SEÇÃO IV - FERTILIDADE DO SOLO E NUTRIÇÃO DE PLANTAS

BIOMASS PRODUCTION AND PHOSPHORUS USE OF FORAGE GRASSES FERTILIZED WITH TWO PHOSPHORUS SOURCES[(1)]

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SUMMARY

A major constraint to agricultural production in acid soils of tropical regions is the low soil P availability, due to the high adsorption capacity, low P level in the source material and low efficiency of P uptake and use by most of the modern varieties grown commercially. This study was carried out to evaluate the biomass production and P use by forage grasses on two soils fertilized with two P sources of different solubility. Two experiments were carried out, one for each soil (Cambisol and Latosol), using pots filled with 4 dm³ soil in a completely randomized design and a 4 x 2 factorial scheme. The treatments consisted of a combination of four forage plants (*Brachiaria decumbens*, *Brachiaria brizantha*, *Pennisetum glaucum* and *Sorghum bicolor*) with two P sources (Triple Superphosphate - TSP and Arad Reactive Phosphate - ARP), with four replications. The forage grasses were harvested at pre-flowering, when dry matter weight and P concentrations were measured. Based on the P concentration and dry matter production, the total P accumulation was calculated. With these data, the following indices were calculated: the P uptake efficiency of roots, P use efficiency, use efficiency of available P, use efficiency of applied P and agronomic efficiency. The use of the source with higher solubility (TSP) resulted, generally, in higher total dry matter and total P accumulation in the forage grasses, in both soils. For the less reactive source (ARP), the means found in the forage grasses, for use efficiency and efficient use of available P, were always higher when grown in Latosol, indicating favorable

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(1) Parte da dissertação de mestrado do primeiro autor, financiado pelo CNPq e FAPEMIG. Recebido para publicação em agosto de 2007 e aprovado em janeiro de 2009.

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conditions for the solubility of ARP. The total dry matter of *Brachiaria brizantha* was generally higher, with low P uptake, accumulation and translocation, which indicated good P use efficiency for both P sources and soils. The forage plants differed in the P use potential, due to the sources of the applied P and of the soils used. Less than 10 % of the applied P was immobilized in the forage dry matter. Highest values were observed for TSP, but this was not reflected in a higher use efficiency of P from this source.

Index terms: use efficiency, phosphorus use, phosphate fertilization.

RESUMO: *PRODUÇÃO DE BIOMASSA E UTILIZAÇÃO DE FÓSFORO POR GRAMÍNEAS FORRAGEIRAS ADUBADAS COM DUAS FONTES DE FÓSFORO*

*A maior limitação na produção agrícola em solos ácidos de regiões tropicais é a baixa disponibilidade de P no solo, dada a alta capacidade de adsorção, o baixo teor do nutriente no material de origem e a baixa eficiência de absorção e utilização do P apresentada pela maioria das variedades modernas utilizadas comercialmente. Nesse sentido, o presente trabalho objetivou avaliar, em dois solos, adubados com duas fontes de P de diferentes reatividades, a produção de biomassa e utilização de P por gramíneas forrageiras. Para isso, conduziram-se dois experimentos, um em cada solo (Cambissolo e Latossolo), utilizando-se vasos com 4 dm^3 de solo. O delineamento experimental, para cada solo, foi inteiramente casualizado, em esquema fatorial 4 x 2, sendo quatro espécies forrageiras (*Brachiaria decumbens, Brachiaria brizantha, Pennisetum glaucum *e* Sorghum bicolor*) e duas fontes de P (Superfosfato Triplo – SFT e Fosfato Reativo de Arad – FRA), com quatro repetições. As gramíneas forrageiras foram colhidas na fase de pré-florescimento, quando se obtiveram o peso da matéria seca e os teores de P. Com o teor de P e a produção de matéria seca produzida, foi determinado o acúmulo de P. Com esses dados, foram calculados os índices de eficiência das raízes na absorção de P, eficiência de utilização, uso eficiente do P disponível, eficiência de aproveitamento do P aplicado e eficiência agronômica do P. A utilização da fonte de P de maior solubilidade (SFT) promoveu, de maneira geral, para ambos os solos, maior produção de matéria seca e acúmulo de P nas gramíneas forrageiras. Para a fonte menos reativa (FRA), as médias encontradas para a eficiência de utilização de P e uso eficiente do P disponível pelas gramíneas forrageiras foram sempre superiores quando cultivadas no Latossolo, indicando condições favoráveis para a solubilização do fosfato reativo. De maneira geral, o braquiarão apresentou melhor produção de matéria seca com baixa absorção, acúmulo e translocação de P, o que conferiu à gramínea boa eficiência de utilização de P para ambas as fontes e solos. As gramíneas mostraram diferenças no potencial de uso do P, em função das fontes aplicadas e dos solos utilizados. Menos de 10 % do P aplicado foi imobilizado na matéria seca das gramíneas, sendo os maiores valores observados para o SFT; contudo, isso não se refletiu em maior eficiência de uso de P dessa fonte.*

Termos de indexação: eficiência de utilização, aproveitamento de fósforo, adubação fosfatada.

