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Agronomic performance and silage quality of Massai grass fertilized with organic and inorganic nitrogen sources

Características agronômicas e qualidade da silagem de capim-massai adubado com fontes nitrogenadas orgânicas e inorgânicas

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Abstract: In this study, we aimed to evaluate the effects of different nitrogen fertilization sources on the growth and biomass yield of Massai grass, as well as on the chemical composition of the resulting silage at harvest. A completely randomized design was used with three treatments and eight replicates: poultry litter (PL), cattle manure (CM), and urea. Productive and structural variables were analyzed, including canopy height, tiller population density (TPD), live leaf count (LLC), and total forage biomass. Chemical variables of the silage were also evaluated, including dry matter, moisture, mineral matter, organic matter, neutral detergent fiber (NDF), acid detergent fiber, crude protein (CP), ether extract, total carbohydrates, and non-fibrous carbohydrates. The type of nitrogen source significantly affected canopy structure ($P < 0.05$), with urea showing superior values for TPD and LLC. In terms of silage composition, significant differences ($P < 0.05$) were observed only for NDF and CP. The CM treatment exhibited the highest NDF (69.55%) and the lowest CP (5.90%) compared to those of the urea and PL treatments. Organic fertilization with PL or CM can enhance biomass production without compromising silage quality, and a nitrogen application rate of 300 kg N ha^{-1} yielded the best results for forage biomass.

Key-words: biomass; plant structure; sustainable production; silage.

Resumo: O estudo teve por objetivo analisar o efeito do tipo de fonte de adubação nitrogenada sobre o desenvolvimento e produção da biomassa de capim-massai, bem como a composição química da silagem produzida na colheita. O experimento foi desenvolvido em um delineamento inteiramente casualizado com três tratamentos e oito repetições, sendo-os: Adubação com cama de frango (CF), esterco bovino (EB) e ureia. Foram analisadas variáveis produtivas e estruturais, tais como: altura do dossel, densidade populacional de perfilhos, número de folhas vivas e biomassa de forragem total; e variáveis químicas da silagem, como: matéria-seca, umidade, matéria mineral, matéria orgânica, fibra em detergente neutro, fibra em detergente ácido, proteína bruta, extrato etéreo, carboidratos totais e carboidratos não fibrosos. Observou-se que o tipo de fonte influenciou a estrutura do dossel ($P < 0{,}05$), tendo o tratamento com ureia apresentado superioridade nas variáveis DPP e NFV. Já na composição química da silagem, notou-se apenas diferença significativa ($P < 0{,}05$) em FDN e PB, tendo o tratamento com EB apresentado o maior (69,55%) e menor (5,90%) valor, respectivamente, quando comparado com U e CF. A adubação orgânica utilizando CF ou EB pode ser utilizada como agente de intensificação da produção de biomassa sem comprometer a qualidade da silagem, sendo a aplicação na dose de 300 kg de N ha^{-1} a que apresentou melhores resultados quanto à produção de biomassa de forragem.

Palavras-chave: biomassa; estrutura vegetal; produção sustentável; silagem.

1. Introducion

In semi-arid regions, irregular rainfall and shallow soils pose significant challenges to forage production. Therefore, the use of more resistant and adapted cultivars, along with the adoption of management strategies that enhance the productivity of these species, has become increasingly necessary among producers[1].

Currently, several forage species have high production potential, provided they are managed appropriately. Among them, those belonging to the genus Megathyrsus maximus (syn. Panicum maximum Jacq.) stand out. These cultivars are adapted to diverse soil and climate conditions in Brazil and are recognized for their high biomass productivity per hectare. According to Lopes *et al.*[2], Massai grass is an outstanding cultivar widely used by small, medium, and large producers and is highly responsive to intensive management systems.

Among the practices that enhance productivity and forage quality, nitrogen fertilization plays a central role. According to Vasconcelos *et al.*[3], nitrogen contributes significantly to biomass production and promotes structural and morphogenetic changes in the forage canopy. This is because nitrogen is the most mobile element in plants and directly participates in the synthesis of chlorophyll, proteins, and nucleic acids. In this context, grass silage has emerged as an efficient strategy for conserving forage, enabling the use of surplus production during the rainy season and ensuring a supply of quality bulky feed during the dry season.

