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Biomass production and nutrient accumulation in some important tropical forage grasses for use in integrated crop-livestock systems

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Abstract: integrated crop-livestock systems refer to a production technique in which pasture, crops, and/or trees are intentionally integrated, either in consortium or rotation, aiming to harness the synergistic effects of the components. In this context, the selection of the forage plant that will make up the pasture component of the system must be done with careful rigor, aiming to harness the synergy in production. It was aimed to evaluate the productive characteristics, the accumulation of nutrients, and the carbon/nitrogen ratio on biomass of forage grasses cultivated in the off-season, in Cerrado soils, aiming for their use as cover plants in integrated crop-livestock systems. The treatments were distributed in a randomized block design with four replications each. They comprised of different tropical forage grasses: *Brachiaria ruziziensis*, *Brachiaria brizantha* (Piatã grass), and *Panicum maximum* (Zuri grass). The productive characteristics, nutrient accumulation and carbon/nitrogen ratio in the biomass of forage grasses were evaluated. There was no effect of cultivar on the stem accumulation rate ($P>0.05$). However, the Zuri grass stood out as it presented higher rates of forage and leaf accumulation ($P<0.05$), resulting in higher values of total forage mass and leaf blade for this growing crop ($P<0.05$). No significant ($P>0.05$) variations were identified in the concentrations of phosphorus, potassium, copper, iron, and zinc between the different cultivars. However, it is noteworthy that Ruziziensis and the Zuri grass showed greater ($P<0.05$) accumulation of calcium and magnesium. Higher values ($P>0.05$) of N accumulation (kg ha^{-1}) were recorded in the Piatã and Zuri grass. The C/N ratio did not change depending on the cultivars ($P>0.05$), with an average value of 39.1 ± 4.3. Zuri grass is a viable option for straw production in integrated crop-livestock systems, due to the greater accumulation of forage and minerals in its biomass.

Keywords: forage accumulation; *Brachiaria;* Cerrado; nutrients; *Panicum maximum.*
Abbreviations: Al_ aluminum, Ca_calcium, C/N_carbon/nitrogen ratio, cm_cetimeter, Cu_copper, DMM_dead material mass, DM_dry matter, FAR_accumulation rate, Fe_iron, FM_forage mass, g_gram, H_hydrogen, ha_hectare, INMET_National Institute of Meteorology, K_potassium, kg_kilogram, LBM_leaf blade mass, m_meter, Mg_magnesium, mm_ millimeter, Mn_manganese, mg_milligram, N_nitrogen, NH_3_ Ammonia, NH_4^+_ Ammonium Ion, P-value_Probability of significant effect, SEM_standard error of the mean, S_sulfur, SB_sum of bases, STM_stem mass, T_cationic exchange capacity at pH 7, V_saturation by bases, Zn_zinc.

Introduction

"Matopiba" is a term that refers to the region that encompasses Cerrado areas in the Brazilian states of Maranhão, Tocantins, Piauí, and Bahia. This region covers around 73 million hectares and represents the most recent frontier for the expansion of agricultural production in Brazil. In this region, it is typical to find soils that are highly vulnerable to degradation, characterized by high sand content and low amounts of organic matter (Almeida et al., 2019). Therefore, there is a need to adopt technologies for soil conservation. An effective alternative is the use of integrated crop-livestock systems, a production technique in which pastures, crops, and/or trees are intentionally integrated, either in consortium or rotation, with the goal of maximizing the synergistic effects among the components (Carvalho et al., 2014). In these systems, forage plants are used as cover crops during the off-season, providing straw for no-till planting, preventing erosion, cycling nutrients, and reducing leaching (Fernandes et al., 2023; Bublitz et al., 2024).

