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Does calcined bone meal serve as phosphate for pastures in family farming?

Farinha de ossos serve como fosfato para pastos na agricultura familiar?

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Abstract

To support rural extension activities for family farming in the western Amazon, we evaluated the production of Mombasa grass (*Panicum maximum* Jacq) as a function of phosphorus sources (single superphosphate and calcined bone meal) and rates (100, 200, and 400 kg ha^{-1} P_2O_5). The experimental design was a randomized complete block, in a 2x3+1 factorial scheme. The use of calcined bone meal yielded a dry matter (1.73 t ha^{-1} cutting^{-1}) and a plant height (55 cm) higher than the control (1.03 t ha^{-1} cutting^{-1} and 35 cm, respectively). However, the values were lower than those obtained with single superphosphate (3.19 t ha^{-1} DM and 91 cm in height). Regarding the dry matter production in the experimental period (202 days, five cuttings), the calcined bone meal promoted 54% of the production obtained with the use of single superphosphate.

Additional keywords: Nutrient cycling; *Panicum maximum*; phosphate solubility.

Resumo

A fim de apoiar ações de extensão rural para agricultura familiar na Amazônia Ocidental, avaliou-se a produção de Mombaça (*Panicum maximum* Jacq) em função de fontes de fósforo (superfosfato simples e farinha de ossos calcinada) e doses (100; 200 e 400 kg ha^{-1} de P_2O_5), em blocos casualizados, em esquema fatorial 2x3+1. O uso de farinha de ossos calcinada proporcionou produção de matéria seca (1,73 t ha^{-1} corte^{-1}) e altura das plantas (55 cm) superiores aos da testemunha (1,03 t ha^{-1} corte^{-1} e 35 cm, respectivamente). Contudo, os valores foram inferiores aos obtidos com superfosfato simples (3,19 t ha^{-1} MS e 91 cm de altura). Em relação à produção de massa seca no período experimental (202 dias, cinco cortes), a farinha de ossos calcinada promoveu 54% da produção obtida com o uso de superfosfato simples.

Palavras-chave adicionais: Ciclagem de nutrientes; *Panicum maximum;* solubilidade de fosfato.

Introduction

In the Amazon, pasture areas are stablished after slash and burn the forest, since it's a low cost practice of removal the vegetation cover and cleaning the area. However, the initial soil fertility declines gradually, and after 5 or 8 years, the productivity of the system is compromised (Noronha et al., 2010). Factors such as low natural fertility of soils, low P levels, the use of poorly adapted germplasm, and inadequate management practices also reduce the pasture productivity sustainability over 30 million hectares of the Brazilian Legal Amazon, that is, in 50% of the planted pastures (Townsend et al., 2010; Dias-Filho, 2015). In a general context, soils under pasture are acidic and of low natural fertility. Once degraded, there is interest in opening up new areas. As an alternative to pasture recovery, cereal planting is promoted in order to provide residual effect from the soil correction and fertilization for forage reestablishment and cost reduction (Teixeira et al., 2016).

Among the nutritional deficiencies, phosphorus has been highlighted, especially in the forage establishment (Almeida et al., 2005). Readily soluble P sources increase dry matter production in the first crop year, but this effect does not last until the second year. For less soluble sources, the inverse is verified (Ieiri et al., 2010). For pasture establishment in the state of Rondônia, Costa (2004) recommends the use of readily soluble sources in the furrow for forage establishment, in addition to broadcasting low solubility sources for forage persistence. However, low solubility sources of phosphate are not available at Rondônia trade. In this sense, the calcined bone meal is a potential P source, since it allows the supply of phosphorus and calcium to the plants (Mattar et al., 2013).

In the state of Rondônia, the solid waste of small meat-processing establishments is mostly destined to landfills or even discarded without proper sanitary control, generating environmental and public health problems. This action represents a nutrient wasting since the bones are constituted basically by hydroxyapatite or biological apatite that, if calcinated, decompose into tricalcium phosphate, calcium oxide, and water (Miyahara et al., 2007; Mattar et al., 2013; Mattar et al., 2014). Concentrations of total P and citric acid-soluble P in calcinated bones make it compatible to be used as phosphate fertilizers according to the Brazilian fertilizer legislation (Brasil, 2007).

