



ORIGINAL ARTICLE

Natural reactive phosphate and poultry litter association on growth of forage grasses in an Amazonian Oxisol

Associação fosfato natural reativo e cama de aviário no crescimento de gramíneas forrageiras num Latossolo da Amazônia

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ABSTRACT: The interaction of natural reactive phosphate with poultry litter may increase the production of forage grasses as a result of phosphorus (P) uptake. This study's goal was to analyze growth, production and P concentration of diagnostic leaves of forage grasses fertilized by an Arad reactive phosphate + poultry litter association. The experiment employed a 2³ factorial, with the following factors: forage grasses (*Urochloa brizantha* and *Panicum maximum*), Arad rates (0 and 50 mg dm⁻³ P₂O₅), and poultry litter (0 and 7.5 g dm⁻³). At the first harvest, the highest dry-matter production of leaves, sheaths + stems and shoots occurred in the interaction *P. maximum* × Arad × poultry litter. P concentrations in diagnostic leaves as well as number of leaves were similar between forage grasses, but higher in the interaction between Arad + poultry litter when compared to isolated fertilizers. At the second harvest, dry-matter production of shoots and sheaths + stems was higher in the *U. brizantha* + poultry litter interaction than in other interactions. Compared to the other fertilizers, P concentration in the diagnostic leaves at second harvest was higher in grasses fertilized with poultry litter. At second harvest, the number of leaves and tillers was highest in the *U. brizantha* + Arad + poultry litter interaction, followed by the Arad + poultry litter interaction. The association of Arad and poultry litter promotes adequate P nutrition and biomass production of forage grasses, and can therefore be considered an important instrument for the establishment of these grasses.

RESUMO: A interação do fosfato natural reativo de Arad com a Cama de aviário pode incrementar a produção de gramíneas forrageiras como resultado da absorção de fósforo (P). O objetivo deste artigo foi analisar o crescimento, a produção e a concentração de P nas folhas diagnósticas de gramíneas forrageiras de acordo com a associação arad + cama de aviário. O experimento foi conduzido num fatorial 2³, com os fatores: forrageiras (*Urochloa brizantha* e *Panicum maximum*), doses de Arad (0 e 50 mg dm⁻³ de P₂O₅) e doses de Cama de aviário (0 e 7,5 g dm⁻³). No primeiro corte, os maiores valores de massa seca de folhas, colmo + bainha e parte aérea ocorreram na interação *P. maximum* × Arad × Cama de aviário. A concentração de P nas folhas diagnósticas e o número de folhas foram similares entre as forrageiras, contudo maiores na interação entre Arad × Cama de aviário, em comparação aos fertilizantes isolados. No segundo corte, a massa seca da parte aérea e de colmo + bainha foi maior na interação *U. brizantha* × Cama de aviário do que nas demais combinações. A concentração de P nas folhas diagnósticas do segundo corte foram maiores nas gramíneas fertilizadas com cama de aviário em relação aos outros fertilizantes. No segundo crescimento, o número de folhas e de perfilhos foram maiores nas interações *U. brizantha* × Arad × Cama de aviário e Arad × Cama de aviário, respectivamente. A associação Arad + Cama de aviário promoveu adequados suprimento de P e produção de massa para forrageiras, caracterizando-se como importante ferramenta para o estabelecimento dessas gramíneas.

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1 Introduction

The worldwide production of poultry meat is 92.7 million tons per year. Brazil is the third largest producer, with an output of 11.6 million tons per year, and also the main poultry meat exporter, selling 3.7 million tons of the product to other countries every year (Food and Agriculture Organization, 2014). This activity has increased in Brazil and specifically in the state of Pará (Amazonia region), generating many tons of organic waste. This organic waste is mainly composed by feces and urine mixed with sawdust bed residue, also known as poultry litter. The nutrient-rich composition as well as the chemical and physical properties of poultry litter favor its use as a fertilizer and/or a soil conditioner, which also allows this residue to be sustainably reused (Orrico Júnior et al., 2010, 2013).