INTRODUCTION

A major constraint to agricultural production in the acid soils of tropical and subtropical regions is the low soil P availability, since the soil adsorption capacity is high and nutrient contents of the source material, as well as the efficiency of P uptake and use of most modern varieties grown commercially are low (Novais & Smyth, 1999). These conditions have required the application of high rates of phosphate fertilizers, and are also a constant concern of the scientific community, intensifying the search for more efficient plants in P uptake and use, with a view to raise crop yields, reduce production costs and reduce environmental damage.

According to Werner (1986), P deficiency causes severe disturbances in the metabolism and development of grasses, such as slow growth and low tillering, undermining productivity. Phosphate fertilization is therefore considered of vital importance for the establishment of grasses.

Accordingly, phosphate fertilization in soils of the Cerrado region is mostly based on soluble sources, e.g., triple superphosphate, single superphosphate and phosphate monoammonium. Recently, reactive sources have been evaluated, such as Arad phosphate. In the first year, results with these phosphates are similar to those obtained with soluble sources, while costs are lower (Rajan et al., 1996, Sousa & Lobato, 2003; Horowitz & Meurer, 2004), in soils with medium initial P levels (Choudhary et al., 1994), as well as with low levels (Fotyma et al., 1996). According to Novais & Smyth (1999), the fertilizers with lower reactivity that make P available more slowly, minimize the fixation processes and may favor an improved nutrient use by crops.

In terms of plant influence on the efficiency of phosphate fertilization, the selection of plants well-adapted to conditions of low soil fertility may significantly increase the use efficiency of the applied fertilizers. According to Baligar & Fageria (1999), the term nutrient use efficiency has been used to distinguish plant species, cultivars and genotypes according to the nutrient uptake and use capacity. According to these authors, nutrient use efficiency may be related to the nutrient uptake capacity, incorporation and use efficiency of plants. Several factors such as soil, plant, climate and the respective interactions affect nutrient uptake and use by plants (Fageria, 1998). In this context, it is also worth mentioning the solubility of the fertilizer used, mainly in the case of phosphates.

The purpose of this study was therefore to evaluate the biomass production and P use of forage grasses fertilized with two P sources in two different soils.

MATERIAL AND METHODS

Two experiments were conducted in a greenhouse of the Departamento de Ciência do Solo da Universidade Federal de Lavras, using 4 dm^3 pots filled with soil, from the 0–20 cm layer of a typical dystrophic Haplic Cambisol (Typic Dystrochept) and a typical dystrophic Red Latosol (Typic Haplorthox). The first soil was sampled in the county of Nazareno - MG and the second on the campus of UFLA, Lavras - MG, both under natural vegetation without prior cultivation.

By physical and chemical soil analyses, according to Embrapa (1999), and by mineralogical analyses, according to Giarola (1994) for the Cambisol, and according to Souza (2005) for the Latosol, the following data were obtained, respectively: clay content: 29 and 70 dag kg^{-1}; water pH: 5.4 and 4.7; SOM: 2.1 and 4.9 dag kg^{-1}; P (Mehlich-1): 0.6 and 0.9 mg dm^{-3}; K: 20 and 20 mg dm^{-3}; Ca: 0.7 and 0.6 $cmol_c$ dm^{-3}; Mg: 0.2 and 0.2 $cmol_c$ dm^{-3}; Al: 0.7 and 1.1 $cmol_c$ dm^{-3}; H+Al: 2.3 and 7.0 $cmol_c$ dm^{-3}; P-rem: 25.2 and 10.2 mg L^{-1}; Fe_2O_3: 23.0 and 171.8 g kg^{-1} and Al_2O_3: 155.0 and 319.1 g kg^{-1}.

In both experiments, the experimental design was completely randomized in a factorial 4 x 2, four forages (*Brachiaria decumbens, Brachiaria brizantha*, *Pennisetum glaucum* - millet and *Sorghum bicolor* - sorghum) x two P sources of different solubility (Triple Superphosphate - TSP, with 46.1 % total P_2O_5 and 46.1 % soluble in neutral ammonium citrate + water and Arad reactive phosphate - ARP, with 33.1 % total P_2O_5 and 9.4 % soluble in citric acid) with four replications.

Based on the chemical soil analysis, liming was performed to raise the base saturation to 50 %, using calcined dolomitic lime, as micropowder, with 35 % CaO, 14 % MgO and TNP = 100 %.

After a 20 day incubation of the soils at humidity close to 60 % of the total pore volume (TPV), the P sources were incorporated at rates of 150 and 250 mg dm^{-3} P, respectively, in the Cambisol and Latosol, based on total P from each source. Before being incorporated into the soil, the TSP was ground approximately to ARP size. To evaluate the capacity of forage cover to use the soil applied P, it was intended to apply lower P levels than recommended by Alvarez V. & Fonseca (1990) for pot experiments, for both sources. For this reason, higher P doses were applied to the Latosol, which is more clayey and has specific mineralogical characteristics that are more favorable to P adsorption.