In addition, properly fertilized Massai grass silage can have higher nutritional content, particularly in terms of crude protein (CP) and digestibility, thereby adding value to the production system. According to Silva *et al.*[4], ensiling tropical grasses is an interesting alternative, but has limitations, as these plants generally have low levels of dry matter (DM) and soluble carbohydrates, along with a high buffering capacity at the ideal cutting time.

Therefore, in this study, we aimed to evaluate the effects of different nitrogen fertilization sources on the productivity of Massai grass and the chemical composition of its silage.

2. Material and methods

2.1 Characterization of the experimental area and study period

The experiment was conducted between March and June 2024 at the Faculty of Technology CENTEC Sertão Central (FATEC Sertão Central) located in the municipality of Quixeramobim. Both the agronomic and chemical analyses of the silage were performed during this period. The municipality of Quixeramobim is located in the mesoregion of Sertão Central, Ceará, approximately 211 km from Fortaleza, Brazil. It has a territorial area of 3,324.98 km^2 and an estimated population of 82,122[5], with 39.59% residing in rural areas[6]. The climate is classified as semi-arid (BSh'w') according to the Köppen–Geiger classification[7], with a rainy season from January to June. The area is located at an altitude of 191.74 m, with latitude and longitude of 05°11'57'' and 39°17'34'', respectively. Data on maximum, average, and minimum temperatures during the experimental period were collected from the meteorological station of the National Institute of Meteorology, located 0.1 km from the experimental site (Figure 1).

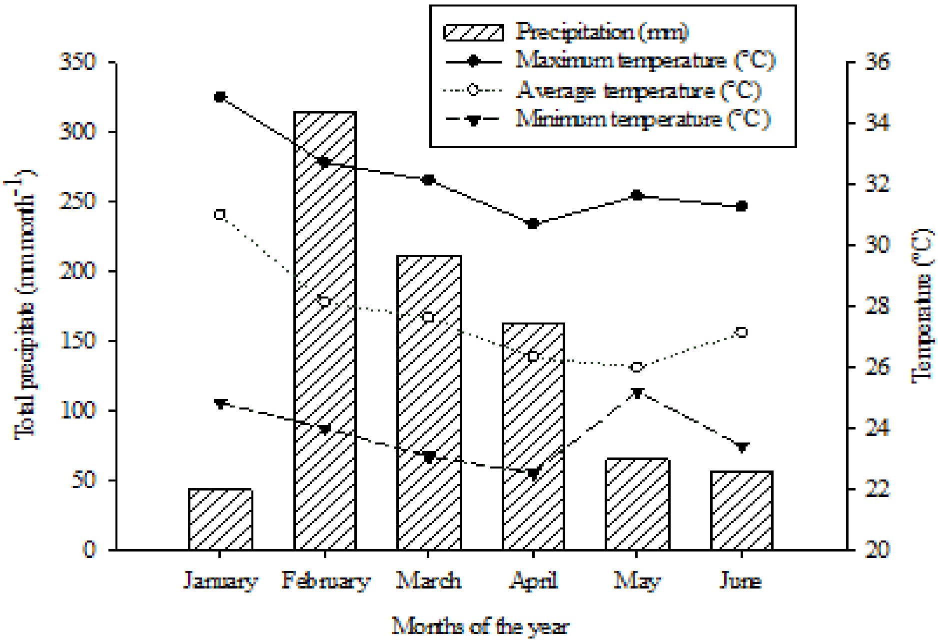

Figure 1. Precipitation (mm) and maximum, average, and minimum temperatures (°C) during the rainy season at the experimental site.

2.2 Treatments and experimental design

The treatments involved evaluating the productive performance and chemical composition of Massai grass silage (*M. maximus* Jacq. B. K. Simon and Jacobs; Syn. P. *maximum* Jacq. cv. Massai), managed under different nitrogen fertilization sources, namely poultry litter (PL), cattle manure (CM), and urea, under dryland conditions during the months of January–June 2024. The grass was cultivated in experimental plots of 2.03 m^2, with eight replicates per treatment, in a completely randomized design for 60 days, using 15 kg of seeds per hectare, as determined according to Equations 1 and 2[8].

(1) CV (%)=((P × G))/100

where CV, P, and G are the cultural value, purity, germination, respectively.

(2) MSR (kg of seeds/ha)=(CVP/ha)/(CV (%))

where MSR is the minimum seeding rate and CVP is the cultural value points.

