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Management of nitrogen fertilization for the millet culture (*Panicum miliaceum* L.)

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ABSTRACT

Background: For millet culture, are still incipient the information about the nitrogen fertilization management and its effect on grain yield and yield and quality of dry matter. **Objective:** The aim of this study was to evaluate the effect of doses and the ideal period of nitrogen (N) application in order to improve grain yield and productivity and the quality of dry matter. The experimental design was randomized blocks in a factorial 4 x 4, with four replications for each treatment, which consisted of a combination of four different nitrogen doses (BUN) (0, 30, 60 and 90 kg ha^{-1}) and four managements applications of N: 100% sowing; 30% sowing + 70% at 15 Days After Emergence (DAE); 30% sowing + 70% at 30 DAE; 30% sowing + 70% at 45 DAE. **Results:** Based on the results it can be observed mainly for the managements tested when the goal is yield and quality of dry matter, the managements M1 and M2 are the most appropriate. Already when the purpose is the productivity of grain yield the M4 management is indicated. For the doses tested in general the best effects were observed for the maximum dose tested in the variables evaluated. **Conclusion:** It was observed that independent of the method of application, the doses of N applied to the crop increased dry matter, accumulated protein, accumulated phosphorus, and the grain yield. For the production of dry matter, as well as accumulation of protein, phosphorus, and potassium, the application of N of 100% at sowing and 30% sowing + 70% at 15 DAE showed the highest increases when submitted doses of 60 to 90 kg ha^{-1} of N. The highest grain yield independent of the application distribution was observed for the dose of 90 kg ha^{-1} N.

INTRODUCTION

The millet (*Panicum miliaceum* L.) is an annual cycle crop, originally from Africa, one of the oldest and most important cereals used by man, after wheat and barley (Kalinova and Moudry, 2006). It was a staple food in semi-arid regions of East Asia (China, Japan, Russia and India) and across the Eurasian continent before rice and wheat gained popularity.

In Brazil, this cereal is not often cultivated in comparison to other more traditional crops such as wheat, oats, and sorghum. Millet has been cultivated in some regions of São Paulo, Mato Grosso do Sul, and Rio Grande do Sul, for the purpose of economic exploitation of grain for animal feed, primarily for captive birds. There are few studies that analyze the quality of dry matter produced in the millet crop for both nutrients that can be cycled as cover crops in the system, and for the nutritional value as animal feed.

Nitrogen is one of the nutrients of greatest interest in agriculture; it is responsible for the productivity of most crops and usually demanded in large quantities by these cultures (El-Shaarawi *et al*., 2011). The

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importance of nitrogen is related to its effects on the crop; it affects the metabolism of the plants participating in the proteins production, amino acids, chlorophyll and other important compounds in plant metabolism (Barhoumi *et al*., 2010). In this context, to obtain a better development of millet crops, and positive results in dry matter yield and/or grains, the use of technologies that help monitoring and managing the nitrogen fertilization are of great importance. The GreenSeeker (Trimble Navigation Ltd., Sunnyvale, California, USA), has been appointed as a monitoring tool to identify the nitrogen demand in real time in cultures. This sensor has the red and infrared (NIR) sensors which provide the vegetation index by normal differentiation (NDVI) that is influenced by the dry weight and leaf area index (Cao *et al*., 2015) which correlates with the N concentration in the plant (Erdle *et al*., 2011).

Thus the purpose of this study was to evaluate the effect of nitrogen doses and the optimum period of coverage application on grain productivity, yield, and the quality of dry matter in the millet crop.

MATERIAL AND METHODS

This study was conducted in the experimental area of the Federal University of Santa Maria campus Frederico Westphalen, RS, whose coordinates are 27 23'47.58 "S and 53 25'41.24" W, at an altitude of 566 meters. The regional climate according to the Köppen´s global climatic classification is humid subtropical (Cfa), with an average annual temperature of 18.1 ºC and annual rainfall of the order of 1,900 mm.

The soil is classified as Oxisol (Santos *et al*., 2013a) with clay; The cultivated area was managed under a no-tillage system for more than 10 years with soybean and corn crops during summer, and wheat and oats during fall and winter. Soil sampling was performed at a depth of 0.00 to 0.20 m for chemical characterizations of the soil (CQFS-RS / SC, 2004) with the following results: pH in H_2O (1:1) 4.8, SMP index: 5,5, clay 650 g kg^{-1}, organic matter 29 g kg^{-1}, P-mehlich 13,0 mg dm^{-3}, potassium 252 mg dm^{-3}, calcium 3,1 $cmol_cdm^{-3}$, magnesium 1,7 $cmol_cdm^{-3}$, H + Al 5,6 $cmol_cdm^{-3}$, Al 1,0 $cmol_cdm^{-3}$, CTC 11,3 $cmol_cdm^{-3}$, and CTC with base and Al of 50,6 and 14,8%, respectively. Six months prior to the experiment, there was application of lime to raise the pH to 6.0 following the recommendation of the chemistry and fertility committee (CQFS-RS / SC, 2004).