Organic matter on the soil surface constitutes an important source of nutrients for crops (Gut et al., 2022). To choose the ideal cover crop, it is necessary to pay attention to some factors such as the need for nutrients in the subsequent crop, the accumulation of forage in the cover crop, and the persistence of its straw in the soil. These factors are essential to maximize forage production and nutrient availability in the short off-season period (Silva et al., 2021). In this context, grasses stand out for their high forage production potential (Gurgel et al., 2021; Rodrigues et al., 2023), presenting a high carbon/nitrogen ratio that contributes to reducing the rate of straw decomposition

(Benvenutti et al., 2009; Costa et al., 2015). Furthermore, their resistance to water stress makes them promising crops and can be used both in the harvest and the off-season (Silva et al., 2021). Grasses of the genus *Brachiaria*, especially the species *ruziziensis* and are medium-sized perennial plants, adapted to soils of medium fertility. Furthermore, they stand out for their versatility as forage crops, being suitable for various applications, such as grazing, direct planting, and integration systems (Euclides et al., 2016; Dias et al., 2020). *Panicum maximum* cv. Zuri is a tall perennial forage plant with a caespitose growth habit. It is adapted to medium and high fertility soils and stands out for being a forage with high productivity, vigor, and resistance to leaf spot (*Bipolaris maydis*). It is recommended for silage and use under grazing in intensive systems (Jank et al., 2013).

Therefore, considering that the identification of forage plants with potential use in integrated production systems requires knowledge of information such as straw production and quality, this study aimed to evaluate the productive characteristics, nutrient accumulation, and the carbon/nitrogen ratio in the biomass of forage grasses cultivated in the off-season, in Cerrado soils, aiming for their use as cover plants in integrated production systems.

Results

There was no effect of cultivar (P>0.05) on the stem accumulation rate (Figure 1). However, the Zuri grass exhibited higher forage (P<0.05) (P=0.0077) and leaf (P<0.05) accumulation rates. The rate of accumulation of dead material was higher (P<0.05) in the Zuri grass compared to the Piatã grass, with an intermediate value observed in Ruziziensis grass (Figure 1).

The stem mass (STM) did not differ (P>0.05) between cultivars (Table 1). The Zuri grass presented higher (P<0.05) forage mass (FM) and leaf blade mass (LBM). The dead material mass (DMM) was higher in the Zuri grass compared to the Piatã grass (P<0.05), with no statistical difference between them and Ruziziensis grass. The leaf: stem ratio was highest (P<0.05) in the Zuri grass and lowest in Ruziziensis grass, with an intermediate value observed in the Piatã grass (Table 1).

The concentrations of phosphorus and potassium (g kg^{-1}), as well as the accumulation of phosphorus and sulfur (kg ha^{-1}), remained stable (P>0.05) depending on the cultivar (Table 2). On the other hand, the concentrations of calcium and magnesium were higher (P<0.05) in the biomass of Zuri grass and Ruziziensis grass. The Ruziziensis grass presented higher (P<0.05) sulfur concentrations compared to the Zuri grass, with no differences between these and the Piatã grass. The Zuri grass demonstrated higher (P<0.05) levels of calcium, magnesium, and potassium accumulation (Table 2).

The concentrations (mg kg^{-1}) and accumulation (kg ha^{-1}) of copper, iron, and zinc did not (P>0.05) show changes depending on the cultivar (Table 3). However, the concentration of manganese was higher in the Piatã grass and lower in the Ruziziensis grass, with no significant difference between these cultivars and Zuri grass. On the other hand, the Zuri grass showed higher manganese accumulation values compared to Ruziziensis grass, with an intermediate value observed in Piatã grass (Table 3).

No effect of cultivar (P>0.05) on nitrogen concentration in biomass was observed, with an average of 12.7 ± 1.4 g kg^{-1} (Figure 2). However, higher accumulations (P<0.05) of nitrogen (kg ha^{-1}) were recorded in the Piatã and Zuri grass. There was an influence of the cultivar on carbon accumulation (P<0.05), the highest value was observed in the Zuri grass (Figure 2). The C/N ratio did not change (P>0.05) depending on the cultivars, with an average value of 39.1 ± 4.3.

