Revista Brasileira de Zootecnia
© 2010 Sociedade Brasileira de Zootecnia
ISSN 1806-9290
www.sbz.org.br

R. Bras. Zootec., v.39, n.9, p.1883-1888, 2010

Production, nutritional status and chemical properties of soils with addition of cattle manure, reactive natural phosphate and biotite schist in Massai cultivar

Adônis Moreira[1], Nand Kumar Fageria[2], Gilberto Batista de Souza[1], Alfredo Ribeiro de Freitas[3]

[1] Embrapa Amazônia Ocidental, Caixa postal 319, CEP: 69010-970, Manaus, AM.
[2] Embrapa Arroz e Feijão, Santo Antônio de Goiás, GO.
[3] Universidade Federal de São Carlos, São Carlos, SP.

ABSTRACT - The objective of this work was to evaluate the effects of cattle manure, reactive natural phosphate and biotite schist on the soil fertility, yield and nutritional status of *Megathyrsus* spp. cv. Massai. The experiment was conducted under field conditions, in a dystrophic Red Yellow Latosol (Oxisol). It was used a randomized block experimental design with the following treatments: three natural reactive rock phosphate from Algeria (Djebel-Onk) doses (0, 100 and 200 kg ha^{-1} of P_2O_5), three biotite schist doses (0, 150 and 300 kg ha^{-1} of K_2O) and three cattle manure doses (0, 20 and 40 t ha^{-1}). The application of natural phosphate increased dry matter yield, however, application of cattle manure and biotite schist did not influence this variable. Foliar levels of nitrogen, potassium and magnesium (cattle manure), phosphorous and boron (natural rock phosphate) and potassium (biotite schist) were influenced by the applied fertilizer doses. Only the levels of phosphorous in the soil and in the plant and levels of magnesium and boron in the plant show interaction with dry matter yield of Massai cultivar.

Key Words: alternative sources, *Megathyrsus* spp., mineral nutrition, soil fertility

Produção, estado nutricional e propriedades químicas do solo com aplicação de esterco bovino, fosfato natural reativo e biotita xisto na cultivar Massai

RESUMO - Objetivou-se avaliar os efeitos de esterco bovino, fosfato natural reativo e biotita xisto sobre a fertilidade do solo, a produção e o estado nutricional de *Megathyrsus* spp. cv. Massai. O experimento foi realizado em condições de campo, em Latossolo Vermelho Amarelo distrófico (Oxisol). O delineamento experimental utilizado foi o de blocos casualizados, com os seguintes tratamentos: três doses de fosfato natural reativo da Argélia, Djebel-Onk (0, 100 e 200 kg ha^{-1} de P_2O_5), três doses de biotita xisto (0, 150 e 300 kg ha^{-1} de K_2O) e três doses de esterco bovino (0, 20 e 40 t ha^{-1}). A aplicação de fosfato natural aumentou a produção de matéria seca, enquanto as aplicações de esterco bovino e a biotita xisto não influenciaram esta variável. Os teores de nitrogênio, potássio e magnésio (esterco bovino), fósforo e boro (fosfato natural) e potássio (biotita xisto) nas folhas foram influenciados pelas doses de fertilizante aplicadas. Somente os níveis de fósforo no solo e na planta e os de magnésio e boro na planta apresentam interação com a produção de matéria seca da cultivar Massai.

Palavras-chave: fertilidade do solo, fontes alternativas, *Megathyrsus* spp., nutrição mineral

Introduction

In intensive cattle dairy system, pasture field grazing capacity could be improved by application of fertilizers, including limestone, sodium, phosphorous and potassium and micronutrients. Werner et al. (1996) recommend the use of 40, 100 and 60 kg ha^{-1} of N, P_2O_5 and K_2O in new pasture fields set in soils with low fertility, while for its maintenance, 80, 50 and 50 kg ha^{-1} would be necessary, respectively.

