doi: 10.17138/TGFT(13)82-93

Research Paper

Protected urea as a nitrogen source for Mulato II grass: impacts on forage production, feed value and composition

Urea protegida como fuente de nitrógeno para el pasto Mulato II: impactos en la producción de forraje, el valor nutritivo y la composición

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Abstract

The growing demand for high-yielding forage cultivars with drought tolerance, broad environmental adaptation and sustained feed quality has stimulated the development of new *Urochloa* (syn. *Brachiaria*) genotypes, such as Mulato II. Efficient nitrogen (N) fertilization strategies are essential to optimize their productivity and nutritional value. This study aimed to evaluate the effects of N fertilization, using conventional and protected urea at 0, 50, 100 and 150 kg N/ha on green mass production (GMP), dry matter production (DMP), leaf:stem ratio (LSR), nutritional value, apparent nitrogen recovery (ANR), apparent nitrogen conversion efficiency (ANCE), and crude protein yield per hectare (CP/ha) of Mulato II. The experiment followed a completely randomized 4 × 2 factorial design. The results showed that the N source significantly affected GMP, DMP, neutral detergent fiber (NDF) during the second growth period, and ANCE. Increasing N rates led to higher GMP, DMP and CP concentration, while decreasing ANCE. Fertilization with protected urea improved ANCE and reduced NDF concentration, indicating greater efficiency in nitrogen utilization. These findings support the strategic use of protected urea at moderate N rates to enhance forage productivity and nitrogen use efficiency in Mulato II.

Keywords: biomass production, fiber concentration, nitrogen conversion, nitrogen fertilization, nitrogen recovery.

Resumen

La creciente demanda de cultivares de forraje de alto rendimiento con tolerancia a la sequía, amplia adaptación ambiental y calidad sostenida del valor nutritivo ha estimulado el desarrollo de nuevos genotipos de *Urochloa* (sin. *Brachiaria*), como Mulato II. Las estrategias eficientes de fertilización nitrogenada (N) son esenciales para optimizar su productividad y valor nutricional. Este estudio tuvo como objetivo evaluar los efectos de la fertilización con N, utilizando urea convencional y protegida a 0, 50, 100 y 150 kg N/ha en la producción de de biomasa fresca (GMP), de materia seca (DMP), relación hoja:tallo (LSR), valor nutricional, recuperación aparente de nitrógeno (ANR), eficiencia aparente de conversión de nitrógeno (ANCE) y rendimiento de proteína cruda por hectárea (PC/ha) del pasto Mulato II. El experimento siguió un diseño factorial 4 × 2 completamente aleatorizado. Los resultados mostraron que la fuente

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de N afectó significativamente GMP, DMP, fibra detergente neutro (FDN) durante el segundo período de crecimiento y ANCE. El aumento de las dosis de N resultó en una mayor GMP, DMP y contenido de PC, a la vez que disminuyó la ANCE. La fertilización con urea protegida mejoró la ANCE y redujo la concentración de FDN, lo que indica una mayor eficiencia en la utilización del nitrógeno. Estos hallazgos respaldan el uso estratégico de urea protegida con dosis moderadas de N para mejorar la productividad del forraje y la eficiencia en el uso del nitrógeno en Mulato II.

Palabras clave: Concentración de fibra, eficiencia de conversión de nitrógeno, fertilización nitrogenada, producción de biomasa, recuperación de nitrógeno.

Introduction

In central Brazil, particularly in regions with Oxisol soils, pasture degradation remains a major constraint to sustainable livestock production. This degradation is largely driven by the inherent low fertility of these soils, combined with inadequate fertilization practices and improper pasture management (Dupas et al. 2016; Galindo et al. 2017). Strategies to enhance forage productivity are therefore essential to support more profitable and sustainable livestock systems in these regions.