Discussion

Higher rates of forage and leaf accumulation were observed in the Zuri grass (Figure 1), which resulted in greater amounts of FM and LBM in this cultivar (Table 1). The productive potential

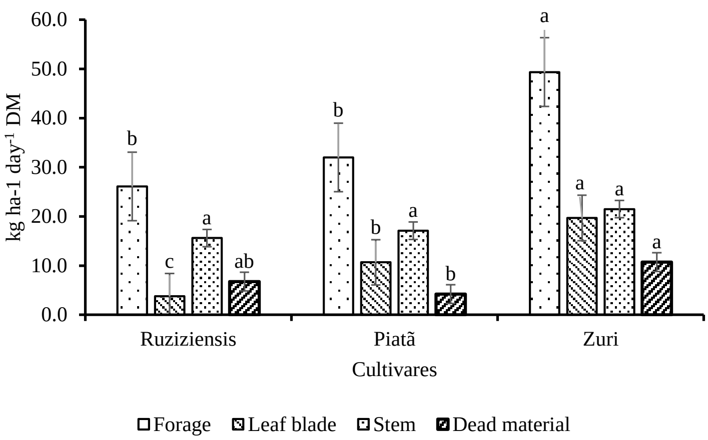

Figure 1. Forage accumulation rate and morphological components of tropical forage grasses for use in integrated crop-livestock system. Different lowercase letters differ from each other in the same line using the Tukey test (P<0.05).

is a relevant characteristic of the *Panicum* genus, since, among forage cultivars that are propagated by seeds, this genus stands out for its high forage production and nutritional value (Jank et al., 2013). Furthermore, to be used in integrated systems, it is essential to achieve greater production since this mass will be incorporated into the soil, contributing to improving its chemical, physical, and biological characteristics (Costa et al., 2016).

However, the high responsiveness to production factors, combined with the rapid initial growth of the Zuri grass and the extensive growing periods, common in cover crop cultivation during the off-season (Dias et al., 2020), may result in excessively high pasture, generating an overload of forage mass. This creates challenges in desiccation operations due to the vigorous expansion the plant will experience (Costa et al., 2016; Dias et al., 2020). Consequently, the practice of direct planting of annual crops, when in rotation, becomes more complex due to the difficulty of adjusting the planter to cut the straw in the opening of the planting furrow.

Therefore, the use of the Zuri grass in integrated agricultural production systems must be accompanied by the introduction of the animal component during the off-season, aiming to mitigate the adverse effects of excess straw. It is noteworthy that the introduction of the animal component contributes to increasing the overall profitability of the system (Fernandes et al., 2023). Furthermore, increases in soil carbon content have been observed, as well as a reduction in aluminum saturation and soil acidity in response to grazing (Almeida et al., 2023).

The DMM was more significant in the Zuri grass, followed by Ruziziensis grass, with Piatã grass being the one that showed the least senescent material. It is therefore observed that Zuri grass stood out in almost all productive characteristics evaluated, due to its higher growth rates (Figure 1). In pastures in the vegetative stage, growth is dictated by the morphogenic rhythm, which is genetically determined (Gastal and Lemaire, 2015). Thus, the genetic potential of Zuri grass resulted in an accelerated flow of tissue emergence and death, impacting the accumulation rates and masses of the morphological components of this cultivar.

Regarding the accumulation of nutrients in the biomass, the phosphorus and sulfur contents, as well as most micronutrients, remained stable, regardless of the cultivar, this being partially attributed to the similar fertilizer management practice adopted before the implementation of the different cultivars. However, it is noteworthy that the Zuri grass showed greater calcium, magnesium, and potassium cumulus in its biomass. These values are greater forage mass results obtained in this cultivar since the accumulation of nutrients is obtained by multiplying the nutrient concentration in the biomass by the respective forage mass.