The bone meal presents substantial phosphate contents, but with low solubility (Ferreira, 2014). There are reports indicating the efficiency and economic viability of using bone meal as phosphorus (P) source for forage sugarcane (Caione et al., 2011), tomatoes (Cavallaro Júnior et al., 2009) and orchids (Rodrigues et al., 2010) production. The use of calcined bone meal in pastures can reduce the use of sources of industrialized phosphates and the pressure on P reserves, estimated to run out in about 150 years (Schroder et al., 2011). Therefore, it is necessary looking for alternative P sources that minimize the use of industrialized fertilizers, in addition to management practices that result in greater efficiency in the use of the forage resource in order to reduce the pressure on non-deforested areas in the Amazon (Freitas et al., 2005, Noronha et al., 2010).

Management systems that promote minor changes to reduce environmental degradation are indicated (Rodrigues et al., 2017). Thus, for farmers in Rondônia, it has been proposed to adopt agroforestry systems as sustainable agricultural models, also aiming to preserve the forest (Couto et al., 2016). Some family farmers have used calcined bone meal to fertilize forages and vegetables aiming to reduce production costs. However, there is still some doubts regarding the real efficiency of calcinated bone meal efficiency as a P source in the Amazonian cultivated pastures. Then, the objective of this study was to evaluate the agronomic performance of irrigated Mombasa grass when fertilized with calcinated bone meal as phosphate fertilizer.

Material and methods

Characterization of the experimental area

The experiment was carried out at the experimental farm of the Federal University of Rondônia (11°35'0"S 61°46'16"W), from November 2012 to September 2013, with the following geographical coordinates: longitude, with an altitude of 240 m. The climate of the region is Aw according to the Köppen-Geiger classification (Pell et al., 2007), equatorial with variation for hot and humid tropical, with a well-defined dry season (June/September), mean minimum temperature of 24 °C, mean maximum temperature of 32 °C, and average temperature of 28 °C; mean annual rainfall of 2,250 mm year^{-1}; and high relative humidity, of about 85%. The climatic variables during the experimental period are presented in Figures 1 and 2.

The soil of the field is classified as an Haplustox and presented the following attributes at 0-0.2 m depth prior the experiment installation: pH (in water) = 4.9; Organic Matter = 21 g dm^{-3}; $P_{Mehilich}$ = 2.2 mg dm^{-3}; $K_{Mehilich}$ = 0.15 cmol$_c$ dm^{-3}; Ca = 0.32 cmol$_c$ dm^{-3}; Mg = 0.16 cmol$_c$ dm^{-3}; Al = 0.44 cmol$_c$ dm^{-3}; H + Al = = 5.5 cmol$_c$ dm^{-3}; CEC_{pH7} = 6.1 cmol$_c$ dm^{-3}; Sum of Bases (SB) = 0.6 cmol$_c$ dm^{-3}; Base Saturation (V) = 10%; Sand = 322 g kg^{-1}; Silt = 89 g kg^{-1}; Clay = = 589 g kg^{-1}.