The experimental design was randomized blocks in a factorial 4 x 4, with four replications; the treatments consisted of a combination of four nitrogen doses (0, 30, 60 and 90 kg ha-1) and four application managements of N, 100% at sowing (M1); 30% sowing + 70% at 15 DAE (days after emergence) (M2); 30% sowing + 70% at 30 DAE (M3) and 30% sowing + 70% at 45 DAE (M4). The application of N was always performed by throwing urea (45% N) to each plot that measured 3 x 2m. The fertilization of phosphorus and potassium, was performed by throwing five days before sowing triple superphosphate and potassium chloride, respectively.

Along the experiment, a total of 491.6 mm of rainfall was recorded, concentrated in the month of October (Figure 1); this facilitated the management of nitrogen where urea was applied in the late afternoon under moist soil. Average temperatures were recorded for the months of September, October and November, showing minimum of 14.6; 16.1 and 17.3 ° C and maximum of 26.1; 26.1 and 29.1 ° C respectively.

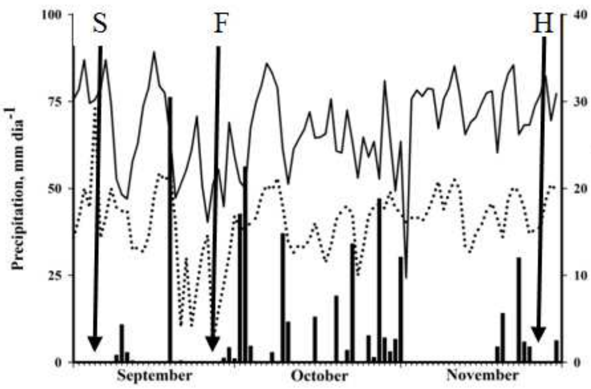

Fig. 1: Precipitation (▌), maximum temperature (▬) and minimum temperature (···), during the experiment period in the field in 2012, and dates of sowing (S); flowering (F) and harvest (H).

The experiment was conducted in soybean stubble harvested in March, with seeds of AL Tibagi cultivar manually sowed on 09/05/12 with a spacing of 0.17 m between lines and 80 seeds per meter.

At the full flowering stage, an area of 0.25 m^2 was delineated for evaluation of dry matter and nitrogen accumulation in the aerial part of the millet. For this, samples were taken to an oven with air circulation and a temperature of 65 °C in order to achieve a consistent weight. After weighing and evaluating the dry matter, samples were ground for laboratory analysis of nitrogen, phosphorus and potassium following the methodology described by Tedesco *et al*. (1995). With the determination of nitrogen in the whole plant tissue, one can estimate crude protein content through the methodology proposed by Tedesco *et al*. (1995), by multiplying the N content in the tissue by the factor 6.25. Having the production of dry matter, phosphorus percentage, potassium, and crude protein content, we calculated the total accumulation per hectare for each treatment.

Grain productivity was obtained by hand-picking the 8 centered lines, discarding 0.5m of each end portion (2.7 m^2) subsequently being performed the track of each treatment with the aid of trailed equipment and the weight of each sample adjusted to 13% moisture.

The determinations of the NDVI (Vegetation Index Normalized Difference) were performed during the flowering period of the crop with Greenseeker® equipment. To obtain readings, the device was placed at a height between 0,8 to 1,0 m above and parallel to the ground surface (Grohs *et al*., 2009), and the representative index of each relevant treatment was represented by an average of five readings per plot.

The results were submitted to analysis of variance (F test) and if the results were significant to the variables, the averages were compared by Tukey test ($p < 0.05$). For doses of N, a regression analysis was preformed, adjusting for the significant degree of the equation. For these analyzes, we used the Statistical Analysis System - SAS 8.0 software (SAS Inc, Cary, USA).

RESULTS AND DISCUSSIONS

From the analysis of variance, the results showed that there was an interaction ($p<0.05$) between the factors dose and N application period to dry matter, and phosphorus and protein accumulated as well as for grain yield. For NDVI and for the accumulated potassium the only interaction was related to the dose factor.