Together with phosphate, fertilization was performed with 80 mg N, 80 mg K, 60 mg S, 0.5 mg B, 1.5 mg Cu and 5 mg Zn per dm^3 of soil in the form of nutrient solution, using the following sources: NH_4NO_3, KNO_3, $(NH_4)_2SO_4$, H_3BO_3, $CuSO_4.5H_2O$ and $ZnSO_4.7H_2O$. After application of the P sources, subsamples were taken from both soils for chemical analysis (Table 1). Then 10 seeds of each forage species were sown per pot and thinned to four seedlings one week after emergence. During cultivation, the forages were treated with N and K fertilization as side dressing, at rates of 400 mg dm^{-3} of each nutrient for *Brachiaria decumbens* and *Brachiaria brizantha* grass and 500 mg dm^{-3} of each nutrient for sorghum and millet, split into seven applications. During the whole period of forage growth, soil moisture was maintained at 60 % of the TPV, measured by the pot weight and the addition of deionized water.

The forages were grown until pre-flowering, when the shoots were cut 2 cm above the soil surface. Roots were washed under deionized running water and the shoots oven-dried at 65–70 °C, weighed and summed to determine the total dry matter production (TDM). Subsequently, they were ground and chemically analyzed to determine the P levels (Malavolta et al., 1997). The total P accumulation (TPA) of the forage grasses was determined by relating the P levels with the dry matter produced in each part.

To evaluate the nutritional efficiency of grasses, based on data of dry matter production, P accumulation, applied P and available P, the following indices were estimated:

Table 1. Chemical properties of the Cambisol and Latosol after the treatments

Property [(1)]	Cambisol		Latosol	
	TSP	ARP	TSP	ARP
pH H_2O (1:25)	5.3	5.4	5.2	5.1
P (mg dm^{-3})	45.9	96.9	30.9	108
P-resin (mg dm^{-3})	87.4	53.2	76.2	58.1
K (mg dm^{-3})	76.0	86	90	86
Ca^{2+} ($cmol_c dm^{-3}$)	1.3	1.6	2.9	2.9
Mg^{2+} ($cmol_c dm^{-3}$)	0.7	0.3	1.0	1.0
Al^{3+} ($cmol_c dm^{-3}$)	0.2	0.2	0.3	0.2
H + Al ($cmol_c dm^{-3}$)	2.1	1.9	5.6	5.6
SB ($cmol_c dm^{-3}$)	2.2	2.1	4.1	4.1
t ($cmol_c dm^{-3}$)	2.4	2.3	4.3	4.3
T ($cmol_c dm^{-3}$)	4.3	4.0	9.7	9.7
V (%)	51.0	52.7	42.4	42.4
m (%)	8.0	9	7.0	5.0
SOM (dag kg^{-1})	2.2	0.9	4.8	4.8
P-rem (mg L^{-1})	26.8	25.2	10.9	9.7

[(1)] P and K: Extractant Mehlich-1; Ca^{2+}, Mg^{2+} and Al^{3+}: Extractant KCl 1 mol L^{-1} H + Al–SMP Method; SB: Sum of bases; (t): effective CEC; (T): CEC potential (a pH 7.0); V: base saturation; m: aluminum saturation; SOM: oxidation of $Na_2Cr_2O_7$ 0.67 mol L^{-1} + H_2SO_4 5 mol L^{-1} (Embrapa, 1999). P-rem–equilibrium P (Alvarez V. et al., 2000). TSP: Triple Superphosphate; ARP: Arad Reactive Phosphate.

- P root uptake efficiency (PRUE) = mg total P accumulated in plant / g root dry weight (Swiader et al., 1994);
- Use efficiency (UE) = (g total dry weight)^2/ mg total P accumulated in plant (Siddiqi & Glass, 1981);
- Use efficiency of available P (UEAvP) = g total dry weight / mg available P in soil (P-resin) (Procópio et al., 2005);
- Use efficiency of P applied (UEApP) = (mg total P accumulated in plant / mg P applied) x 100 (Chien et al., 1996);
- Agronomic efficiency of P (AEP) = mg total dry weight / mg P applied (Fageria, 1998).

It is emphasized here that due to extremely low P levels in natural soils, 0.6 and 0.9 mg dm^{-3} in Cambisol and Latosol, respectively (Table 1) no control treatment without P application was included in this study. Moreover, considering the negligible contribution of natural soil to plant nutrition and growth of forage grasses, no control treatment was included in the calculation of some indices, as proposed by some authors cited.

Data were subjected to analysis of variance and mean tests using the statistical program SISVAR® (Ferreira, 2000). The means of the factorial components of the treatments were compared by the Scott Knott test ($p \leq 0.05$).

RESULTS AND DISCUSSION

The variables were significantly affected by P sources and grasses (Figures 1 and 2). The total dry matter production (TDM) was higher when the grasses were fertilized with TSP, with the exception of *Brachiaria decumbens* and millet, grown on the Latosol (Figure 1a and b). Similarly, Maciel et al. (2007) evaluated the effect of different P sources on dry matter production of *Brachiaria brizantha* in a Rhodic Hapludox. The authors found that a higher dry matter yield was obtained by TSP in both soils. Lima et al. (2007) evaluated the effect of P sources and levels on the formation and establishment of *Brachiaria brizantha* in the Southern State of Tocantins. They also observed that TSP improved the crop establishment and increased dry matter production. On the other hand, Corrêa et al. (2005) compared TSP with Gafsa phosphate rock, as P sources for maize on soils with different P uptake capacities, and observed equal efficiency of these sources in the dry matter production of the crop.