Grasses of the genus *Urochloa* have been widely adopted across tropical regions owing to their adaptability to diverse soil types and climatic conditions, especially in areas of low to medium soil fertility. These grasses also provide flexible grazing management and competitive forage yields, making them preferred for improving pasture productivity under challenging conditions (Hunegnaw et al. 2022; Dupas et al. 2016). Among the newer genotypes, *Urochloa* hybrid 'Mulato II' (Mulato II), formerly marketed as Convert HD364 in Brazil, has gained prominence. Although this hybrid shows promising agronomic characteristics, including tolerance to drought and high productivity, its responses to nitrogen fertilization are still not fully understood. Comprehensive research is needed to study forage yield potential, morphological traits and nutritional quality under nitrogen fertilization.

According to Liebig's Law of the Minimum (van der Ploeg et al. 1999), plant growth is constrained by the scarcest essential nutrient. In tropical pastures, nitrogen (N) is typically the most limiting nutrient for forage production and quality, especially in highly weathered soils such as Oxisols (Delevatti et al. 2019; Dupas et al. 2016; Galindo et al. 2017) and for *Urochloa* hybrids (Pereira et al. 2021). Adequate N supply is crucial for promoting pasture recovery, enhancing forage productivity, and supporting sustainable animal production. N plays a key role in plant metabolism and directly influences tillering, leaf expansion and protein synthesis. However, due to its mobility and susceptibility to losses via leaching, volatilization and denitrification, its efficient use is a major challenge in pasture-based systems (Dupas et al. 2016). In tropical soils, N levels are often below the plant's requirement. In addition, N source and amount can influence N absorption and the production and feed value of grasses. Among the N sources available, urea is commonly used. However, variations in the form and speed of release of N in fertilizers can affect its use by the plant (Espindula et al. 2021; Ransom et al. 2020). Therefore, optimizing N use is a key factor to enhance sustainability of pasture-based systems. The development and use of enhanced-efficiency N fertilizers, such as protected urea, aim to reduce losses and improve N use efficiency.

Mulato II was selected for this study due to its widespread adoption in tropical forage systems, particularly in Brazil. Despite the potential benefits of N fertilization, limited studies have explored their effects on Mulato II under tropical conditions in Brazil. Existing research with other tropical grasses such as *Urochloa brizantha* and *Megathyrsus maximus* suggests positive effects of N fertilization on dry matter yield and forage quality (Dupas et al. 2016; Galindo et al. 2017), reinforcing the need to evaluate these effects in Mulato II.

This study evaluated the forage production, feed value and N recovery efficiency of Mulato II under N fertilization using prilled urea (conventional) and polymer-coated urea (protected urea). We hypothesized that the use of protected urea would enhance N recovery and improve both forage productivity and nutritional quality compared to conventional urea.

Materials and Methods

Experiment location

The experiment was carried out at the facilities of the Animal Science Department of the Veterinary School of the Federal University of Goiás, Goiânia city, Goiás State (16°36' S, 49°16' W; 727 masl). The soil in the experimental area is classified as dystrophic Red Latosol (Santos et al. 2018). Soil samples were collected before the establishment of the experimental plots at a depth of 0 to 20 cm for chemical and physical soil characterization (Table 1).

Table 1. Experimental area soil physical and chemical properties.

Soil parameter	Units	Data
pH	$CaCl_2$	5.0
S	mg/kg	13
P[1]		2
P[2]		5
K		120
K	cmol/kg	0.31
Ca		1.7
Mg		0.7
H+Al		2.2
Al		0.0
CEC		5.0
Clay	%	45
Silt		19
Sand		36
Base saturation		56
Al saturation		0
Organic matter		2.7
Ca/CEC		34
Mg/CEC		14
K/CEC		6

P[1]=Mehlich-1 (Mehlich 1 phosphorus extraction); P[2]=Ion-exchange resin extraction (“resin” method) as described by Medeiros et al. (2021).

