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Organomineral phosphate fertilization in millet in sandy soil

Maria D. M. Araújo[1], Henrique A. de Souza[2], Vinicius M. Benites[3], Roberto C. F. F. Pompeu[4], William Natale[5] & Luiz F. C. Leite[2]

[1] Universidade Estadual Vale do Acaraú/Centro de Ciência Agrárias e Biológicas/Programa de Pós-Graduação em Zootecnia. Sobral, CE, Brasil. E-mail: mariadianamello@gmail.com - ORCID: 0000-0001-7050-1239

[2] Empresa Brasileira de Pesquisa Agropecuária/Embrapa Meio-Norte. Teresina, PI, Brasil. E-mail: henrique.souza@embrapa.br (Corresponding author) - ORCID: 0000-0002-2209-4285; luiz.f.leite@embrapa.br - ORCID: 0000-0001-9648-705X

[3] Empresa Brasileira de Pesquisa Agropecuária/Embrapa Solos. Rio de Janeiro, RJ, Brasil. E-mail: vinicius.benites@embrapa.br - ORCID: 0000-0002-2602-0750

[4] Empresa Brasileira de Pesquisa Agropecuária/Embrapa Caprinos e Ovinos. Sobral, CE, Brasil. E-mail: roberto.pompeu@embrapa.br - ORCID: 0000-0002-4099-3575

[5] Universidade Federal do Ceará/Centro de Ciências Agrárias. Fortaleza, CE, Brasil. E-mail: natale@ufc.br - ORCID: 0000-0001-9572-4463

ABSTRACT: Evaluation of fertilizers is an important premise, given the need for knowing new alternative sources to increase the efficiency in the use of nutrients, especially phosphorus. The objective of this study was to evaluate the growth of millet cultivated in sandy soil under phosphorus doses and sources. The experiment was carried out in a greenhouse, in Sobral, CE, in soil with low phosphorus concentration in the randomized block experimental design, with two sources (monoammonium phosphate - MAP and organomineral fertilizer prepared with MAP and organic compost of waste from small ruminant production - OMF) and four doses of P_2O_5 (35, 70, 140 and 210 kg ha^{-1}), plus an additional treatment without phosphate fertilization, with three replicates, conducted in the second half of 2015. The variables measured were dry mass production, phosphorus accumulation in the plant and agronomic, physiological and recovery efficiencies. Evaluations were carried out in two cuts in millet plants(65 and 110 days after germination). The data were subjected to analysis of variance, followed by t-test for the sources and regression analysis for the doses, in addition to the Dunnett's test to compare the phosphate fertilization with the control. In the first cut, it was observed that even at low doses of P_2O_5 (35 kg ha^{-1}of P_2O_5), the biomass increases compared to the control. Increment in phosphorus doses increased the accumulation of this nutrient in millet plants. Considering the total accumulated in the two cuts of millet, the organomineral fertilizer promoted higher nutrient content compared to monoammonium phosphate from 127 kg ha^{-1} of P_2O_5.

Key words: *Pennisetum glaucum*, animal waste, small ruminants

Adubação fosfatada organomineral em milheto em solo arenoso

RESUMO: A avaliação de fertilizantes é premissa importante, dada à necessidade de conhecer novas fontes alternativas para aumentar a eficiência do uso de nutrientes, principalmente fósforo. Objetivou-se com o presente ensaio avaliar o crescimento da cultura do milheto cultivado em solo arenoso com doses e fontes de fósforo. O experimento foi realizado em casa de vegetação, em Sobral, CE, em solo com baixa concentração de fósforo no delineamento experimental em blocos casualizados, com duas fontes (fosfatomonoamônico - MAP e fertilizante organomineral elaborado com MAP e composto orgânico de resíduos da produção de pequenos ruminantes - FOM) e quatro doses de P_2O_5 (35, 70, 140 e 210 kg ha^{-1}), além de tratamento adicional sem adubação fosfatada, com três repetições, conduzido no segundo semestre de 2015. As variáveis mensuradas foram produção de massa seca, acúmulo de fósforo na planta, eficiência agronômica, fisiológica e de recuperação. As avaliações foram realizadas em dois cortes nas plantas de milheto (65 e 110 dias após germinação). Com os dados realizou-se análise de variância seguida do teste de t para as fontes e análise de regressão para as doses, além de teste de Dunnet para comparar a adubação fosfatada com a testemunha. No primeiro corte, constata-se que mesmo em doses baixas de P_2O_5(35 kg ha^{-1} de P_2O_5), a biomassa aumenta em relação à testemunha. O incremento das doses de fósforo aumentou o acúmulo deste nutriente em plantas de milheto. Quando analisa-se o acumulado dos dois cortes de milheto, o fertilizante organomineral proporcionou maior conteúdo do nutriente em relação ao fosfato monoamônico a partir de 127 kg ha^{-1} de P_2O_5.

