ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

OPEN ACCESS Journal of Agronomy

ISSN 1812-5379
DOI: 10.3923/ja.2016.104.113

Research Article
Availability of Phosphorus in Soil and Straw in Successive Tropical Grasses Crop Fertilized with Different Phosphates

[1]José Salvador Simoneti Foloni, [2]Juliano Carlos Calonego, [3]Alexandrius de Moraes Barbosa, [3]Tiago Aranda Catuchi and [3]Carlos Sergio Tiritan

[1]Research, Embrapa Soja, Rodovia Carlos João Strass, Distrito de Warta, Caixa Postal 231, CEP 86001-970, Londrina, Paraná, Brasil
[2]Departamento de Produção e Melhoramento Vegetal, Fazenda Experimental Lageado, Research, Universidade Estadual Paulista, Caixa Postal 237, CEP 18610-307, Botucatu, São Paulo, Brasil
[3]Departamento de Produção Vegetal, Universidade do Oeste Paulista, Rodovia Raposo Tavares, Km 572, CEP 19067-175, Presidente Prudente, São Paulo, Brasil

Abstract

Objective: The aim of this study was to evaluate the availability of P in soil and straw during successive tropical grasses crop fertilized with different phosphates. The crops were grown in 18 dm^{-3} pots for 50 days. **Methodology:** The experimental design was completely randomized, using a 4×4 factorial design with four replication. The experimental trataments were *Urochloa brizantha*, *Urochloa ruziziensis*, *Urochloa decumbent* and *Pennisetum glaucum* and those grasses were fertilized with 0 (control) e 100 mg P kg^{-1} with triple superphosphate, Arad rock phosphate and Alvorada rock phosphate. **Results:** The pots were subjected to seven cycles of growing plants and the phosphate fertilizers were applied only in the first cycle. If the goal is fast response and high agronomic efficiency, the best alternative is to use triple superphosphate associated with pear millet. If the intention is to increase P labile of soil in the long term, the best option is the arad phosphate rock, which can be management with the *U. brizantha*, *U. decumbens*, *U. ruziziensis* or *Pennisetum glaucum*. **Conclusion:** The Alvorada rock phosphate does not have satisfactory performance but the agronomic efficiency of this source of P can be increased if it is associated with *U. decumbens*.

Key words: Triple superphosphate, Arad rock phosphate, Alvorada rock phosphate (nonreactive), cover crop, *Urochloa* spp., *Pennisetum glaucum*

Received: March 11, 2016 Accepted: May 16, 2016 Published: June 15, 2016

Citation: José Salvador Simoneti Foloni, Juliano Carlos Calonego, Alexandrius de Moraes Barbosa, Tiago Aranda Catuchi and Carlos Sergio Tiritan, 2016. Availability of phosphorus in soil and straw in successive tropical grasses crop fertilized with different phosphates. J. Agron., 15: 104-113.

Corresponding Author: Alexandrius de Moraes Barbosa, Departamento de Produção Vegetal, Research, Universidade do Oeste Paulista, Rodovia Raposo Tavares, Km 572, CEP 19067-175, Presidente Prudente, São Paulo, Brasil

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Tropical soil, in general has high levels of iron oxides (Fe) and aluminum (Al) due to the high rate of weathering that, in line with low levels of pH, result in the low availability of phosphorous (P) for crops[1,2]. In these crop conditions the use of phosphate fertilizers is impaired being estimated around 10% for most crops[3]. According to Bedin *et al.*[4] many tropical soils show themselves to be strong drainers of phosphorous, in which a large part of the P added via fertilization is retained in solid phase with low rates of nutrient return to the more labile forms.

In addition to the soil properties, the efficiency of phosphate fertilizer varies depending on fertilizer, handling and crop specie[3,5]. In regards to the fertilizers, the classifications in terms of P are basically made based on solubility[6]. According to Fontoura *et al.*[7], in Brazilian agriculture soluble phosphate fertilizers are predominant also called acidulates (superphosphates, etc.) obtained from the acid treatment of phosphate rocks, as with the example of the triple superphosphate (TSP). However, due to the high cost of these P sources interest in natural sources has increased[8].

The solubility among the natural phosphates can be variable depending on origin and degree of ionic isomorphic replacement[7]. The Brazilian apatitics (Alvorada, Araxá, Catalão, etc.) for example, present low solubility. On the other hand, there are phosphates termed reactive, such as Arad and Gafsa, which have demonstrated agronomic efficiency similar to acidulate sources in different situations, i.e., in soils with high phosphorus adsorption capacity and long crops cycle[2]. The soluble phosphates promote P availability in the plants, in the first cultivation cycles after application, as they are sources that immediately free phosphate ions in the soil solution, in relation to the natural phosphates[9]. Among natural phosphates, the example of Arad presents a growing agronomic efficiency after the second year of fertilizer application. This confirms its characteristics of gradual P availability in soil[10], being able after many diverse crop years to have similar effects to those of the soluble phosphates[11].

Another relevant factor is the crop species, in such a way that in the fertilizer programs of tropical soils, the ability to extract P from the crops is considered crucial[5,12]. There is for example, the phosphate application for the pastures formation, in which it is considered that the natural sources make P more quickly available when associated with the grass crops tolerant to soil acidity, such as some of those of the *Urochloa* spp. genus (Syn. *Brachiaria* spp.) commonly termed brachiarias[13]. These plants can present a variety of mechanisms that facilitate the acquisition of phosphorous in soil, such as acidification of the rhizosphere by way of the liberation of protons[14], exudation of organic acids[15] and secretion of phosphates[16] in addition to morphological alterations[17,18].

In addition to the brachiarias, the pear millet (*Pennisetum glaucum*) is also highly utilized in the handling of tropical soils, mainly for the elevated production of biomass (straw) during the dry winter of xentral Brazil, within the no-tillage system (NTS) and/or the crop livestock integration system (CLIS). These grasses are also considered very efficient with nutrient recycling[19,20]. Due to the vegetable species have different abilities to absorb nutrients in soil, either by morphological adaptations of roots or by biochemical mechanisms, it is possible that some of these species show greater efficiency in the P absorption over time with alternative sources of this nutrient as is the case of phosphates rock, which are cheaper and produce less waste to be made. In this context, the objective of this study was to evaluate the availability of P in the soil and in the straw in successive crops of pear millet and *Brachiaria brizantha*, *B. ruziziensis* and *B. decumbens* fertilized by triple superphosphate, Arad rock phosphate (origin in Israel) and Alvorada rock phosphate (origin in Brazil).