In a comparison of the forage grasses of this study on the Cambisol, dry matter yield was lowest for sorghum, when fertilized with ARP (Figure 1a). This performance was not repeated in the Latosol, where TSP induced a higher TDM production of sorghum than of the others, and ARP a higher TDM production of *Brachiaria decumbens* (Figure 1b).

P accumulation by plants depends on the nutrient contents in tissues and, mainly, on the dry matter production. The total P accumulation (TPA) by forage grasses therefore had a performance similar to the TDM, as related to the P sources for both soils (Figure 1c,d). In a comparison of the P sources applied to each forage grass, it was therefore observed that, with the exception of *Brachiaria decumbens* on the Latosol, P accumulation was always higher for TSP. These results agree with those obtained by Richart et al. (2006), who reported better results in terms of P accumulation in soybean tissues with TSP fertilization, compared to the natural reactive phosphate. Likewise, in an experiment conducted with *Brachiaria brizantha* on a Latosol, Faquin et al. (1997) observed higher P accumulation after application of TSP than of Araxá phosphate rock. *Brachiaria decumbens* and *Brachiaria brizantha* fertilized with TSP in both soils, and for both P sources on the Latosol, the P accumulation potential of the forages was lower, which corroborates the finding of Garcia et al. (2004) and Macedo (2004) that these grasses are less P-demanding than sorghum and millet.

It is worth emphasizing that with ARP as P source, the mean values of the forage grasses found for TDM and TPA were higher on the Latosol (38.28 g plant^{-1} and 39.69 mg plant^{-1}) than on Cambisol (21.8 g plant^{-1} and 24.10 mg plant^{-1}), which corresponded to an increase of nearly 60 % of both variables. This can be explained by the higher P and Ca drain to the soil solution in the Latosol, where P fixation and CEC are higher. Under these conditions, the balance of the dissolution equation of applied ARP was altered, increasing P dissolution and, consequently, P availability to plants. Novais & Smyth (1999) explain that the dissolution of reactive phosphate rock is more intense in soils with higher CEC, particularly in those with higher levels of organic matter.

