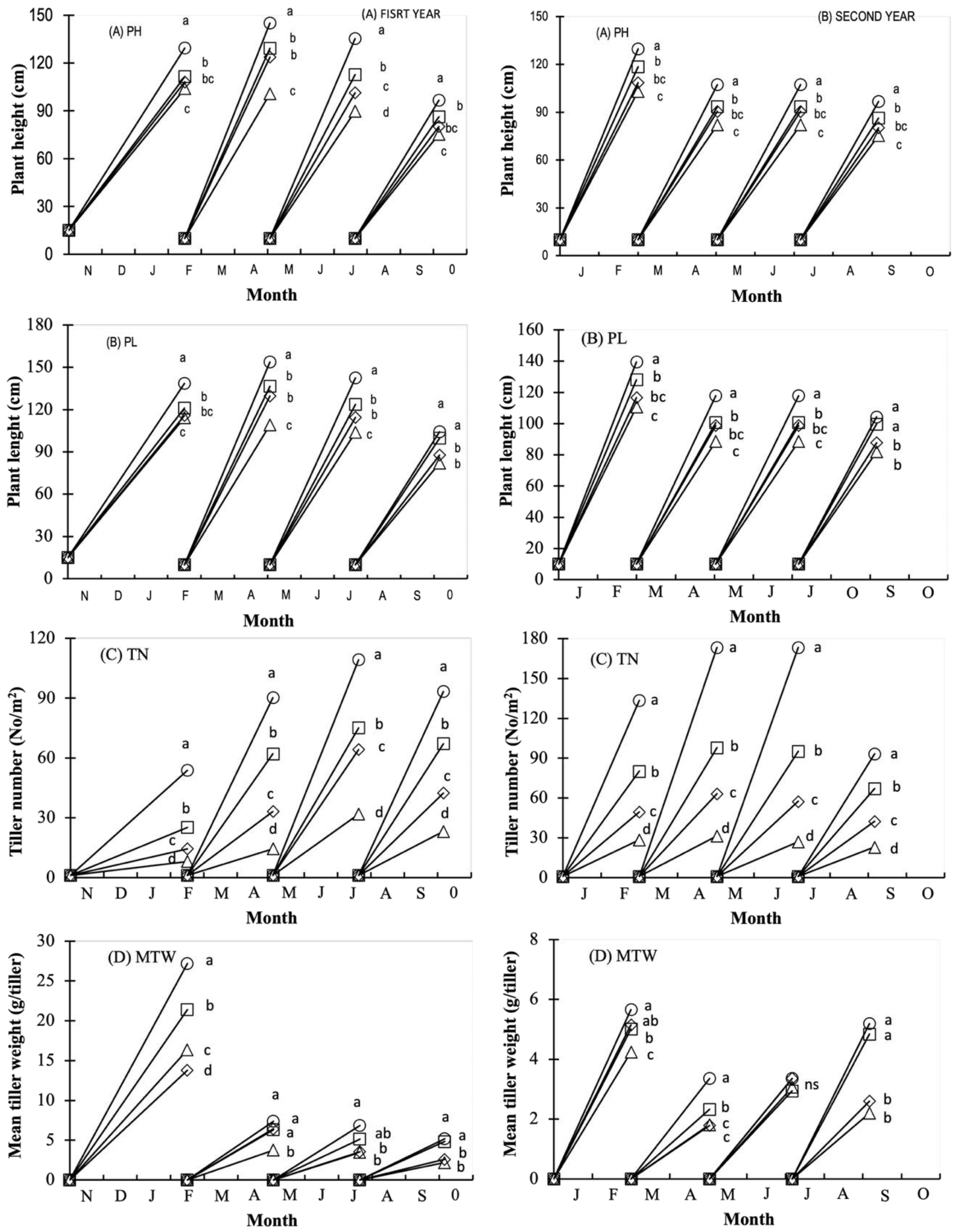

Figure 1. Changes in: A. Plant height, B. Plant length, C. Tiller number, and D. Mean tiller weight in DL Napiergrass under different treatments in the first year and second year. Treatment: No-manure (△), Low (◇), Medium (□), and High (○) manure level. Symbols with different letters denote significant differences between treatments on the same date at the 5 % level. Ns: P>0.05

