Productivity and chemical composition of pearl millet (*Pennisetum glaucum*) as response to NPK fertilization and biofertilizer

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An experiment was carried out at the rural community "Las Canoas" from the municipality Montes Claros, Minas Gerais to evaluate the productivity and chemical composition of the pearl millet (*Pennisetum glaucum*), variety ADR 500 as response to NPK fertilization and biofertilizer. A completely randomized design with three replications and an additional treatment with mineral fertilization were applied. Dosages used were 0, 81.2, 161.2, 202.4 and 245.6 m^3 ha^{-1} for the biofertilizer, 200 kg ha^{-1} of the complete formula and l50 kg^{-1} of urea in the chemical treatment. The chemical properties of the soil, the nutrient levels in the foliar biomass and the productivity of the pearl millet were determined. There were no differences between fertilization methods for the pearl millet productivity and the chemical composition of the soil. Only the relationship H + AL was higher ($P < 0.05$) in the chemical fertilization. Nutrient concentration in the plant was lower for P (0.53 dag kg^{-1}) and K (1.03 dag kg^{-1}) with mineral fertilization. The productivity of the pearl millet, the OM soil content, the ammonia nitrogen ($N\text{-}NH_4+$) and the total mineral N augmented with increasing dosages of biofertilizer. Maximum values of fresh matter (25.49 t ha^{-1}) and DM (5.31 t ha^{-1}) were reached with dosages of 120.19 and 134.64 m^3 ha^{-1}, respectively. The application of 64.39 m^3 h^{-1} of biofertilizer showed the highest OM content in the soil (3.42 dag kg^{-1}). There was a linear increase for $N\text{-}NH_4+$ (83.00 mg dm^{-3}) and total mineral N (141.28 $mgdm^{-3}$). The increasing application of biofertilizer reduced linearly the percentage of mineral material (MM) and ADF, besides improving the quality of the pearl millet for animal feeding. This strategy favored the P, K and Ca content of the pearl millet biomass. It is recommended under the conditions of this experiment to apply the dosage of 134.64 m^3 ha^{-1} of biofertilizer for obtaining the maximum productivity of dry biomass in pearl millet.

Key words: *forages, fertilization, pearl millet*

Forage production for the supplementation in the poor rainy period is a necessary practice for animal production in the tropics. The productive potential of forage plants under unfavorable conditions can be improved with the application of organic manure that enrich the physical, chemical and biological characteristics of the soil (Sobrinho 2007) and benefit the retention capacity through the formation of organic complexes and the development of negative loads (Galbiatti 1996).

The Pearl millet (*Pennisetum glaucum*) is an annual grass, native from Africa. It shows tolerance and drought resistance characteristics, with excellent efficiency in water use for forage and grain production. It can grow in sandy and low fertility soils, with an annual rainfall mean of 200 mm (Tabosa *et al*. 1999).

This species adapts to diverse environments and edaphoclimatic conditions. It is used for animal feeding e.g. grazing, hay, silages and grains. It is mainly supplied to dairy cows during the dry period, due to its forage potential, precocity, nutritive value and good palatability (Guimarães *et al*. 2006, Sobrinho 2007, Sobrinho *et al*. 2009). The variety ADR 500 outstands because its plant disease resistance (Pereira *et al*. 2003 and Nettoy Durães 2005). It attains productions between 1500 and 2000 kg ha^{-1} of grains, with fresh forage yield varying from 29 to 52 t ha^{-1} in three cuts.

The objective of this study was to evaluate the effect of the application of different dosages of biofertilizer and MPK on the production and chemical composition of the pearl millet, variety ADR 500.

Materials and Methods

The study was conducted at the Rural Community of Canoas, municipality of Montes Claros, Minas Gerais, located at the coordinates UTM 23 K 0631286 – 8163372, between March and May, 2010. The areas used for this experiment belong to family agriculture. They are mainly intended for milk, meat and horticulture production. There was irrigation for this study.