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at the West Paulista University (Universidade do Oeste Paulista-UNOESTE), in Presidente Prudente-SP, Brazil from September, 2006 to August, 2007. A portion of soil collected from the layer of depth 0-20 cm of a ultisol dystroferric of medium texture[21] was utilized, which had been occupied by grain crops. The soil was air dried, sieved (2 mm mesh) and part was submitted to the characterization of their chemical attributes[22], particle size and water retention capacity[23] with the following results: pH of 5.2 ($CaCl_2$ 1 mol L^{-1}), 12 g dm^{-3} of Mo, 20 mg kg^{-1} of P_{resin}, 15 $mmol_c$ dm^{-3} of H+Al, 1.2 $mmol_c$ dm^{-3} of K, 8 $mmol_c$ dm^{-3} of Ca, 6 $mmol_c$ dm^{-3} of Mg, CTC (pH 7.0) of 30.2 $mmol_c$ dm^{-3}, 50% of base saturation (V), 10 mg kg^{-1} of Mn, 13 mg kg^{-1} of Fe, 0.3 mg kg^{-1} of Cu, 0.8 mg kg^{-1} of Zn, 0.13 mg kg^{-1} of B, 760 g kg^{-1} of sand, 180 g kg^{-1} of clay, 60 g kg^{-1} of silt and field capacity of 176 g kg^{-1} (unstructured soil).

Limestone with 390 g kg^{-1} CaO, 130 g kg^{-1} MgO and Effective Calcium Carbonate (ECC) equivalent 91% was applied to elevate the base saturation[24] to 70%. After wards at sowing time, 120 mg K kg^{-1}, 50 mg N kg^{-1}, 2 mg Mn kg^{-1}, 6 mg Zn kg^{-1}, 1.5 mg Cu kg^{-1}, 2 mg B kg^{-1} and 1 mg Mo kg^{-1} with the sources: KCl, NH_4NO_3, $MnSO_4$, $ZnSO_4$, $CuSO_4$, H_3BO_3 and $(NH_4)_2MoO_4$ were applied, founded on the studies of Moreira *et al.*[25] and Foloni *et al.*[26].

The experimental design adopted was in complete randomized blocks with four repetitions, in a 4×4 factorial scheme. Two factors were evaluated, understanding the grass species: *Brachiaria brizantha* (*Urochloa brizantha* cv. Marandu), *Brachiaria ruziziensis* (*Urochloa ruziziensis* cv. Ruziziensis), *Brachiaria decumbens* (*Urochloa decumbens* cv. Basilisk) and pear millet (*Pennisetum glaucum* cv BN-2) and the phosphorous sources: Arad, Alvorada phosphorite, triple superphosphorous and a control without the addition of P. The dose utilized in the treatments with the different sources of P was 100 mg P kg^{-1}.

The phosphates were mixed manually with the soil of each pots (18 dm^3), in the implementation of the experiment. In the other six crop cycles there was no phosphate fertilizer, in other words, the pots were maintained intact for seven consecutive crop cycles with the same species, in accordance with the experimental design mentioned above. Due to the limiting size of the plots was necessary manage the crops every 50 days after emergence and repeat sowing of the crops seven times to evaluate the treatments for a year. The period 50-60 days is the time of growing of some cover crops for straw production in no-till.

The sieved and fertilized soil was placed in the pots with a density near to 1.2 g cm^{-3}. To obtain in the soil 100 mg P kg^{-1} were considered, the total levels of P of eachphosphates, determined in accordance with Brasil[27]: (1) Alvorada phosphorite with 240 g kg^{-1} of P_2O_5 total, 32 g kg^{-1} of P_2O_5 in citrate+water and 77 g kg^{-1} of P_2O_5 in citric acid, (2) Arad with 331 g kg^{-1} of P_2O_5 total, 48 g kg^{-1} of P_2O_5 in citrate+water and 97 g kg^{-1} of P_2O_5 in citric acid and (3) Triple superphosphate with 432 g kg^{-1} of P_2O_5 total, 391 g kg^{-1} of P_2O_5 in citrate+water and 419 g kg^{-1} of P_2O_5 in citric acid.

Five days after seedling emergence (DAE), in the seven crop cycles thinning was carried out, leaving five plants per pot. Daily controlled watering was carried out to replace the evopotranspired water and maintained the level of water in the soil similar to that of the field. Between 15 and 30 DAE for all of the seven crop cycles, 100 mg kg^{-1} of N were incrementally applied to the pots via irrigation water with urea concentration. Therefore, the pots received a total of 750 mg kg^{-1} of N, throughout all of the crop cycles. Before beginning the fourth crop cycle, the pots received 60 mg kg^{-1} of K (KCl), 100 mg kg^{-1} of Ca ($CaSO_4$) and 40 mg kg^{-1} of Mg ($MgSO_4$) with the intent of reestablishing the fertility of the soil, according to the chemical analysis carried out after the third crop cycle and following the procedures of Moreira *et al.*[25].

At 50 DAE for all seven crop cycles, a chemical dissection of the grass was made with glyphosate (2.4 kg ha^{-1} of active ingredient), utilizing a manual precision sprayer pressurized with CO_2 and applying 200 L ha^{-1} of spray volume. Next the plant shoots were cut and the material collected was dried to constant weight in a forced-air oven at 65°C. After the removal of the plants, in all of the seven crop cycles, samples of the soil were taken of the pots profile, at random spots utilizing tubular probes.

The Dry Matter (DM) yields of grass shoots were determined and the P levels were analyzed[28]. With these data were calculated the accumulations of P in the straws. The soil samples were analyzed to determine the levels of P by ion exchange resin (P_{resin})[22].

From the P_{resin} levels of the soil, the relative P availability (DRP) was determined in accordance with Eq. 1[25]:

$$\text{DRP (\%)} = \frac{P_{\text{fertilizer}} - P_{\text{control}}}{\text{P dose}} \times 100 \quad (1)$$

which the variable $P_{fertilizer}$ equates to the P level in the soil cultivated with a grass and a phosphate fertilizer and the variable $P_{control}$ corresponding to the level of P in the soil of the control treatment (absence of phosphate application) for the same grass.

With the sum of P accumulated from the straw of the seven crop cycles, the accumulated P extraction for each grass was determined. The balance between the input and output of P in the system was calculated in the following way: An initial level of P_{resin} of the soil of 20 mg kg^{-1} (control treatment) added to 100 mg P kg^{-1} for the fertilizers with triple superphosphate, Arad and Alvorada phosphorite were considered as the input and as the output of P from the system, the sum of P accumulated in the straw of the grass of the seven crop cycles (accumulated P extraction) was made, plus the P_{resin} of the soil after the last crop cycle (residual P).