2.3 Crop management and response variables

Thirty days after planting, topdressing was carried out manually, and the experimental plots were demarcated with colored tapes to facilitate the differentiation of each treatment, namely, black for urea, gray for PL, and gold for CM. Approximately 20 t of PL ha^{-1}, 85 t of CM ha^{-1}, and 0.667 t of urea ha^{-1} were applied. These quantities corresponded to 300 kg ha^{-1} $year^{-1}$ of N, the rate recommended for systems with a higher technological level[9], and were applied simultaneously. The average N contents of 3% and 0.7% for PL and CM, respectively, were also considered with mineralization rates of 50%[10] for PL and 45% of N for urea.

Sixty days after planting, the grass was cut (DM = 26% + 1.2%). This cutting age was chosen because it coincided with approximately 95% interception of photosynthetically active radiation and optimal root development, ensuring high-quality biomass due to a favorable leaf:stem ratio[11]. This period also complies with the grace period for pasture use established by the Ministry of Agriculture and Livestock [12, 13].

The variables analyzed included canopy height (CH), tiller population density (TPD), live leaf count (LLC), and total forage biomass (TFB) expressed in kg DM ha^{-1}. CH was measured using a retractable graduated stick, from the soil surface to the curvature of the last fully expanded leaf, at a minimum of 10 points per experimental plot. These same points were used to quantify the LLC. To determine TPD, a 0.0625 m^2 frame was used at a minimum of two locations per plot to obtain a representative average. Subsequently, the fresh forage biomass within the frame was harvested, maintaining a residue height of 15 cm. The samples were weighed, and a 200 g aliquot was placed in paper bags and dried in a ventilated oven at 55°C with forced air circulation until a constant weight was achieved. The samples were then reweighed and further dried at 105°C to determine TFB in kg DM ha^{-1}.

To evaluate the chemical composition of the silage, the remaining material from the plots was chopped into particles between 10 and 30 mm (1–3 cm) and stored in experimental PVC (Polyvinyl Chloride) silos equipped with lids, a Büsen valve (to allow gas release and prevent air entry), an exclusion screen, and sand (to absorb effluents produced during fermentation). A PVC pipe was used for each treatment. Each tube had a storage capacity of 0.00241 m^3, as calculated using Equation 3.

(3) $V=\pi \times r^2 \times h$
where V = volume (m^3); π = 3.1416 (Pi); r^2 = radius squared; h = height.

The PVC cylinders measured 10 cm in diameter and 26 cm in height. Approximately 1.22 kg of material was stored in each tube, yielding a compaction density of 600 kg m^{-3}. The silos remained sealed for 30 days[14]. After this period, the silage was evaluated. It was first pre-dried at 55°C and then dried at 105°C to determine DM, moisture, organic matter (OM), mineral matter (MM), CP, ether extract (EE)[15], neutral detergent fiber (NDF), acid detergent fiber (ADF)(16), total carbohydrates (TC), and non-fibrous carbohydrates (NFC).

To calculate TC, Equation 4 was used, as described by Sniffen *et al.*[17], whereas to determine NFC, Equation 5 was used.

(4) $TC=100-(CP\%+EE\%+MM\%)$
where TC = total carbohydrates; CP = crude protein; EE = ether extract; MM = mineral matter.

(5) $NFC=100-(CP\%+NDF\%+EE\%+MM\%)$
where NFC = non-fibrous carbohydrates; CP = crude protein; NDF = neutral detergent fiber; EE = ether extract; MM = mineral matter.

2.4 Statistical analysis

For statistical analysis, the data were subjected to a normality assessment using the Kolmogorov–Smirnov test ($P < 0.05$) and to homoscedasticity evaluation based on graphical visualization of the residuals. When assumptions were met, analysis of variance (ANOVA) was performed using the "F" test. When significant, means were compared using the Tukey's test ($P < 0.05$), implemented via the PROC MIXED command in the SAS University Edition statistical program. Graphs were generated using SigmaPlot[18].

3. Results and discussion

A significant difference (P < 0.05) was observed for the structural variables CH (P = 0.0188), TPD (P < 0001), and LLC (P < 0001), demonstrating that the type of nitrogen source affected plant development dynamics. For the TFB variable, no significant difference was observed (P = 0.1009), with a mean production of 3,751.60 kg DM ha^{-1}.