The soil of the experimental area was identified as Chernosol, of average texture, with 53.1 dag of fine sand kg^{-1}, 12.9 dag kg^{-1} of coarse sand, 20.0 dag of limo kg^{-1} and 14.0 dag kg^{-1} of clay. Its chemical composition at 0-20 cm depth was pH in water 7.2, P 36.2 mg dm^{-3}, K 220 $cmolcdm^{-3}$, Ca 6.2 $cmolcdm^{-3}$, Mg 1.4 $cmolcdm^{-3}$, Al 0.0 $cmolcdm^{-3}$, H + Al 1.07 $cmolcdm^{-3}$, SB 8.16 $cmolcdm^{-3}$, CTC d.23 $cmolcdm^{-3}$, V 88.0% and OM 4.23%.

The variety ADR 500 of *Pennisetum glaucum* was sown at a density of 20 seeds per linear meter, in experimental plots of 3 m long by 2 m width, with 4 rows per treatment, 0.5 m apart and a total surface of 6 m^2 per plot. The two external rows and l linear meter at the ends of the plot were considered as border effects. For samplings, 2 linear meters from the central rows of the plots were used.

The biofertilizer used came from the experimental farm, belonging to the Institute of Agricultural Sciences of the Federal University of Minas Gerais, in Montes Claros. It was obtained from the anaerobic decomposition of the dairy cattle feces in an iron dome biodigestor, Indian model. Its chemical characteristics are the following: pH (6.8), organic carbon (17.35 g L^{-1}), N (0.76 g L^{-1}), P (0.93 g L^{-1}), K (1.32 g L^{-1}), Ca (1.27 g L^{-1}), Mg (0.43 g L^{-1}) and S (0.15 g L^{-1}), respectively.

A completely randomized design with three repetitions and an additional treatment with mineral fertilization were used. The biofertilizer dosages (0, 81.2, 161.2, 202.4 and 245.6 m^3 ha^{-1}) were defined according to the total amount of available nitrogen for the culture. Thirty per cent were applied at sowing. As coverage fertilization, 30 days after sowing, and 10 days after the first coverage fertilization, 70% was fractioned in equal parts. In the chemical treatment a dosage of 200 kg ha^{-1} of the complete formula (4-30-10) was applied at sowing and 150 kg ha^{-1} of urea as coverage fertilization according to the recommendations for the culture by Pereira *et al*. (2003).

The cutting was performed 70 d after germination. Samples of the fourth leaf below the inflorescence were collected for the nutrient analysis in the plant. The samples, ground in a Wiley type mill, with 1 mm sieve, were dried in a stove at 55ºC for 72 h. The N, P, K, Ca and Mg levels were determined (Tedesco *et al*. 1995). According to the methodology proposed by Silva and Queiroz (2006), DM, mineral matter (MM), EE, CF, NDF, ADF and CP were determined. Non-fibrous carbohydrates (NFC) concentrations were obtained from the equation: NFC = 100 – (% of CP + % EE MM + % + % NDF (Sniffen *et al*. 1992). Soil samples were jointly collected at 0-20 cm depth for the analyses of OM, pH, N, P, K, Ca, Mg and Al, according to the methodology proposed by Embrapa (1997).

Data were submitted to an analysis of variance to compare the chemical fertilization with the different biofertilizer dosages by orthogonal contrasts: 5NPK – 0, 81.2 m^3 ha^{-1}, – 161.2 m^3 ha^{-1}, 202.4 m3ha^{-1}, 245.6 m^3 ha^{-1}. Means of biofertilizer dosages were adjusted to regression models. In all cases the parameters were tested for Student t until 5% probability.

Results and Discussion

The productivity of pearl millet and the chemical composition of the soil did not show differences between the chemical fertilization (NPK) and the biofertilizer dosages (table 1). Only the H + Al relationship was superior ($P < 0.05$) in the chemical fertilization which can be attributed to the release of H+ ions from the urea hydrolysis. Araujo (2007) indicated this performance on comparing the effects of chemical and organic fertilization on the chemical properties of the soil. This author concluded that the utilization of biofertilizer, in absence of NPK mineral fertilization, increased pH, OM and Ca content, and reduced aluminum and hydrogen quantity in the soil.