From the sum of the DM of the grass obtained in the seven crop cycles, the Agronomic Efficiency Index (AEI) and the triple superphosphate equivalent (TSPEq) was determined, according to Moreira *et al.*[25] starting with Eq. 2 and 3, respectively:

$$\text{IEA (\%)} = 100 \times [(DM_{\text{fertilizer}} - DM_{\text{control}}) - (DM_{\text{TSP}} - DM_{\text{control}})] \quad (2)$$

where, $DM_{fertilizer}$ equals to DM of a grass crop with a phosphate fertilizer the $DM_{control}$ corresponds to the DM of the same grass without phosphate fertilizer and the DM_{TSP} equals to the DM of the same grass crop with triple superphosphate:

$$\text{TSPEq (\%)} = \frac{DM_{\text{TSP}}}{DM_{\text{fertilizer}}} \times 100 \quad (3)$$

where, the DM_{TSP} equals to the DM of a grass crop with triple superphosphate and the $DM_{fertilizer}$ corresponds to the DM of the same grass with another phosphate fertilizer.

The results were submitted to a variance analysis at the 5% level of probability by the F-test. When there were statistical differences, the Tukey test was applied also with a 5% probability to compare the averages of the treatments.

RESULTS AND DISCUSSION

The millet stood out in the DM yield in the first crop cycles, however, in all of the phosphate application conditions/phases/stages the brachiarias got close to it during the process of P exhaustion from the soil or in other words, the millet was considerably damaged by reducing of the P available, contrary to the brachiarias (Fig. 1). In the second growing cycle there was a drastic reduction in the DM production by the brachiarias. This happened probably because it coincided with the winter and these grasses required higher temperatures for an optimal development. In terms of phosphate fertilizer, the triple superphosphate (TSP) increased the millet DM in the short term (first crop cycle), with earnings above 100% in comparison to the absence of fertilizer (control) or even in relation to the fertilizer with Arad (Fig. 1).

Such results confirm the argument of Foloni *et al.*[26], which discuss that the corrective phosphate applications in the NTS should not be made with the fallow area but should be made during sowing of cover crops with fast initial growth, such as millet, reducing the exposure of P fixation in the soil, in addition to minimizing other forms of loss such as that of erosion. Ramos *et al.*[9] report that the soluble phosphates, as with the example of TSP makes the P available to the plants already in the first crop cycles after the application, contributing to the accumulation of the crop's dry material.

With regard to the P accumulated in the straw, the millet also stood out in the first crop cycles, mainly when it received TSP (Fig. 2c). These results reinforce the argument

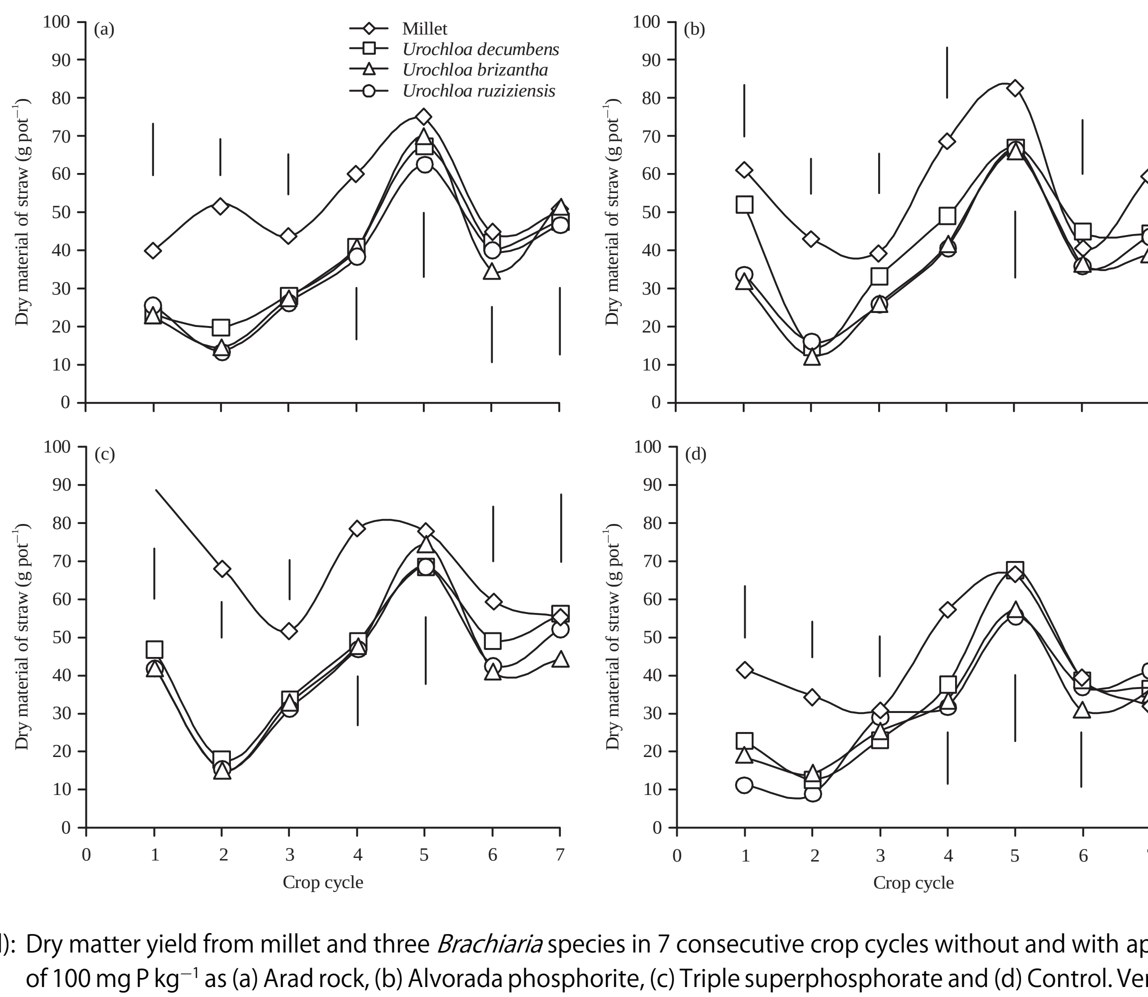

Fig. 1(a-d): Dry matter yield from millet and three *Brachiaria* species in 7 consecutive crop cycles without and with application of 100 mg P kg^{-1} as (a) Arad rock, (b) Alvorada phosphorite, (c) Triple superphosphorate and (d) Control. Vertical bars represent the least significant difference by Tukey test with 5% probability