Palavras-chave: *Pennisetum glaucum*, resíduos animais, pequenos ruminantes

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Introduction

Phosphorus (P) deficiency is recognized in Brazilian soils in general, and in the semiarid region, P is an element that has limiting concentrations (Menezes et al., 2012).

Several studies report that the use of organic composts or even wastes from agricultural or agro-industrial activities can partly meet the P requirement of agricultural crops (Borges et al., 2019). On the other hand, the combined use of mineral fertilizers with wastes or by-products can enhance or increase P use efficiency (Teixeira et al., 2014; Sá et al., 2017).

Joint application of mineral and organic fertilizers is based on the synergy between these two types, since the organic fertilizer, even at small doses, through the release of organic acids, could reduce P fixation and consequently increase its availability in the soil (Fernandes et al., 2015). However, it is important to consider that there may be a difference of response for organomineral fertilizer according to the organic matrix employed (Corrêa et al., 2016; Frazão et al., 2019).

Using wastes from the production and slaughter of animals as fertilizer is a promising alternative, due to nutrient cycling and the appropriate destination for possible environmental liabilities, and in some cases the disposal of animal waste refers to burying, incineration or even burning, which are not environmentally adequate options (Corrêa et al., 2016; Pierre & Araújo, 2017). Furthermore, some studies using animal production wastes applied to agricultural crops have shown increments in soil fertility (Nunes et al., 2015; Souza et al., 2016).

Millet assumes importance as a crop used for soil cover in no-tillage systems, in some situations its cultivation as a second crop also aims at grain production and, in semiarid regions, millet has been used to produce forage for use as silage, besides the possibility of using the regrowth. For dry mass yields around 3,300 kg ha^{-1}, millet extracted around 16 kg ha^{-1} of P_2O_5 in a study carried out in the Cerrado of Goiás (Pacheco et al., 2011), whereas in Minas Gerais, with dry mass yields around 7,100 kg ha^{-1}, P accumulation was equal to 64 kg ha^{-1} of P_2O_5 (Perín et al., 2010).

Considering the above, the objective was to evaluate the response of millet to phosphorus doses and sources, with organomineral fertilizer from the composting of wastes from goat/sheep production and slaughter and monoammonium phosphate.

Material and Methods

The experiment was carried out in a greenhouse at Embrapa Caprinos e Ovinos, located in the municipality of Sobral, CE, Brazil, in the second half of 2015. The physical structure used is equipped with control of relative humidity and temperature, and the mean values along the experiment were 85% and 28 °C, respectively. In addition, the structure has sprinkler irrigation system, which maintains pot moisture close to 70% of the total pore volume.

The soil used in the experiment was an Alfisol, collected in Irauçuba, CE, which shows signs of degradation (absence of vegetation cover) and low concentration of P in the surface layer (0-0.20m) (Table 1), besides being a soil representative of the macro-region of Sobral, CE.

The experimental design adopted was in randomized blocks (RCBD) in a factorial 2 x 4 + 1 scheme, with three replicates. The RCBD was chosen because the greenhouse was shaded on one of its sides and due to the presence of expanded clay on one of its sides, which is used to control relative humidity. One of the experimental factors consisted of two sources of phosphate fertilizer, while the other was represented by four P doses, plus an additional treatment, which was the non-application of phosphate fertilizer, whose plots were pots with capacity for 10 dm^3.