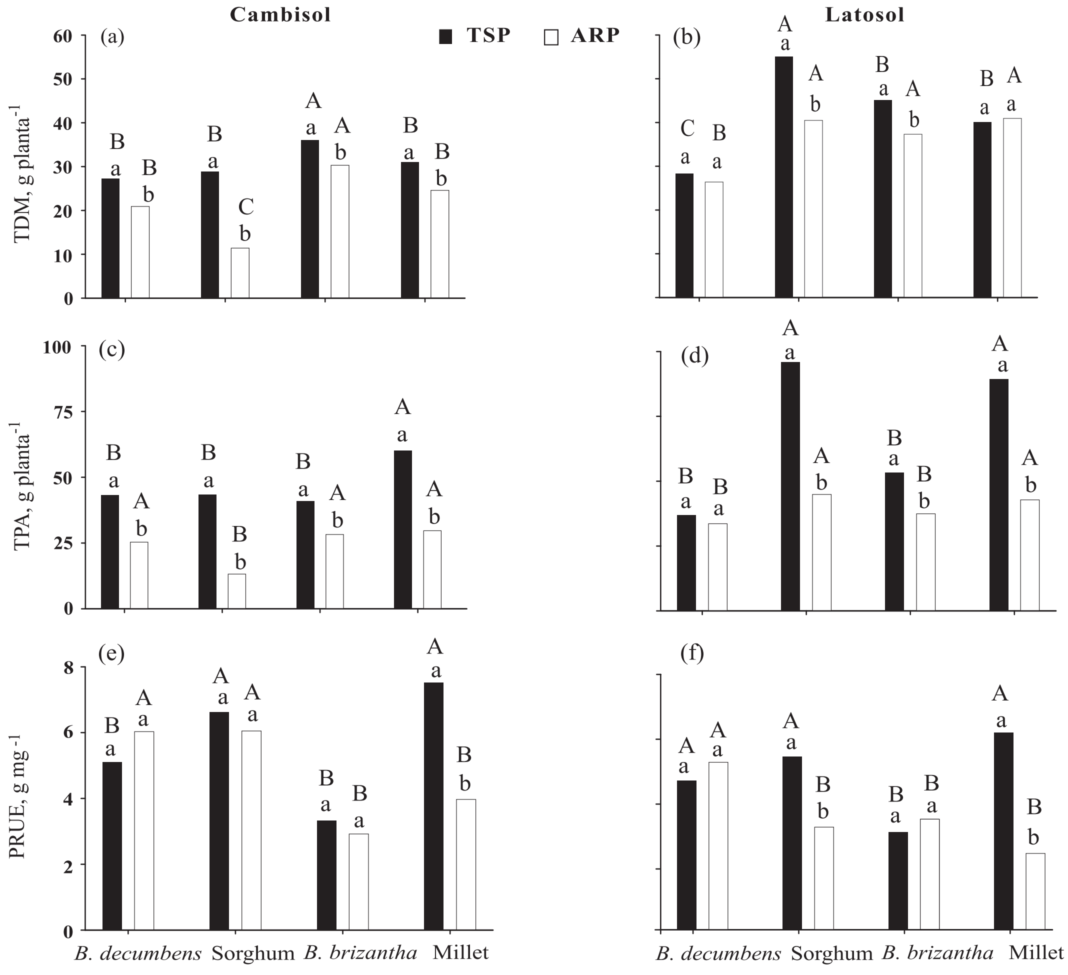

Figure 1. Total dry matter (TDM) (a and b), total P accumulation (TPA) (c and d) and P root uptake efficiency (PRUE) (e and f) of *Brachiaria decumbens*, sorghum, *Brachiaria brizantha* and millet, fertilized with triple superphosphate (TSP) and Arad reactive phosphate (ARP) on a Cambisol and a Latosol. Means did not differ from each other when followed by the same lower-case letter for both soils, in the comparison of P sources for each forage grass, and upper-case letters, in the comparison of forage grasses for each P source (Scott Knott 5 %).

Although the TSP resulted in a greater P accumulation (TPA) in forage grasses (Figure 1c,d), P root uptake efficiency (PRUE) did not follow this trend (Figure 1e,f). It was observed that PRUE was greater after TSP than after ARP application only for millet in both soils and for sorghum in the Latosol. Bedin et al. (2003) emphasized the importance of the solubility of P sources in relation to their efficiency. According to the authors, TSP favors the nutrient uptake since it is a more readily available P source, particularly for annual crops. This fact was corroborated by the results found here for millet in both soils and for grain sorghum in the Latosol. Comparing the forage grasses for the same P source in relation to PRUE, no clear difference was observed in the species studied for both P sources. These results differ from those reported by Goedert et al. (1986) and Sousa et al. (2002), who mentioned that *Brachiaria brizantha* is a forage considered very efficient in P uptake, even in the case of little soluble P sources.

It was found that the mean PRUE in grasses on Cambisol were 5.75 and 4.72 mg g^{-1}, but 4.92 and 3.45 mg g^{-1} on the Latosol, for TSP and ARP, respectively. These values show that in the Latosol, due to the higher clay content and lower P-rem value, i.e., a higher phosphate buffer capacity in the soil, the uptake of applied P was on average the lowest (Figure 1e,f).

To avoid the selection of plants with high nutrient use efficiency but with low yields, Siddiqi & Glass (1981) proposed the calculation of use efficiency (UE) as related to the nutrient concentration in dry matter. In general, for both soils and P sources, *Brachiaria brizantha* was therefore superior in TDM production (Figure 1a,b) and UE of P (Figure 2a,b). However, this species accumulated relatively little P (Figure 1c,d) and the PRUE was also lower (Figure 1e,f). These data show that, among the species evaluated, *Brachiaria brizantha* has a good rate of P use efficiency in dry matter production.

With exception of sorghum grown on Cambisol, ARP performed similarly or better than TSP in terms of P use efficiency by forage grasses. According to Novais & Smyth (1999), the fertilizers of lower reactivity, which make P available more slowly, minimize the processes of fixation and can result in a greater nutrient use efficiency of crops.

Regarding the use efficiency of available P (UEAvP), i.e., dry matter production per unit of available soil P (P-resin) on the Latosol, the lowest value for UEAvP was observed in *Brachiaria decumbens* for both P sources, and on the Cambisol, for sorghum fertilized with ARP (Figure 2e,f). The best mean use rates of available soil P, for the conversion of dry matter with both P sources were observed for the Latosol. Under ARP application, the mean values found for UEAvP of these grasses were 0.155 and 0.1025 g mg^{-1}, and with TSP, these values were 0.1375 and 0.0925 g mg^{-1}, respectively, on the Latosol and Cambisol. The higher drain of P and Ca into the Latosol can explain this fact, as mentioned earlier.

The use efficiency of applied P (UEApP) expresses the percentage of P applied to soils through the different P sources absorbed by the forages. The values of UEApP increased by TSP application (Figure 2 e and f), except in *Brachiaria decumbens* grown on the Latosol (Figure 2f). Franzini (2006), studying phosphate sources and application modes for maize grown on a Typic Hapludox, also noted an increased use of P from TSP.

It was found that the means of the forages in the recovery of P applied to the Latosol were 6.88 and 4.01 %, and from the Cambisol, between 7.81 and 4.09 %, respectively, for TSP and ARP. Similar results were obtained by Novelino (1999) and Bonfim et al. (2003), who observed lower P recovery with the increased phosphate buffer power of soils. In soils with low clay content and high P-rem value, the means of recovery of applied P were therefore highest (Figure 2e).

Of the forages on Cambisol, sorghum was the one with lowest UEApP, when fertilized with ARP (Figure 2e); an opposite performance was observed on Latosol, where UEApP was higher. Comparing the P sources for each forage, it is observed that with the exception of *Brachiaria decumbens* on Latosol, the use of P from TSP was always greater. In general, regardless of the P source, the values of the recovery rate of P applied to the forages, for both soils, were below 10 %, agreeing with the report of Fageria (1998) that P recovery by crops is on average around 10 %. According to Novais & Smyth (1999), the soils of tropical regions, usually acid and with predominance of clay sesquioxides, act as a strong drain of P applied via fertilizers, sharply reducing the availability of applied P and its use by crops.