Application of cattle manure and/or reactive natural rock phosphates revealed productivity increases in pasture fields (Scherer et al., 1984; Sanzonowiscz & Goedert, 1986; Moreira & Malavolta, 2001). However, in organic systems, the sources of potassium are restricted to ashes, potassium sulfate, vinasse (from sugarcane processing) and mulch (AAO, 2000), making necessary to find new alternative sources of K.

Oliveira et al. (2006) and Castro et al. (2006) found that the application of crushed biotite schist or alkaline

Received March 18, 2009 and accepted November 18, 2009.
Corresponding author: adonis.moreira@cpaa.embrapa.br

ultramaphic rocks to soybeans and sunflowers crops caused an increase on dry matter yield similar to that obtained with the application of potassium chloride.

Most of the Brazilian dairy pasture fields are planted with *Urochloa* spp. and *Megathyrsus* spp. In the case of *Megathyrsus* spp., the Massai cultivar, a natural hybrid of *M. maximum* and *M. infestam*, appears to be a promising alternative forage for tropical edaphoclimatic conditions, because of its low seasonal variation, good crude protein content and good growth even in soils with low natural fertility (Valentim et al., 2001).

The objective of this study was to evaluate the effect of cattle manure, reactive natural rock phosphate (RNRP) and biotite schist on soil fertility and production and on nutritional value of a hybrid of *Megathyrsus* spp., Massai cultivar.

Material and Methods

The experiment was performed in 2006 at the Embrapa Pecuária Sudeste above a dystrophic Red Yellow Latosol (Oxisol or Typic Hapludox - Fageria, 1989), with medium texture (483 g kg^{-1}). After correction with dolomitic limestone [27.1% of CaO, 17.5% of MgO and ECC = 92.1% (percent of effective calcium carbonate)] to raise the base saturation to 70% (Werner et al., 1996), the top layer (0-20 cm) presented the following chemical characteristics: pH in $CaCl_2$ = 6.0; P = 16.1 mg dm^{-3}; K = 0.8 $mmol_c$ dm^{-3}; Ca = 45.0 $mmol_c$ dm^{-3}; Mg = 21.0 $mmol_c$ dm^{-3}; H+Al = 22.0 $mmol_c$ dm^{-3}; and CEC = 88.9 $mmol_c$ dm^{-3}.

The treatments consisted of three doses (0, 100 and 200 kg ha^{-1} of P_2O_5) of reactive natural rock phosphate (RNRP) from Algeria (Djebel-Onk), with 29% P_2O_5 (9% being soluble in citric acid) and 12% of Ca, three doses (0, 150 and 300 kg ha^{-1} of K_2O) of biotite schist (2.0 mm - crushed): pH_{H2O} = 8.5, K_2O = 4.3%, CaO = 2.8%, MgO = 15.1%, P_2O_5 = 0.01%, PN = 0% and SiO_2 = 54.6%, and three doses (0, 20 and 40 t ha^{-1}) of cattle manure: N = 5.0 g kg^{-1}, P = 2.6 g kg^{-1}, K = 6.0 g kg^{-1}, S = 1.0 g kg^{-1} and Ca = 2.0 g kg^{-1} (Berton, 1997). Full doses of natural rock phosphate, $^2/_3$ of the cattle manure and $^2/_3$ of the potassic rock were incorporated to soil 20 days before planting. After the third cutting, the remaining potassic rock and cattle manure were applied as top dressing.

A randomized block design with confounding treatment was used, with one replicate (Gomes & Garcia, 2002). The distribution of the treatments (cattle manure, natural rock phosphate and biotite schist) was the following: Block I, 000, 012, 021, 101, 110, 122, 202, 211 and 220; Block II, 001, 010, 022, 102, 120, 200, 212 and 221; Block III, 002, 011, 020, 112, 121, 201, 210 and 222, and an additional with cattle manure, natural rock phosphate and potassium chloride (60% K_2O), in proportions of 40 t ha^{-1}, 100 kg ha^{-1} of P_2O_5 and 150 kg ha^{-1} of K_2O. The quantities of KCl and cattle manure were used similarly in the treatments. The land plots were rectangular, 5.0 meters by 3.0 meters, with a useful area of 3.0 m^2, and the plant samples were collected from a square of 1.0 m^2 randomly chosen in the plots.