When analyzing the effects of N application period on the dry matter produced in the millet crop (Table 1), it is observed that with increasing doses of N, the managements M1 and M2 stood out in relation to the dry mass produced, with the highest yield obtained for the M2 management at a dose of 90 kg ha^{-1}, even though there was no significant difference from M1, where the yield of dry matter for the two periods weas 5643.50 kg and 5806.80 kg ha^{-1}, respectively. Compared to crops that are sown in the same period of millet, such as black oat, white oat, and wheat which can reach yields in dry matter of about 6000 to 12000 kg ha^{-1} (Silva *et al*., 2009), 3000 to 5000 kg ha^{-1} (Bortolini *et al*., 2005) and 500 to 2000 kg ha^{-1} (Santos *et al*., 2013b) respectively, the millet crop has great potential for dry matter productivity, being an alternative to hedge plants in no-tillage system and forage production for animal feed.

The effect of the doses within the management M1 and M2 on the dry weight yield was linear (Table 1), and managements for both tested doses provided an increase of 59.48 and 90.45% respectively.

Table 1: Breakdown of significant interaction between nitrogen application doses and periods to dry mass, accumulated protein, and accumulated phosphorus in the millet crop.

Nitrogen Management	Nitrogen rates kg ha^{-1}		
	Dry matter kg ha^{-1}	Accumulated protein kg ha^{-1}	Accumulated phosphorus kg ha^{-1}
---0 kg ha^{-1}---			
M1	3390.00 a [(1)]	252.09 a	3.25 a
M2	3253.10 a	252.47 a	3.29 a
M3	3133.60 a	252.14 a	3.41 a
M4	3377.60 a	261.89 a	3.39 a
---30 kg ha^{-1}---			
M1	4523.80 a	365.10 a	5.23 ab
M2	3495.10 b	279.10 b	3.90 b
M3	4317.40 a	356.93 a	4.58 b
M4	4516.30 a	388.00 a	5.57 a
---60 kg ha^{-1}---			
M1	4763.90 a	377.45 a	4.67 b
M2	4890.80 a	429.02 a	5.61 a
M3	4329.60 a	376.66 a	4.34 b
M4	3901.40 b	365.82 a	4.20 b
---90 kg ha^{-1}---			
M1	5643.50 a	459.14 a	6.16 a
M2	5806.80 a	393.89 a	3.89 b
M3	4480.50 bc	387.09 a	3.38 c
M4	4198.60 c	341.18 b	4.63 b
---Regression equation---			
M1	$y = 3530.21+23.33^{**}x$ ($R^2$0.85)	$y = 268.42 + 2.11^{**}x$ ($R^2$0.85)	$y = 3.60 + 0.027^{*}x$ ($R^2$0.67)
M2	$y = 3002.93+30.18^{**}x$ ($R^2$0.71)	$y = 252.49 + 1.91^{**}x$ ($R^2$0.60)	$y = 2.68 + 0.084^{*}x – 0.00075^{*}x^2$ ($R^2$0.63)
M3	$y = 4065.27$	$y = 279.52+1.41^{**}x$ ($R^2$0.73)	$y = 3.63 + 0.045^{*}x – 0.00053^{**}x^2$ ($R^2$0.73)
M4	$y = 4248.47$	$y = 366.22$	$y = 4.70$

(1) Averages followed by the same letter in the column do not differ by Tukey test at 5% probability * and ** Significant at 5 and 1% probability by the F test M1: 100% sowing; M2: 30% sowing + 70% at 15 DAE; M3: 30% sowing + 70% at 30 DAE and M4: 30% sowing + 70% at 45 DAE.

For the managements M1 (Figure 2a) and M2 (Figure 2b), the dose of N had linear effect on the NDVI readings; For the managements M3 and M4 NDVI readings were not affected by the dosage of N. These results show the importance of N management during the initial stage of cultivation as addressed by Basso *et al*. (2015). The increasing levels in management M1 and M2 in NDVI were 5.50 and 3.58% respectively. The correlation between dry matter and NDVI was 0.62 (Figure 2c), demonstrating that there is a significant correlation between the NDVI and production of dry matter; it can be inferred that the plants which showed the highest values NDVI were the ones that had the greatest increase in dry matter. Therefore, the analysis of these results demonstrated that the NDVI can be used as a nutritional quality indicator in millet cultures due to the possibility of identifying a response to N doses for this attribute in the yield of dry matter. This is relevant to the management of M1 and M2, where NDVI refers to quantifying the growth of vegetation and accumulated dry matter (Aguilar *et al*., 2012, Schiavo *et al*., 2015). However, further studies should be done to improve the estimative of N demand in millet cultivation with NDVI at different growth stages and environmental conditions.