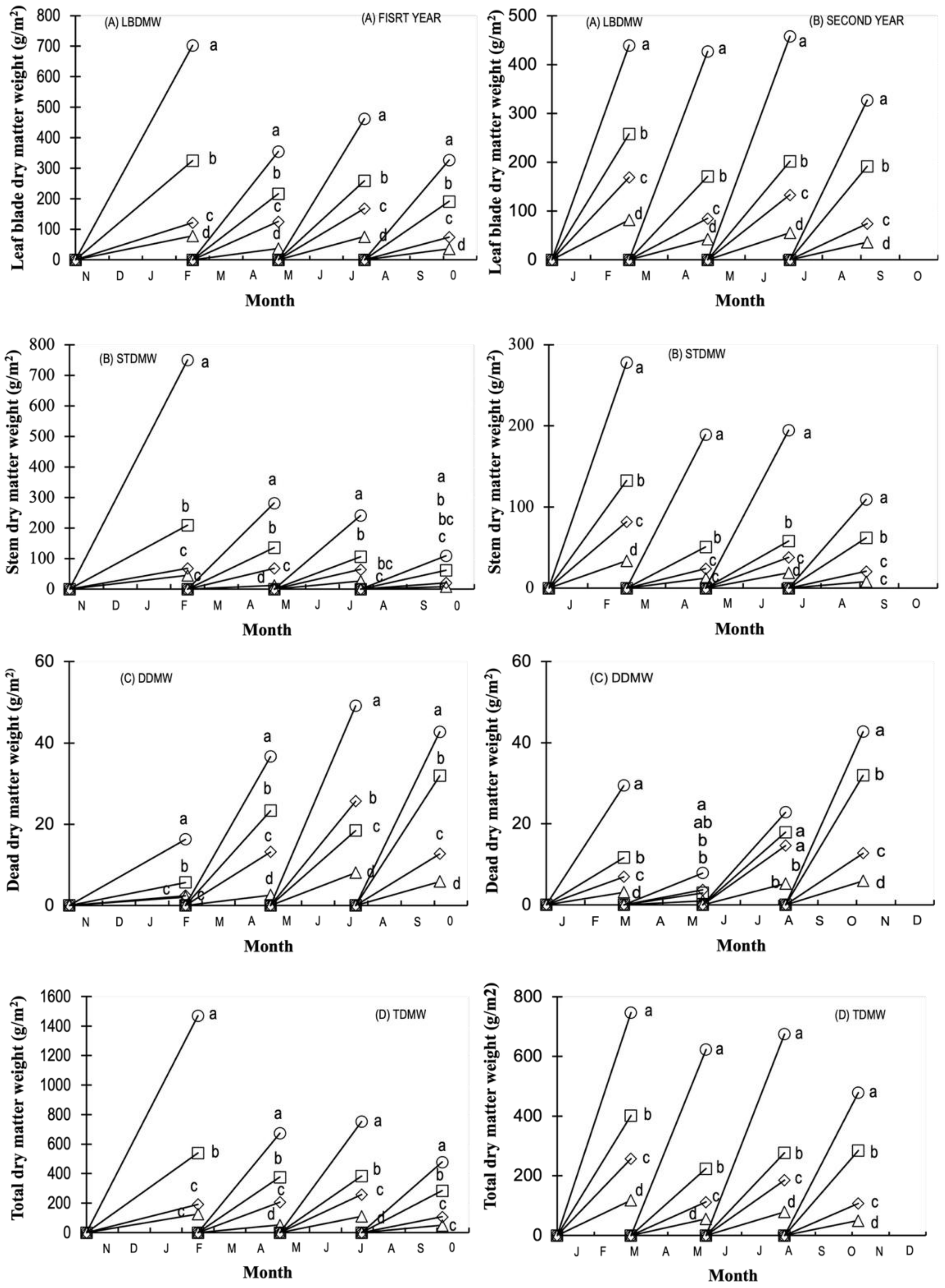

Figure 2. Changes in: A. Leaf blade dry matter weight, B. Stem dry matter weight, C. Dead dry matter weight, and D. Total dry matter weight in DL Napiergrass under different treatments in the first year and second year. Treatment: No-manure (△), Low (◇), Medium (□), and High (○) manure level. Symbols with different letters denote significant differences between treatments on the same date at the 5 % level. Ns: P>0.05.