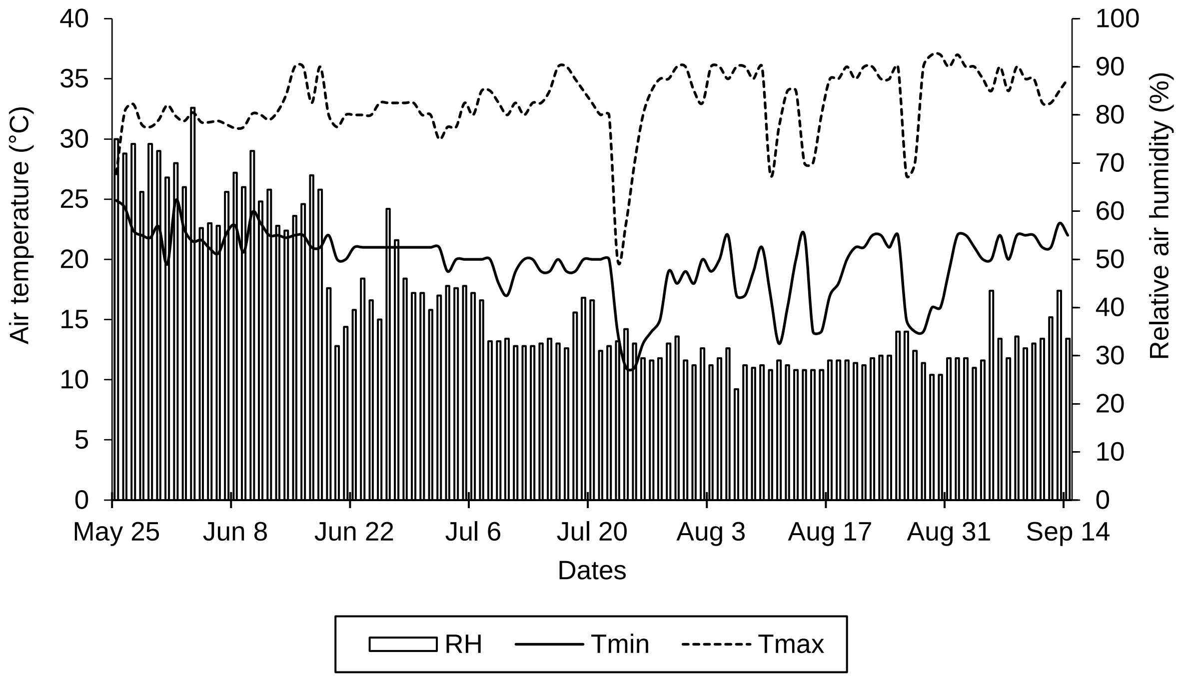

Figure 1 - Maximum temperature (Tmax) and minimum temperature (Tmin) and relative air humidity (RH) from in the experimental field May to September 2013.

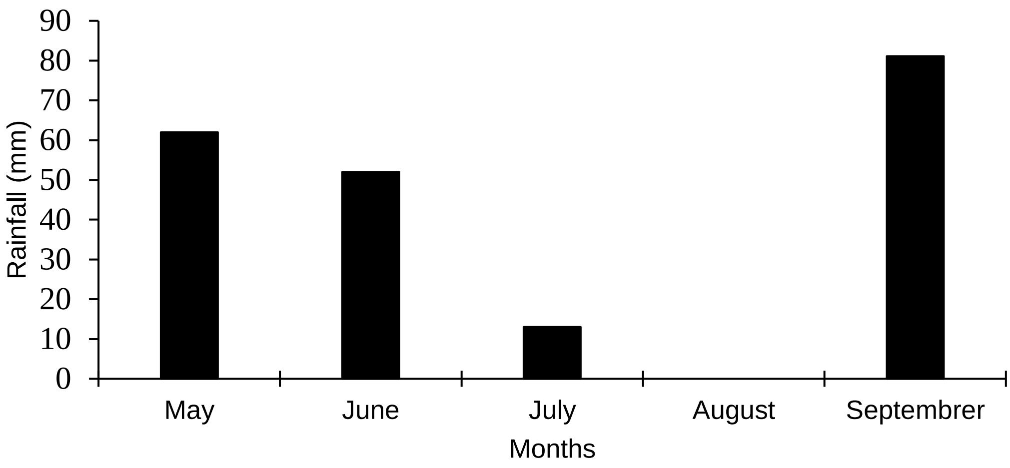

Figure 2 - Rainfall in the experimental field from May to September 2013.

Field experiment installation and management

Soil preparation consisted in one subsoiling and two disc-harrowings. The first harrowing was performed after the application of dolomitic limestone (80% TNRP) on 12/31/2012, to obtain a base saturation of 60%, and the last one was performed prior to the sowing of Mombasa grass (*Panicum maximum* cv Mombasa), on 02/23/2013. For seeding were used 30 kg ha^{-1} of seeds with cultural value 30. Potassium chloride (60 kg ha^{-1} K_2O) was broadcast 20 days after sowing and urea (120 kg ha^{-1} N), was broadcast after each cutting, according Costa (2006).