For CH, the CM treatment had the highest average (94.26 cm), which was 4.61% and 7.08% higher than those of the PL and urea treatments, respectively. This pattern was the opposite of that observed for the other structural variables, where the highest averages occurred in the urea treatment—27.10% and 66.85% higher for TPD and 20.83% and 29.08% higher for LLC compared to those of the PL and CM treatments, respectively. This is likely associated with nitrogen availability, as it becomes rapidly accessible from the inorganic source (urea) compared to the slower-release organic sources (PL and CM) (Table 1).

Different fertilizer sources influence the rate at which nutrients are released into the soil, which can affect both the productivity and quality of the resulting forage biomass(19, 20). In general, organic fertilizers, such as PL and CM, gradually release nutrients, promoting residual effects that are considered beneficial for the long-term sustainability of the system. By contrast, urea, classified as a rapidly available inorganic source, can result in losses through volatilization, thereby reducing nitrogen use efficiency. According to Primavesi *et al.*[(21)], such losses are related to the absence of rainfall and high temperatures shortly after urea application. These factors are crucial, particularly in long-term evaluations, as they influence the efficiency of other inputs and plant responses over successive cycles. According to Primavesi *et al.*[(21)], pasture fertilization, particularly with nitrogen, is one of the most important factors in determining the level of forage biomass production. The largest increases typically occurs within the range of 300–400 kg N ha^{-1} year-^{1}, which was the value adopted in this study.

Table 1. Productive and structural variables of Massai grass at 60 days managed under different sources of nitrogen fertilization during the rainy season.

Treatment	CH (cm)	TPD (tiller m^{-2})	TFB kg DM ha^{-1}	LLC Leaves tiller^{-1}
Ureia	88.02B	1,419.50^{a}	3,655.50A	4.35A
Poultry litter	90.12AB	1,116,75B	3,643.12A	3.60B
Cattle manure	94.26A	850,75C	3,956.19A	3.37BC
Mean	90.80	1.129,00	3.751,60	3.77
CV (%)	2.77	6.41	5.46	3.90
P-Value	0.0188	<.0001	0.1009	<.0001

Canopy height (CH), Tiller population density (TDP), total forage biomass (TFB), live leaf count (LLC), coefficient of variation (CV). Means followed by different letters, capitalized in columns, differ from each other according to Tukey's probability test (p < 0.05).

This demonstrates the potential of using PL as a nitrogen fertilizer to replace urea, given its N concentration. According to Marques *et al.*[(22)], the linear response of tillering to nitrogen fertilization is associated with the stimulatory effect of nutrients on the growth and multiplication of plant cells, as these are composed of proteins and cellular nucleic acids capable of boosting the germination of dormant buds and increasing the LLC. In addition, Fialho *et al.*[(23)] reinforced that, to optimize solar radiation use, the plant reduces its height (a behavior observed in this study under the urea treatment), which facilitates light penetration into the canopy (size–density relationship) and promotes the germination of basal buds.

Furthermore, Lopes *et al.*[2] reported that a higher LLC in tillers indicates a more advanced developmental stage, as the LLC per tiller reflects leaf lifespan and is considered a stable genotypic trait in the absence of nutritional deficiencies. However, increased nitrogen fertilization may accelerate defoliation due to the advanced physiological age of the canopy.

No significant difference was noted in DM (P = 0.2366; CV = 4.55%), moisture (P = 0.2366; CV = 1.44%), MM (P = 0.6234; CV = 10.66%), and OM (P = 0.5434; CV = 2.70%), with mean values of 24.01%, 75.98%, 11.04% and 89.81%, respectively (Figure 2A and 2B). These results indicate that applying organic sources such as PL and CM at 300 kg N ha^{-1} can be a viable strategy for intensifying biomass production with lower operational costs than those associated with the inorganic source (urea).