Generally, the application of mineral fertilizers provokes a decrease of soil pH. However, in this study this did not occur. The urea acidifying effect is due to the nitrification of NH_4+ ions. Also, the lixiviation of NO_3- ions can drag cations from the system, on increasing H+ ion concentration in the soil and favor the acidity increase when mineral fertilization is used (Pires *et al*. 2008). Urea acidity can also be attributed to the reactions produced between the root and the soil, due to the increase of cation capture over the anions. In this way, was reported by Costa *et al*. (2008) on studying the changes in the chemical characteristics of fertilized soils with different N sources for pasture production. These authors demonstrated the occurrence of the acidification process with nitrogen fertilization, which is more accentuated when ammonia sulfate instead of urea, is used.

Other elements that must be considered are the natural chemical conditions and the good soil fertility where this experiment was carried out, as distinctives of the influence of the calcareous rock formation process. These soils have lower fertilization demand regarding those where the clay is involved in their formation process.

Similar productive results are found with the mineral fertilization and the biofertilizer, even in soils of good fertility. This latter alternative has been demonstrated that can substitute efficiently the conventional fertilization in forage production of pearl millet. Sobrinho (2007) reported that pearl millet productivity with NPK fertilizer was the same that when fertilized with cattle manure. For other cultivated species, as the yellow passion fruit (maracuyá), this effect has not been observed (Júnior 2007).

Campos (2006) and Galbiatti *et al*. (2011) showed that the use of biofertilizers promoted greater plant growth and higher yields compared to the mineral fertilization. These authors attributed the difference to the balanced supply of macro and micronutrients around the roots and the increase of water and nutrient absorption by the plants, due to the greater contact surface of the roots with the biofertilizer.

Nutrient concentration in the plant only showed difference for P and K, in spite of the possible effect that the humic acids can exert on the increase of ion absorption by the plants (table 2). K is an element of high mobility in the soil. Differences found are related to the fertilization application way and the use of irrigation to cover the water requirements in the culture. Mineral fertilization with K, at sowing, could have favored to the higher lixiviation of this element compared to the organic fertilization which was fractionated throughout

Table 1. Forage productivity and chemical composition of the soil cultivated with pearl millet in function of the NPK application and biofertilizer

Variables	NPK	Biofertilizer dosage (m^3 ha^{-1})					Contrast[1]
		0.00	81.02	161.02	202.04	245.06	
Fresh matter productivity (t ha^{-1})	24.70	12.01	24.82	25.64	24.09	22.92	14.20ns
Dry matter productivity (t ha^{-1})	4.70	2.18	5.13	5.41	5.00	4.98	0.08ns
OM (dag kg^{-1})	3.03	2.75	3.50	3.00	3.10	2.84	-0.04ns
pH (H_2O)	7.70	7.77	7.70	7.83	7.93	7.67	-0.40ns
N-NO_3- (mg kg^{-1})	53.92	54.01	57.88	64.00	50.13	49.71	-6.13ns
N-NH_4+ (mg kg^{-1})	77.97	67.81	82.88	80.87	96.62	97.13	$^{-3}$5.46ns
Total N (mg kg^{-1})	131.89	121.81	140.76	144.87	146.76	146.85	-41.60ns
P (mg dm^{-3})	59.6	52.01	69.04	65.02	55.07	42.04	13.20ns
K (mg dm^{-3})	167.67	141.00	309.33	208.67	227.33	263.67	$^{-3}$11.65ns
Ca (cmolcdm^{-3})	6.1	5.03	5.08	5.09	5.02	5.07	2.60ns
Mg (cmolcdm^{-3})	1.97	2.30	1.77	2.17	2.27	2.27	-0.93ns
Base sum H+Al (cmolcdm^{-3})	8.53	7.99	8.40	8.57	8.02	8.64	1.03ns
H+Al (cmolcdm^{-3})	0.77	0.73	0.76	0.73	0.68	0.73	0.22*
t (cmolcdm^{-3})	8.53	7.99	8.40	8.57	8.02	8.64	1.03ns
T (cmolcdm^{-3})	9.30	8.73	9.16	9.30	8.70	9.38	1.23ns
V (%)	91.67	91.67	92.00	92.33	92.33	92.00	$^{-1}$.98ns