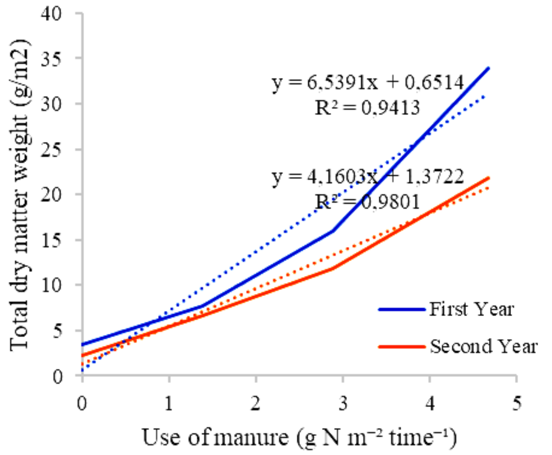

Figure 3. Relationship between Total dry matter weight (g/m²) (X) and Use of manure (g N m^{-2} time^{-1}) (Y). Symbols with different letters denote significant differences between treatments on the same date at the 5 % level. Ns: P>0.05

Discussion

Soil conditions on marginal land

The results showed that the use of manure improved soil conditions on marginal land in the first and second years. Essential nutrients in the soil, such as phosphorus and organic carbon, can be enhanced through manure application (Holatko et al. 2022b). In general, soil health indicators characterized by nutrient content and microbial activity are improved by manure (Holatko et al. 2022a). Manure improves soil fertility and can be applied to various crops (Langewitz et al. 2022), including barley, where it stimulates higher growth. Another study reported that soil condition improved with the use of kendang fertilizer due to the increase in nutrient availability (Zhao and Naeth 2022).

The soil Total Nitrogen (TN) content increased from the first to the second year, showing that application of manure improved soil fertility. TN is a crucial element in forming amino acids and proteins, making it vital for plant growth as well as crop yield and quality (Hossen et al. 2021). According to Xu et al. (2020a), combining organic and inorganic fertilizers as part of fertilization strategies greatly enhances national resources by strengthening soil health and increasing plant productivity.

The Total Phosphoric acid (TP) concentration in the second year was greater than in the first year. This shows that using manure in the long term will improve soil fertility. Organic P mineralization improves overall availability through increased alkaline phosphatase activity. Phosphorus is needed as the primary nutrient in ensuring metabolic activity and energy transfer (Xu et al. 2020a).

Soil pH under manure fertilization generally increased, specifically at medium and high levels. Studies conducted over several years have shown that the prolonged application of organic fertilizers tends to increase soil pH more significantly than chemical ones (Hayatu et al. 2023). Indirect pH stabilization can be achieved by adding organic fertilizer, which improves soil structure and increases nutrient availability (Du et al. 2020). The cations released help raise soil pH by counteracting acidity (Hayatu et al. 2023).

The use of manure up to the highest level in this study is still considered reasonable. Manure can be applied at a rate exceeding 170 kg N/ha without adverse effects on water quality with proper management (Quilez et al. 2025). The use of manure is more recommended on margin land because, in addition to improving soil fertility, it also has a positive impact on the environment that synthetic fertilizers do not have. The use of manure reduces dependence on synthetic fertilizers while contributing to the reduction of greenhouse gas emissions and soil degradation (De Rosa et al. 2022). Manure can be used in a variety of environmental conditions, such as different soil types and climates. Manure substitution is more effective in monsoon and temperate continental climates with lower average annual rainfall (Ren et al. 2023). Manure applications are highly effective in non-tropical climatic conditions (Gross and Glaser 2021).