The agronomic efficiency of P (AEP) refers to total dry matter production per unit of fertilizer applied P (Figure 2g,h). There was a similar trend in TDM production (Figure 1a,b), that is, in both soils, the AEP values were higher when the grasses were fertilized with TSP, except for *Brachiaria decumbens* and millet on Latosol. Of the forages, the AEP value was lowest for sorghum on Cambisol fertilized with ARP, and for *Brachiaria decumbens* on Latosol, for both P sources.

The average AEP values of the evaluated forage grasses were 42.11 and 36.28 mg mg^{-1} in Latosol, and 51.27 and 36.32 mg mg^{-1} in Cambisol, for ARP and TSP, respectively. Opposite to TDM, these values demonstrate a higher total dry matter production of the grasses on the Cambisol per unit of applied P, although P accumulation by plants on this soil was lower (Figure 1c). This fact can be explained by the lower application of P to the Cambisol (150 mg dm^3) than to the Latosol (250 mg dm^3) and the lower

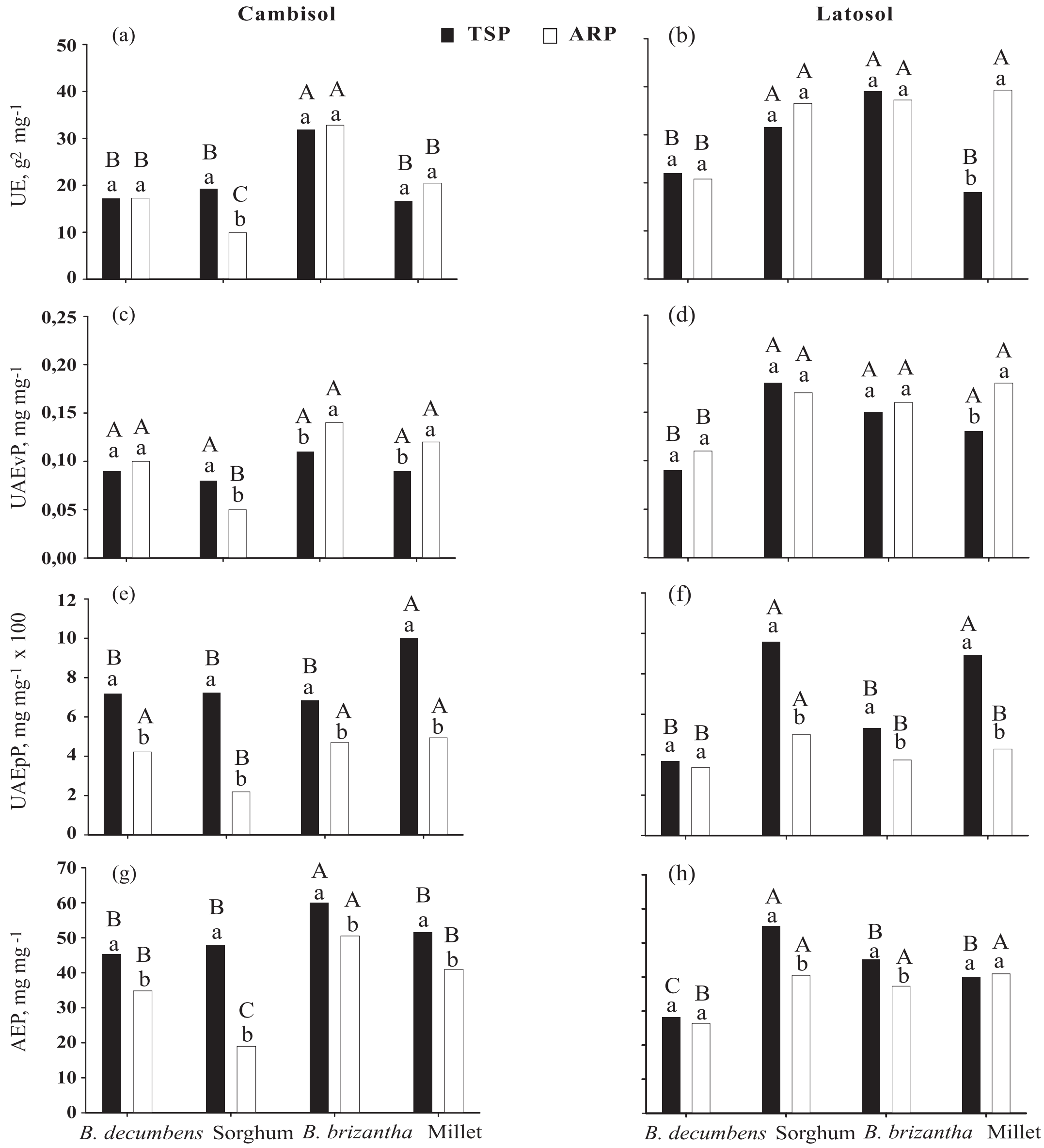

Figure 2. Use efficiency of P (UE) (a and b), use efficiency of available P (UEAvP) (c and d), use efficiency of applied P (UEApP) (e and f) and agronomic efficicency of P (AEP) (g and h) of *Brachiaria decumbens*, sorghum, *Brachiaria brizantha* and millet, fertilized with super triple phosphate (TSP) and Arad reactive phosphate (ARP) on a Cambisol and a Latosol. Means did not differ from each other when followed by the same lower-case letter for both soils, in the comparison of P sources for each forage grass, and upper-case letters, in the comparison of forage grasses for each P source (Scott Knott 5 %).

phosphate fixation in the sandier soil. This result is in agreement with Scivittaro (1993), who reported greater agronomic efficiency of P fertilizer in corn on a soil with lower phosphate retention capacity.

