Original Article

NITROGEN IN THE PRODUCTION OF GREEN AND DRY MASS AND THE EFFICIENCY OF NITROGEN CONVERSION AND APPARENT RECOVERY OF PEARL MILLET CULTIVARS

NITROGÊNIO NA PRODUÇÃO DE MASSA VERDE E SECA, EFICIÊNCIA DE CONVERSÃO E RECUPERAÇÃO APARENTE DO NITROGÊNIO DE CULTIVARES DE MILHETO

Wilian Henrique Diniz BUSO[1]; Aldi Fernandes de Souza FRANÇA[2]; Eliane Sayuri MIYAGI[2]; Daniel Staciarini CORRÊA[3]

1. Professor, Doctor, Department of Agriculture and Animal Science – Goiano Federal Institute - IF Goiano, Campus Ceres, Ceres, GO, Brazil. wilian.buso@ifgoiano.edu.br; 2. Professor, Doctor, Department of Animal Prduction, School of Veterinary and Animal Science - Federal University of Goiás – UFG, Goiânia, GO, Brazil; 3. Animal Scientist, PhD student, School of Veterinary and Animal Science - Federal University of Goiás – UFG, Goiânia, GO, Brazil

ABSTRACT: The potential of dry (DM) and green (GM) matter yield, plant nitrogen concentration (NC), apparent nitrogen conversion efficiency (NCE) and apparent N recovery (ANR) of pearl millet cultivars with nitrogen fertilization are analyzed. Current experiment was conducted in the municipality of Ceres GO Brazil, within the Cerrado (Brazilian savannah) biome. A 3x4x2 randomized factorial block design was employed, with three repetitions. Treatments were composed of three pearl millet cultivars (ADR-7010, ADR-500 and BRS-1501), four N doses (0, 50, 100 and 200 kg ha^{-1}) and two sowing times (December and February). Plants from each seeding were harvested twice at a height of 0.70 m. There was a significant effect on the interaction between cultivars and N doses. GM yield of ADR-7010 cultivar increased up to 140 kg.ha^{-1} of N. There was a quadratic effect of N doses on DM yield, with maximum production at 158 kg ha^{-1} N. The quantity of N extracted by the plants varied according to the cultivar, with BRS-1501 accumulating the highest N quantities in the shoots. Maximum NC of pearl millet shoots would be achieved with 147 kg N ha^{-1}. The highest NCE occurred with N doses of 50 kg ha^{-1}, with a DM yield of 11.60 kg per kg of applied N. ANR was also highest for N doses of 50 kg ha^{-1}, with a 53% maximum recovery.

KEYWORDS: Sowing time. Forage. *Pennisetum glaucum.* Urea.

Abbreviations: ANR, apparent nitrogen recovery; CP, crude protein; DM, dry matter; GM, green matter; NC, plant nitrogen concentration; NCE, apparent nitrogen conversion efficiency.

INTRODUCTION

Cattle-breeding in Brazil is mainly based on pasture as opposed to grain-feeding, for lower costs. However, animal productivity indexes in the savannah biome are low owing to the degradation of many areas and to the low technological level of herd management, with high liabilities in potential earnings.

Pearl millet (*Pennisetum glaucum* (L.) R. Brown), an annual plant with high nutrition rates, may be used for grain production, mulching and forage for grazing and production of silage. Due to its physiological characteristics, pearl millet is highly resistant to water stress and adapts well to acidic and low-fertility soils which are limiting factors for corn (Pires et al., 2007). Results obtained by Pires et al. (2007) demonstrate that the dry matter yield (DM) of three pearl millet cultivars increased as the plants attained full flowering and reached 19.29 t ha^{-1} of DM.

Nitrogen (N) availability is one of the most important factors in the growth and development of plants. Increase in N contents of the soil by fertilization is one of the main strategies to boost forage plant yields (MARTUSCELLO et al., 2005).

According to Fagundes et al. (2006), the supply of adequate quantities of N during the development of forage plants is fundamental for the growth of pastures since N available from the mineralization of organic matter does not supply the needs of high-yield forage plants. Increased nitrogen fertilization raised DM production of Mombasa grass in the rainy and dry seasons. In fact, the average N dose of 307 kg ha^{-1} was highly efficient for the conversion of nitrogen fertilizer by the grass (Mello et al., 2008).