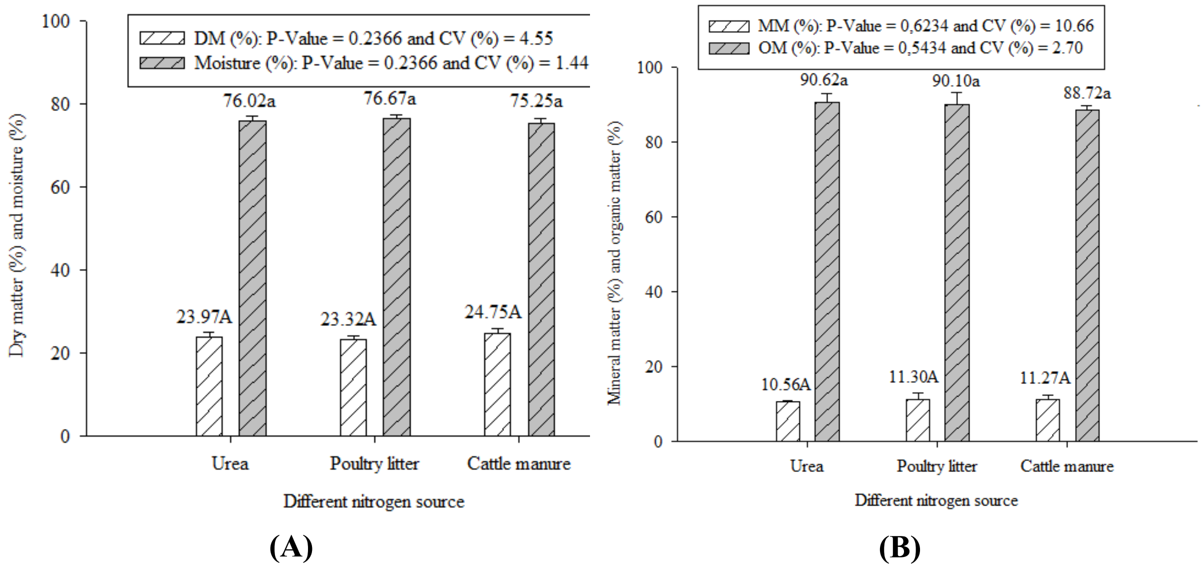

Figure 2. Dry matter and moisture (A) and mineral and organic matter (B) of Massai grass silage managed under different nitrogen fertilization sources.

Means followed by different letters, lowercase in gray columns and uppercase in white columns, differ from each other according to the Tukey's probability test (P < 0.05).

A significant difference (P < 0.05) was observed only for NDF (P = 0.0009; CV = 0.94%) and CP (P = 0.0003; CV = 3.10%). No significant differences were found for ADF (P = 0.2636; CV = 2.19%), EE (P = 0.7401; CV = 25.91%), TC (P = 0.4996; CV = 1.74%), or NFC (P = 0.2198; CV = 10.04%). The average values observed were: 46.94% (ADF), 2.07% (EE), 80.48% (TC), and 12.30% (NFC).

The NDF and CP values indicate that the treatment with CM resulted in the highest and lowest averages, respectively, suggesting that this management influenced cell wall accumulation, thereby reducing their content. However, the values for both variables were relatively close across treatments, supporting the hypothesis that organic sources may be a favorable strategy for intensifying biomass production. Similar values were reported by Orrico Júnior *et al.*[24], who evaluated different cutting ages and their effect on the bromatological composition of Massai grass silage. Notably, high NDF levels reduce biomass intake in ruminants due to the increased ruminal fill effect. Conversely, lower NDF values are considered beneficial, as this fiber fraction plays a key role in regulating intake because of its slow degradation and reduced passage rate. A key component of ADF is lignin, a phenolic polymer associated with structural carbohydrates such as cellulose and hemicellulose in plant cell walls.

Excessive lignin content negatively affects the degradation of fibrous feeds, as it limits the digestion and absorption of structural carbohydrates in the rumen, which are among the primary energy sources for ruminants[25].

One approach studied in recent years to mitigate the effects of high NDF in silage involves applying higher doses of nitrogen, which—depending on environmental conditions—can alter NDF content in forages (typically greater than 55%–60% of DM)[26]. Another strategy is the inclusion of agro-industrial co- and by-products, which serve as additional sources of soluble carbohydrates during silage fermentation, thereby enhancing nutritional value and improving biomass digestibility. Bonfá *et al*.[27] observed that the incorporating up to 50% passion fruit by-products reduced the concentration of NDF to 63.53% and ADF to 36.39%. The same behavior was observed by Bonfá *et al.*[28] when pineapple peel was used as a by-product. These findings suggest that PL, as used in this study, did not reduce fiber content or alter cell wall structure significantly, thus maintaining biomass with good acceptability for ruminants.