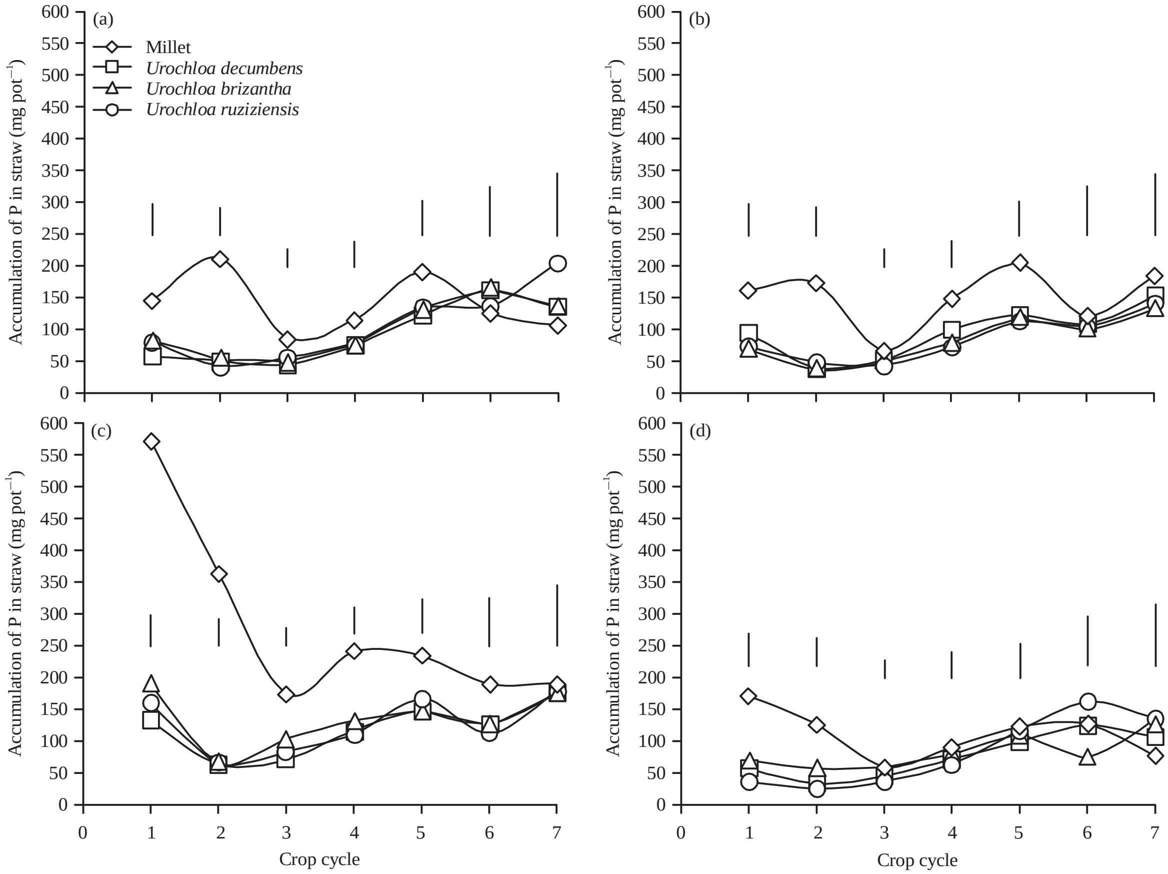

Fig. 2(a-d): Accumulation of P in millet straw and of and three *Brachiaria* species in seven consecutive crop cycles without and with application of 100 mg P kg^{-1} as (a) Arad rock, (b) Alvorada phosphorite, (c) Triple superphosphorate and (d) Control. Vertical bars represent the least significant difference by Tukey test with 5% probability

about the benefits of applying soluble phosphates in sowing furrows of grass with fast initial growth. In the first crop cycle, the millet fertilized with TSP presented a gradual increase of P in the straw superior to 250% in relation to the average of the three brachiarias (Fig. 2c). On the other hand, during the process of nutrient exhaustion, the brachiarias began to have considerable increases of P in the straw for all of the studied phosphates; contrary to the millet that had a strong decline in the last cycles, mainly when fertilized with a soluble source (Fig. 2 and 3).

The accumulated P maintenance response in the millet straw after the third crop cycle over the natural source (Arad and Alvorada phosphorite) in relation to the soluble source (TSP) is related the characteristics of gradual availability of P in the soil, utilizing a soluble source[10].

In the present study, a dystroferric red utisol of medium texture was utilized, which presented 20 mg kg^{-1} of initial P level, classified as average availability for effect of phosphate fertilizer for annual crops (soybean, corn, etc.) in Brazilian soils[24]. In the first crop cycle, for example, the TSP, Arad and Alvorada increased the levels of P in the soil for 67, 48 and 30 mg kg^{-1}, respectively for the average of the four studied grasses (Fig. 3). In the last crop cycle, on the other hand, the TSP, Arad and Alvorada provided 17, 25 and 16 mg P kg^{-1} in the soil, respectively also for an average of the four grasses and in the absence of phosphate application the P of the soil was reduced to 5 mg kg^{-1} on average. However, the process of the P reduction was significantly more intense in the soil that received the TSP.

In the context of crop response to the phosphate fertilizer, beyond the immediate impact on the existing crop, it is necessary to consider the residual effect over subsequent crops, which holds a direct relation with the source utilized, among other factors[5]. In the case of the FNs, in spite of being commonly judged as inefficient in terms of availability of P in the short term, it is argued that there can be a gradual increase in the supply of the nutrient throughout cultivation[10].

In relation to the relative availability of P in the soil, the TSP was superior to the other sources in the first crop cycle (Fig. 4). However, with the passage of the crop cycles there