In their study on forage pearl millet, Mesquita and Pinto (2000) reported that N influenced DM yield, with a quadratic regression curve best fitting the data, according to which maximum yield of 8,913 kg ha^{-1} was reached with a

Received: 08/04/14
Accepted: 10/06/15

maximum N dose of 139 kg ha^{-1}. Heringer and Moojen (2002) noted that DM production of pearl millet responded quadratically to nitrogen fertilization and also verified that the efficiency of the use and recovery rates of N declined as N doses increased.

We aimed to evaluate green and dry matter forage yield as well as the efficiency of apparent nitrogen conversion (NCE), apparent N recovery (ANR) and N concentration (NC) of three pearl millet cultivars with four N doses at two sowing times, on the Brazilian savannah Biome.

MATERIAL AND METHODS

The experiment was conducted on the experimental farm of the Instituto Federal Goiano, Ceres Campus, in the municipality of Ceres GO Brazil, at 15º 21' 00" S and 49º 35' 57" W, altitude 564 m. The region´s climate is Aw, according to Köeppen classification, or rather, hot and semi-humid with well-defined wet and dry seasons. The average annual rainfall is 1550 mm, with the rainy season running from October to April and the dry season from May to September. Figure 1 shows monthly rainfall and average temperatures during the experiment period.

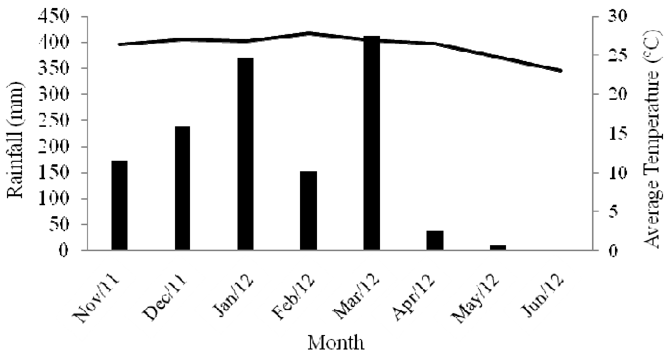

Figure 1. Monthly rainfall (mm) and average temperature (°C) during the experimental period (November 2011 to June 2012).
Source: Weather season from IF Goiano Campus Ceres.

The soil in the experimental area has been classified as dystrophic red Latosol (Embrapa, 2006). Samples were collected from the top layer (0 to 20 cm) for chemical and physical characterization. The results were Ca: 2.4; Mg: 1.3; CTC: 7.67; Al: 0; H: 3.7 ($cmol_c$ dm^{-3}); P (Melich): 5.0; K: 101 (mg dm^{-3}), pH ($CaCl_2$): 5.6, saturation bases: 51.8; organic matter: 1.5; sand: 39; clay: 50 (%). Soil in the experimental field was prepared conventionally with two passages of a disk harrow followed by one with a leveling harrow on the day before sowing.

Treatments were composed of three pearl millet cultivars (ADR-7010, ADR-500 and BRS 1501), four N doses (0, 50, 100 and 200 kg N ha^{-1}) and two sowing times (December 2010 and February 2011). The experimental design consisted of fully randomized blocks in a 3x4x2 factorial scheme, with three replications, for a total of 72 experimental units.

The seeds were planted manually on December 1, 2010 and on February 20, 2011. Each experimental plot was composed of four rows, 5 meters in length, spaced 0.30 m apart, covering an area of 4.5 m^2. The seeds were planted at a density of 20 pure viable seeds per meter. Forty-five kg P_2O_5 ha^{-1} (simple phosphate) was applied in the furrows at the time of sowing. Ten days after germination, potassium was applied at 30 kg ha^{-1} K_20 (potassium chloride) as top dressing. Nitrogen fertilizer (urea) was also applied, in two portions, or rather, 60% ten days after germination and the remaining 40% the day after the harvest for the first evaluation.

The plant´s material samples were taken from the two central rows, eliminating the last 0.50 m at the two ends (two rows measuring 4 m in length). The plants from each sowing time were harvested twice, on the 5^{th} and 27^{th} January 2011 for the first and on the 27^{th} March and 21^{st} April 2011 for the second. They were harvested when at least 50% of the plants were 0.70 m high. After each harvest, the material was weighed to determine green matter yield (GM in kg ha^{-1}). Total GM was the sum of the two harvests.