[1]Orthogonal contrast ns = not significant
*Significant for F test at 5% probability
t: Effective cationic interchange capacity
T: Total cationic interchange capacity
V: Base saturation

the whole culture cycle. Ernani *et al*. (2007) pointed out that owing to the high K lixiviation risk, because of its high mobility, potassium fertilizations must be carried out in two or more times during the growing stage of the culture.

Costa (2001) indicated greater K absorption in cultures receiving the application of humic substances. This author attributed this effect to the change in the charge balance within the cells, due to the molecule absorption of the humic substances, with predominantly anionic character, that increase the number of negative charges in the cytoplasm and helps cation absorption.

Differences found for P are also related to the presence of humic acids in the biofertilizer that could have stimulated greater root growth and favor better absorption of this element. According to Rodda *et al*. (2006), the application of vermin compounds in the irrigation water provokes an increase in the development of the radicular system. Also, it makes possible a marked stimulation of the ATP hydrolysis by the H+ bombs responsible for the generation of the necessary energy for ion absorption and cell growth in the roots.

The regression analysis showed that pH, N-NO_3, K, Ca, Mg, SB and H + Al in the soil and the N, P and Mg content in the plant did not influence on the increase of the biofertilizer dosage, mainly due to the favorable conditions of natural fertilization of the area where the experiment was developed. Silva (2009) reported

Table 2. Nutrient content in pearl millet leaves fertilized with chemical (NPK) fertilizers and dosages of biofertilizers

Nutrients	NPK	Biofertilizer dosage (m^3 ha^{-1})					Contrast[1]
		0.00	81.02	161.02	202.04	245.06	
Nutrients level in pearl millet leaves (dag kg^{-1})							
N	2.01	2.01	2.02	2.02	2.01	2.04	-0.05ns
P	0.53	0.76	0.65	0.74	0.67	0.56	-0.73**
K	1.03	1.31	1.43	1.47	1.40	1.09	$^{-1}$.55*
Ca	0.91	0.83	0.86	1.06	0.98	0.99	-0.17ns
Mg	0.14	0.19	0.16	0.20	0.23	0.19	-0.27ns

[1]Orthogonal contrast: ns = not significant
*, ** Significant at 5 and 1% probability, respectively for F test

an increase in these indicators when using bovine biofertilizer as fertilization strategy in millet culture.

The productivity of fresh millet and of dry matter augmented with increasing biofertilizer dosage, reaching maximum values of 25.49 t ha^{-1} and 5.31 t ha^{-1}, with dosages of 120.19 m3ha^{-1} and 134.64 m^3 ha^{-1}, respectively (table 3). These values are lower than those reported by Boer *et al*. (2007), who obtained a production of 63.52 t FM ha^{-1}. This result is similar to that of Moraes (2001) who attained 28.58 t FM ha^{-1}. Differences found among these studies are attributed to the genetic material used, to the edaphoclimatic conditions and to the culture management practices.

There were increases in the OM content of the soil on augmenting the biofertilizer dosage, which attained its maximum value (3.42 dag kg^{-1}) with the application of 64.39 m^3 h^{-1} of biofertilizer. However, it must be kept in mind that with the application of the dosage with which the highest productivity of the pearl millet was obtained, the OM content in the soil was 3.28 dag kg^{-1} (table 3). According to Alvarez *et al*. (1999), this is considered a medium value in terms of soil fertility.

Ammonia nitrogen (N-NH_4+) and the total mineral N increased linearly until the maximum biofertilizer dosage (245.6 m^3 ha^{-1}), with maximum values in the soil of 97.48 and 149.07 mgdm^{-1}, respectively (table 3). These indicators only reached 83.00 mg dm^{-3} for N-NH_4+ and 141.28 mg dm^{-3} for total mineral N, with the dosage achieving the highest pearl millet productivity. Studies on the N dynamics in the soil, after biofertilizer application based on pig feces, oat and maize (Aita *et al*. 2006), demonstrate a linear increase of the amount of total mineral N, and underline that N losses by ammonia volatilization could occur.