According to the Köppen classification (Dubreuil et al. 2018), the climate of the region is Aw (hot and semi-humid, with well-defined seasons, with the dry season from May to October and rainfall between November and April) with a minimum temperature of 13 ºC and maximum of 32 ºC throughout the year. Climatic data for the experimental period from December 2016 to June 2017 were obtained from the Evaporimetric Station of Goiânia, located at the School of Agronomy and Food Engineering at the Federal University of Goiás, located 1 km away from the experimental area.

Experimental design and treatments

A completely randomized factorial experimental design was used with 4 N treatments (0, 50, 100 and 150 kg N/ha), 2 N sources (conventional and protected urea) and 3 replications, totaling 24 experimental plots.

Polymer coated urea protection technology was used and urea granules were coated with additive layers of Kimcoat N polymers by Kimberlit. The additives present in Kimcoat N protect the urea from the main losses that occur in the fertilization process (NH_3 volatilization, nitrification and denitrification) and allow a greater N presence in the form of ammonium in the soil (Roberto 2007).

Planting and management

Soil preparation was carried out using a disc harrow followed by a levelling harrow prior to planting. Experimental plots of 2 × 3 m separated by paths of 0.5 m wide were established in December 2015 and Mulato II seeds were sown manually at a rate of 12 kg of viable pure seeds (VPS)/ha. During the establishment phase, phosphorus was applied at a rate of 61.1 kg P/ha (140 kg P_2O_5/ha from single superphosphate), along with 50 kg FTE BR12/ha, a slow-release micronutrient fertilizer. This formulation provides essential micronutrients including boron (B), copper (Cu), manganese (Mn), and zinc (Zn) in balanced proportions, based on technical recommendations for tropical pastures on Oxisols (Martha Júnior et al. 2007).

The 50 kg/ha application was selected to supply adequate levels of these nutrients for optimal early plant development, particularly in soils known to be deficient in micronutrients due to low natural fertility. No liming was required, as soil pH and base saturation were within suitable ranges for *Urochloa* cultivation.

Plots were maintained by mechanical cutting at an average height of 35 cm during the establishment phase. Forage canopy height was measured using a graduated stick and an acetate sheet, which was slid along the stick to the height of the leaf horizon plane without disturbing the canopy surface following the method of Pequeno et al. (2014).

Plots were cut to 15 cm height at the start of the experiment on December 5, 2016, and the treatments of 0, 50, 100 and 150 kg N/ha were applied. The higher treatments of 100 and 150 kg N/ha were divided to 2 applications in an attempt to reduce nutrient losses (Martha Júnior et al. 2007) with the second application applied on February 25, 2017.

Forage harvest using intermittent defoliation regimes based on forage canopy height with pre- and post-harvest heights of 0.35 and 0.15 m, respectively, was done using a brush cutter. The 0.50 m from the edges of each plot were excluded to avoid border effects. The determination of the forage harvest time was based on the forage canopy height, which did not allow establishing specific cutting dates. Evaluations were carried out in Period I (summer), from December 2016 to February 2017 and Period II (autumn) from March to June 2017. For the treatment using conventional urea, the average cutting days were 93, 66, 60 and 70 days and, for the treatment using protected urea, were 80, 62, 55 and 52 days for the 0, 50, 100 and 150 kg N/ha respectively. Forage harvested was expressed proportionally to a full standard cut (1.00), where a value of 1.00 represents the total harvested biomass during the period, 0.33 indicates that only 33% of the biomass (compared to a full cut) was harvested and 1.33 means that the amount harvested was 133% of the biomass observed in a standard single cut. In Period I, using conventional urea, 1 full cut (1.00) was performed for the treatments of 0, 50, and 100 kg N/ha, and 1.33 for the 150 kg N/ha treatment. In Period II, 1 cut (1.00) was carried out for all N levels. For the protected urea treatment, in Period I, only 0.33 of the standard biomass was harvested for the control (0 kg/ha), and a full cut (1.00) was performed for the other N levels. In Period II, a full cut was made for levels of 0 and 50 kg N/ha, and 1.33 for 100 and 150 kg N/ha.