Regarding CP content, values were found to be 7%, 2.14%, and 15.71% lower in the PL, urea, and CM treatments, respectively, compared to the recommended minimum level (7%) required for ruminal function[29]. Nitrogen fertilization is essential for increasing the CP content in forage grasses, contributing to accelerated plant growth and improved forage nutritional quality. Several studies have indicated that an adequate nitrogen supply can increase CP levels to meet or exceed the critical threshold of 7%, which is required to support ruminal microbial activity and ensure efficient forage digestibility. However, the CP values observed in this study were below the minimum threshold, possibly reflecting the rapid nitrogen release, particularly from urea[22].

These results were similar to those reported by Orrico Júnior *et al*.[24], who evaluated the composition of Massai grass silage without the addition of a bacterial inoculant. Bonfá *et al.*[27] reported an increase in CP content in elephant grass silage, reaching approximately 5% after the addition of 50% pineapple peel to the ensiled mass. This increase was associated with reduced levels of neutral and acid detergent-insoluble proteins. According to Anderson[30], CP can be better utilized by ruminal microorganisms, thereby improving silage nutrient efficiency. Lira Júnior *et al*.[31] evaluated the inclusion of passion fruit peel to elephant grass silage and observed a positive effect on CP content (10.00%) in silage without the addition of passion fruit peel (6.56% CP). This effect was attributed to the higher protein content of passion fruit peel compared to that of elephant grass, except in silage where 25% peel was added without wilting. In the present study, high moisture content may have contributed to CP losses, as such conditions promote protein degradation via butyric fermentation, thereby reducing the nutritional value of the silage.

The EE values observed were similar to those reported by Oliveira *et al*.[32], in Massai grass silage without the inclusion of licuri cake (*Syagrus coronata*). Oliveira *et al.*[32] and Anjos *et al.*[33], also reported NFC and TC values similar to those observed in this study, suggesting that nitrogen source did not significantly influence these variables, as other management practices may play a more dominant role in modifying their concentrations. Cruz *et al.*[34], in a study evaluating the inclusion of 0%, 10%, 20%, and 30% dehydrated passion fruit peels in elephant grass silage, observed a reduction in TC and an increase in NFC. Lira Júnior *et al.*[31] reported similar results when evaluating 0%, 25%, 50%, 75%, and 100% inclusion of passion fruit peel in elephant grass silage, along with varying wilting times. At 0% inclusion and 0 h of wilting, CT and NFC values were 84.04% and 22.24%, respectively.

Thus, organic fertilization using PL and CM did not alter carbohydrate composition, as no external ingredients—such as agro-industrial by-products rich in pectin (e.g., passion fruit peel)—were added (Figure 3A, 3B, and 3C).