Samples of approximately 500 g were used for laboratory analyses. The samples were dried for 72 hours in a forced-air chamber at 60°C to determine dry matter (DM) yield. They were then ground in a Wiley mill and passed through a 1 mm sieve. The ground material was stored in duly identified acrylic flasks and shut with plastic lids. The samples from the two harvests within the respective sowing groups were mixed and homogenized for subsequent laboratory analyses. The material from the two harvests was not evaluated individually because the second harvest was influenced by the first portion of the nitrogen fertilization.

The plant´s dry matter (DM) and N concentration (NC) rates, determined according to method described by Silva and Queiroz (2002), were performed at the Animal Nutrition Laboratory of the Animal Production Department of the Veterinary School of Goiás Federal University.

Since nitrogen in roots and residue was not measured, the recovery of N absorbed from the total applied only took into account the shoots´ NC. Nitrogen conversion efficiency (NCE) and apparent nitrogen recovery (ANR) were determined following Carvalho and Saraiva (1987).

Data on GM and DM yield, NC, crude protein (CP), NCE and ANR were submitted to joint analysis of variance; the two sowing times and mean rates were compared by Tukey´s test at 5% significance. Variables were also evaluated by fitting regression equations as a function of N dose applied as top dressing. The statistical analysis was performed with R software (R Development Core Team, 2010).

RESULTS

The interaction between cultivars and nitrogen doses provided significant effects ($p<0.05$), with different responses of the cultivars to different N doses for GM yield. There was no significant interaction ($p>0.05$) between cultivars and N doses, sowing time and N doses and cultivars and sowing times and also between the triple interaction of time, cultivar and N dose for the variables DM, CP, NC, NCE and ANR.

Table 1 shows significant interaction ($p<0.05$) between cultivars and N doses. All the pearl millet cultivars were significantly affected by the application of nitrogen: increasing N caused an increase in the GM yield of the cultivars. Regression analysis demonstrated that GM yield of cultivars ADR 7010 and BRS 1501 responded quadratically to increased nitrogen doses (Figure 2).

Table 1. Green matter (GM) of pearl millet cultivars (kg ha^{-1}) with increasing nitrogen doses.

Cultivar	Nitrogen Doses (kg ha^{-1})			
	0	50	100	200
ADR – 7010	26,650 a	27,550 a	34,830 a	32,010 b
ADR – 500	26,890 a	28,280 a	33,240 a	33,780 ab
BRS – 1501	21,370 a	29,060 a	35,290 a	38,490 a

Means followed by the same small letters in the columns do not differ statistically by Tukey´s test at 5% probability.

In the case of ADR 7010, the maximum GM yield (34,522.1 kg ha^{-1}) would be achieved with 140 kg N ha^{-1}. For BRS 1501, the application of 184 kg N ha^{-1} would produce 38,663.7 kg GM ha^{-1} (Figure 2), whereas cultivar ADR 500 demonstrated linear response to nitrogen application.

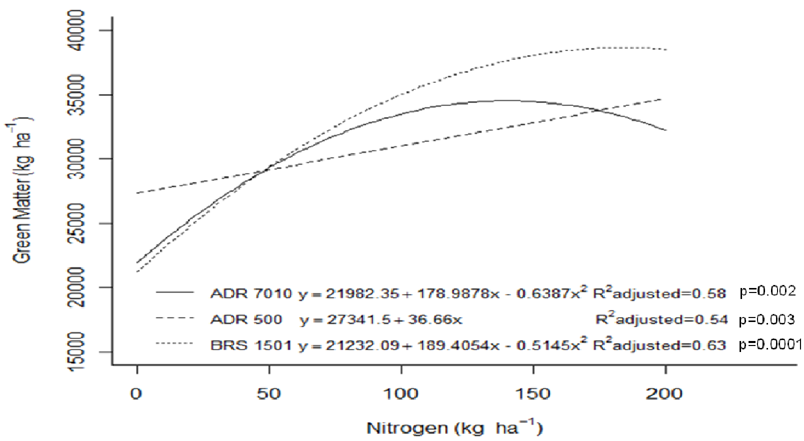

Figure 2. Green matter yield of pearl millet cultivars in response to nitrogen application.