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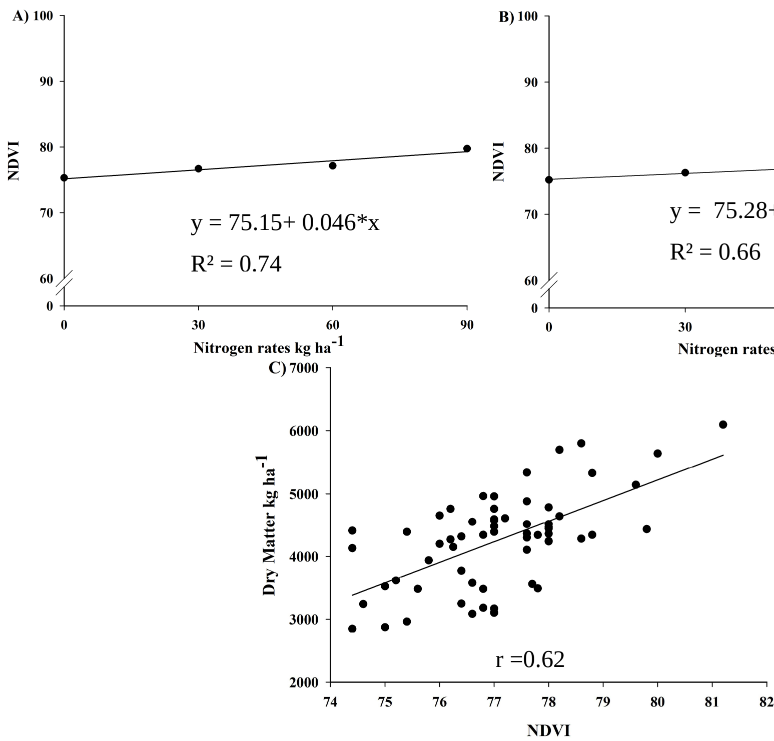

Fig. 2: NDVI in the millet crop related to the levels of N, where A) M1; B) M2; and C) Pearson's correlation between the NDVI 5% and production of dry matter. * and ** Significant at 5 and 1% probability level for the F test.

The results of managements for the accumulated protein was similar to accumulated dry matter with an increase of N doses from 0 to 90 kg ha^{-1} (Table 1), the highest protein accumulation was seen in the dose 90 kg^{-1} of N in the management M1, with an accumulation of 459.14 kg ha^{-1}; however, there was no significant difference from the managements M2 and M3. The management M1, M2, and M3 linearly responded to the doses of N, representing an increase of 70.75; 68.15 and 45.40% respectively. Regarding the crops of corn and sorghum, which are crops widely used for animal feed having on average an accumulation of 1105 (Oliveira *et al*., 2011) and 129 (Rezende *et al*., 2011) kg protein ha^{-1} respectively, millet excels in nutritional terms for animal feed; other studies can be made with this culture in order to adapt the best form of animal supply.

The management of N doses for the accumulated phosphorus showed different results as the levels of doses increased (Table 1). For 30 kg ha^{-1}, the management M4 provided the best growth but did not differ from management M1. At the dose of 60 kg ha^{-1} N, the management of M2 saw the greatest accumulation. For the rate of 90 kg ha^{-1} N, the highest phosphorus accumulation was in the management M1, the largest accumulation among managements in the tested doses (6.16 kg ha^{-1}), which agrees with Viana and KIehl (2010) where it was observed that wheat which had the highest concentration of phosphorus in the aerial part correlated with the highest nitrogen dose (280 mg dm^{-3}).

For the N dose's effect on the accumulated phosphorus, only the M4 management was not influenced by N dosages (Table 1). The effect was linear for M1 with an increase of 67.5%. For the managements M2 and M3 the effect of the doses was quadratic, where the maximum technical efficiency was 56 and 42.45 kg^{-1} of N, respectively. Li *et al*. (2014), points out that the best efficiency of N use can be passed on in higher phosphorus accumulation. Masoni *et al*. (2007) relates the greatest accumulation of phosphorus to the soil in which clay soils, such as the soil used in this study, has a tendency to accumulate more phosphorus in dry matter.