Irrigation was carried out in the dry season, between May and September 2013, in a conventional sprinkler system, with three sprinklers (Aperjato® model Junior) spaced 13 m apart applying. Every two days a water depth corresponding to 100% of the potential evapotranspiration (Equation 1), were applied in a rate of 1.6 mm h^{-1}.

$$ET_{pc} = ET_o \times Kc \quad (1)$$

Wherein: ET_{pc} is the potential crop evapotranspiration (mm day^{-1}); ET_o is the reference evapotranspiration (mm day^{-1}); and Kc is the crop coefficient as a function of days after cutting described by Delgado-Rojas et al. (2004) for *Panicum maximum* cv. Tanzania.

The reference evapotranspiration (ET_o) was estimated by the method of Hargreaves & Samani (Samani, 2000) as in Equation 2:

$$ET_o=0.0135 \times K \times Ra \times \sqrt{(Tmax-Tmin) \times (Tmean+17.8)} \quad (2)$$

Wherein: ET_o is the reference evapotranspiration (mm day^{-1}); K is a coefficient equal to 0.162 for continental regions and 0.190 for coastal regions; Ra is the solar radiation at the top of the atmosphere, tabulated for each month and latitude; and Tmax, Tmin and Tmean are the maximum, minimum, and mean air temperatures (°C), respectively.

The gross irrigation depth was determined by the Equation 3:

$$GD = (ET_{pc} - Rainf)/Ae \quad (3)$$

Wherein: GD is the cumulative daily gross depth to be applied (mm day^{-1}); ET_{pc} is the potential crop evapotranspiration (mm day^{-1}); Rainf is the daily rainfall, when observed (mm); and Ae is the application efficiency of the irrigation system, which for the conventional sprinkler was 85%.

Experimental design, treatments, data collection, and analyzed variables

The experimental design was a randomized complete block, in a 2x3+1 factorial scheme, with three replications. The first factor was the P sources calcined bone meal (CBM) and single superphosphate (SS). The the second factor were the rates 100, 200, and 400 kg ha^{-1} P_2O_5 (total P). A control plot without P fertilization was included. Bone meal was finely ground (2.00 mm, 9 mesh sieve) and had 34.3% Ca, 36.3% total P_2O_5 and 0.26% water-soluble P_2O_5. The single superphosphate had 17% Ca, 12% de S, 21% total P_2O_5, and 17% water-soluble P_2O_5.

The treatments were applied 20 days after sowing (DAS). Forage cutting began 90 DAS, on 05/25/2013, at a height of 0.3 m from the ground. The cuttings for evaluation were carried out every 28 days (at 90, 118, 146, 174, and 202 DAS). Forage dry mass (DM), forage canopy height (FCH), and accumulated dry mass were evaluated. The plot area was 9 m^2 (3 x 3 m), and the data collection area corresponded to $0.16 m^2$ (0.4 x 0.4 m). The plants were weighed to obtain the fresh mass (FM), and then taken to an oven with forced ventilation at 105 °C for 72 hours, to obtain the DM. Forage canopy height was measured at three points, considering the top line of the grass canopy.

The accumulated dry mass was obtained by adding the values obtained in the five cuttings during the experimental period. Once the samples were collected, the grass of the entire plots was cut with motorized brush cutter. The cut material was removed, nitrogen was broadcast, and the field was irrigated overnight.

The data were submitted to analysis of variance. Qualitative treatments were compared by Tukey's HSD test. For quantitative treatments regression analysis was performed. For statistical procedures were used the free statistical program Assistat (Silva & Azevedo, 2009).

Results

There was interaction between rates and sources of applied phosphate ($p<0.01$) for plant dry mass at 90, 118, 146, 174, and 202 DAS. The DM was higher in the 5th cutting (Figure 3), both for treatments with CBM and for SS.