Total Nitrogen (T-N) and Total Phosphoric acid (T-P) in dwarf late napiergrass

Prolonged use of organic fertilizers led to Elevated Total Nitrogen (T-N) and Total Phosphoric acid (T-P) concentrations. T-N and T-P content in all parts of the plant showed an increasing trend with higher manure concentrations. Nitrogen (N) levels and plant biomass were positively correlated, as evidenced by a 2-4 fold rise in T-N content corresponding to increased nitrogen deposition in urban environments (Ponette-González et al. 2021). The interaction between availability and plant nutrient dynamics can be shown in the response of plant N concentrations to fertilization (Chen et al. 2023).

The use of inorganic chemicals and nutrients in agricultural activities is a threat to biodiversity (Salinas et al. 2024). On the other hand, processed manure poses a low risk of spreading antibiotic resistance in the soil (Flores-Orozco et al. 2024). Substituting chemical fertilizers with organic fertilizers led to higher absorption and phosphorus balance in rice plants (Hayatu et al. 2023). Using organic fertilizers in the long term positively affects agricultural productivity, leading to sustainable crop yield, while reducing dependence on chemical fertilizers (Chen et al. 2022a). Therefore, plant development requires phosphorus because it affects photosynthesis and biomass production (Vázquez et al. 2023).

Plant growth with manure application at different level

Based on the results, the growth rate of DL Napiergrass on marginal land increased along with the higher manure concentrations. Manure application in the initial two years led to a significant increase in plant height, length, number of tillers, and average tiller weight. In comparison, DL Napiergrass without manure experienced low growth. The results are similar to a previous study stating that manure application significantly increased plants' height and length in DL Napiergrass (Głowacka et al. 2020). The nutrients available from manure contributed to stem lengthening and affected the overall development of plants (Luo et al. 2020).