The effect of the doses in the management of M1 (Figure 3a) was linear and M2 (Figure 3b) square to the accumulated potassium, and for the managements M3 and M4 they were not influenced by the N doses. In the management of M1, the doses provided an increase of 129.52%, and for M2 the maximum technical efficiency was 81.87 kg ha^{-1} of N. It should be noted that even the soil , being with a high potassium content (252 mg dm^{-3}) which was identified in the chemical analysis of the initial characterization, it was possible to increase the yields of the plants. This result may be related to the fact that potassium is involved in the onset of metabolic nitrogen processes in the cytoplasm, such as in the incorporation of mineral nitrogen and especially in nitrate reductase (Ruan *et al*., 1999). Nitrate reductase acts in the regulation of the nitrogen metabolism in the plant, and may be indirectly related to the increases in crop yields, as plants with high activity of nitrate reductase may have greater capacity to assimilate the available nitrate leading to a greater ability to respond to nitrogen fertilization (Viana and Kiehl, 2010).

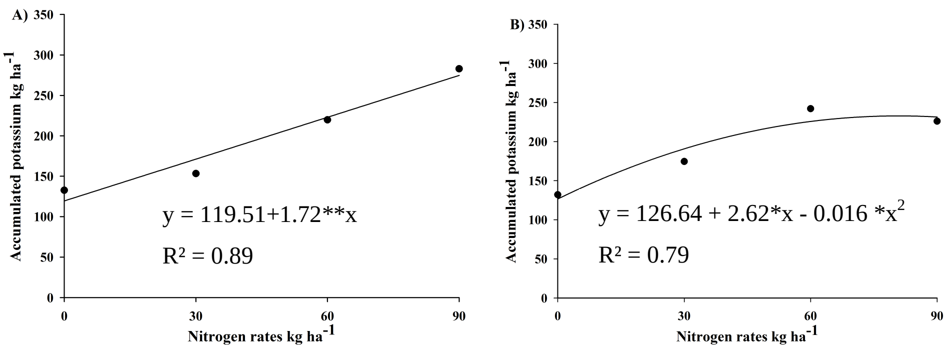

Fig. 3: Potassium accumulated in the millet crop in function of the doses of N, where A) M1; B) M2. * and ** Significant at 5 and 1% probability level for the F test.

Regarding the productivity for the doses of 30 and 60 kg ha^{-1}, the best managements were M2 and M4 with a productivity of 3169.48 and 3135.98 kg ha^{-1} respectively (Table 2). The highest yields were observed for the dose of 90 kg ha^{-1}, where the management M4 provided the greatest productivity, but there was no significant difference between the managements. Based on this, it can be asserted that the highest yields were at the dose of 90 kg ha^{-1} N, independent of the management adopted.

Only M2 was influenced by the N among the managements, which had a quadratic response, with the MET of 64.05 kg ha^{-1}. In studies with doses and an applications of N in millet crops, Soratto *et al*. (2007) observed that regardless of the period of application of N (14 or 28 DAE), a positive response in grain yield with application of N in coverage was obtained; however, for the doses of N applied at 14 DAE the response was linear, which differs from this study, where the doses applied at 15 DAE had a quadratic response.

Table 2: Breakdown of significant interactions between doses and nitrogen application period for productivity in millet cultivation.

Nitrogen Management	Nitrogen rates kg ha^{-1} 0	30	60	90	Regression equation	R^2
M1	2496.75 a[(1)]	2574.65 b	2650.22 b	3005.24 a	y = 2681.71	-
M2	2783.43 a	3169.48 a	3071.82 a	3117.12 a	$y = 2814.76 + 11.53^{**}x – 0.09^{**} x^2$	0.64
M3	2280.07 a	2739.43 b	2778.94 ab	3077.79 a	y = 2719.05	-
M4	2760.36 a	3135.98 a	3020.16 a	3248.80 a	y = 2969.32	-

[(1)] Averages followed by the same letter in the column do not differ by Tukey test at 5% probability * and ** Significant at 5 and 1% probability by the F test M1: 100% sowing;. M2: 30% sowing + 70% at 15 DAE; M3: 30% sowing + 70% at 30 DAE and M4: 30% sowing + 70% at 45 DAE.

Conclusions:

Regardless the management adopted, the N doses resulted in an increase in dry matter and the qualitative variables related to accumulated protein, accumulated phosphorus, and grain yield.

In the production of dry matter and its qualitative variables related to accumulated protein, accumulated phosphorus, and accumulated potassium, the managements of 100% sowing and M2: 30% sowing + 70% at 15 DAE showed the greatest increases when exposed to doses of 60 to 90 kg ha^{-1} N.

The N dose of 90 kg ha^{-1} had the highest productivity of grains, independent of management.

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