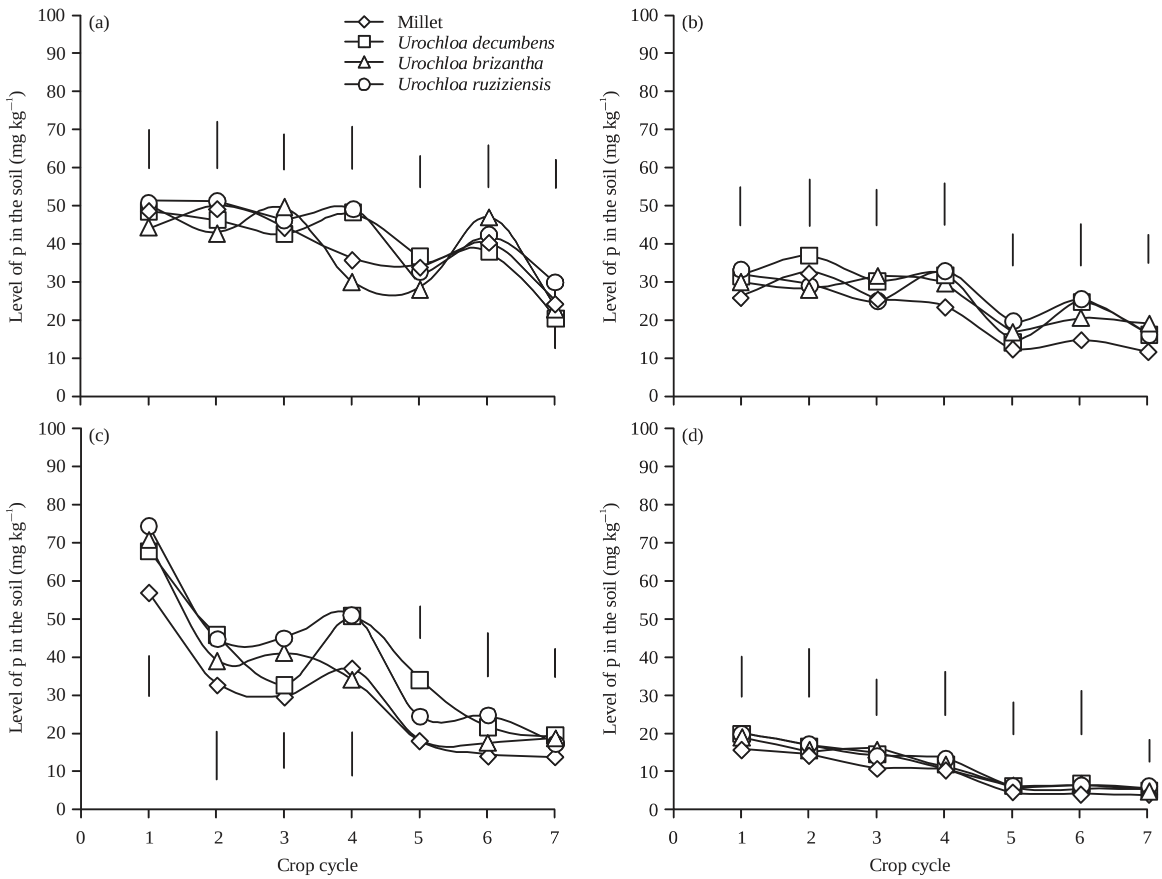

Fig. 3(a-d): Level of P_{resin} in the soil throughout the seven consecutive crop cycles with millet and three *Brachiaria* species without and with application of 100 mg P kg^{-1} as (a) Arad rock, (b) Alvorada phosphorite, (c) Triple superphosphorate and (d) Control. Vertical bars represent the least significant difference by Tukey test with 5% probability

was a strong decline of availability of P, where TSP was applied, contrary to the soil that received Arad, in which the P available maintained relatively stable during all of the seven crop cycles. In the case of the non-reactive FN Alvorada, there was not satisfactory performance at any moment during in the entire process of nutrient exhaustion (Fig. 4).

The relative availability of P in the soil in the first crop cycle was 49, 29 and 11% for the TSP, Arad and Alvorada, respectively. In the last cycle the P available evolved to 13, 25 and 10% for the TSP, Arad and Alvorada, respectively taking the average of the four studied grasses (Fig. 4). As such, it is observed that the soil that received soluble phosphate had its P available greatly reduced, in such a magnitude as to match the soil fertilized with non-reactive FN. On the other hand, the reactive FN Arad maintained the P available in the soil varying between 25 and 29% throughout the entire process of exhaustion, reinforcing the reports of a relatively elevated capacity of availability of P in the long term (Fig. 5).

Novais *et al.*[2] emphasize that fertilizers for the implementation of crops or "startup" should be made with soluble phosphates with the intention of obtaining an elevated initial response from the plants or in other words, it is understood that there should be a balance between the high rate of vegetative growth, elevated demand for the nutrient and significant supply of P from these sources in the short term. It is also emphasized that the soluble phosphates, as long as they are well-handled (localized application, granulated fertilizer, etc.) present high performance in heavily weathered tropical soils. On the other hand, to maintain the supply of P in the long term, the researchers argue that fertilizers less reactive than the soluble sources and more reactive than the Brazilian apatitic FNs are necessary, such as the sedimentary FNs Arad and Gafsa of intermediate solubility for example.

In Fig. 5a the results of the accumulated extraction of P from the grasses are displayed, which were calculated based on the sum of the quantities of P immobilized in the straw of the seven crop cycles. The millet stood out under all conditions of phosphate application, although, when this grass was fertilized with TSP, the quantity of P supplied in the