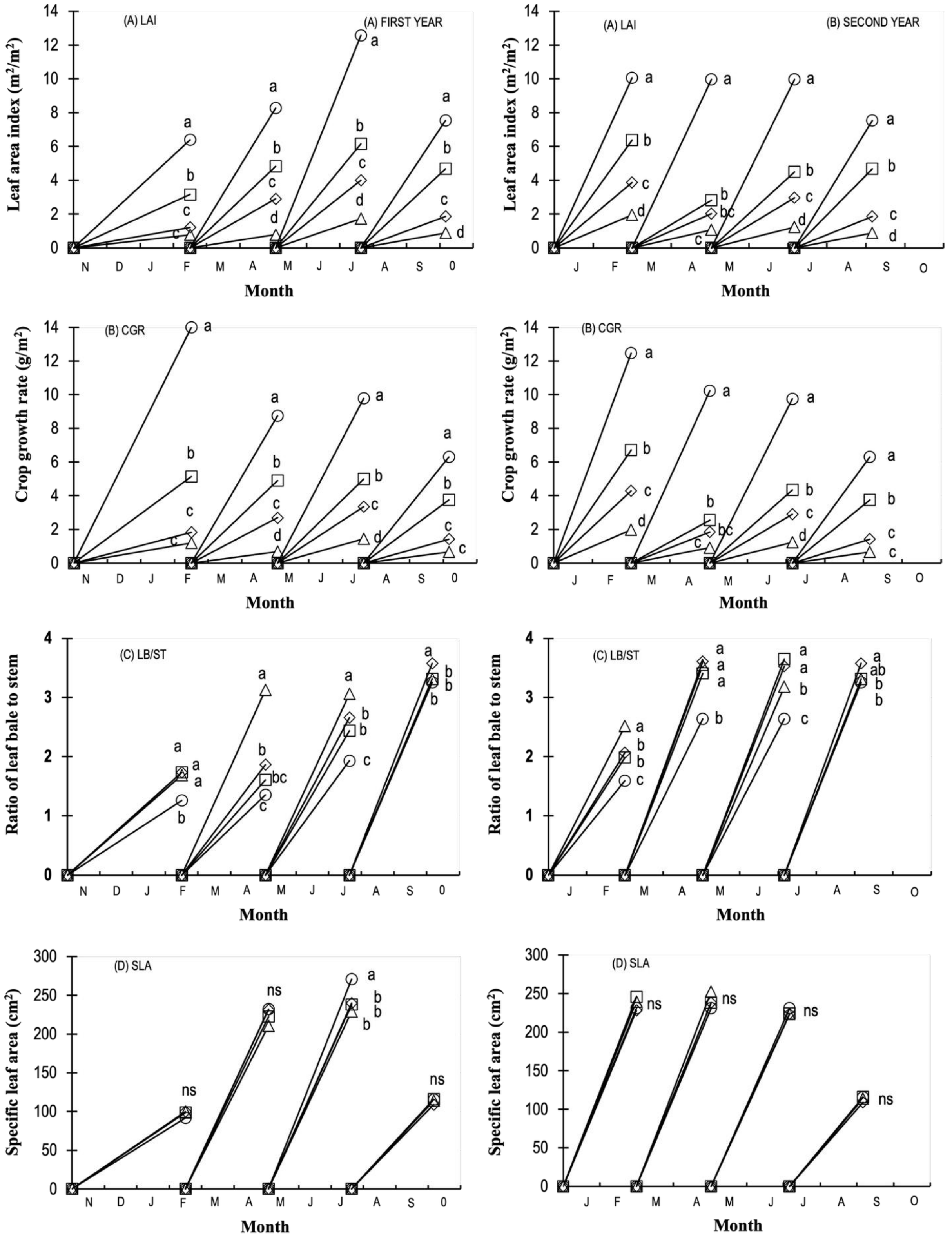

Figure 4. Changes in: A. Leaf Area Index (LAI), B. Crop Growth Rate (CGR), C. Ratio of Leaf Blade to stem with Leaf Sheath (LB/ST), and D. Specific Leaf Area (SLA) in DL Napiergrass under different treatments in the first year and second year. Treatment: No-manure (△), Low (◇), Medium (□), and High (○) manure level. Symbols with different letters denote significant differences between treatments on the same date at the 5 % level. Ns: P>0.05