First cutting was carried out 60 days after sowing and six cuttings (harvest) were performed. After the harvest, the vegetable material was weighed and dried at ±65ºC to determine dry matter yield. Before planting and after each cutting (harvest), samples were taken from the topsoil at a 0-20 cm depth to determine the pH ($CaCl_2$), available phosphorous and exchangeable potassium, calcium, magnesium and H+Al, soil organic matter and $S\text{-}SO_4$ (Raij et al., 2001). After each cutting, cattle were allowed to graze on the parts of the not sampled plots.

After drying, samples from the aerial parts were ground and submitted to chemical analyses. Total nitrogen was extracted by sulfur digestion and measured by the micro-Kjeldahl method (Bataglia et al., 1983). Total P, K, Ca, Mg, S, Cu, Fe, Mn and Zn were determined according to the method described by Malavolta et al. (1997).

The data were submitted to variance analysis (ANOVA) and the least square means obtained were compared by Tukey test and regression analysis at $p\leq0.05$ (Gomes & Garcia, 2002). Pearson correlation coefficients between dry matter yield (DMY) and levels of available and exchangeable elements in the soil and plants were also estimated.

Results and Discussion

A significant effect of natural rock phosphate application was observed on dry matter yield of Massai cultivar, while the use of up to 40 t ha^{-1} of cattle manure and 300 kg ha^{-1} of K_2O in the form of biotite schist and their interactions had no effect (Table 1). In case of reactive natural rock phosphate (RNRP), there was an increase of 25% in forage volume, which is equivalent to an estimated enhance of 2.3 t ha^{-1} $year^{-1}$.

Similar increases in dry matter yield with the addition of phosphorous on *Urochloa decumbens* were obtained by Yost et al. (1982) and Soares et al. (2000) by incorporating 150 kg ha^{-1} of natural rock phosphate from North Carolina (30% of P_2O_5) and 100 kg ha^{-1} of reactive natural rock phosphate from Gafsa (28% of P_2O_5), respectively. Similar quantities of triple superphosphate (soluble source – 40% of P_2O_5) were also obtained with the use of RNRP (Arad and North Carolina) by Moreira & Malavolta (2001) with alfalfa

Table 1 - Least square means of dry matter yield (DMY) of Massai cultivar obtained under different treatments

Cattle manure	Dry matter yield	Natural rockphosphate	Dry matter yield	Biotite schist	Dry matter yield
t ha^{-1}	t ha^{-1}	P_2O_5 - kg ha^{-1}	t ha^{-1}	K_2O - kg ha^{-1}	t ha^{-1}
0	10.45	0	0.89b	0	9.94
20	10.07	100	10.28ab	150	9.71
40	9.88	200	11.19a	300	10.74
Cattle manure		Natural rockphosphate		Potassium chloride	
40	9.80	100	9.80	150	9.80

Analysis of variance	
Variable	F test
Cattle manure (a)	NS
Natural rock phosphate - RNRP (b)	*
Biotite schist (c)	NS
CV%	16.63

*, NS - Significant and non significant at $p \leq 0.05$.
[1] Means followed by the same letter in the each column are not significantly different at $p \leq 0.05$ level by Tukey test. Σ of six harvest.

(*Medicago sativa*) and Brazilian butterfly peas (*Centrosema pubescens* Benth). These gains in yield are because of the function of phosphorous in plant metabolism, which plays an important role in energy storage and transfer, acting mainly in the form of adenosine diphosphate (ADP) and triphosphate (ATP) on respiration of the plants, photosynthesis, synthesis of nucleic acids and transport of ions through cell membranes (Hopkins, 1995; Fageria, 2009).