Forage accumulation and morphological composition

A forage sample was taken in each plot at each harvest to quantify the accumulated forage using metal quadrats measuring 0.5 m^2 (0.5 × 1 m), with feet at 0.15 m cutting height. Fresh material was cut and weighed in the field and a subsample of approximately 500 g was taken for nutritional analysis. The subsample was weighed, dried in a forced air circulation oven at 55 ºC for 72 h and then weighed to calculate the sample dry weight. Average accumulation rates were calculated for each regrowth interval. The forage accumulation of each regrowth was considered as the forage mass harvested above the residue height. The dry matter production was calculated as the sum of forage accumulated above the residue in all harvests during the experiment.

The morphological samples of forage collected (accumulated forage) were subsampled and manually separated into their morphological components (leaves, stem and/or pseudostem and dead material). For this experiment, the pseudostem was defined as the lower portion of the shoot formed by the overlapping sheaths of the leaf bases, which gives the appearance of a stem but does not show true internodal elongation. This structure is typical in grasses such as *Urochloa* spp., where the pseudostem contributes significantly to the plant's vertical growth and supports the emerging leaves. Subsamples of each component were weighed and dried in a forced air circulation oven at 55 ºC for 72 h. These data were used to determine the percentage of each component in the forage mass, leaf:stem ratio and leaf area index from each quadrat. Average values were calculated for each plot.

Forage nutritional quality

The subsamples collected from the accumulated forage and dried in an oven at 55 °C for 72 hours were ground in a Wiley mill with a 1 mm sieve, and later analyzed for dry matter (DM), neutral detergent fiber (NDF), acid detergent fiber (ADF), crude protein (CP), mineral matter (MM), hemicellulose (HEM) and lignin (LIG), according to the methodology described by AOAC (2019).

Conversion efficiency, apparent nitrogen recovery and crude protein production per hectare

The method of Carvalho and Saraiva (1987) was used to calculate the apparent N conversion efficiency (ANCE) and the percentage apparent N recovery (ANR), using the formulas:

ANCE=kg of DM produced/kg of applied N

%ANR=100 × [(Nfert - Ncontrol)/Napplied)].

where:
Nfert is the total N absorbed in the fertilized plot (kg/ha);
Ncontrol is the total N absorbed in the unfertilized (control) plot (kg/ha); and
Napplied is the amount of applied N (kg/ha).

Statistical analysis

The statistical model used was:

$$Y_{jk}=\mu+D_j+F_k+(DF)_{jk}+e_{jk},$$

where:
Y_{jk} are the values observed in the variables;
μ is the mean of the characteristic;
D_j is the effect of the ith N amount;
F_k is the effect of the jth N source;
$(DF)_{jk}$ is the interaction effect of the ith amount with the jth N source; and
e_{jk} is the associated experimental error.

The evaluated characteristics were submitted to analysis of variance and the means were compared by the Tukey test at 5% probability. If there was interaction, the data were adjusted using a regression equation. The analyses were carried out using R statistical software (R Core Team 2023).

Results

There was no effect of the interaction between N amounts and source (P>0.05) for green biomass production (GMP), dry matter production (DMP) and leaf:stem ratio (LSR) (Table 2).

There was also no significant effect (P>0.05) of amount of N on these variables, with the exception of GMP, with a linear effect observed. The increase in N resulted in an increase of 84.6% in GMP, from 22,576 kg/ha at 0 to 41,683 kg/ha at 150 kg N/ha. Linear regression of GMP as a function of N treatments is represented by the equation y=23,656.33+126.89x. The N source influenced (P<0.05) the GMP and DMP and fertilization with conventional urea resulted in lower biomass production (dry and green) than fertilization with protected urea. Leaf:stem ratio was not affected by N source or amount.

Table 2. Mean values of green biomass production, dry matter production and leaf:stem ratio of Mulato II under levels and sources of nitrogen fertilizer.