In this context, more effective and efficient practices for soil conservation and species with greater P uptake and use capacity would be desirable, with a view to reducing the concern of soil degradation and exploiting more of the nutrients applied by fertilizers; besides, the quantities of fertilizers required could be reduced.

CONCLUSIONS

1. In general, the use of the source of higher P solubility (TSP) resulted in a higher dry matter production and P accumulation in forage grasses on both soils. For the less soluble source (ARP), the means of P efficiency and efficient use of available P by grasses were always higher when grown on the Latosol, indicating favorable conditions for the solubilization of the reactive phosphate.

2. In general, dry matter production of *Brachiaria brizantha* was better, with low P uptake and accumulation, which made the forage highly efficient in P use for both sources and soils.

3. Differences were observed in the forage grasses in terms of the potential of P use, as related to P sources and soils. Less than 10 % of P applied was immobilized in the forage dry matter, and the highest values were observed for TSP; although this is not reflected in a higher use efficiency of P from this source.

LITERATURE CITED

ALVAREZ V., V.H. & FONSECA, D.M. Definição de doses de fósforo para determinação da capacidade máxima de adsorção de fosfatos e para ensaios em casa de vegetação. R. Bras. Ci. Solo, 14:49-55, 1990.

ALVAREZ V., V.H.; NOVAIS, R.F.; DIAS, L.E. & OLIVEIRA, J.A. Determinação e uso do fósforo remanescente. B. Inf. SBCS, 25:27-33, 2000.

BALIGAR, V.C. & FAGERIA, N.K. Plant nutrient efficiency: Towards the second paradigm. In: SIQUEIRA, J.O.; MOREIRA, F.M.S.; LOPES, A.S.; GUILHERME, L.R.G.; FAQUIN, V.; FURTINI NETO, A.E. & CARVALHO, J.G., eds. Inter-relação fertilidade, biologia do solo e nutrição de plantas. Viçosa, MG, Sociedade Brasileira de Ciência do Solo; Lavras, Universidade Federal de Lavras, 1999. 819p.

BEDIN, I.; FURTINI NETO, A.E.; RESENDE, A.V.; FAQUIN, V.; TOKURA, A.M. & SANTOS, J.Z.L. Fertilizantes fosfatados e produção da soja em solos com diferentes capacidades-tampão de fosfato. R. Bras. Ci. Solo, 27:639-646, 2003.

BONFIM, E.M.S.; FREIRE, F.J.; SANTOS, M.V.F.; SILVA, T.J.A. & FREIRE, M.B.G.S. Avaliação de extratores para determinação de fósforo disponível de solos cultivados com *Brachiaria brizantha*. Acta Sci. Agron., 25:323-328, 2003.

CHIEN, S.H.; MENON, R.G. & BILLINGHAM, K.S. Phosphorus availability from phosphate rock enhanced by water-soluble phosphorus. Soil. Sci. Am. J., 60:1173-1177, 1996.

CHOUDHARY, M.; PECK, T.R.; PAUL, L.E. & BAILEY, L.D. Longterm comparison of rock phosphate with superphosphate on crop yield in two cereal-legume rotations. Can. J. Plant Sci., 74:303-310, 1994.

CORRÊA, R.M.; NASCIMENTO, C.W.A.; SOUZA, S.K.S.; FREIRE, F.J. & SILVA, G.B. Gafsa rock phosphate and triple superphosphate for dry matter production and P uptake by corn. Sci. Agric., 62:159-164, 2005.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. Manual de análises químicas de solos, plantas e fertilizantes. Brasília, Embrapa Comunicação para Transferência de Tecnologia, 1999. 370p.

FAGERIA, N.K. Otimização de eficiência nutricional na produção das culturas. R. Bras. Eng. Agric. Amb., 2:6-16, 1998.

FAQUIN, V.; ROSSI, C.; CURI, N. & EVANGELISTA, A.R. Nutrição mineral em fósforo, cálcio e magnésio do braquiarão em amostras de Latossolo dos Campos das Vertentes sob influência de calagem e fontes de fósforo. R. Bras. Zootec., 26:1074-1082, 1997.

FERREIRA, D.F. Análise estatística por meio do SISVAR (Sistema para Análise de Variância) para o Windows versão 4.0. In: REUNIÃO ANUAL DA REGIÃO BRASILEIRA DA SOCIEDADE INTERNACIONAL DE BIOMETRIA, 45., 2000, São Carlos. Anais. São Carlos, Universidade Federal de São Carlos, 2000. p.255-258.

FRANZINI, V. Efeito do superfosfato triplo (^{32}P) na absorção do fósforo do fosfato natural pelas plantas de milho e soja. Piracicaba, Escola Superior de Agricultura Luiz de Queiroz, 2006. 202p. (Tese de Mestrado)

FOTYMA, M.; HAMMOND, L. & KESIK, K. Suitability of North Carolina natural phosphate to Polish agriculture. Fert. Res., 43:83-86, 1996.