There was no significant increase in dry matter yield after application of cattle manure (Table 1) was probably because of the predominant organic form of the nitrogen present after incorporation of the manure into the soil (Kiehl, 1999). Nitrogen is assimilated from fresh manure only if mineralization or ammonification of the soil organic matter occur before, but in this period the nitrogen becomes immobilized by decomposing microorganisms, which is intimately related to the metabolism of carbon (Aita & Giacomini, 2007). By reducing the availability of nutrients to the plants (mainly C_4 plants), nitrogen assimilation is accelerated (Hopkins, 1995).

The effects of manure application have also been analyzed by other authors (Scherer et al., 2006; Oliveira et al., 2007), showing a significant increase in productivity through a quadratic effect, except at the highest doses. Machado et al. (1983) also observed the effect of cattle manure with the application of 20 t ha^{-1}, where the yields of two harvests of irrigated rice (*Oryza sativa*) were similar to those of control plants.

In the case of biotite schist, although other authors have found significant enhancement of dry matter yield of sunflowers and soybeans (Castro et al., 2006; Oliveira et al., 2006), in other crops such as corn (Resende et al., 2006) there was no significant effect, regardless to the dose applied in it. According to Straaten (2007), in structure of biotite schist, potassium is present in the phyllosilicates between the tetrahedron layers of aluminum and octahedron layers of silicon or magnesium, avoiding release of the nutrient and availability to the plants. In this study, the dry matter yield with application of biotite schist was similar to that after KCl application (Table 1).

Seasonal variation of Massai cultivar forage yield was 61.2% in the spring and summer and 38.8% in the fall and winter. Lempp et al. (2001) found low seasonable variation of forage on this species, with 52.7% of yield in rainy season and 47.3% in dry season. This phenomenon, which occurs in most of tropical forage species, is determined mainly by climatic limitations, particularly those caused by water and temperature fluctuations (Müller et al., 2002).

The analyses of the dry matter yield showed that the addition of cattle manure raised the sodium and potassium levels and reduced the magnesium one (Table 2). The application of natural rock phosphate caused an increase in the phosphorous level and a reduction in the boron level, while the addition of biotite schist significantly raised only the potassium level (Table 2). The three types of fertilizers did not influence the levels of calcium, sulphur, copper, iron, manganese and zinc in the dry matter yield. (Table 2).

The addition of phosphate reduced the level of boron (Table 2) probably because of the nutrient own limitation caused by the positive interaction among phosphorus and boron which enhances the uptake. (Fageria, 2009).

In the absence of foliar concentration indicated as standard on the evaluation of the nutritional state of Massai cultivar in Brazilian conditions, the average concentrations in the plant tissue (aerial dry matter) presented the following order for macronutrients and micronutrients: K>N>Mg>P>Ca>S, and Fe>Mn>Zn>B>Cu, respectively (Table 2).

Table 2 - Least square means of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn levels in aerial dry matter of Massai cultivar, under different treatments. Values are averages of six harvests

Variable	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	$g\ kg^{-1}$						$mg\ kg^{-1}$				
Manure, t ha^{-1}											
0	19.53b	8.07	17.76b	6.17	17.77b	3.25	6.17	5.89	251.58	65.86	24.49
20	20.68ab	7.55	24.06a	6.34	13.29a	2.99	5.94	6.11	284.87	71.17	24.35
40	20.95a	7.53	24.59a	6.25	12.91a	2.99	6.04	6.13	297.61	62.70	24.60
F test	*	NS	*	NS	*	NS	NS	NS	NS	NS	NS
Phosphate, kg ha^{-1}											
0	19.91	6.70c	21.62	6.27	14.03	3.06	6.69a	6.03	284.80	65.99	24.99
100	20.63	7.64b	21.66	6.22	14.40	2.90	6.11a	5.93	279.57	62.98	24.06
200	20.63	8.82a	23.13	6.26	15.53	3.25	5.35b	6.17	299.61	70.84	24.39
F test	NS	*	NS	NS	NS	NS	*	NS	NS	NS	NS
Biotite, kg ha^{-1}											
0	20.32	8.04	21.09b	6.31	15.50	3.23	6.17	5.87	297.31	64.47	23.76
150	20.40	7.12	21.13b	6.32	14.45	2.99	5.95	6.12	284.37	69.44	25.02
300	20.44	8.00	24.19a	6.12	14.02	3.00	6.04	6.24	282.30	64.50	24.66
F test	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
CV%	5.56	22.91	21.00	5.89	21.91	15.80	11.98	7.27	20.11	13.61	7.97
CPK[(2)]	20.37	6.97	27.26	5.65	11.27	2.67	6.01	5.88	307.77	88.19	21.81