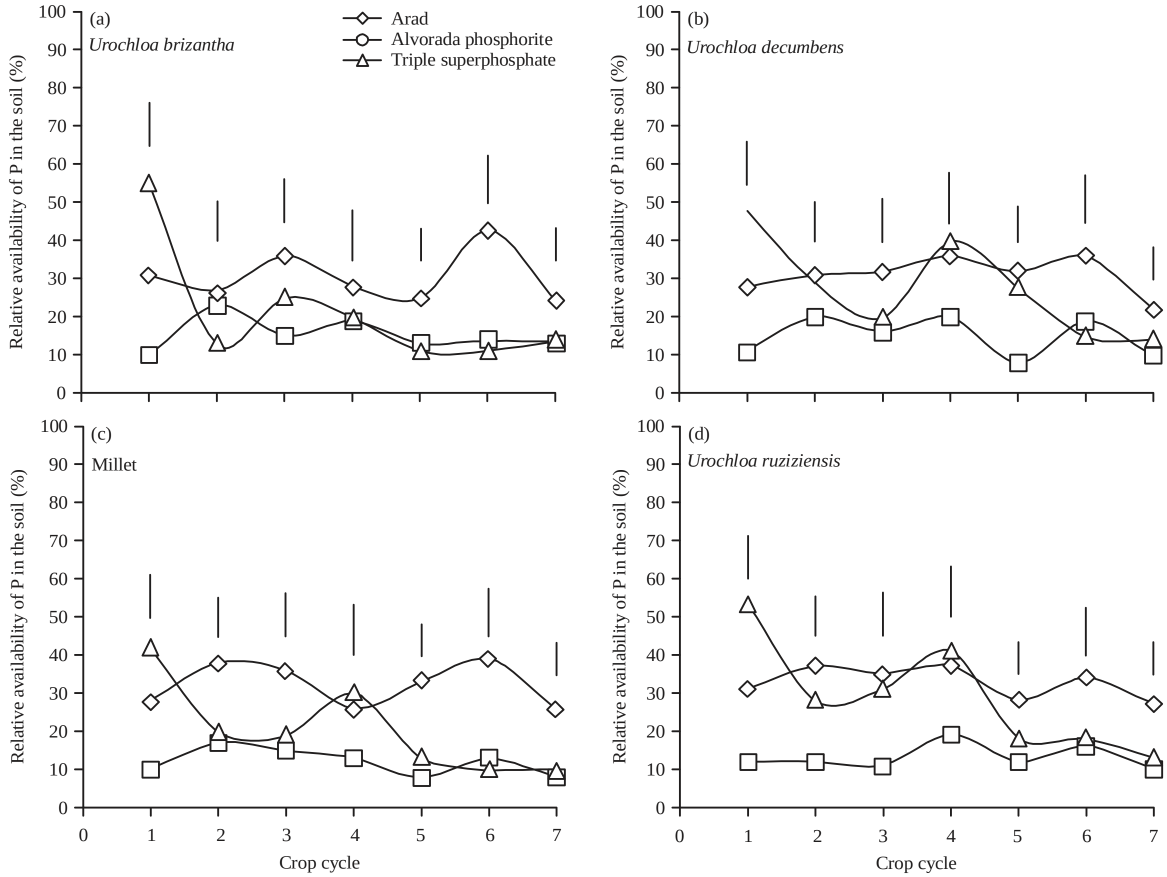

Fig. 4(a-d): Relative availability of P_{resin} in the soil throughout the seven consecutive crop cycles with millet and three *Brachiaria* species without and with application of 100 mg P kg^{-1} as (a) Arad rock, (b) Alvorada phosphorite, (c) Triple superphosphorate and (d) Control. Vertical bars represent the least significant difference by Tukey test with 5% probability

biomass almost doubled or in other words, the millet presented an accumulated extraction of P along the lines of 1,956, 987 and 1,065 mg pot^{-1} for TSP, Arad and Alvorada, respectively. In terms of handling the phosphate fertilizer[5], emphasize that there are crops, such as corn, which need an elevated "status" (availability) of P in the soil to achieve high productivity. However, the researchers make reservations as to the strategy for increasing levels of P in the soil or in other words initially species that achieve high productivity only with the localized application of soluble phosphates in the sowing furrows, such as soybean should be prioritized. As such based on the data of the present study, although the fertilizer with P had been mixed with the entire volume of soil in the pot, it confirms that applications of phosphates during sowing of cover grasses could make an interesting strategy for increasing the supply of P in integrated crop systems.

The balance between the input and output of P in the soil-straw system was calculated (Fig. 5b) for which the input was considered to be the initial P_{resin} of the soil (control) added or not to the nutrient supply via phosphate applications with different sources and the output was the sum of the accumulated extraction of P in straw (Fig. 5a) with the P_{resin} of the soil after the last crop cycle (Fig. 2). The millet was significantly superior to the brachiarias in the recuperation of P made available in the system, for all the conditions of phosphate application (Fig. 5b). In addition, for the soil that received the TSP the depletion of P provided by the millet was so great that the balance was negative, confirming the high potential this grass has of recycling nutrients[19,20].

Still for Fig. 5b, it is observed that in the treatments without phosphate application (control) the balances of P were negative for all the grasses in the study. However, it is speculated that these species may have solubilized P in the soil beyond what was quantified by the ion exchange resin (Fig. 2). According to Machado and Furlani[29], differences between genotypes in terms of the capacity to extract P from the soil are explained, in part, by morphological and physiological variations of the roots.

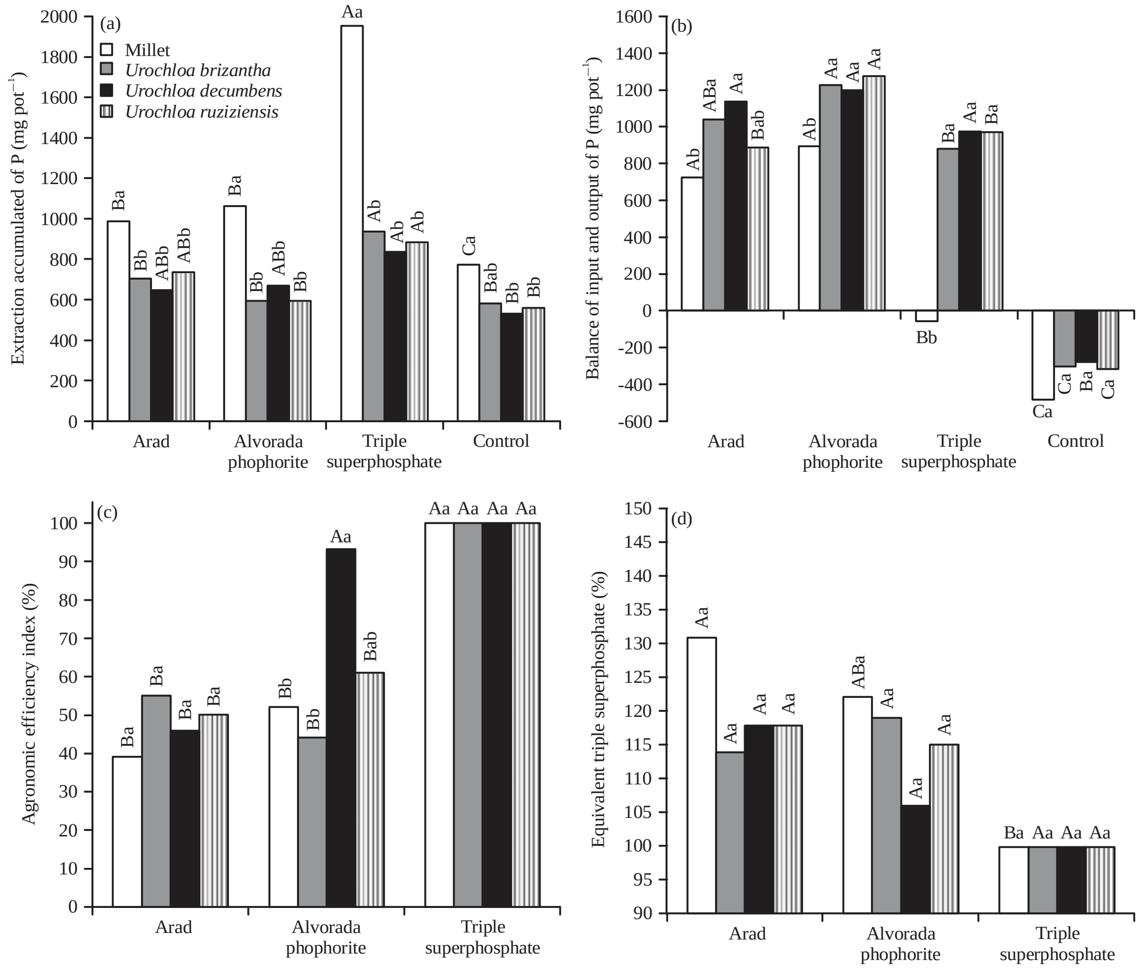

Fig. 5(a-d): (a) Accumulated extraction of P, (b) Input and output balance of P in the system, (c) Agronomic efficiency index and (d) Triple superphosphate equivalente para millet and three *Brachiaria* species due to without (control) and with application of 100 mg P kg^{-1} as Arad rock, Alvorada phosphorite and triple superphosphorate. Capital letters compare P sources within each grass and smaller case compare grass within each source of P. Averages followed by the same letters do not differ amongst themselves by the Tukey test with 5% probability