Phosphorus-based fertilizers were monoammonium phosphate (P_2O_5 – 50% and N – 16%) and organomineral fertilizer- OMF (P_2O_5 – 16%, N – 4% and K_2O –1%), which was produced using as organic matrix a compost (P_2O_5 – 2.1%, N – 2.1% and K_2O –1.9%) generated from wastes of the production and slaughter of goats and sheep (Souza et al., 2019) and, as a mineral matrix, MAP, in the proportion of 67% of compost and 33% of MAP. OMF was granulated in a disc granulator, dried at 65 °C until reaching constant moisture and classified in a sieve with mesh between 1 and 4 mm, all procedures performed by Embrapa Solos (Rio de Janeiro, RJ).

The doses used for P were 35, 70, 140 and 210 kg $ha^{-1}$of P_2O_5, and 70 kg ha^{-1} was the standard dose, considering the recommendation of Fernandes (1993). In all experimental units, amounts of N and K were increased, when necessary, due to the presence of these nutrients in the sources used (MAP and OMF), applying the equivalent to 36 and 40 kg ha^{-1} of N and K_2O, respectively, at planting and 24 kg ha^{-1} of N as top-dressing. The amounts of nitrogen and potassium were adjusted due to the percentages present in the MAP and OMF, so that there were no differences in the values applied. The sources used were urea for N and potassium chloride for K_2O. In addition, no lime application was performed because the recommended values of base saturation were close to those recommended for grain crops.

The fertilizers were applied in the furrow, at 5 cm depth in each pot, but the top-dressing fertilization was performed with

Table 1. Chemical and particle-size characteristics of the Alfisol used in the experiment

pH	OM ($g\ dm^{-3}$)	P ($mg\ dm^{-3}$)	K ($mg\ dm^{-3}$)	Ca ($mmol_c dm^{-3}$)	Mg ($mmol_c dm^{-3}$)	H+Al ($mmol_c dm^{-3}$)	SB ($mmol_c dm^{-3}$)	CEC ($mmol_c dm^{-3}$)	V (%)	$S\text{-}SO_4^{2-}$ ($mg\ dm^{-3}$)	Na ($mg\ dm^{-3}$)
5.4	5	8	47	16	7	22	26.2	48.2	54	4	47

Cu ($mg\ dm^{-3}$)	Fe ($mg\ dm^{-3}$)	Zn ($mg\ dm^{-3}$)	Mn ($mg\ dm^{-3}$)	B ($mg\ dm^{-3}$)	Clay ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Total Sand ($g\ kg^{-1}$)	Coarse Sand ($g\ kg^{-1}$)	Fine Sand ($g\ kg^{-1}$)
0.1	19	0.55	8.2	0.16	72	48	880	780	100

pH- Hydrogen potential (in water); OM- Organic matter (Walkley-Black method); P- Phosphorus and K-potassium (Mehlich-1 method); Ca- Calcium, Mg- Magnesium (1 M KCl method); H+Al -Potential acidity (Ca acetate method); SB- Sum of bases; CEC- Cation exchange capacity; V- Base saturation (calculated variable); S- Sulfur ($BaCl_2$ method); Na- Sodium; Cu-Copper; Fe- Iron; Zn- Zinc; Mn- Manganese (Mehlich-1 method); B-Boron (hot water). Clay, silt and total sand- Pipette method dilution in water. Considering the regrowth of millet plants, fertilization was also performed in these plants, but only with N and K_2O in the same amounts reported for planting, i.e., 60 and 40 kg ha^{-1}, respectively.

The experiment was conducted in pots with 9.0 dm^3 of soil, and 10 millet seeds were sown. Seven days after seedling emergence, thinning was performed, leaving the two most vigorous plants; the experiment was conducted from 65 days after germination to the first cut and, after regrowth, for more 45 days, totaling 110 days.

The variables evaluated were: shoot dry biomass, determined by drying the material in forced air circulation ovens (60 °C) until reaching constant mass, followed by weighing on a precision scale; and P content in plant tissue, determined after the material was ground (Miyazawa et al., 2009). P content was then multiplied by the total mass of the plants per pot, thus calculating the accumulation of the nutrient per plant. The analyses were performed in the cultivated millet plants and in their regrowth, so that the results of two cuts of the plants are presented.