The increase of biofertilizer dosage enhanced the P content in the soil. Its maximum value (68.97 mgdm^{-3}) was attained with the dosage of 108.95 m3ha^{-1} (table 3). On using drain mud in forage plants as sunflower and sorghum, Chiaradia *et al*. (2009) found increase in the phosphorus content in the soil by increasing the dosage. In this study the amount of mineral P recommended for each culture, was also applied. This contributed to a greater phosphorus availability in the soil. In this research study, the initial phosphorus levels in the soil (36.2 mg dm^{-3}) are classified as "good" according to Alvarez *et al*. (1999), reaching figures of 68.82 mg dm^{-3} with the dosage showing the maximum productivity of pearl millet and finished with levels qualified as "very good".

The nutrient content (N, P and Mg) in the pearl millet leaves was not affected by the biofertilizer application, augmenting with increasing dosage for K and Ca (table 3). In the first case a maximum of 1.51 dag kg^{-1} was attained with the application of 107.13 m^3 ha^{-1} of biofertilizer. It was similar to that recorded with the dosage showing maximum DM yield of pearl millet (1.50 dg K^{-1} of K).

Table 3. Regression equations for pearl millet productivity, nutrient content in the soil and nutrient content in the plant with increasing dosages of biofertilizer

Variables	Regression equation	R²	MD	MV	MVP
Forage production					
Fresh forage productivity (t ha^{-1})	Y = 11.98 + 2.463685*X0.5 – 0.112361ºX	0.9973	120.19	25.49	-
Dry matter productivity (t ha^{-1})	Y = 2.18 + 0.540254*X – 0.02328ºX2	0.9940	134.64	5.31	-
Soil nutrient contents					
MO (dag kg^{-1})	Y = 2.75 + 0.166203ºX0.5 - 0.010356ºX	0.8481	64.39	3.42	3.28
N-NH_4+ (mg dm^{-3})	Y = 69.12 + 0.115492ºX	0.8578	245.60	97.48	84.67
Total N (mg dm^{-3})	Y = 123.12 + 1.656020ºX0.5	0.9675	245.60	149.07	142.34
P (mg dm^{-3})	Y = (2.785.89 + 36.177966**X -0.166024**X2)0.5	0.9812	108.95	68.97	68.17
Nutrient contents in pearl millet leaves (dag kg^{-1})					
K	Y = 1.29 + 0.004133**X – 0.00001929**X2	0.8704	107.13	1.51	1.50
Ca	Y = 0.84 + 0.0007905*X	0.6523	245.60	1.03	0.95

MD = Biofertilizer dosage of maximum value obtained (m^{3}ha^{-1})
MV = Maximum value obtained from the variable
MPV = Value obtained with the maximum productivity dosage of dry matter of pearl millet
º, *, ** = significant at 10; 5 and 1% probability, respectively by T test
Total N: P total mineral nitrogen

Ca content in the leaf was higher linearly, on applying increasing biofertilizer amounts, with a maximum of 1.03 kg dag^{-1}, when 245.60 m^3 ha^{-1} were used. Sediyana *et al*. (2009) evaluated the nutritional state of cultures of short cycles fertilized with manure. These authors found Ca increase in the leaf. However, different to what was observed in this study, they also recorded high N and Mg foliar levels, together with the decrease of the P values.

The type of fertilization used and the increase of the biofertilizer dosage did not show influence on the chemical composition of the pearl millet (table 4). Between the chemical characteristics assessed, only the ADF percentage was higher with the mineral fertilization, regarding the biofertilization. There was a linear decrease of the MM and NDF percentages with the increase of the biofertilizer dosage.