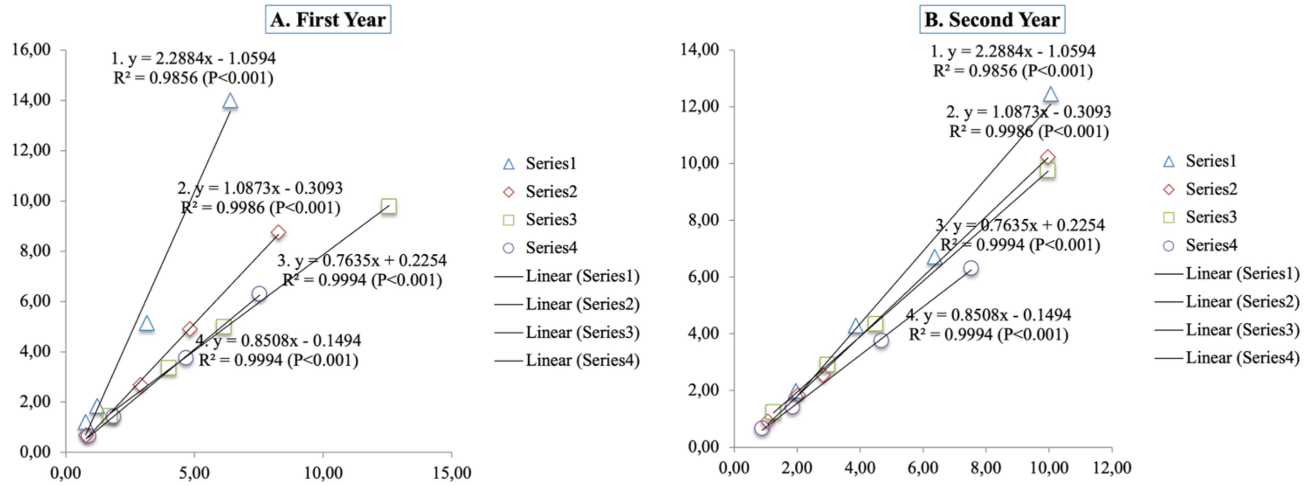

Figure 5. Relationship between Leaf Area Index (LAI) (X) and Crop Growth Rate (CGR) (Y). First year (A) and second year (B). Treatment: No-manure (△), Low (◇), Medium (□), and High (○) manure level. Symbols with different letters denote significant differences between treatments on the same date at the 5 % level. Ns: P>0.05

Applying manure as fertilizer significantly enhances sapling growth, a key factor in improving animal feed production. Manure improves sapling growth by influencing genetic factors that regulate nutrient uptake and hormone balance (Xu et al. 2020c). It also provides essential nutrients, supporting development and biomass accumulation (Głowacka et al. 2020). The quality of forage is affected by the weight of the saplings, which is attributed to manure management in grass cultivation (Luo et al. 2020).

The use of manure up to the highest level in this study is still considered reasonable. Manure can be applied at a rate exceeding 170 kg N/ha without adverse effects on water quality with proper management (Quilez et al. 2025). The use of manure is more recommended on margin land because, in addition to improving soil fertility, it also has a positive impact on the environment that synthetic fertilizers do not have. The use of manure reduces dependence on synthetic fertilizers while contributing to the reduction of greenhouse gas emissions and soil degradation (De Rosa et al. 2022). Manure can be used in a variety of environmental conditions, such as different soil types and climates. Manure substitution is more effective in monsoon and temperate continental climates with lower average annual rainfall (Ren et al. 2023). Manure applications are highly effective in non-tropical climatic conditions (Gross and Glaser 2021).

Total Nitrogen (T-N) and Total Phosphoric acid (T-P) in dwarf late napiergrass

Prolonged use of organic fertilizers led to elevated Total Nitrogen (T-N) and Total Phosphoric acid (T-P) concentrations. T-N and T-P content in all parts of the plant showed an increasing trend with higher manure concentrations. Nitrogen (N) levels and plant biomass were positively correlated, as evidenced by a 2-4 fold rise in T-N content corresponding to increased nitrogen deposition in urban environments (Ponette-González et al. 2021). The interaction between availability and plant nutrient dynamics can be shown in the response of plant N concentrations to fertilization (Chen et al. 2023).

The use of inorganic chemicals and nutrients in agricultural activities is a threat to biodiversity (Salinas et al. 2024). On the other hand, processed manure poses a low risk of spreading antibiotic resistance in the soil (Flores-Orozco et al. 2024). Substituting chemical fertilizers with organic fertilizers led to higher absorption and phosphorus balance in rice plants (Hayatu et al. 2023). Using organic fertilizers in the long term positively affects agricultural productivity, leading to sustainable crop yield, while reducing dependence on chemical fertilizers (Chen et al. 2022a). Therefore, plant development requires phosphorus because it affects photosynthesis and biomass production (Vázquez et al. 2023).

Plant growth with manure application at different level

Based on the results, the growth rate of DL Napiergrass on marginal land increased along with the higher manure concentrations. Manure application in the initial two years led to a significant increase in plant height, length, number of tillers, and average tiller weight. In comparison, DL Napiergrass without manure experienced low growth. The results are similar to a previous study stating that manure application significantly increased plants' height and length in DL Napiergrass (Głowacka et al. 2020). The nutrients available from manure contributed to stem lengthening and affected the overall development of plants (Luo et al. 2020).

Applying manure as fertilizer significantly enhances sapling growth, a key factor in improving animal feed production. Manure improves sapling growth by influencing genetic factors that regulate nutrient uptake and hormone balance (Xu et al. 2020c). It also provides essential nutrients, supporting development and biomass accumulation (Głowacka et al. 2020). The quality of forage is affected by the weight of the saplings, which is attributed to manure management in grass cultivation (Luo et al. 2020).