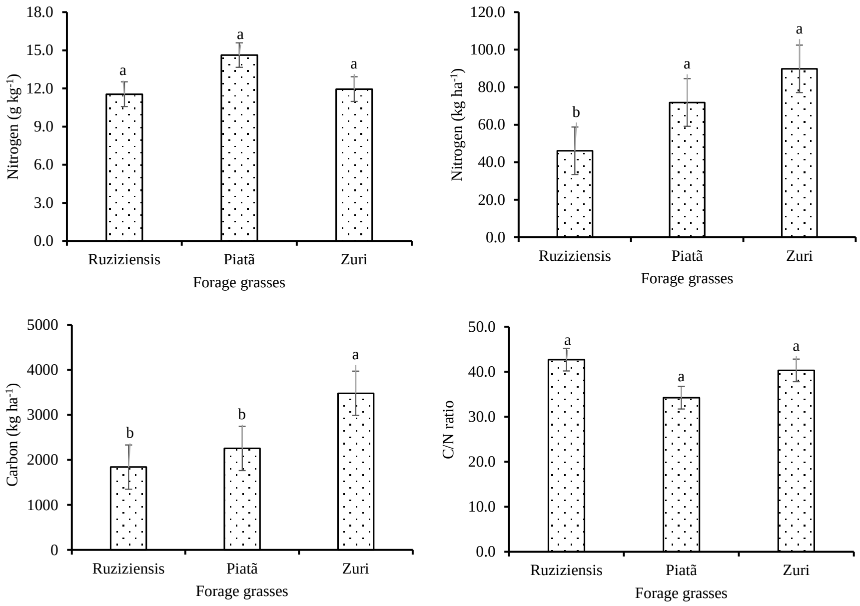

Figure 2. Quantities and carbon/nitrogen ratio in the biomass of tropical forage grasses for use in integrated crop-livestock systems. Different lowercase letters differ from each other using the Tukey test (P<0.05).

Table 1. Productive characteristics of tropical forage grasses for use in integrated crop-livestock systems.

	Forage grasses			SEM	P-value
	Ruziziensis	Piatã	Zuri		
FM (kg ha^{-1} DM)	3917.9^{b}	4798.4^{b}	7402.7^{a}	519.3	0.0077
LBM (kg ha^{-1} DM)	595.0^{c}	1599.7^{b}	2447.5^{a}	176.3	0.0011
STM (kg ha^{-1} DM)	2343.7^{a}	2571.4^{a}	3349.4^{a}	397.7	0.2506
DMM (kg ha^{-1} DM)	979.1^{ab}	627.3^{b}	1605.8^{a}	84.5	0.0089
Leaf:stem ratio	0.25^{b}	0.62^{ab}	0.78^{a}	0.08	0.0126

FM: Forage mass; LBM: leaf blade mass; STM: stem mass; DMM: dead material mass; SEM: standard error of the mean. Lowercase letters differ from each other in the same line using the Tukey test (P<0.05).

Table 2. Quantities and accumulation of macronutrients in the biomass of tropical forage grasses for use in integrated crop-livestock systems

	forage grasses			SEM	P-value
	Ruziziensis	Piatã	Zuri		
		Quantity in biomass (g kg^{-1})			
Ca	5.9^{a}	2.2^{b}	5.5^{a}	0.19	0.0001
Mg	7.5^{a}	5.1^{b}	8.2^{a}	0.28	0.0005
P	1.9^{a}	1.8^{a}	1.4^{a}	0.33	0.5847
K	6.9^{a}	5.3^{a}	6.2^{a}	0.55	0.2163
S	8.8^{a}	4.7^{ab}	3.9^{b}	0.97	0.0245
		Accumulation in biomass (kg ha^{-1})			
Ca	23.2^{b}	10.6^{c}	41.2^{a}	1.8	0.0001
Mg	29.6^{b}	24.4^{b}	61.4^{a}	4.0	0.0012
P	7.8^{a}	8.8^{a}	10.7^{a}	1.8	0.5477
K	26.9^{b}	25.6^{b}	45.5^{a}	2.9	0.0050
S	34.4^{a}	23.2^{a}	28.6^{a}	1.1	0.3231

SEM: standard error of the mean. Different lowercase letters differ from each other in the same line using the Tukey test (P<0.05).