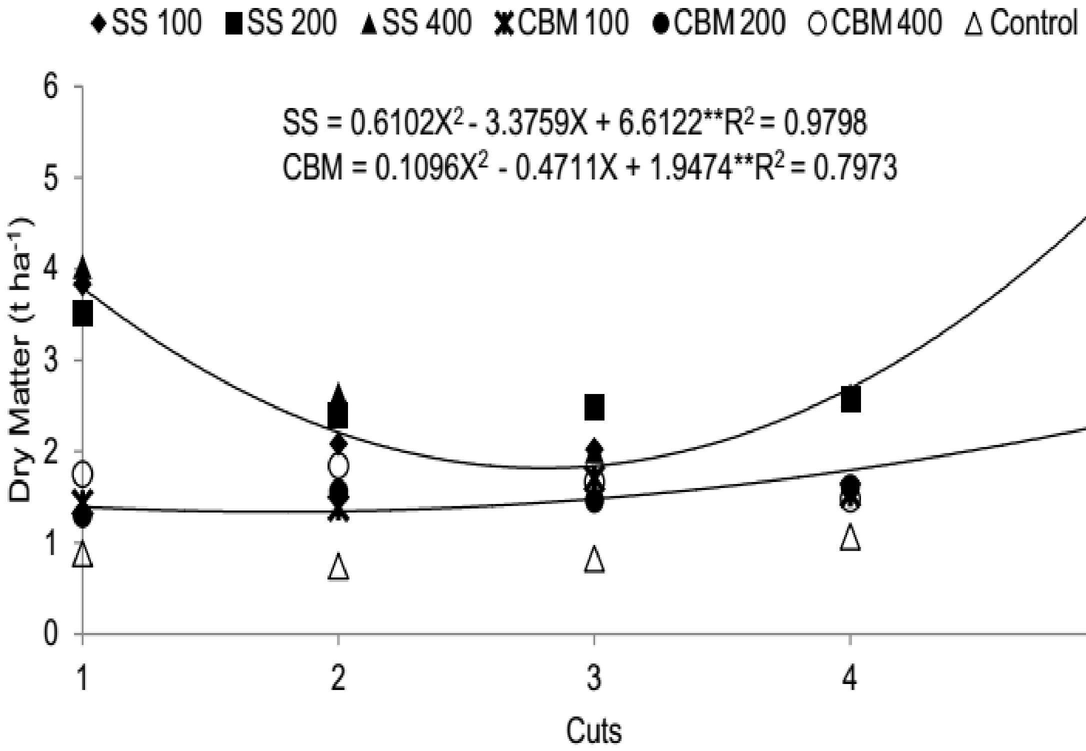

Figure 3 - Dry mass (DM) production of Mombasa grass as affected by sources (calcined bone meal - CBM and single superphosphate - SS) and rates (100, 200 and 400 kg ha^{-1} of P_2O_5) of phosphorus, in five evaluation cuts. ** Significant by the F test at 1% probability ($p <0.01$).

Although phosphate fertilization positively influenced yield ($p<0.01$), the difference in DM production between sources was 2.6 t ha^{-1}. The minimum DM production for both P sources occurred between the 2nd and 3rd cuttings. In the first cutting, when using SS the dry mass production was higher than in the three subsequent cuttings (Figure 3). For the yield behavior, in the fourth and fifth cuttings (174 and 202 DAS), there was an increase in yield (Figure 3), related to the end of the seasonality period for the region.

For both P sources, there was a significant increase (Figure 4) in the accumulated DM yield when P was added to the soil, showing the importance of this nutrient to the production of the Mombasa grass. When calcined bone meal was used, there was a linear increase ($p<0.01$) for the accumulated DM yield as a function of the increase in P rates (Figure 4). For CBM, the highest yield was obtained when 400 kg ha^{-1} P_2O_5 was used, producing 9.4 t ha^{-1} DM, an increase of 81% in relation to the control plot.

Forage canopy height (FCH) was increased with the P rates, for both P sources (Figure 5). The highest forage canopy height was obtained when SS was used. This level was equivalent to the application of 283 kg P_2O_5 ha^{-1}, similar to that related to the maximum accumulated DM yield (278 kg P_2O_5 ha^{-1}). The correlation between accumulated DM and forage canopy height was 99.96% ($p<0.01$). DM production is directly linked to FCH, the higher the forage canopy heights, the larger the DM content.