As a function of the responses of millet plants to the treatments, the following parameters were calculated: agronomic efficiency (production with fertilizer$_{(pot)}$ – production in the control$_{(pot)}$/applied amount of P$_{(pot)}$); physiological efficiency (production with fertilizer$_{(pot)}$ – production in the control$_{(pot)}$/ accumulation of P with fertilizer$_{(pot)}$ – accumulation of P in the control$_{(pot)}$); and recovery efficiency (accumulation of P with fertilizer$_{(pot)}$ – accumulation of P in the control$_{(pot)}$/applied amount of P$_{(pot)}$) of the applied phosphorus, performed according to Fageria (1998). The two cuts were considered to calculate the efficiencies because the fertilizers were applied all at once.

The data were subjected to analysis of variance and, according to the significance, F test was performed for the sources of P and regression analysis for the doses of P. Sources and doses were compared to the control by the Dunnett's test, using R software (version 3.4.2) and the package 'Desc Tools'.

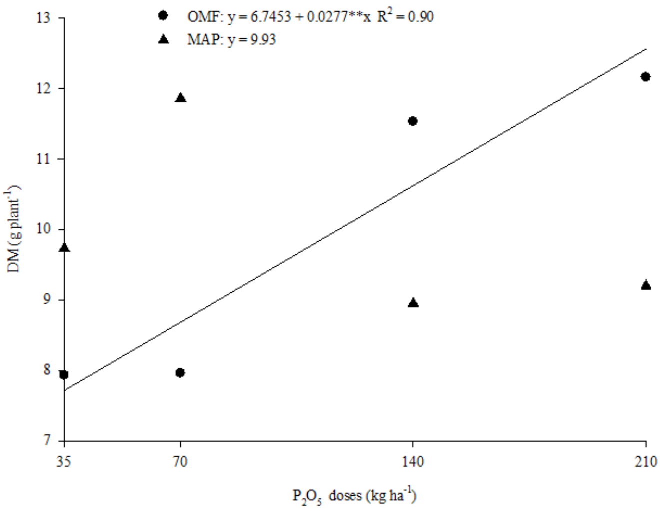
Results and Discussion

In relation to the biomass, there was no difference between the types of fertilizers. For the doses, in the first cut, there was a reduction with the amounts applied (Table 2); however, in the second cut, there were no significant results. The reduction in biomass with P dose in the first cut can be a consequence of the large amounts applied, such as double and three times the recommended dose.

The interaction between sources and doses for dry mass of millet plants in the second cut caused a significant difference, whose results indicate an increment in plant biomass with the amounts that were applied for organomineral fertilizer; for monoammonium phosphate there was no difference between doses (Figure 1).

Considering the result of dry mass in the second cut, when MAP did not cause changes in yield with the doses, unlike OMF, which led to increment in production, this may be an indication of possible residual effect with the use of this source, especially at the higher doses, because the fertilizers were applied at the planting of the crop. Another hypothesis that can be raised but was not measured is the improvement in soil biological activity.

In an experiment with organomineral fertilizer based on poultry litter with four successive corn crops, Sá et al. (2017)



** - Significant at $p \leq 0.01$ by F test

Figure 1. Dry mass of millet plants as a function of P_2O_5 doses for different sources, in the second cut

Table 2. Mean values, F test and coefficient of variation for dry mass (DM), phosphorus accumulated in the plant (Pac), and agronomic, physiological and recovery efficiencies of phosphorus, as a function of doses and sources of P_2O_5 in millet cultivation