Treatments	Green biomass production (kg/ha)	Dry matter production (kg/ha)	Leaf:stem ratio
Amount N (kg/ha)			
0	22,576b	6,739	3.93
50	31,153ab	8,990	3.31
100	37,280a	9,618	3.69
150	41,683a	9,676	3.29
N Sources			
Common Urea	29,607b	7,935b	3.57
Protected Urea	36,739a	9,570a	3.54
P value			
N amount	0.005	0.065	0.153
N Sources	0.048	0.05	0.893
Amount × Sources	0.50	0.64	0.70
C.V. (%)	24.60	22.57	15.21

Averages followed by different lowercase letters in the columns differ from each other at a 5% probability level according to the Tukey test.

The average nutritional composition of the forage was grouped into summer (period I) and autumn (period II). No interaction (P>0.05) was observed between N treatment and source for any of the nutritional response variables evaluated in Mulato II (DM, MM, CP, NDF, ADF and HEM) in any of the periods (Table 3). In both periods, there was an effect (P<0.05) of the N amount only for DM and CP concentration. A positive linear effect was observed (P<0.05) for CP concentration, represented by the equation y=5.07+0.041x and y=3.02+2.04x and determination coefficient (R^2) of 0.67 and 0.69 for period I and II, respectively. The N source had no significant effect (P>0.05) on any of the nutritional variables analyzed during the summer period and affected only NDF (P<0.05) in the autumn period.

Table 3. Average dry matter (DM), mineral matter (MM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and hemicellulose (HEM) of Mulato II grass under levels and sources of nitrogen (N) in summer (period I) and autumn (period II).

Period	Treatment	DM %	MM %	CP %	NDF %	ADF %	HEM %
Period I - Summer	Amount N (kg/ha)						
	0	28.70a	8.23	5.07b	55.34	27.37	27.97
	50	27.34ab	7.66	7.10b	52.26	27.67	24.59
	100	24.47ab	7.21	9.14ab	56.44	29.23	27.21
	150	20.81b	8.08	11.18a	58.98	27.04	22.93
	N Sources						
	Common Urea	25.29	7.9	10.75	54.16	28.30	25.85
	Protected Urea	24.71	7.7	8.57	52.85	27.35	25.50
	P value						
	N amount	0.05	0.26	0.05	0.10	0.11	0.14
	N Sources	0.53	0.60	0.15	0.49	0.15	0.82
	Amount × Sources	0.64	0.87	0.88	0.42	0.15	0.30
	C.V. (%)	8.85	11.85	6.51	8.67	5.60	15.41
Period II - Autumn	Amount N (kg/ha)						
	0	28.04a	8.26	5.13c	57.67	29.69	27.97
	50	27.71ab	8.08	6.95bc	57.96	31.03	26.93
	100	22.75b	7.84	9.22ab	59.07	29.40	28.56
	150	22.98b	7.48	11.16a	56.06	29.50	26.55
	N Sources						
	Common Urea	25.79	7.71	8.50	58.99a	30.62	28.08
	Protected Urea	24.95	8.13	7.73	56.39b	29.20	26.92
	P value						
	N amount	0.01	0.13	0.001	0.29	0.43	0.20
	N Sources	0.52	0.08	0.29	0.02	0.08	0.11
	Amount × Sources	0.57	0.06	0.43	0.48	0.84	0.88
	C.V. (%)	12.26	7.14	6.28	4.57	6.34	5.8

Means followed by the same lowercase letter in the same row and uppercase in the column do not differ (P>0.05) by Tukey's test at 5% probability.

Lignin levels did not differ with the treatments and there was no interaction between amounts and sources. A significant difference was observed for dead material (Table 4), where amounts of 0 and 50 kg N/ha showed lower losses.

For ANR, no interaction between N sources and amount was observed, and there was also no difference in ANR for N sources, however there was a difference (P<0.05) for the amount of 150 kg N/ha (Table 5). The ANR values showed a linear response to N amount.