Siqueira *et al.*[12] confirm that the potential of species or crops to absorb P from the soil is dependent on the morphology and quantity of roots, such as may have interaction with mycorrhizae, solubilizing mineral microorganisms, secretions from organic acids, protons, phosphatases enzymes and/or chelating substances in the rhizosphere, in addition to the adaptability to adverse edafoclimatic conditions.

From these fundamentals, there are indications that the millet presents high root length per soil volume, in relation to the other cover species such as crotalaria juncea, crotalaria spectabilis and dwarf pigeon pea[30]. In addition, study carried out in the field confirm the significant potential of the initial growth of millet, such as for example: (1) 10.7 Mg ha^{-1} of DM at 60 days after the emergence of the spring crop[31], (2) 10.8 Mg ha^{-1} of DM at 51 days after sowing in the off season in Brazilian savanna[32] and (3) 12.4 Mg ha^{-1} of DM in the consortium millet+crotalaria juncea at 128 days after sowing in spring, also in Brazilian savanna[33].

In Fig. 5c the Agronomic Efficiency Index (AEI) is presented, calculated from the sum of the DM of the grasses in the seven crop cycles. In statistical terms, the reactive FN Arad presented agronomic efficiency equivalent to the non-reactive FN Alvorada for nearly all of the grasses (except *Bracharia decumbens*). In regards to the AEI of Alvorada Phosphorite, what stood out was the phosphate application associated with *Brachiaria decumbens*, which obtained an AEI of 93%, statistically equivalent to that of the soluble TSP source. However, if there is a need to use the apatitic FN Alvorada, there is potential for incremental growth of the AEI if applied together with the *Brachiaria decumbens* crop, relatively tolerant to soils that are acidic and poor in nutrients[34,35]. In the work of Foloni *et al.*[26], the fertilizer with FN Alvorada in the *Branchiaria brizantha* and millet was evaluated and confirmed that, in spite of millet's high potential to produce DM in a short term, the levels of P of its straw were significantly inferior to those of the *Brachiaria*, mainly in the smaller doses of the FN. In addition, the *Branchiaria brizantha* demonstrated elevated capacity of P absorption per unit of DM produced, which can be positive in terms of occupation of soil with low P supplies and/or for the use of low reactivity FNs.

In Fig. 5d it is observed that only the millet presented a significant statistical difference for the triple superphosphate equivalent (TSPEq). However, the millet needed incremental increases in quantity of fertilizer by 31% for the source Arad and 21% for Alvorada, so that it could maintain the same level of production of DM achieved by the soluble source TSP. The results of TSPEq reinforced the argument of Novais *et al.*[2] that species with rapid initial growth, such as millet, should receive fertilizer implemented with soluble phosphates to satisfy the equilibrium between the intense vegetative growth, the high demand for the nutrient and the large initial offer of P.

CONCLUSION

For situations of quick response and elevated agronomic efficiency, the greatest potential among the cover grasses is millet, fertilized with the soluble source triple superphosphate.

To make P available in the soil in the long term, the use of the natural reactive phosphate Arad is promising, regardless of the cover grass associated with it.

The apatitic phosphate Alvorada does not present a satisfactory performance, however, there is a possibility of increasing its agronomic efficiency if applied together with the brachiaria decumbens.

REFERENCES

1. Hinsinger, P., 2001. Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: A review. Plant Soil, 237: 173-195.
2. Novais, R.F., T.J. Smyth and F.N. Nunes, 2007. Fosforo. In: Fertilidade do Solo, Novais, R.F., V.H. Alvarez, N.F. Barros, R.L.F. Fontes, R.B. Cantarutti and J.C.L. Neves (Eds.)., Chapter 8. Sociedade Brasileira de Ciencia do Solo, Vicosa, MG., pp: 472-550.
3. Van Raij, B., 2004. Fosforo no Solo e Interacao com Outros Elementos. In: Fosforo na Agricultura Brasileira, Yamada, T. and S.R.S. Abdalla (Eds.). Chapter 4, Associacao Brasileira Para Pesquisa da Potassa e do Fosfato, Piracicaba, pp: 107-114.
4. Bedin, I., A.V. de Resende, A.D. Furtini Neto, L.A. Mendonca and L.C.S. Vilela, 2003. [Phosphorus sources and corn growth in soils with different phosphate buffering capacities]. Ciencia Agrotecnologia, Special Edition: 1522-1531, (In Portuguese).
5. Novais, R.F. and T.J. Smyth, 1999. Fosforo em solo e planta em condicoes tropicais. Universidade Federal de Vicosa, Vicosa.
6. Horowitz, N. and E.J. Meurer, 2004. Eficiencia Agronomica dos Fosfatos Naturais. In: Fosforo na Agricultura Brasileira, Yamada, T. and S.R.S. Abdalla (Eds.)., Chapter 23, Potafos, Piracicaba, pp: 665-687.
7. Fontoura, S.M.V., R.C.B. Vieira, C. Bayer, P.R. Ernani and R.P. de Moraes, 2010. [Agronomic performance of phosphate fertilizers in an oxisol under no-tillage]. Rev. Bras Cienc Solo, 34: 1907-1914.
8. Prochnow, L.I., J.C. Alcarde and S.H. Chien, 2004. Eficiencia Agronomica de Fosfatos Totalmente Acidulados. In: Fosforo na Agricultura Brasileira, Yamada, T. and S.R.S. Abdalla (Eds.). Chapter 23, Associacao Brasileira Para Pesquisa da Potassa e do Fosfato, Piracicaba, pp: 605-663.
9. Ramos, S.J., V. Faquin, C.R. Rodrigues, C.A. Silva and P.F. Boldrin, 2009. Biomass production and phosphorus use of forage grasses fertilized with two phosphorus sources. Rev. Bras. Cienc. Solo, 33: 335-343.
10. Caione, G., F.M. Fernandes and A. Lange, 2013. [Residual effect of phosphorus sources in soil chemical properties, nutrition and biomass productivity of sugarcane]. Rev. Bras Cienc Agrar, 8: 189-196.
11. Resende, A.V., A.E.F. Neto, V.M.C. Alves, J.A. Muniz and N. Curi *et al*., 2006. [Phosphorus sources and application methods for maize in soil of the cerrado region]. Rev. Bras. Cienc. Solo, 30: 453-466.
12. Siqueira, J.O., A.T. Andrade and V. Faquin, 2004. O Papel dos Microrganismos na Disponibilizacao e Aquisicao de Fosforo Pelas Plantas. In: Fosforo na Agricultura Brasileira, Yamada, T. and S.R.S. Abdalla (Eds.)., Chapter 5. Associacao Brasileira Para Pesquisa da Potassa e do Fosfato, Piracicaba, pp: 117-149.
13. De Sousa, D.M.G. and E. Lobato, 2004. Adubacao Fosfatada em Solos da Regiao do Cerrado. In: Fosforo na Agricultura Brasileira, Yamada, T. and S.R.S. Abdalla (Eds.)., Chapter 6. Associacao Brasileira Para Pesquisa da Potassa e do Fosfato, Piracicaba, pp: 157-196.
14. Zeng, H., G. Liu, T. Kinoshita, R. Zhang, Y. Zhu, Q. Shen and G. Xu, 2012. Stimulation of phosphorus uptake by ammonium nutrition involves plasma membrane H^+ ATPase in rice roots. Plant Soil, 357: 205-214.
15. Hinsinger, P., C. Plassard, C. Tang and B. Jaillard, 2003. Origins of root-mediated pH changes in the rhizosphere and their responses to environmental constraints: A review. Plant Soil, 248: 43-59.