Sources - S	$DM_{(1st\ cut)}$	$DM_{(2nd\ cut)}$	$DM_{(1st+2nd)}$	$Pac_{(1st\ cut)}$	$Pac_{(2nd\ cut)}$	$Pac_{(1st+2nd)}$	Agronomic efficiency	Physiological efficiency	Recovery efficiency ($g\ g^{-1}$)
	($g\ plant^{-1}$)			($mg\ plant^{-1}$)			($mg\ mg^{-1}$)		
OMF	20.3	9.9	30.2	50	22 b	72	241	635	0.38
MAP	21.4	9.9	31.3	48	27 a	75	268	846	0.43
F test	ns	ns	ns	ns	*	ns	ns	ns	ns
Doses – D P_2O_5 ($kg\ ha^{-1}$)									
35	23.2	8.8	32.0	24	15	39	564	1539	0.39
70	22.6	9.9	32.5	36	19	55	269	959	0.38
140	18.5	10.2	28.7	58	29	87	106	271	0.43
210	19.3	10.7	30.0	77	35	112	78	193	0.41
F test	*[1]	ns	ns	**[2]	**[3]	**[4]	**[5]	*[6]	ns
S x D	ns	**	ns	*	ns	*	**	ns	ns
CV (%)	13.6	16.7	8.6	30.8	22.5	21.0	13.8	52.6	40.1

ns, * and ** - Not significant and significant at $p \leq 0.05$ and $p \leq 0.01$, respectively; [1]Regression equation for $DM_{(1st\ cut)}$: $y = 23.85 - 0.0261x^2$ ($R^2 = 0.75$); [2]Regression equation for accumulated $P_{(1st\ cut)}$: $y = 14.29 + 0.3025x$ ($R^2 = 0.99$); [3]Regression equation for accumulated $P_{(2nd\ cut)}$: $y = 11.06 + 0.116x$ ($R^2 = 0.99$); [4]Regression equation for accumulated $P_{(1st+2nd)}$: $y = 25.35.33 + 0.418381x$ ($R^2 = 0.99$); [5]Regression equation for Agronomic Efficiency: $y = 822.3 - 9.02x + 0.0263x^2$ ($R^2 = 0.97$); [6]Regression equation for Physiological Efficiency: $y = 1606 - 7.61x$ ($R^2 = 0.87$); OMF - Organomineral fertilizer; MAP – Monoammonium phosphate found no differences in dry mass yield after the first cultivation, justified by the extraction of nutrients by the crop, but these authors observed results for dry mass accumulation with four successive cuts of corn. However, in the present study the second cut was represented by the regrowth of millet plants and not a new crop, so the plants used part of their reserve. In addition, the possible extractions of nutrients by the crop could justify the absence of difference between the sources and doses (Table 2).

Phosphorus accumulation in millet plants in the first cut did not differ significantly among the studied sources; however, in the second evaluation there was superiority of MAP in comparison to OMF. For the doses (regardless of the source), there was significance for P content in the plant, and the best response model was the increasing linear in the two cuts of millet plants and, consequently, in the sum of P accumulation (1st cut + 2nd cut) (Table 2).

Regarding the interaction for P accumulation in the first evaluation, the use of OMF promoted increments with the doses, but for MAP, the maximum accumulation occurred at the P_2O_5 dose of 170 kg ha^{-1} (Figure 2). Considering P accumulation in both cuts, there is an increase in the plant with the applied amounts of P for the two sources, with greater increment using OMF from the P_2O_5 dose of 127 kg ha^{-1} (Figure 2A).

In the first cut, for the effect of P doses, regardless of the source, millet plants showed a reduction in dry mass and an increase in P accumulation. Thus, some inferences may be indicated, such as a possible effect of concentration in the plants, i.e., P was accumulated, but not metabolized, hence not translating into an increase in dry mass.

For P accumulation in the first cut (Figure 2A) and the sum of the two accumulations (Figure 2B), when the effect of each source is compared by dose, it can be observed that always at the highest dose used (210 kg P_2O_5 ha^{-1}) there is superiority of OMF in relation to MAP.