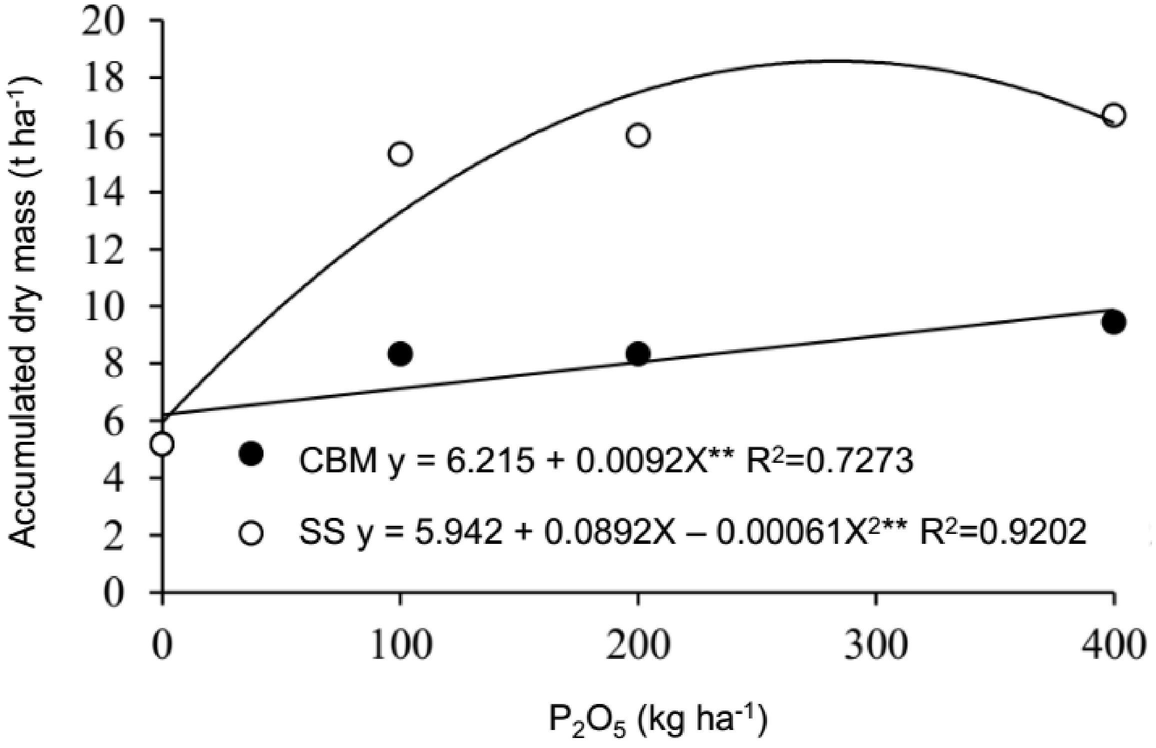

Figure 4 - Accumulated dry mass production of Mombasa grass as affected by sources (calcined bone meal - - CBM, and single superphosphate - SS) and rates (100, 200 and 400 kg ha^{-1} of P_2O_5) of phosphorus. ** Significant by F test at 1% probability (p <0.01).