ANCE showed no interaction between N source and amounts but differed (P<0.05) between N rates and sources evaluated (Table 5). The regression for ANCE used the equation y= 58.73-0.36x, demonstrating decreasing linear behavior. CP/ha did not show interaction between the sources and amounts of N and between evaluated sources but presented interaction for the amounts of N (P<0.05), showing the highest value observed for 150 kg N/ha.

Table 4. Mean values of dead material and lignin content determined for Mulato II for amounts and sources of nitrogen (N).

Treatments	Dead material (kg/ha)	Lignin (%)
Amount N (kg/ha)		
0	430b	7.398
50	520b	6.982
100	810a	7.320
150	970a	7.345
N Sources		
Common Urea	830	7.257
Protected Urea	430	7.625
P value		
N amount	0.027	0.925
N Sources	0.137	0.985
Amount × Sources	0.316	0.127

Means followed by the same lowercase letter in the same column do not differ from each other (P>0.05) by the Tukey test at 5% probability.

Table 5. Average values of apparent nitrogen recovery (ANR), apparent nitrogen conversion efficiency (ANCE) and crude protein/hectare (CP/ha) from Mulato II under amounts and sources of nitrogen (N).

Treatments	ANR (%)	ANCE (kg DM)	CP/ha (kg/ha)
Amount N (kg/ha)			
0	-0.15b	-	165.27b
50	5.44b	42.64a	247.68b
100	12.09b	19.14b	318.52b
150	29.56a	6.43b	762.34a
N Sources			
Common Urea	14.32	16.28b	401.58
Protected Urea	9.15	29.71a	345.32
P value			
N amount	0.001	0.001	0.001
N Sources	0.154	0.026	0.479
Amount × Sources	0.591	0.268	0.624
C.V. (%)	72.15	44.89	45.80

Means followed by the same lowercase letter in the same column do not differ from each other (P>0.05) by the Tukey test at 5% probability.

Discussion

Green mass production, dry matter and leaf:stem ratio

Previous research has shown that the response of tropical grass pastures to N fertilization increases up to amounts of 180 kg N/ha/growth cycle and, on average, the N conversion efficiency (dry matter of forage/kg of N) decreases from 120 kg/ha/growth cycle (Martha Júnior et al. 2007). In the present experiment, the amounts used in each cycle were lower with a maximum of 75 kg N ha/cycle, supplying a total of 150 kg N/ha divided into 2 applications, and a positive response was seen in GMP and not DMP. The increase in GMP observed in the present experiment is likely associated with the positive effects of N on tillering, plant growth rate, senescence and pasture structure (Faria et al. 2018; Lee et al. 2017), which stimulate carbon accumulation, the main constituent of plant tissue synthesized during photosynthesis and predominantly stored in leaves (Gastal et al. 1992). Additionally, N is a structural component of amino acids, proteins, nucleic acids, hormones, and chlorophyll (Paśmionka et al. 2021; Rütting et al. 2018). N deficiency can lead to reduced tillering and increased dormancy of buds (Souza et al. 2021a). In previous studies with *Urochloa* hybrids, GMP reached up to 30 t/ha when 200 kg/ha of N was applied to *Urochloa brizantha* (Teixeira et al. 2018). The GMP values in this experiment are consistent with those reported in the literature.

The average DMP recorded in this study was 8,756 kg/ha, compared with pastures of Mulato II managed under continuous stocking at 0.40 m height, reporting 13,400 kg DM/ha/year with 250 kg N/ha and 7,940 kg/ha using 50 kg N/ha (Silva et al. 2016). Other studies report DMP values of 10,630 and 10,090 kg/ha for 0.40 and 0.50 m cutting heights over 90–120 days (Marques et al. 2017). Despite being lower, the results in this study exceeded those obtained by Alves (2016), who recorded 3,543 kg/ha with 80 kg N/ha under similar conditions. The absence of significant effects of N on DMP may be associated with a lower dry matter concentration noted by Cantarella et al. (2007), who observed decreased DM content with increasing N levels. This may be due to the stimulation of leaf growth, which has higher water content and is more digestible (Faria et al. 2019).