These results could be attributed to the delay in the physiological ripening of the pearl millet, when biofertilizer are employed. According to Júnior *et al*. (2007), in mature cells, hemicellulose as a NDF component is more associated to lignin than to other polysaccharides by covalent bonds. Also, it prevents its solubility and increases the NDF percentage.

MM concentrations (10.35%) and ADF (39.72%) were similar to those found by Amaral (2005) and Santos *et al*. (2007), which attained maximum pearl millet productivity for forage production. Andrade *et al*. (2003) indicated that forages with NDF levels close to 30%, do not compromise the nutritional value of the forage. However, the increase of its contents provokes a decrease of the DM digestibility. On evaluating forage yield and the chemical composition of the pearl millet under different nitrogen levels, Silva *et al*. (2006) reported a tendency to the decrease in the ADF percentage, with increasing dosage of this nutrient.

This MM decrease, with increasing biofertilizer dosage, can be associated to the dilution effect. This is manifested by the increase of the DM productivity of the pearl millet (table 1) with the increase of the biofertilizer dosage until 134 m^3 ha^{-1}. In this case, it was 244% higher regarding the unfertilized treatment. The MM, including numerous minerals existing in small amounts in the forage, plays a main function in carbohydrate, lipid and protein metabolism, and contributes also to the improvement of the quality of the forage produced. The mineral composition of the forage species depends on various factors, among which outstand soil fertility, plant age, fertilizer used, climatic season and differences among species and varieties (Santos *et al*. 2007).

Similar results to those of this experiment reported Sobrinho (2007) who demonstrated that pearl millet plants receiving fertilizer or mineral fertilizer showed different levels of MM, crude protein and NDF. Also, this author did not find differences in the percentage of ADF fertilization, unlike what was found in this study. The fertilization effect on the DM percentage of the plant confirmed what was expected. Leonel (2007) indicated that nutrient increase in the soil is not related to the increase of the important DM components, as cellulose, hemicellulose and lignin.

From results obtained, it is concluded that the pearl millet productivity, its chemical composition and the chemical characteristics of the soil are similar when the culture is fertilized with mineral or organic fertilizers. The increasing application of biofertilizer reduced linearly the MM and ADF percentages and improved the quality of the pearl millet for animal production use. This strategy favored the P, K and Ca contents in

Table 4. Chemical composition of pearl millet fertilized with two nutrient sources and regression equations for the increasing biofertilizer dosage

Variable	NPK	Dosage of biofertilizer (m^3 ha^{-1})					Contrast[1]
		0.00	81.02	161.02	202.04	245.06	
DM %	19.07	18.57	20.75	20.91	20.82	21.86	-7.56ns
MM (%)	9.20	12.32	10.12	9.98	9.31	8.86	-4.59ns
CP (%)	4.73	5.28	5.93	5.48	5.23	5.73	-4.00ns
EE (%)	1.96	1.88	2.04	1.98	1.33	3.11	-0.54ns
CF (%)	12.48	13.54	13.85	14.41	15.01	15.07	-9.48ns
NDF (%)	69.44	69.63	67.23	67.45	67.74	67.04	8.11ns
ADF (%)	43.02	42.11	40.40	38.71	39.07	36.55	18.26*
Non-fibrous carbohydrates (%)	14.67	10.89	14.68	15.11	16.39	15.26	1.02ns

Variable	Regression equation	R^2	MD	MV	MVP
MM (%)	Y = 11.89 - 0.012835**X	0.89	0.00	11.89	10.35
FAD (%)	Y = 42.14 – 0.020104*X	0.91	0.00	42.14	39.72

[1]Orthogonal contrast: ns = not significant; * significant for F test at 1% probability.
MD = Biofertilizer dosage of maximum value obtained (m^{3}ha^{-1})
MV = Maximum value obtained from the variable
MPV = Value obtained with the maximum productivity dosage of dry matter of pearl millet
*, ** = significant at 10; 5 and 1% probability, respectively by T test

the biomass of this grass. It is recommended, under the conditions of this experiment, to apply the dosage of 134.64 m^3 ha^{-1} of biofertilizer for obtaining the maximum dry biomass productivity in pearl millet.

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