Table 2 shows GM and DM yields produced by plants according to sowing time. There were significant differences ($p<0.05$) for GM and DM yield between the two groups. Plants´ yield from seeds sown in December was higher due to better climate conditions, mainly water availability. On the other hand, less water availability in February and average lower temperature were factors that tended to reduce GM production.

Table 2. Total production of green (GM) and dry (DM) matter for the three pearl millet cultivars at two sowing times, December 2010 and February 2011.

Sowing Time	GM (kg ha^{-1})	DM (kg ha^{-1})
December	34,198.31 a	3,446.65 a
February	26,376.56 b	2,750.85 b
CV (%)	10.67	14.32

Means followed by the same letters in the columns are statistically the same by Tukey´s test at 5% probability.

There were no significant interactions ($p>0.05$) between cultivars and N doses for DM production, but there was a significant difference in DM yield between cultivars ($p<0.05$), as Table 3 shows.

Table 3. Mean rates of dry matter (DM) yield of pearl millet according to cultivar and nitrogen doses determined for the two sowing times.

Cultivar	DM (kg ha^{-1})
ADR-7010	2,560.63 c
ADR-500	3,205.25 b
BRS-1501	3,530.38 a
CV (%)	14.32

Means followed by the same letter in the columns do not differ statistically by Tukey´s test at 5% probability.

There was a significant difference ($p<0.05$) between nitrogen concentrations (NC) and crude protein (CP) for sowing time, cultivar and N dose. In plants sown on December 2010, there was a 124.49 kg ha^{-1} of N accumulation in the shoots and CP production was 778.07 kg ha^{-1}, while those planted on February 2011 accumulated 92.12 kg ha^{-1} of N and produced 575.77 kg ha^{-1} of CP.

N quantity extracted by the plants and CP varied according to the cultivar. As Table 4 demonstrates, cultivar BRS-1501 accumulated higher amounts of N in the shoots and also produced more CP. This latter factor was related to DM yield, since cultivar BRS-1501 had the highest productivity. NC and CP rates increased up to 147 kg N ha^{-1}.

Table 4. Mean rates of nitrogen concentration (NC) and crude protein (CP) of pearl millet cultivars submitted to nitrogen doses

Cultivar	NC (kg ha^{-1})	CP (kg ha^{-1})
ADR-7010	90.21 c	563.80 c
ADR-500	110.45 b	690.29 b
BRS-1501	124.73 a	776.67 a

Means followed by the same letters in the columns are statistically the same by Tukey´s test at 5% probability.

The application of N doses and DM yield produced a quadratic effect (Figure 3). A lower DM yield of N rate 200 kg ha^{-1} was probably due to losses of N by volatilization and leaching and to the decrease of dry matter contents in plants submitted to nitrogen fertilization.

Nitrogen fertilization significantly affected ($p<0.05$) DM production (Figure 3). The highest DM production (3,585.48 kg ha^{-1}) would be reached by 158 kg N ha^{-1}.

A quadratic effect of nitrogen doses was also observed on NC (kg ha^{-1}) and CP (kg ha^{-1}), as Figures 4 and 5 show. The highest N accumulation (128.734 kg ha^{-1}) and crude protein production (804.59 kg ha^{-1}) would occur with the application of 147 kg N ha^{-1}.

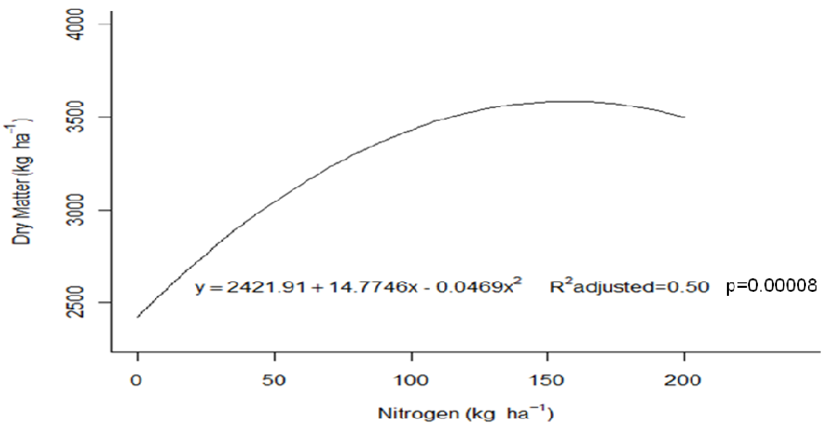

Figure 3. Dry matter yield in response to nitrogen application.