The reduced GMP and DMP observed with conventional urea can be attributed to its faster release and higher potential for N losses. In contrast, protected urea resulted in a 24% increase in GMP, likely due to its controlled release mechanism, which minimizes leaching, volatilization, and denitrification (Dias 2016). Typically, pasture response to N fertilization follows a linear trend; as N increases, production increases (Martha Junior et al. 2007; Teixeira et al. 2018). However, environmental stressors such as high temperatures and water deficit, as observed during parts of this experiment (October 2016 and January 2017), may increase N loss. Souza et al. (2021b) found that water stress negatively impacted the growth of several *Urochloa* genotypes, especially with application of N above 50–60 kg N/ha/cycle. Such responses may also be influenced by the type and frequency of N application (Carvalho et al. 2018; Faria et al. 2018).

Although no significant differences were detected in leaf:stem ratio, the values recorded are considered satisfactory because maintaining a high leaf:stem ratio is desirable with leaves providing more digestible nutrients (Oliveira et al. 2016). Accordingly, maximizing the leaf fraction in forage can improve digestibility and overall nutritional quality (Faria et al. 2019).

Feed value

The highest average dry matter (DM) contents were observed in the control treatment, which may be explained by the longer regrowth interval (80 days), resulting in plants at a more advanced stage of maturity at harvest. As N application increased, the regrowth interval was reduced to 55 days, which led to plants with higher water content and lower DM content. Additionally, GMP increased with higher N treatments. A similar trend was observed by Teixeira et al. (2018) for *Urochloa brizantha* 'Marandu' as moisture content decreased with maturation (Duarte 2012).

The lack of significant differences in mineral matter (MM) content among treatments may be associated with the chemical characteristics of the soil, which likely provided sufficient mineral availability. The MM values obtained (7.14 to 8.26%) are within the range reported in the literature (3.8 to 11.86% in dry matter) for fertilized tropical grasses (Fernandes and Coalho 2018; Silva et al. 2018).

N fertilization resulted in a linear increase in crude protein (CP) in Mulato II. The highest CP (11.18 and 11.16%) was observed using 150 kg N/ha in periods I and II, respectively. This increase reflects greater N availability and uptake by the plant. Marques et al. (2017) also reported a positive relationship between N and CP content in Mulato II corroborating the present findings.

NDF levels affect intake and rates of passage in the digestive tract of ruminants, while ADF is associated with digestibility (Van Soest 1994). NDF levels in tropical grasses may be above 70% (Marques et al. 2017) but in this study, NDF for the amounts and sources of N tested were below the 60% limiting consumption (Van Soest 1994), indicating that Mulato II provides adequate amounts of NDF for ruminal function and fiber supply for cattle without compromising consumption. In period II (autumn), lower NDF was observed when fertilized with protected urea compared to conventional urea. This response is related to the plant structure, mainly the leaf:stem ratio because the accelerated growth of the plant due to the application of N promoted a greater proportion of plant stem, increasing the levels of NDF. The amount of indigestible fiber should be 30% or less to favor increased consumption of DM by the animal (Mertens 1997). Thus, the values obtained in Mulato II are satisfactory for use in ruminant feeding, regardless of the amount or source of N used for fertilization during forage production.

Although differences in climatic conditions, soil and fertilization can lead to differences in hemicellulose contents, NDF and ADF, there were no differences with amount and source of N in Mulato II in this experiment. The observed values are within the range reported in the literature for tropical grasses (Guerra et al. 2019). Lignin levels were expected to decrease with increasing N (Maranhão et al. 2009). However, this decrease was not observed in the present study, which can be attributed to the lack of difference in other fibrous components, which were below those reported by Maranhão et al. (2009) when evaluating the cultivars *Urochloa brizantha* and *U. decumbens* under N fertilization. The results obtained also agree with those of Cantarino (2017), who reported no effect of N amount on lignin levels for *Urochloa ruziziensis.*

Lower senescence-related losses and accumulation of dead material were recorded at 0 and 50 kg N/ha, probably due to slower plant growth under reduced N availability. In contrast, higher levels of N resulted in greater growth rates and increased senescence, leading to a higher proportion of dead material in those treatments.