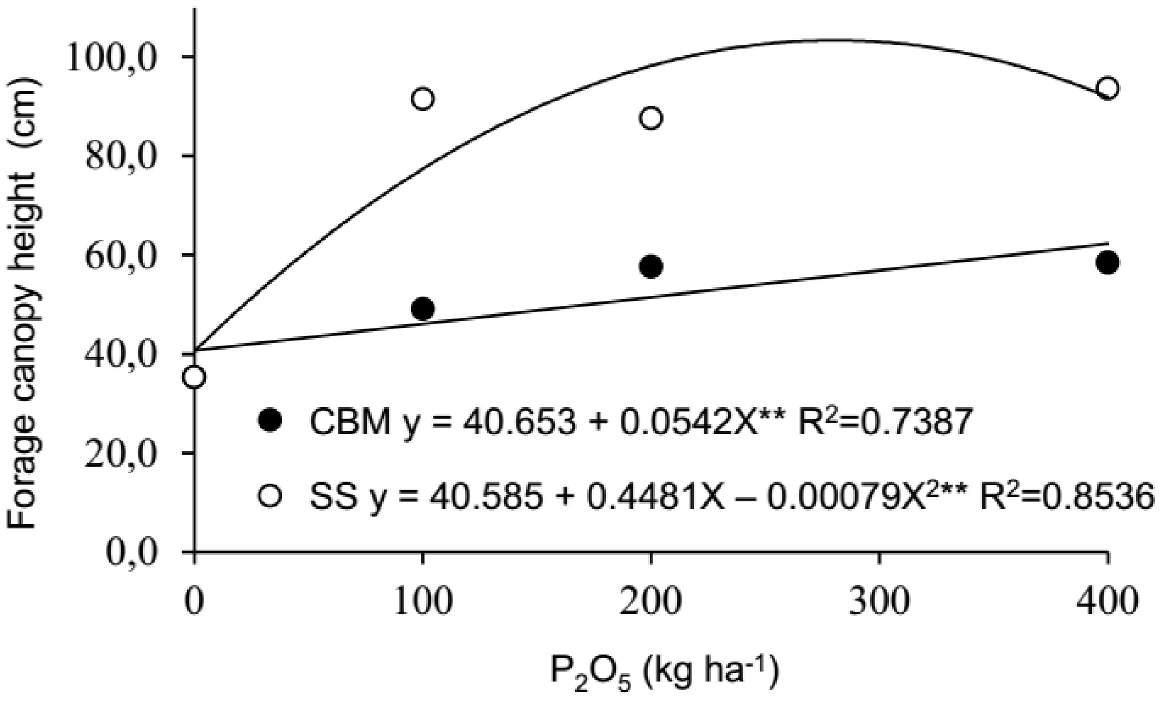

Figure 5 - Forage canopy height (FCH) of Mombasa grass as affected by sources (calcined bone meal - CBM and single superphosphate - SS) and rates (100, 200 and 400 kg ha^{-1} of P_2O_5) of phosphorus. ** Significant by the F test at the 1% probability level (p <0.01).

Discussion

Dry mass of Mombasa as a function of cuttings

In the seasonal behavior, climatic variables decisively influenced forage yield. This seasonal decline can occur in a period of 65 to 70 days, even though the water needs of the plant are satisfied (Rassini, 2004; Alencar et al., 2009). Other factors such as nutrient availability, soil aeration, the plant's genetic potential, solar radiation, and temperature are cited (Alencar et al., 2009). Under such conditions, irrigation is not able to fully equate the problem of seasonality of production, as in places with higher latitude and altitude, where larger reductions in temperature during winter took place (Alencar et al., 2009; Pariz et al., 2011).

For the region where this study was carried out, it has been observed that the high temperatures (between 30 and 35 ºC) compromise the dry mass production due to the increase of the vapor pressure difference between the intercellular spaces and the leaf surface (leaf-to-air vapor pressure deficit) and, consequently, may lead to reduced stomatal conductance (Raven et al., 2007). Moreover, the low levels of relative humidity (RH) can compromise the rate of gas exchange, which, in turn, is proportional to the leaf-to-air vapor pressure deficit. Even under irrigated conditions, if relative air humidity is low, especially in the hottest hours of the day, plants can reduce stomatal conductance in order to decrease their loss of water to the atmosphere and prevent their dehydration. This reduce the primary net productivity, since the gradient between the soil and the roots and the maximum root conductivity are much smaller than the maximum gradient and conductivity between the leaf and the atmosphere (Pimentel et al., 2004). Along evaluation period (114 days; from the 1st to 5th cutting), 80% of the time, RH levels were below 60%, reaching 23% some days. Furthermore, the reproductive cycle of forages begins in the dry season, interrupting plant growth, due to other physiological reasons (Rassini, 2004).

In the first cutting (90 DAS), it was observed a higher production in relation to the others (Figure 3) due to the longer interval, the better conditions at the end of the rain season and the leaf and stem elongation of Mombasa grass when the cutting intervals are longer than 28 to 42 days (Costa, 2004). This longer interval until first cutting / grazing is a pasture management practice used to ensure forage tillering.

The lower rate of leaf and stem elongation in the following cuttings, reducing the DM production of Mombasa, may even become null since the grass has already bloomed (Santos et al., 2004). In this dynamics, the different effects observed with the use of CBM ($y = 0.110 X^2 – 0.471 X + 1.947$ and $R^2 = 0.80$) in relation to SS ($y = 0.610 X^2 – 3.376 X + 6.612$ and $R^2 = 0.98$) can be explained by the higher SS solubility, which initially allowed higher grass yield, but with a lower leaf/stem ratio, which, with the first cutting (30 cm), resulted in a significant reduction of the active photosynthetic area, resulting in DM productions closer to that observed with the use of CBM for the subsequent cuttings (CBM - cuttings 2 and 3; Figure 3).