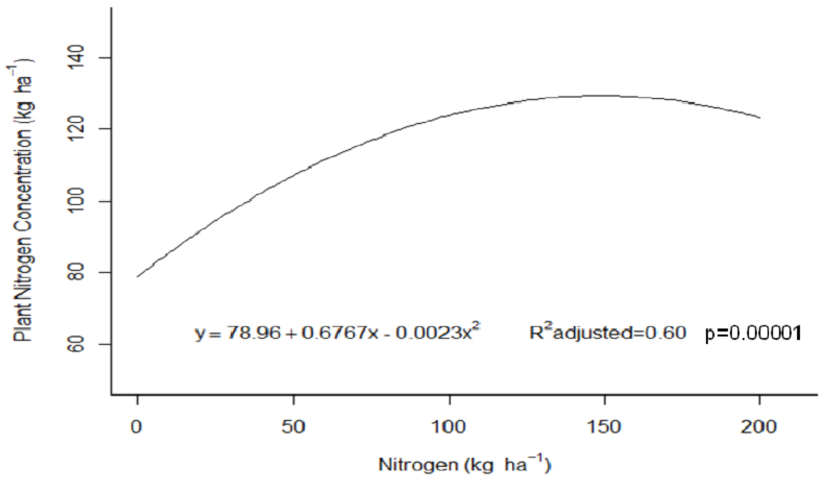

Figure 4. Nitrogen concentration (kg ha^{-1}) in aboveground tissue of pearl millet plants submitted to different nitrogen doses.

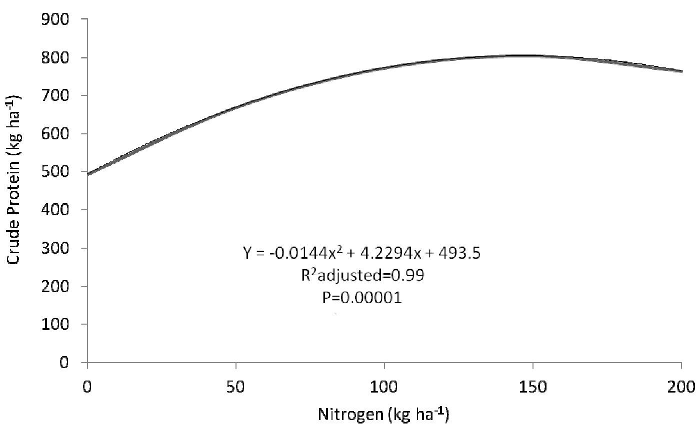

Figure 5. Crude protein production (kg ha^{-1}) in aboveground tissue of pearl millet plants submitted to different nitrogen doses.

Apparent nitrogen conversion efficiency (NCE) and apparent nitrogen recovery (ANR) were significantly affected ($p<0.05$) by N rate. Figure 6 (6A and 6B) show decreasing NCE and ANR as N doses increase.

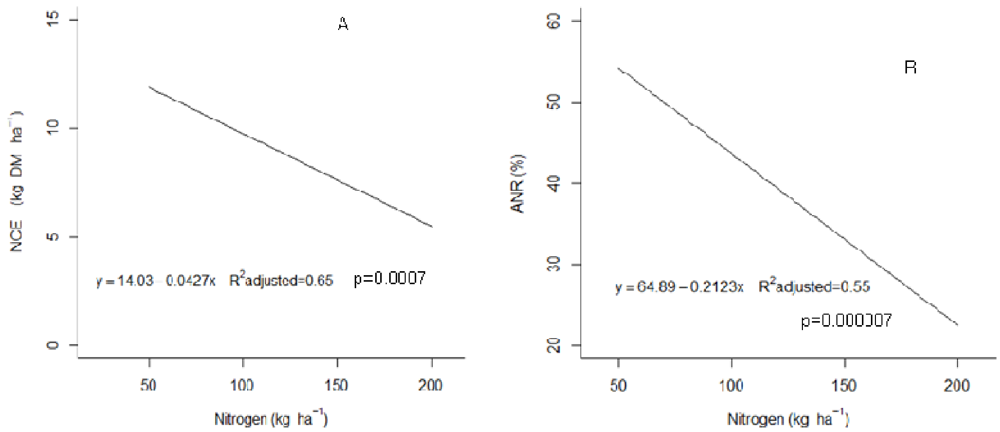

Figure 6. A) Apparent nitrogen conversion efficiency (NCE) and B) apparent nitrogen recovery (ANR) submitted to different nitrogen doses.