Apparent nitrogen recovery, nitrogen conversion efficiency and crude protein production per hectare

N recovery when applied via topdressing showed no difference between the sources of urea with 150 kg N/ha showing the highest N recovery, close to 30%. This does not mean that the applied N was totally lost, because it can be leached or suffer a denitrification process, or immobilization and volatilization due to its high solubility (Austin et al. 2013). Only a part of the applied mineral N can be absorbed by the plants with between 40% and 60% routinely absorbed (Marques et al. 2017).

For tropical pastures, the average efficiency of N use in forage conversion is 30 kg DM/kg N, with a range of 5 to 80 kg DM/kg N (Martha Júnior et al. 2007). The values observed in the present study were within the range reported in the literature where the highest rates of conversion efficiency in tropical grasses was observed at 150 kg N/ha, but was not found in this research.

A decrease in ANCE was observed as N increased, with mean values of 42.64, 19.14 and 6.43 kg DM/ kg N, for 50, 100 and 150 kg N/ha respectively. This result can be attributed to the soil chemical composition of the experimental area, which had a residue of soil fertility from a history of approximately 13 years of cultivation of corn and sorghum crops intended for silage production. Primavesi et al. (2004) evaluated ANCE in coastcross pastures, using urea and ammonium nitrate at 0, 25, 50, 100 and 200 kg N/ha application after cuts performed every 24 days at 10 cm above ground in the rainy season. They reported mean values of conversion efficiency of 25.3, 27.5, 20.9 and 13.2 kg DM/kg N with application of 25, 50, 100 and 200 kg N/ha, respectively. The higher ANCE observed in treatments with protected urea can be attributed to the slower release of the nutrient compared to conventional urea, which can lead to increased losses or inefficiency in the recovery of applied N. The slow release of protected urea can lead to higher conversion efficiency by forage plants, due to lower losses by leaching, volatilization and denitrification (Chagas et al. 2017; Dias 2016).

N fertilization positively improved CP/ha with application of 150 kg N/ha producing 762 kg CP/ha, compared to the control which produced 165 kg CP/ha, showing the great advantage of using N fertilization for pastures. An increasing response in CP/ha was seen with increased N. This can be explained by the greater number of evaluation cuts in the plots where the highest amounts of 150 kg N/ha were applied, with the leaf:stem ratio of 3.29, because of the higher nutrient concentration in the leaves. This is desirable in pasture management because, in addition to increasing forage dry matter, a higher leaf:stem ratio is beneficial since leaves are the main source of nutrients for ruminants. The aim is that the highest proportion of roughage in the animal diet is provided by leaves instead of stems and dead material (Oliveira et al. 2016).

Conclusions

The increase in N provided greater GMP accumulation with protected urea providing greater biomass production. The feed value of Mulato II was not affected by amount and source of N in the 2 evaluation periods (summer and autumn), except for DMP, which was higher with low amounts of N, and CP, which increased with increasing amount of N. The use of protected urea resulted in lower levels of NDF in period II (autumn). Although ANCE was reduced with increasing N, ANR/ha and CP/ha showed linear increases as a function of N fertilization. Fertilization with protected urea resulted in greater ANCE, reflecting the slower release of N from this source.

Acknowledgments

We thank Dow AgroSciences and Agroquima Produtos Agropecuários for providing inputs and seeds used in this research.

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(Note of the editors: All hyperlinks were verified 19 September 2025).

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(Received for publication 16 January 2024; accepted 22 August 2025; published 30 September 2025)