GARCIA, R.; ROCHA, F.C.; BERNARDINI, F.S. & GOBBI, K.F. Forrageiras utilizadas no sistema integrado agricultura-pecuária. In: ZAMBOLIM, L.; SILVA, A.A. & AGNES, E.L., eds. Manejo integrado: Integração agricultura-pecuária. Viçosa, MG, Universidade Federal de Viçosa, 2004. p.331-352.

GIAROLA, N.F.B. Levantamento pedológico, perdas de solo e aptidão agrícola das terras na região sob influência do reservatório de Itutinga/Camargos (MG). Lavras, Escola Superior de Agricultura de Lavras, 1994. 226p. (Tese de Mestrado)

GOEDERT, W.J.; SOUSA, D.M.G. & LOBATO, E. Fósforo. In: GOEDERT, W.J., ed. Solos dos cerrados: Tecnologias e estratégias de manejo. São Paulo, Nobel, 1986. p.129-166.

HOROWITZ, N. & MEURER, E.J. Eficiência agronômica dos fosfatos naturais. In: YAMADA, T. & ABDALLA, S.R.S., eds. Fósforo na agricultura brasileira. Piracicaba, POTAFOS, 2004. p.665-688.

LIMA, S.O.; FIDELIS, R.R. & COSTA, S.J. Avaliação de fontes e doses de fósforo no estabelecimento da *Brachiaria brizantha* cv. marandu no sul do Tocantins. Pesq. Agropec. Trop., 37:100-105, 2007.

MACEDO, M.C.M. Adubação fosfatada em pastagens cultivadas com ênfase na região do cerrado. In: YAMADA, T. & ABDALLA, S.R.S., eds. Fósforo na agricultura brasileira. Piracicaba, POTAFOS, 2004. p.359-400.

MACIEL, G.A.; COSTA, S.E.G.V.A.; FURTINI NETO, A.E.; FERREIRA, M.M. & EVANGELISTA, A.R. Efeito de diferentes fontes de fósforo na *Brachiaria brizantha* cv. marandu em dois tipos de solos. Ci. Animal Bras., 8:227-233, 2007.

MALAVOLTA, E.; VITTI, G.C. & OLIVEIRA, S.A. Avaliação do estado nutricional das plantas: Princípios e aplicações. 2.ed. Piracicaba, POTAFOS, 1997. 319p.

NOVAIS, R.F. & SMYTH, T.J. Fósforo em solo e planta em condições tropicais. Viçosa, MG, Universidade Federal de Viçosa, 1999. 399p.

NOVELINO, J.O. Disponibilidade de fósforo ao longo do tempo em solos altamente intemperizados avaliada por extratores químicos e crescimento vegetal. Viçosa, MG, Universidade Federal de Viçosa, 1999. 70p. (Tese de Doutorado)

PROCÓPIO, S.O.; SANTOS, J.B.; PIRES, F.R.; SILVA, A.A. & MENDONÇA, E.S. Absorção e utilização do fósforo pelas culturas da soja e do feijão e por plantas daninhas. R. Bras. Ci. Solo, 29:911-921, 2005.

RAJAN, S.S.S.; WATKINSON, J.H. & SINCLAIR, A.G. Phosphate rocks for direct applications to soils. Adv. Agron., 57:77-159, 1996.

RICHART, A.; LANA, M.C.; SHULZ, L.R.; BERTONI, J.C. & BRACCINI, A.L. Disponibilidade de fósforo e enxofre para a cultura da soja na presença de fosfato natural reativo, superfosfato triplo e enxofre elementar. R. Bras. Ci. Solo, 30:695-705, 2006.

SCIVITTARO. W.B. Eficiência agronômica de fertilizantes fosfatados fluidos e sólidos. Piracicaba, Escola Superior de Agricultura Luiz de Queiroz, 1993. 111p. (Tese de Mestrado)

SOUSA, D.M.G. & LOBATO, E. Adubação fosfatada em solos da região do Cerrado. Inf. Agron., 102:1-6, 2003. (Encarte Técnico)

SOUSA, D.M.G.; LOBATO, E. & REIN, T.A. Adubação com fósforo. In: SOUSA, D.M.G. & LOBATO, E., eds. Cerrado: Correção do solo e adubação. Planaltina, Embrapa Cerrados, 2002. p.147-168.

SOUZA, R.F. Dinâmica de fósforo em solos sob influência da calagem e adubação orgânica, cultivados com feijoeiro. Lavras, Universidade Federal de Lavras, 2005. 141p. (Tese de Doutorado)

SIDDIQI, M.Y. & GLASS, A.D.M. Utilization index: A modified approach to the estimation and comparison of nutrient utilization efficiency in plants. J. Plant Nutr., 4:289-302, 1981.

SWIADER, J.M.; CHYAN, Y. & FREIJI, F.G. Genotypic differences in nitrate uptake and utilization efficiency in pumpkin hybrids. J. Plant Nutr., 7:1687-1699, 1994.

WERNER, J.C. Adubação de pastagens. Nova Odessa, Instituto de Zootecnia, 1986. 49p.