DISCUSSION

Plants sown in December accumulated more N due to better conditions in temperature, luminosity and water availability, which were factors that raised photosynthesis rates. Rostamza et al. (2011) reported smaller leaf area index (LAI), directly related to the photosynthesis rates, in pearl millet under water stress. Bonfim-Silva et al. (2011) registered that water stress in early development stages compromised dry matter production from maize and pearl millet. Rostamza et al. (2011) also described lower nitrogen conversion efficiency under lower water availability which led to a smaller dry matter production.

Negreiros Neto et al. (2010) studied pearl millet cultivar BRS 1501 and observed a linear response in GM yield with rising N rates (0, 30, 60 and 120 kg ha^{-1}). Further, Pires et al. (2007) studied plants sown in October and harvested before flowering and reported biomass production of approximately 47,330 kg ha^{-1}. Costa et al. (2005) planted seeds in January and March and obtained significantly higher DM yields of 6,535.40 kg ha^{-1} versus 1,422.20 kg ha^{-1}, respectively, whereas Calvo et al. (2010) reported that pearl millet harvested 30 days after sowing produced 2,573.20 kg ha^{-1} of DM.

Nitrogen uptake is limited by N availability, but also by the plant´s N demand. Uptake efficiency depends on factors affecting plant growth (varietal characteristics, and the availability of light, water and other nutrients) when related to N availability (Janssen, 1998).

Results obtained in our research are similar to those in current study and showed that pearl millet planted in the summer had a higher capacity to produce GM and DM when compared to that planted in the off-season.

Results in current study disagree with those by Negreiros Neto et al. (2010) who reported a linear response when nitrogen dose was varied. In fact, they obtained the highest DM yield at dose 120 kg ha^{-1} of N. In their studies on elephant grass, Vitor et al. (2009) also registered a linear effect of nitrogen fertilization, with maximum DM yield occurring at a nitrogen rate of 700 kg ha^{-1}.

In a study on *Brachiaria brizantha* cv Marandu, Benet et al. (2008) also reported a quadratic effect for DM yield due to N doses. The application of an increasing N rate up to 200 kg ha^{-1} promoted increased DM production and also raised the content of crude protein and total digestible nutrients. Results in current experiment corroborated the above authors' findings.

The quadratic effect of nitrogen on DM yield may be due to N losses by volatilization and leaching. According to Janssen (1998), besides the soil´s physical characteristics and the weather during the growing season, both uptake efficiency and utilization efficiency depend on the conditions of other growth factors (e.g., crop production potential, availability of other nutrients and water, irradiation). The author states that the improvement of these growth factors will enhance the efficient use of that specific nutrient.

The quadratic effect from nitrogen on DM yield may also be due to a decrease in dry matter content in plants submitted to nitrogen fertilization. Decrease in dry matter content is constantly observed in tropical grasses. In fact, Henriques et al. (2007) and Castagnara et al. (2011) state that the above is due to a higher water accumulation in plants to support their larger frame.

Silva et al. (2012) observed a decrease in DM content and a quadratic effect in nitrogen doses on pearl millet cultivar ADR 300 harvested at 0.20 m. In their research, the cultivar ADR 300 produced 551.79 kg DM ha^{-1} with 100 kg N ha^{-1} and 489.27 kg DM ha^{-1} with 150 kg N ha^{-1}; dry matter content ranged between 13.9 (0 kg N ha^{-1}) and 12.5 (150 kg N ha^{-1}).

According to Costa et al. (2005), DM yield of BRS-1501, harvested during the flowering stage, was 4,458 kg ha^{-1}, higher than that reported for the same cultivar in current research.

Quadratic responses between N doses and DM production generally occur in researches evaluating several nutrient levels. According to Dougherty & Rhykerd (1985), the above occurs due to the fact that after reaching a certain nutrient level, the nitrogen excess may cause an imbalance among nutrients and may intoxicate the plant.