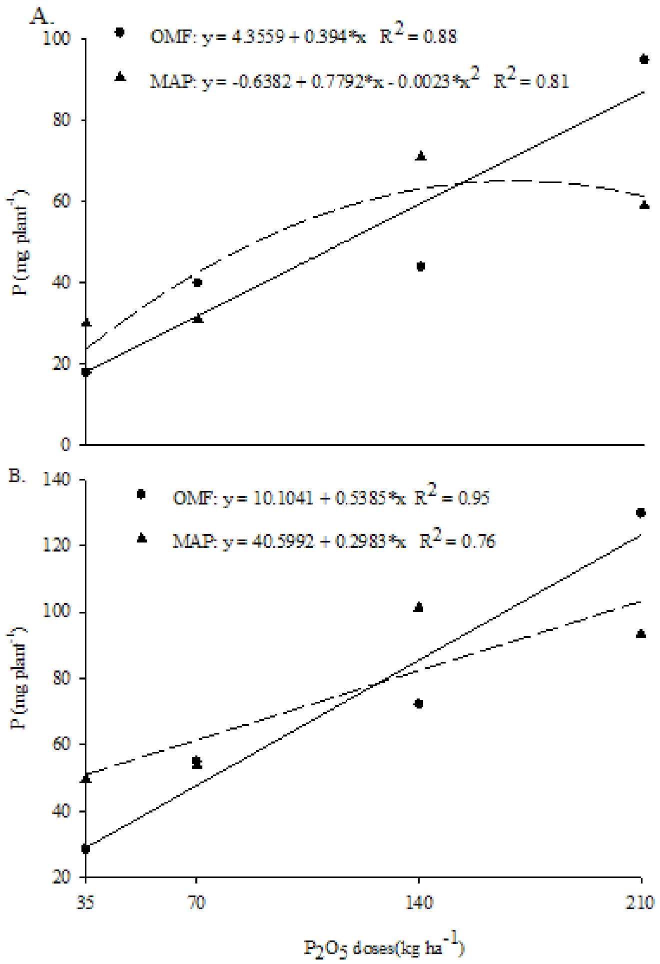
In the second cut, when the results for the variables dry mass and P accumulation for each source were analyzed together, there was a different result; MAP doses did not alter biomass production, but promoted an increase in P accumulation. However, OMF increased the dry mass production and P content in the plant.

Thus, the organomineral fertilizer may have reduced P fixation, enabling better utilization of the nutrient applied, especially from the second cycle of the millet crop. Similar results with organomineral fertilizer, based on residues from sugarcane agroindustry, were observed by Borges et al.(2019), as a possible effect of OMF as slow release fertilizer (Frazão et al., 2019).

Regarding the effect of doses on the agronomic efficiency and physiological efficiency of millet plants, in both cases there was a reduction, and the best response models were quadratic and linear, respectively (Table 2).

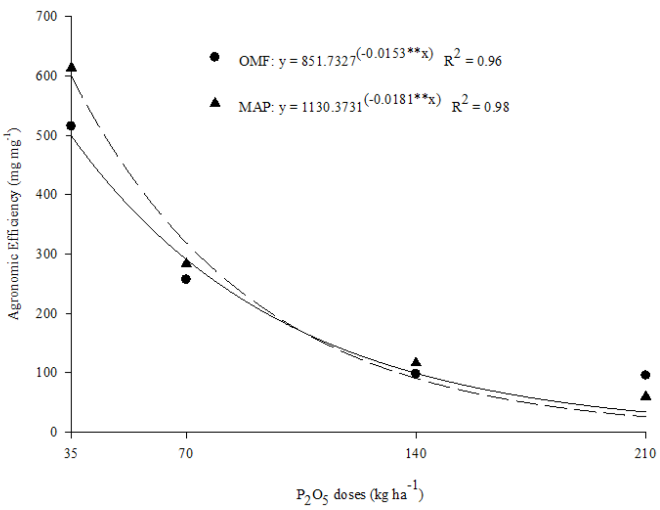
Agronomic efficiency was significantly affected by the interaction (doses x sources), and the best response model was exponential for both sources, with reduction in efficiency as the doses employed increased (Figure 3).

The P recovery efficiency showed no difference between the types of fertilizers and the applied quantities (Table 2).



* and ** - Significant at p ≤ 0.05 and p ≤0.01 by F test, respectively

Figure 2. Phosphorus accumulation in millet plants as a function of P_2O_5 doses for different sources, in the first (A) and in the sum of the first and second cuts (B)



** - Significant at p ≤ 0.01 by F test

Figure 3. Agronomic efficiency in millet plants as a function of P_2O_5 doses for different sources

A comparison of MAP with organomineral fertilizer of poultry litter in pots with corn showed no differences for P recovery rate (Sá et al., 2017). An analogous result also occurred in the comparison of triple superphosphate with organomineral fertilizer from sugarcane production and processing residues (Borges et al., 2019; Frazão et al., 2019).