16. Nahas, N., 2002. [Soil microorganisms phosphatase producers in different agricultural systems]. Bragantia, 61: 267-275.
17. Vance, C.P., C. Uhde-Stone and D.L. Allan, 2003. Phosphorus acquisition and use: Critical adaptations by plants for securing a nonrenewable resource. New Phytol., 157: 423-447.
18. Wissuwa, M., 2005. Combining a modelling with a genetic approach in establishing associations between genetic and physiological effects in relation to phosphorus uptake. Plant Soil, 269: 57-68.
19. Carpim, L.K., R.L. de Assis, A.J.B.P. Braz, G.P. Silva and F.R. Pires *et al*., 2008. [Nutrient release from pearl millet in different phenological stages]. Rev. Bras Cienc Solo, 32: 2813-2819.
20. Rosolem, C.A. and J.C. Calonego, 2013. Phosphorus and potassium budget in the soil-plant system in crop rotations under no-till. Soil Tillage Res., 126: 127-133.
21. Embrapa, 2006. Sistema Brasileiro de Classificacao de Solos [Brazilian System of Soil Classification]. 2nd Edn., Empresa Brasileira de Pesquisa Agropecuaria, Brasilia.
22. Van Raij, B., J.C. Andrade, H. Cantarela and J.A. Quaggio, 2001. Analise quimica para avaliacao da fertilidade de solos tropicais. Instituto Agronomico, Campinas.
23. Empresa, 1997. Manual de Metodos de Analise de Solo [Methods Manual of Soil Analysis]. 2nd Rev. Edn., Centro Nacional de Pesquisa de Solos, Rio de Janeiro.
24. Van Raij, B., H. Cantarella, J.A. Quaggio and A.M.C. Furlani, 1997. Recomendacoes de adubacao e calagem para o Estado de Sao Paulo. Instituto Agronomico, Campinas.
25. Moreira, A., E. Malavolta and L.A.C. Moraes, 2002. [Efficiency of phosphorus sources and rates for alfalfa and centrosema cultivated in an Yellow Latosol (Oxisol)]. Pesq. Agropec. Bras., 37: 1459-1466.
26. Foloni, J.S.S., C.S. Tiritan, J.C. Calonego and J. Alves Junior,, 2008. [Rock phosphate fertilization and phosphorus recycling by pearl millet, *Brachiaria* sp., corn and soybean]. Rev. Bras Cienc Solo, 32: 1147-1155.
27. Brasil, 1983. Secretaria Nacional de Defesa Agropecuaria. Inspecao e Fiscalizacao da producao e do comercio de fertilizantes, corretivos, inoculantes, estimulantes ou biofertilizantes destinados a agricultura. Ministerio da Agricultura, Divisao de Fiscalizacao de Corretivos e Fertilizantes, Brasilia.
28. Malavolta, E., Vitti, G.C. and S.A. de Oliveira, 1997. Avaliacao do Estado Nutricional das Plantas: Principios e Aplicacoes. 2nd Edn., Associacao Brasileira para Pesquisa da Potassa e do Fosfato, Piracicaba, Brazil, Pages: 319.
29. Machado, C.T.D.T. and A.M.C. Furlani, 2004. Kinetics of phosphorus uptake and root morphology of local and improved varieties of maize. Sci. Agric., 61: 69-76.
30. Rosolem, C.A., J.S.S. Foloni and C.S. Tiritan, 2002. Root growth and nutrient accumulation in cover crops as affected by soil compaction. Soil Tillage Res., 65: 109-115.
31. Cazetta, D.A., D.F. Filho and F. Girotto, 2005. [Composition, dry matter production and soil covering in exclusive and consortium growing of millet and sunnhemp]. Acta Sci. Agron., 27: 575-580.
32. Boer, C.A., R.L. de Assis, G.P. Silva, A.J.B.P. Braz, A.L.D.L. Barroso, A.C. Filho and F.R. Pires, 2008. [Biomass, decomposition and soil cover by residues of three plant species in Central-Western Brazi]. Rev. Bras Cienc Solo, 32: 843-851.
33. Teixeira, C.M., G.J. de Carvalho, M.J.B. de Andrade, C.A. Silva and J.M. Pereira, 2009. [Decomposition and nutrient release of pearl millet and pearl millet plus *Crotalaria juncea* straws on bean no-till]. Acta Sci. Agron., 31: 647-653.
34. Vilela, L., W.V. Soares, D.M.G. Souza and M.C.M. Macedo, 1999. Calagem e adubacao para pastagens na regiao do Cerrado. Embrapa Cerrados, Planaltina.
35. Macedo, M.C.M., 2004. Adubacao Fosfatada em Pastagens Cultivadas com Enfase na Regiao do Cerrado. In: Fosforo na Agricultura Brasileira, Yamada, T. and S.R.S. Abdalla (Eds.)., Chapter 14, Associacao Brasileira Para Pesquisa da Potassa e do Fosfato, Piracicaba, pp: 359-396.