*, NS - Significant and non significant at $p \leq 0.05$. Natural rock phosphate – quantity in P_2O_5, biotite schist – quantity in K_2O.

[1] Means followed by the same letter in the same column are not significantly different at $p \leq 0.05$ by Tukey test.

[2] CPK = Cattle manure (40 Mg ha^{-1}), natural rock phosphate (100 kg ha^{-1} of P_2O_5) and potassium chloride (150 kg ha^{-1} of KCl).

Assuming as adequate the nutrient level in *Megathyrsus* spp., regardless of the cultivar, it was found that means of nitrogen (20.4 g kg^{-1}), phosphorous (7.5 g kg^{-1}), potassium (23.4 g kg^{-1}), magnesium (13.8 g kg^{-1}), sulphur (3.0 g kg^{-1}), iron (292.9 mg kg^{-1}) and zinc (7.5 mg kg^{-1}) were above those found by Gallo et al. (1974) and Pinkerton et al. (1997), while those of calcium (6.1 g kg^{-1}), B (6.0 mg kg^{-1}) and manganese (71.6 mg kg^{-1}) were considered low (Table 2). For nitrogen, the average concentration in the treatments was 32% above those found by Lempp et al. (2001) for the same cultivar.

Application of cattle manure increased the content of soil organic matter and available $S\text{-}SO_4$ in the soil, while pH, available phosphorus, potassium, calcium, magnesium and exchangeable H+Al were not significant (Table 3). Addition of 20 and 40 t ha^{-1} of cattle manure increased the organic matter content by approximately 2 and 4 t ha^{-1} of carbon, respectively (Berton, 1997), without considering the mulch and manure left by the grazing animals after each cutting. In the case of the verified enhanced content of $S\text{-}SO_4$ in the soil, it is estimated that over 95% of the sulphur in soils is found in organic compounds, with plant residues and animal droppings constituting the major source (Tabatabai & Bremner, 1972).

The higher the rates of natural rock phosphate, the higher the levels of available P, exchangeable H+Al and soil organic matter (Table 3). In the case of exchangeable H+Al, considering that ammonia is one of the first products formed, the application of P must have been accelerated the initial decomposition of the soil organic matter, increasing the soil acidity. When the ammonia is converted into nitrate, H^+ ions are released, temporarily raising the exchangeable and non-exchangeable acidity of the soil (Sousa et al., 2007).

The application of biotite schist raised the concentration of exchangeable potassium in the soil from 0.8 to 1.1 $mmol_c\ dm^{-3}$ (Table 3). Although this rock contains high quantities of Ca (2.8%), Mg (15.1%) and SiO_2 (54.6%) and it has a high pH_{H2O} index (8.5), these variables were not affected by treatments. It is likely that the mineral structure of the rock avoids solubilization of these elements which are more easily absorbed at the surface of clays when compared to potassium (Straaten, 2007).