Table 3. Quantities and accumulation of micronutrients in the biomass of tropical forage grasses for use in integrated crop-livestock systems

	Forage grasses			SEM	P-value
	Ruziziensis	Piatã	Zuri		
		Quantity in biomass (mg kg^{-1})			
Cu	12.4^{a}	21.1^{a}	6.7^{a}	5.3	0.2288
Mn	40.9^{b}	63.6^{a}	58.7^{ab}	4.9	0.0384
Fe	151.7^{a}	131.8^{a}	105.2^{a}	22.9	0.4096
Zn	64.8^{a}	86.1^{a}	44.7^{a}	27.6	0.5981
		Accumulation in biomass (kg ha^{-1})			
Cu	0.05^{a}	0.10^{a}	0.05^{a}	0.04	0.6699
Mn	0.17^{b}	0.30^{ab}	0.47^{a}	0.06	0.0433
Fe	0.62^{a}	0.62^{a}	0.80^{a}	0.11	0.5167
Zn	0.27^{a}	0.35^{a}	0.37^{a}	0.15	0.8909

EPM: erro padrão da média. Letras minúsculas distintas diferem entre si na mesma linha pelo teste de Tukey (P<0.05).

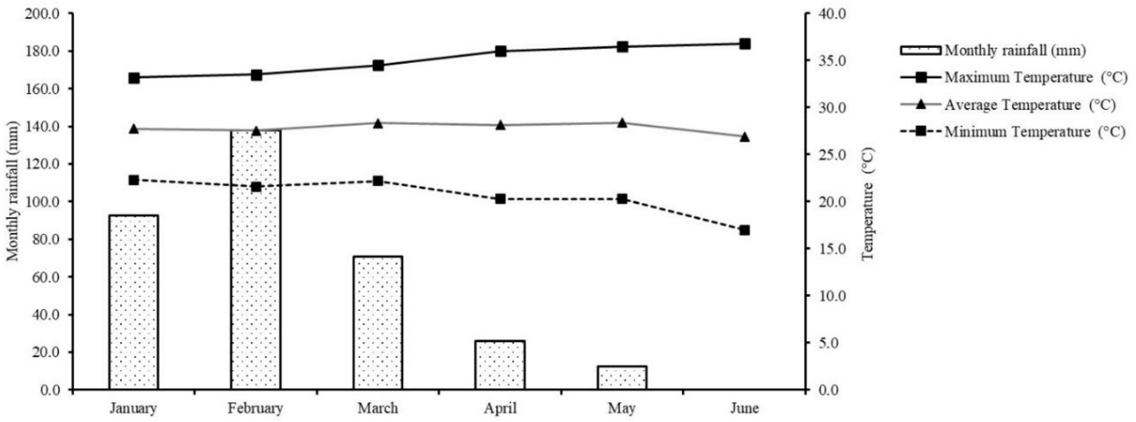

Figure 3. Monthly rainfall (mm), maximum, minimum, and average temperatures of the experimental area during the evaluation period.

Table 4. Chemical characteristics of the soil in the experimental area in the 0 – 20 cm deep layer

Parameters	
pH*	5.5
Ca^{2+} ($cmol_c dm^{-3}$)	2.2
Mg^{2+} ($cmol_c dm^{-3}$)	0.8
K^{+} ($cmol_c dm^{-3}$)	0.1
Al^{3+} ($cmol_c dm^{-3}$)	0.0
H+Al ($cmol_c dm^{-3}$)	2.4
SB ($cmol_c dm^{-3}$)	3.1
CEC ($cmol_c dm^{-3}$)	5.5
V (%)	56.1
P ($mg.dm^{-3}$)	6.5
Organic matter (g/kg)	16.3
Sand (g/kg)	915.0
Silt (g/kg)	3.0
Clay (g/kg)	82.0

* pH in water; SB: sum of bases (Ca + Mg + K); CEC: cation exchange capacity at pH 7.0 [S+(H+Al)]; V: base saturation [(S/T) * 100].