Table 3. Mean values of dry mass (DM) and accumulated phosphorus in the plant (Pac) for sources, doses and additional treatment (control - without application of P_2O_5) in soil cultivated with millet

Source	P_2O_5 doses (kg ha^{-1})	DM (1st cut)	DM (2nd cut)	DM (1st+2nd)	Pac (1st cut)	Pac (2nd cut)	Pac (1st + 2nd)
			(g plant^{-1})			(mg plant^{-1})	
OMF	35	20.4(+)	8.0	28.4(+)	18	10	28
OMF	70	23.6(+)	8.0	31.6(+)	40	15	55
OMF	140	15.9(+)	11.5(+)	27.4(+)	44(+)	28	72(+)
OMF	210	21.4(+)	12.2(+)	23.6(+)	95(+)	35(+)	130(+)
MAP	35	26.0(+)	9.7	35.7(+)	30	19	49
MAP	70	21.6(+)	11.9(+)	33.5(+)	31	23	54
MAP	140	21.0(+)	9.0	30.0(+)	71(+)	30	101(+)
MAP	210	17.2(+)	9.2	26.4(+)	59(+)	34(+)	93(+)
Control		6,8	8.2	15.0	11	17	28

(+) and (-) - Means differ from the control with a higher or lower value, respectively, according to Dunnett's test (5%); OMF - Organomineral fertilizer; MAP – Monoammonium phosphate

For the dry mass of the first cut, better results were obtained with the use of fertilizers compared to the control (Table 3), regardless of the quantity or source applied. However, in the second cut, the OMF source at the highest doses (140 and 210 kg P_2O_5ha^{-1}) and the MAP source at the dose of 70 kg P_2O_5ha^{-1} led to better results of dry mass yield in comparison to the control (Table 3).

The result obtained for biomass, in the first cut, indicates that even low doses of P_2O_5, as practiced in the present study (35 kg ha^{-1} of P_2O_5), lead to increments compared to the non-application (control). For the accumulated dry mass (1st + 2nd cut), there was a difference in all treatments with fertilization compared to the control, that is, the same behavior observed for DM in the first cut.

In the comparison between phosphate fertilization and the control for P accumulation, in the first cut, better results were obtained at the highest doses (140 and 210 kg P_2O_5ha^{-1}) of OMF and MAP, compared to non-application of phosphate fertilizers; in the second cut of millet plants, there were greater accumulations of P compared to the control for the use of the highest dose (210 kg P_2O_5 ha^{-1}) of the two fertilizers (OMF and MAP) (Table3). For the sum of P accumulations, the results were analogous to that observed for the first cut, i.e., superiority compared to the control for the highest doses (140 and 210 kg P_2O_5 ha^{-1}) of OMF and MAP.

For the second cut, OMF promoted an increase in millet biomass, but MAP did not alter the biomass with the P doses applied. When the average dry mass production obtained with MAP is equaled to the first degree equation of dry mass as a function of OMF doses, there was higher yield with the use of organomineral fertilizer from the P_2O_5 dose of 115 kg ha^{-1}.

In a study conducted with incubation of different P sources, the application of soluble phosphates and organomineral fertilizer temporarily increased P availability in the vicinity of the granules (0-2.5 cm), with maximum availability occurring in approximately 32 days (Morais & Gatibonie, 2015). In the present study, the cultivation was carried out in sandy soil, contributing to lower P fixation (Donagemma et al., 2016; Sá et al., 2017; Frazão et al., 2019), thus corroborating the possible positive effects of increment inthe accumulation of this nutrient in millet plants.

Conclusions

1. Phosphorus doses with monoammonium phosphate or organomineral fertilizer derived from organic compost of wastes from the production and slaughter of goats and sheep promoted higher biomass production of millet in the accumulated amount of two cuts compared to the control.

2. In the accumulated amount of the two millet cuts, organomineral fertilizer from organic compost of wastes from the production and slaughter of goats and sheep led to higher nutrient content compare to monoammonium phosphate from high doses of P_2O_5 (127 kg ha^{-1}).

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