The dry matter yield (t ha^{-1}) presented a positive relationship with available P-soil, mg dm^{-3} ($\hat{y} = 8.42+0.13x–0.0023x^2$, r = 0.45) and P-plant, g kg^{-1} ($\hat{y} = 1.24+1.46x–0.040x^2$, r = 0.66), and Mg-plant, g kg^{-1} ($\hat{y} = 18.64+1.27x–0.44x^2$, r = 0.61) and negative with the B-plant, mg kg^{-1} ($\hat{y} = 1.08–1.13x$, r = 0.47). Maximum estimated yield was obtained when the concentration of available P in the soil and plants and of Mg in the plants were 29.5 mg dm^{-3}, 18.3 g kg^{-1} and 14.3 g kg^{-1}, respectively. For the foliar B, the lowest dry matter yield estimated was obtained with a foliar content estimated at 8.5 mg kg^{-1}. These values could be used as a reference to define suitable levels of these elements in the soil and plants. Moreira et al. (2008), analyzing the P:Mg ratio in alfalfa, observed a positive relationship between these elements and the DMY.

Table 3 - Least square means of pH ($CaCl_2$), P, K, Ca, Mg, H+Al, SOM and S-SO_4 after six harvests of Massai cultivar

	Cattle manure, t ha^{-1}			F test	CPK(2)	CV
	0	20	40			%
pH ($CaCl_2$)	5.92	5.72	5.73	NS	5.77	6.03
P (mg dm^{-3})	21.00	17.22	21.78	NS	23.00	23.86
K ($mmol_c$ dm^{-3})	0.77	0.94	1.19	NS	3.07	19.27
Ca ($mmol_c$ dm^{-3})	41.22	36.33	35.67	NS	37.00	20.32
Mg ($mmol_c$ dm^{-3})	20.22	17.11	17.00	NS	19.33	20.73
H+Al ($mmol_c$ dm^{-3})	20.78	23.11	23.00	NS	21.33	19.83
S-SO_4 (mg kg^{-1})	3.00c	5.33b	8.11a	*	6.00	20.04
SOM (g kg^{-1})	32.78b	34.33ab	35.89a	*	37.00	9.77
	RNRP, kg ha^{-1} - P_2O_5					
	0	100	200			
pH ($CaCl_2$)	5.82	5.78	5.78	NS		
P (mg dm^{-3})	14.56b	19.11b	26.33a	*		
K ($mmol_c$ dm^{-3})	1.24	0.82	0.83	NS		
Ca ($mmol_c$ dm^{-3})	38.00	35.78	39.44	NS		
Mg ($mmol_c$ dm^{-3})	17.78	18.33	18.22	NS		
H+Al ($mmol_c$ dm^{-3})	22.67a	35.22b	35.78b	*		
S-SO_4 (mg kg^{-1})	5.89	5.44	5.11	NS		
SOM (g kg^{-1})	32.00b	35.22a	35.78a	*		
	Biotite schist, kg ha^{-1} - K_2O					
	0	150	300			
pH ($CaCl_2$)	5.76	5.83	5.76	NS		
P (mg dm^{-3})	19.00	22.89	18.11	NS		
K ($mmol_c$ dm^{-3})	0.80b	1.00ab	1.10a	*		
Ca ($mmol_c$ dm^{-3})	37.56	39.56	36.11	NS		
Mg ($mmol_c$ dm^{-3})	18.11	18.22	18.00	NS		
H+Al ($mmol_c$ dm^{-3})	23.44	22.22	21.22	NS		
S-SO_4 (mg kg^{-1})	4.11	6.44	5.89	NS		
SOM (g kg^{-1})	34.56	34.11	34.33	NS		

*, NS - Significant and non significant at $p \leq 0.05$.
[1] Means followed by the same letter in the each line are not significantly different at $p \leq 0.05$ by Tukey test.
[2] CPK = Cattle manure (40 Mg ha^{-1}), Natural rock phosphate - RNRP (100 kg ha^{-1} of P_2O_5) and potassium chloride (150 kg ha^{-1} of KCl).

Conclusions

Natural rock phosphate is more efficient in increasing dry matter yield of Massai cultivar than both fresh cattle manure and biotite schist. Concentration of sodium and potassium in dry matter yield increases with cattle manure addition, while the natural rock phosphate enhances phosphorous and boron and the biotite schist the potassium concentration.