Plant production with manure application at different levels

Increasing manure application led to greater dry matter production in DL Napiergrass. The production of dry matter determines the amount of biomass because dry plant material is used more by the livestock. According to a study, the production of dry matter and biomass, including grasses, can be increased by combining organic and chemical fertilizers (Iqbal et al. 2021). The nitrogen content in manure plays a crucial role in leaf photosynthesis and higher biomass accumulation, which is important for the production of dry matter (Ren et al. 2023). Organic fertilizers increase nitrogen mineralization, which will affect the gradual release of nutrients according to the plant absorption rate (Wambacq et al. 2022). Soil organic matter content and nitrogen release are positively correlated with the use of various important nutrients, which improve forage quality and biomass production (Henderson et al. 2022). Furthermore, the root system is important for nutrient uptake and directly correlates with the production of plant biomass (De Pessemier et al. 2022). Another study found that root and shoot biomass showed a positive correlation, indicating the importance of root development in maximizing above-ground growth (Bektas et al. 2023).

In the first and second years, high-concentration manure consistently produced the highest dry matter production in DL Napiergrass across all measured components, including leaf blade, stem, dead matter, and total dry matter weight at every assessment period. Manure application increased biomass productivity by 8.4 Mg ha^{-1} compared to the natural grassland of only 5.0 Mg ha^{-1} (Xu et al. 2022b). Organic fertilizers can enhance leaf dry matter production by approximately 72,000 kilograms per hectare annually (Botero-Londoño et al. 2021). However, the total production of dry matter decreased in the second year, likely due to the depletion of soil nutrients on marginal land with a single application of manure without the addition of chemical fertilizers.

Relationship between LAI and CGR

The results showed a significant relationship between manure, as well as LAI and CGR, in both the first and second years. Increasing the amount of manure enhanced the relationship, showing a more significant connection with higher levels. A previous study stated that combining manure with inorganic fertilizer can increase the photosynthesis of leaf tissue, chlorophyll content, and biomass production, affecting the LAI and CGR (Iqbal et al. 2021). Manure application increases both LAI and CGR, but the effect varies based on soil type, climate, and management practices, specifically in acidic soils and humid climates (Du et al. 2020). Higher LAI will lead to higher biomass and yield, as shown in wheat and maize (Revill et al. 2021).

LAI is a valuable metric for evaluating plant growth and forecasting outcomes, showing the ability to use sunlight in photosynthesis (Sun et al. 2023). The nutrient content of the soil can be increased by applying manure, which elevates LAI and enhances leaf growth (Chen et al. 2022b). The greater the LAI, the higher the CGR for plants with broader leaves, creating conditions for more efficient photosynthesis and maximizing biomass production (De Peppo et al. 2021).

As one of the indicators to assess plant growth, LAI describes the surface area of leaves as a location for photosynthesis. The higher the LAI, the greater the photosynthesis process and the better the CGR (Fu et al. 2023). Moreover, water availability and soil quality affect CGR and forage growth (Terán-Chaves et al. 2022). Another study reported that manure application significantly increased CGR (Walia et al. 2023). The LB/ST ratio did not increase even though the dose of manure use was increasing because manure increased nutrient supply and accelerated biomass growth. However, this increase tends to be proportional to the leaves and stems, so the LB/ST ratio does not change much.

In conclusion, the application of organic manure significantly improved the growth, nutrient content, and biomass production of DL Napiergrass on marginal land except for the LB/ST ratio. Manure treatments increased plant height, tiller number, dry matter yield, and soil fertility, with the highest performance observed at the recommended dosage of 4.67 g N m^{-2} per application. Although the leaf blade-to-stem ratio remained unchanged, total dry matter production reached 33.98 tons/ha/year in the first year and 21.84 tons/ha/year in the second. These results demonstrate that manure application can transform marginal land into productive forage fields, providing a sustainable and economical feed source for livestock while enhancing soil quality. To maximize adoption, policies supporting manure availability and use on marginal land should be prioritized.

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