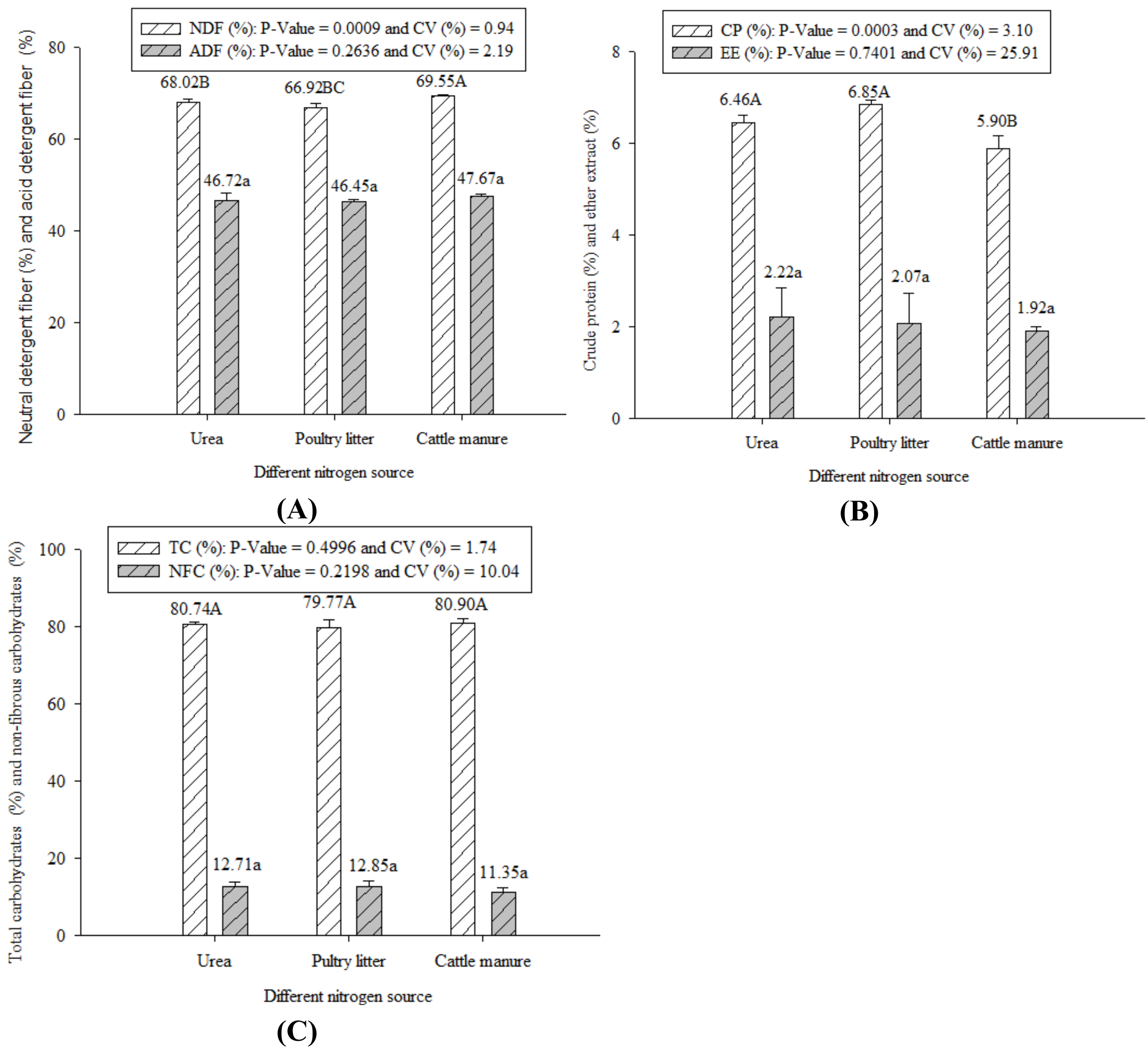

Figure 3. Neutral detergent and acid detergent fibers (A), crude protein and ether extract (B), and total carbohydrates and non-fibrous carbohydrates (C) of Massai grass silage managed under different nitrogen fertilization sources.

Means followed by different letters, lowercase in gray columns and uppercase in white columns, differ from each other according to the Tukey's probability test ($P < 0.05$).

Thus, inadequate soil management, particularly when combined with successive crop cycles and no mineral and/or organic nutrient replenishment, leads to serious issues in plant development and nutrient depletion. These problems are exacerbated in tropical soils, which naturally have low pH and are often managed with minimal or no technological input by farmers. PL and CM, as nitrogen-rich organic fertilizers, represent viable alternatives, particularly because they minimize nitrogen losses to the environment and improve overall nutrient availability[(35)].

4. Concluslion

The type of nitrogen fertilization source does not interfere with total forage biomass production but influences canopy structural development owing to differences in the availability of nitrogen, which in turn affects the chemical composition of the Massai grass silage. Nitrogen fertilization using poultry litter or cattle manure can be applied in a single dose at a rate of 300 kg N ha^{-1}.

Conflict of interest statement

The authors declare no conflict of interest.

Data availability statement

Data will be made available on request.

Author contributions

Data curation: B. Medeiros. Investigation: B. Medeiros. Project Management: B. Medeiros, L. Gomes, F. Oliveira, G. Góes, and J. Conrado. Supervision: B. Medeiros, L. Gomes, F. Oliveira, G. Góes, and J. Conrado. Visualization: B. Medeiros, L. Gomes, F. Oliveira, G. Góes, and J. Conrado. Writing (original draft): B. Medeiros, F. Oliveira, G. Góes, and J. Conrado. Resources: F. Oliveira, G. Góes, and J. Conrado. Conceptualization: J. Conrado. Funding Acquisition: J. Conrado. Methodology: J. Conrado. Validation: J. Conrado.

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