Application of cattle manure improve organic matter content and S-SO_4, the natural phosphate increase phosphorous level, soil organic matter and exchangeable H+Al, and the biotite schist the exchangeable potassium.

Acknowledgments

The authors thank Embrapa and the National Research Council (CNPq) for the funding to the first author, and the Fertilizer Company Heringer S/A for donating the natural rock phosphate from Algeria (Djebel-Onk).

References

ASSOCIAÇÃO DE AGRICULTURA ORGÂNICA - AAO. **Manual de certificação da Associação de Agricultura Orgânica**. São Paulo: Associação de Agricultura Orgânica, 2000. 24p.

ABREU, M.F.; ABREU, A.A.; ANDRADE, J.C. Determinação de boro em água quente, usando aquecimento com microonda. In: RAIJ, B. van; ANDRADE, J.C.; CANTARELLA, H.; QUAGGIO, J.A. (Eds.). **Análise química para avaliação da fertilidade de solos tropicais**. Campinas: Instituto Agronômico de Campinas, 2001. p.231-239.

AITA, C.; GIACOMINI, S.J. Matéria orgânica do solo, nitrogênio nos sistemas de exploração agrícola. In: YAMADA, T.; ABDALLA, S.R.S.; VITTI, G.C. (Eds.). **Nitrogênio e enxofre na agricultura brasileira**. Piracicaba: Potafos, 2007. p.1-41.

BATAGLIA, O.C.; FURLANI, A.M.C.; TEIXEIRA, J.P.F. et al. **Métodos de análise química de plantas**. Campinas: Instituto Agronômico, 1983. 48p.

BERTON, R.S. Adubação orgânica. In: RAIJ, B. van; CANTARELLA, H.; QUAGGIO, J.A.; FURLANI, A.M.C. (Eds.). **Recomendação de adubação e calagem para o Estado de São Paulo**. Campinas: IAC, 1997. p.30-35.

CASTRO, C.; OLIVEIRA, F.A.; MOREIRA, A. et al. Rochas brasileiras como fontes alternativas de potássio para cultura do girassol. **Espaço & Geografia**, v.9, n.2, p.17-31, 2006.

FAGERIA, N.K. **Solos tropicais e aspectos fisiológicos das culturas**. Brasília: Embrapa, 1989. 425p.

FAGERIA, N.K. **The use of nutrients in crops plants**. Boca Raton: CRC Press, 2009. 430p.

GALLO, J.R.; HIROCE, R.; BATAGLIA, O.C. et al. Composição química inorgânica de forrageiras do Estado de São Paulo, **Boletim de Indústria Animal**, v.31, n.1, p.115-137, 1974.

GOMES, F.P.; GARCIA, C.H. **Estatística aplicada a experimentos agronômicos e florestais**. Piracicaba: FEALQ, 2002. 309p.

HOPKINS, W.G. **Introduction to plant physiology**. New York: John Wiley & Sons, 1995. 464p.

KIEHL, E.J. **Fertilizantes organominerais**. Piracicaba: Degaspari, 1999. 146p.

LEMPP, B.; SOUZA, F.H.D.; COSTA, J.C.G. et al. **Capim-Massai (*Panicum maximum* cv. Massai)**: alternativa para diversificação de pastagens. Campo Grande: Embrapa Gado de Corte, 2001. 9p.

MACHADO, M.O.; GOMES, A.S.; TURATTI, A.L. et al. Efeito da adubação orgânica e mineral na produção do arroz irrigado e nas propriedades químicas e físicas do solo de Pelotas. **Brazilian Journal of Agricultural Research**, v.18, n.6, p.583-591, 1983.

MALAVOLTA, E.; VITTI, G.C.; OLIVEIRA, S.A. **Avaliação do estado nutricional das plantas**: princípios e aplicações. Piracicaba: Potafós, 1997. 319p.