It is worth mentioning that the nutrients present in the straw will be made available to the soil through the process of mineralization of organic matter. Therefore, the use of straw with higher concentrations can increase the availability of these nutrients for crops. In the long term, this contributes to improving the chemical aspects of the soil, reducing the need for the use of chemical fertilizers.

Although a significant difference in N concentration was not observed (Figure 2), the Zuri and Piatã grass demonstrated more significant accumulations of this nutrient in their biomass, attributed to the greater forage masses presented by these cultivars. It is important to highlight that the main source of nitrogen in tropical soils results from the mineralization of the organic fraction, representing an important nutrient source for crop development (Gurgel et al., 2020). However, the rate of conversion of organic forms of nitrogen into inorganic forms (NH_4^+ or NH_3) will depend not only on the concentration of N in the straw but also on the carbon/nitrogen ratio of that same straw (Gurgel et al., 2020).

In this context, the varieties presented similar values for the C/N Ratio, indicating a correspondence between carbon and nitrogen accumulation patterns. Furthermore, it is important to highlight that variations in the C/N ratio are mainly associated with the age of the plant and the presence of stalks in the forage mass (Costa et al., 2016; Dias et al., 2020). It is worth highlighting that these variables did not change in this research.

In general, the assessment of the durability of forage plant biomass is commonly carried out through the analysis of the plant's C/N ratio, with a higher decomposition rate being observed when the ratio is lower than 25:1 (Costa et al., 2015). From this perspective, the average value of 39.1 ± 4.3 for the C/N ratio identified in this study suggests that the incorporation of this straw into the soil will result in a more gradual decomposition, providing prolonged soil coverage throughout the soil over time (Dias et al., 2020).

The average C/N ratio values found in this study are similar to those reported by Pacheco et al. (2011), who identified a C/N ratio of 34.0 in *Brachiaria ruziziensis* 200 days after sowing. Similarly, Costa et al. (2016) recorded an average C/N ratio of 34.4 for *Brachiaria brizantha* cultivated for 120 days, while Dias et al. (2020) reported an average C/N ratio of 33.5 for the species *Panicum maximum*, subjected to a cultivation period of 120 days. For years, *Brachiaria ruziziensis* was considered the predominant forage grass species for biomass production in integrated production systems (Dias et al., 2020). However, new cultivars of *Brachiaria* and *Panicum* have shown potential for this purpose (Costa et al., 2016; Dias et al., 2023). In this context, the results obtained in this study are highlighted in the selection of the most appropriate forage plant for integrated crop-livestock systems.

Materials and methods

Location and edaphoclimatic characterization

The experiment was installed in the experimental area of Fazenda Mauri, located in the Serra da Laranjeira in Currais-Piauí (8°48'21.6"S 44°46'23.6"W, altitude 533m), from January 12th to June 8th. 2023. The region's climate is classified as Dry Sub-humid (Thornthwaite and Mather, 1955), characterized by two well-defined seasons, one dry from May to September and the other rainy from October to April (Carvalho et al., 2020). The region records a historical average of precipitation of around 1000 mm, while evapotranspiration reaches 1317.3 mm. The average annual temperature generally varies between 23.5 and 25.8°C (Carvalho et al., 2020).

The climatic data, including monthly precipitation and maximum, minimum, and average temperatures (Figure 3), from the experimental area during the evaluation period were obtained from the database of the INMET (National Institute of Meteorology), at station with code A326.