N dose of 50 kg ha^{-1} had the highest NCE, perhaps due to the plant´s increase in efficiency when lower nitrogen doses were applied. ANR was also highest at 50 kg N ha^{-1}. This finding demonstrated that ANR rates were higher at lower N doses. NC and NCE rates in current research corroborated results by Freitas et al. (2005). The authors evaluated Mombasa grass and reported increasing N concentrations in the plant tissue with increased application of nitrogen fertilizer, reaching maximum accumulation at 280 kg ha^{-1}.

Apparent N recovery in current study ranged between 54.27% (50 kg ha^{-1}) and 22.43% (200 kg ha^{-1}). According to Janssen (1998), between 15 and 20% of total amount of cereals lies in the roots. Hence, even if recovery is 100%, the measured recovery in the aboveground plant parts cannot exceed the 80 - 85% bracket.

Nitrogen conversion efficiency was 11.89; 9.76; 7.62 and 5.49 kg DM ha^{-1} for doses 50; 100; 150 and 200 kg N ha^{-1}, respectively. Dias et al. (2000) evaluated coast-cross grass and found that the highest conversion rate occurred with nitrogen dose 100 ha^{-1} which produced 36 kg of DM per kg of N applied. Above results agree with those in current study in which highest DM yields occurred with N doses 50 and 100 kg ha^{-1}.

According to Martha Junior et al. (2004), N conversion efficiency of tropical forage plants may reach up to 80 kg of DM per kg of N applied when the pasture is well managed. The authors found an average conversion efficiency of 26 kg of DM per kg of N applied, with the highest efficiency at N doses up to 150 kg ha^{-1}.

CONCLUSIONS

Green matter yield of the three pearl millet cultivars was influenced by nitrogen fertilization, although pearl millet cultivars responded differently to N doses.

Cultivar BRS-1501 produced the highest quantity of dry matter. Cultivar ADR 500 presented linear response evaluated doses.

Apparent nitrogen conversion efficiency and apparent N recovery was reduced by increasing N fertilization doses.

ACKNOWLEDGMENTS

The authors would like to thank Sementes Adriana and EMBRAPA for supplying the hybrid seeds; the academic funding agency CAPES for its financial support; the Instituto Federal Goiano, Campus Ceres, for providing research facilities; and the Graduate Program in Animal Science of Universidade Federal de Goiás.

RESUMO: O presente trabalho de pesquisa teve como objetivo avaliar o potencial produtivo de massa verde e a massa seca da planta inteira, N contido na planta, bem como a eficiência de conversão do N e a recuperação aparente do N de cultivares de milheto, sob doses de nitrogênio, em diferentes épocas de semeadura no município de Ceres, Goiás. O experimento foi instalado em delineamento de blocos casualizados em esquema fatorial 3x4x2, constituídos de cultivares de milheto (ADR-7010, ADR-500 e BRS-1501) e doses de N (0, 50, 100 e 200 kg ha^{-1} de N, aplicados na forma de uréia) o fatorial foi avaliado em duas épocas de semeadura (Dezembro/2010 e Fevereiro/2011). Foram realizados dois cortes em cada época quando as plantas atingiram 0,70 m de altura. Ocorreu efeito significativo da interação entre cultivares e doses de nitrogênio. A produção de massa verde para a cultivar ADR-7010 aumentou até a dose de 140 kg ha^{-1} de N. Ocorreu efeito quadrático da aplicação das doses de N na produção de MS, a dose para a máxima produção foi de 158 kg ha^{-1} de N. A quantidade de N extraído pela planta variou de acordo com a cultivar, onde a BRS-1501 acumulou maiores quantidades de N na parte aérea. O máximo teor de nitrogênio contido na parte aérea das plantas de milheto seria atingido com a aplicação de 147 kg N ha^{-1}. A maior eficiência de conversão aparente do nitrogênio ocorreu na dose equivalente a 50 kg ha^{-1} de N, com produção de 11,60 kg de MS por kg de N aplicado. A recuperação aparente do nitrogênio foi maior para a dose de 50 kg ha^{-1} de N, com máxima de recuperação de 53%.

PALAVRAS-CHAVE: Épocas de semeadura. Forragem. Nutrição. *Pennisetum glaucum*. Ureia.

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