MOREIRA, A.; HEINRICHS, R.; FREITAS, A.R. Relação fósforo e magnésio na fertilidade do solo, no estado nutricional e na produção da alfafa. **Revista Brasileira de Zootecnia**, v.37, n.6, p.984-989, 2008.

MOREIRA, A.; MALAVOLTA, E. Fontes, doses e extratores de fósforo em alfafa e centrosema. **Pesquisa Agropecuária Brasileira**, v.36, n.12, p.1519-1527, 2001.

MÜLLER, M.S.; FANCELLI, A.L.; DOURADO-NETO, D. et al. Produtividade do *Panicum maximum* cv. Mombaça irrigado, sob pastejo rotacionado. **Scientia Agrícola**, v.59, p.427-433, 2002.

OLIVEIRA, A.P.; BARBOSA, A.H.D.; CAVALCANTE, L.F. et al. Produção da batata doce adubada com esterco bovino e biofertilizante. **Ciência e Agrotecnologia**, v.31, n.6, p.1722-1728, 2007.

OLIVEIRA, F.A.; CASTRO, C.; MOREIRA, A. et al. Eficiência da adubação residual com rochas brasileiras para cultura da soja. **Espaço & Geografia**, v.9, n.2, p.69-84, 2006.

PINKERTON, A.; SMITH, F.W.; LEWIS, D.C. Pasture species. In: REUTER, D.J.; ROBINSON, J.B. (Eds.). **Plant analysis an interpretation manual**. Collingwood: CSIRO, 1997. p.287-346.

RESENDE, A.V.; MACHADO, C.T.T.; MARTINS, E.S.; et al.Rochas como fontes de potássio e outros nutrientes para culturas anuais. **Espaço & Geografia**, v.9, n.1, p.135-161, 2006.

SANZONOWISCZ, C.; GOEDERT, W.J. **Uso de fosfatos naturais em pastagens**. Planaltina: Embrapa-CPAC, 1986. 33p.

SCHERER, E.G.; CASTILHOS, E.G.; JUCKSCH, I. et al. **Efeito da adubação com esterco de suínos, nitrogênio e fósforo em milho**. Florianópolis: EMPASC, 1984. 26p.

SOARES, W.V.; LOBATO, E.; SOUSA, D.M.G. et al. Avaliação de fosfato natural de Gafsa para recuperação de pastagem degradada em Latossolo Vermelho-Escuro. **Brazilian Journal of Agricultural Research**, v.35, n.4, p.819-825, 2000.

SOUSA, D.M.G.; MIRANDA, L.N.; OLIVEIRA, S.A. Acidez do solo e sua correção. In: NOVAIS, R.F.; ALVAREZ VENEGAS, V.H.; BARROS, N.F. et al. (Eds.). **Fertilidade do solo**. Viçosa, MG: SBCS, 2007. p.205-274.

STRAATEN, P. van. **Agroecology**: the use of rocks for crops. Ontario: Enviroquest, 2007. 440p.

TABATABAI, M.A.; BREMNER, J.M. Distribution of total and available sulfur in select soils and soil profiles. **Agronomy Journal**, v.64, n.1, p.40-44, 1972.

VALENTIM, J.F.; CARNEIRO, J.C.; MOREIRA, P. et al. **Capim Massai (*Panicum maximum* Jacq.)**: nova forrageira para diversificação das pastagens no Acre. Rio Branco: Embrapa Acre, 2001. 16p.

YOST, R.S.; NADERMAN, G.C.; KAMPRATH, E.J. et al. Availability of rock phosphate as measured by an acid tolerant pasture grass and extractable phosphorus. **Agronomy Journal**, v.74, n.3, p.462-468, 1982.

WERNER, J.C.; PAULINO, V.T.; CANTARELLA, H. et al. Forrageiras. In: RAIJ, B. van; CANTARELLA, H.; QUAGGIO, J.A. et al. (Eds.) **Recomendação de adubação e calagem para o Estado de São Paulo**. Instituto Agronômico de Campinas, 1996. p.245-258. (Boletim 100).