In the period before the implementation of the experiment, the area had been under the direct planting system for two years, with the planting of rice (*Oryza sativa*) in the first harvest and corn (*Zea mays*) in the second harvest, corn was planted in consortium with *Brachiaria ruziziensis* as a cover crop for the off-season. The soil in the experimental area is classified as a Yellow Oxisol with a sandy texture (Santos et al., 2018). Before the start of the experiment, the soil was sampled in the 0 to 20 cm layer for chemical analysis (Table 4), with corrections and fertilizations based on the results obtained in the soil analysis.

Experimental design and treatments

The treatments were distributed in a randomized block design with four replications and were made up of different species of cover crops: *Brachiaria ruziziensis*, *Brachiaria brizantha* cv. BRS Piatã and *Panicum maximum* cv. BRS Zuri, totaling 12 experimental plots of 8.75 m^2 (2.50 x 3.50 m). Before implementing forage grasses, weeds present in the area were controlled with herbicide. The soil was prepared mechanically with heavy plowing and a leveling harrow. Sowing was carried out by broadcast and the seeding rate was calculated as described by Dias-Filho (2012), taking into account the cultural value of the seeds. A compactor roller was used to increase soil-seed contact.

Productive characteristics

Forage mass (FM, kg ha^{-1} DM) was estimated by cutting the forage contained within three areas of 1 m^2 per experimental plot. The samples were weighed and dried in a forced air ventilation oven at 55°C until constant weight when they were weighed again to determine the forage dry mass.

To evaluate the morphological components of the forage, three subsamples were taken from the samples collected to determine the FM. These were separated into leaf (leaf blade), stem (culm + sheath), and dead material. The leaf: stem ratio was calculated as the ratio between the leaf blade mass (LBM, kg ha^{-1} DM) and the stem mass (STM, kg ha^{-1} DM). To estimate forage accumulation rates (FAR, kg ha^{-1} day^{-1} DM) and morphological components, the LBM, STM, FAR, and dead material mass values (DMM, kg ha^{-1} DM) were divided by the number of days elapsed from sowing to cutting.

Mineral composition and nutrient accumulation

To analyze the mineral composition, samples from the entire plant were dried in a forced air ventilation oven at 55°C until constant weight, ground on a 1 mm sieve, and sent to the Soil Analysis Laboratory of the Professora Cinobelina Elvas *Campus* of the Federal University of Piauí (CPCE/UFPI).

Phosphorus (P) contents were determined after digestion with nitric-perchloric acid, using UV/VIS spectrophotometry at 660 nm. This measurement was carried out by evaluating the intensity of the blue color of the phospho-molybdenum complex, which is generated by the reduction of molybdate with ascorbic acid, using an IL-592 EVEN® model spectrophotometer.

The levels of potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu) were determined by means of spectrophotometry atomic absorption. These analyzes were conducted on a spectrophotometer model AA240FS VARIAN® (Silva, 2009). The quantification of nitrogen levels was carried out at the CPCE/UFPI Animal Nutrition Laboratory, using the Kjeldahl method (AOAC, 2015). Nutrient accumulation in biomass was calculated by multiplying nutrient concentration by FM.

Quantification of carbon and carbon/nitrogen ratio in biomass

To calculate the carbon stored in the biomass of forage cultivars, the FM (kg ha^{-1} DM) was multiplied by the correction factor of 0.47, by the recommendations of the IPCC (2006). The carbon/nitrogen ratio (C/N) was determined by the carbon accumulation (kg ha^{-1}) divided by the nitrogen accumulation (kg ha^{-1}) in the biomass of the cultivars.

Statistical analysis

The variables were subjected to analysis of variance according to the following model: Yij = μ + Ci + Bj + αij, where: Yij= value observed in cultivar i, block j; μ= overall average effect; Ci= effect of cultivar i; Bj= effect of block j; αij= effect of random error. When significant by the F test, the effects of the cultivars were analyzed by the Tukey test, at 5% significance.

Conclusions

The Zuri grass stands out for its greater forage production and accumulation of nutrients in its biomass and its high C/N ratio, constituting a viable option for straw integrated crop-livestock systems.

Acknowledgment

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