Accumulated dry mass

CBM is a potential P source, however its use alone must undergo acid treatment, to improve its solubility, and even be amended with S, to compete with SS, since a involved in the differences in forage production in short term is the higher solubility and S content in the industrial source.

In the results obtained with the use of SS, the maximum DM accumulated production was estimated for a rate of 278 kg ha^{-1} P_2O_5 as being 18.4 t ha^{-1} DM. This represents an increase of 283% compared to control plot. This accumulated DM production threshold for the period is similar to that observed by Costa et al. (2004), in the state of Rondônia, that obtained the best productions of *Panicum maximum* cv Tobiatã when applying 258 kg ha^{-1} P_2O_5.

Considering the DM yield potential of Mombasa in 21 t ha^{-1} year^{-1} (Alencar et al., 2009), the average DM accumulation of the P rates was 41% of the yield potential for CBM and 76% for SS.

In relation to the accumulated yield, CBM has reached 54% of the production obtained with the use of SS. This emphasize the use potential of CBM as a low solubility P source to provide P over time as its dissolved by soil acidity, especially in the Amazonian soils, rich in iron and aluminum oxides/hydroxides that irreversibly adsorbs high-soluble P. Moreover, the potential use of CBM is also evidenced by these results (54% of production in relation to SS), since there was no treatment of this source aiming to increase its solubility. The use of hydrochloric acid (0.5%) or even citric acid (30%) can solubilize this source by 42.7% and 100%, respectively (Duarte et al., 2003). The development of this technology would allow the economy of use of industrial sources, the reduction in the use of machines for the management of phosphate fertilizers, and even the recycling of this nutrient in pasture agroecosystems.

Forage canopy height

The lower heights observed with the use of CBM are certainly related to the low solubility in water of this P source (0.26% P_2O_5 soluble), and to the absence of S. At the end of the experimental period the the plots fertilized with CBM presented a green color with lower intensity compared to those treated with SS, suggesting an inadequate S nutrition. Notwithstanding, other visible symptoms of sulfur deficiency were not observed, such as: small leaves, generalized chlorosis, leaf whitening, plant height reduction, necrosis and defoliation, short internodes, reduction of flowering, among others (Avalhares et al. 2009; Ferreira, 2012). It reinforces the importance of including S analysis in the routine reports to evaluate the fertility of the soils of the region when sources such ammonium sulfate, SS or phosphogypsum are not adopted in the management of fertility.

The general recommendation for P fertilization in forage formation is applying high-solubility P sources in the the planting row, to promote forage establishment. The source of lower solubility must be applied in the total area so that, with its temporal solubilization, it can provide P to the plants and promote the forage over the years of pasturing. Although CBM has a potential use in pasture fertilization by enabling the supply of P to the forage in a longer period, its treatment in acidic environment can make P available while changing its dynamics in the soil-plant system. This treatment can take place with the prior use of organic or inorganic acids and generate different levels of solubility for this source as a function of their combination, concentration, and time of application (Ferreira et al., 2014).

For the rational exploitation of agroecosystems, the study of bacteria and fungi capable of solubilizing phosphates comes to fill another gap for nutrient cycling, based on phosphate. Microorganisms isolated from Amazonian soils present this capacity due to the production of 2-ketogluconic acid, for example (Chagas Júnior et al., 2010; Souchie et al., 2010). The particularities of Amazonian soils indicate that the adoption of agroforestry systems in the context of family farming can promote the maintenance of soil fertility (Menezes et al., 2008; Silva et al., 2011). Therefore, the development of technologies that rationally use calcined bone meal stands as an important nutrient cycling pathway for the pasture system, mainly when considering that commercial phosphate reserves are a non-renewable resource.

Conclusions

Using calcined bone meal as a phosphate source for irrigated Mombasa leads to about a half (54%) of the dry mass production obtained when single superphosphate is used.

Forage yield was certainly influenced by the differences of solubility and nutrient content between the phosphate sources.

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