The use of poultry litter as a fertilizer has been the object of much interest since its conversion into animal feed was forbidden. Its nutritional composition varies according to the type of poultry bed, but it is potentially a good source of phosphorus (P) (Ranatunga et al., 2013). This nutrient is mineralized by the action of bacteria and fungi which decompose the organic matter, releasing P to the soil solution (Pratt & Tewolde, 2009). Pitta et al. (2012) verified a P concentration of 17 g kg⁻¹ in poultry litter fertilizer.

P is the most deficient nutrient in tropical soils, and this deficiency strongly limits the establishment and growth of tropical forage grasses (Rossi & Monteiro, 1999a; Costa et al., 2008). Feasible P sources for soils with low availability of this nutrient are mainly superphosphates, but the reduced soil conditioning effect and high cost of soluble fertilizers have encouraged the use of less soluble ones, such as Arad reactive phosphate. The main limitation of Arad phosphate is its reduced supply of P (Guedes et al., 2012), and also the fact that this supply cannot be tapped by the forage grass during its establishment phase, when it is most needed. However, the use of organic fertilizers rich in phosphorus may improve conditions for the establishment of forage grasses not only by supplying the nutrient, but also through the interaction of organic matter with phosphatic rocks that improve the solubilization of phosphate and increase P uptake by root plants.

We found no studies on the effects of associating poultry litter and Arad phosphate fertilizer over growth response and production of tropical forage grasses such as *Urochloa brizantha* and *Panicum maximum*. However, the positive effects of poultry litter on corn (*Zea mays*) and soybean (*Glycine max*) yields, as well as the effect of Arad phosphate on dry-matter production, have already been described (Adami et al., 2012; Orrico Júnior et al., 2013; Ragagnin et al., 2013). In this context, we tested the hypothesis that Arad phosphate fertilization associated with poultry litter would favor tropical forage grasses production and development, as well as P concentration in diagnostic leaves.

This study aimed to analyze changes of growth, production, and P concentration in diagnostic leaves of *Urochloa brizantha* and *Panicum maximum* fertilized with Arad phosphate and poultry litter in an Eastern Amazonian Oxisol.

2 Material and Methods

The experiment was carried out in a greenhouse, from January to April 2013, using individual pots. The average temperature

inside the greenhouse was 33°C and the relative air moisture was 79% (measured daily using a thermo-hygrometer). The soil in the pots was obtained from a degraded pasture area, cultivated without fertilization for more than five years, at a depth of 0–0.2 m. The pasture area is located in the Municipality of Castanhal (Eastern Amazonia, State of Pará).

The soil was classified as a Yellow Oxisol according to the United States soil classification system (United States Department of Agriculture, 1999). After the air was dried, the soil particles were put through a 2 mm sieve and homogenized. Soil samples were submitted to chemical and physical analysis for soil characterization at the Soil Science Laboratory of the “Luiz de Queiroz” College of Agriculture (ESALQ-USP). The employed methodology was proposed by Silva (2009). Obtained values were: pH (H₂O) = 5.1; organic matter, sand, silt, and clay contents = 18, 920, 20, and 60 g kg⁻¹ respectively; K⁺, Ca²⁺, Mg²⁺, and Al³⁺ contents = 0.13, 0.58, 0.44, and 0.92 cmol_c dm⁻³ respectively; and P contents = 1.61 mg dm⁻³.

The study's experimental design was fully randomized, with three replications and a 2³ factorial. Factors were: 1. Tropical forage grasses – *Urochloa brizantha* (Marandu palisade grass) and *Panicum maximum* (Mombasa grass); 2. Arad phosphate (0 and 50 mg dm⁻³ P₂O₅); 3. Poultry litter (0 and 7.5 g kg⁻¹). The control treatment was comprised of forage grasses cultivated without fertilization (rate 0), used as a reference to verify possible increases or decreases in the values of measured variables.

The poultry litter used in the experiment came from a single batch of broiler chickens raised in an “all in, all out” system with a closed shed and a sawdust bed, located at the Federal Rural University of Amazonia. The poultry litter was collected at the end of the batch cycle, and then underwent a fermentation process below shade for 60 days. A chemical analysis for the characterization of poultry litter was also performed (Table 1). This process was undertaken in order to prevent poultry litter fermentation in the soil, since this would lead to the production of compounds that are toxic to the plants. It also ensured the elimination of pathogenic microorganisms.

Table 1. Organic matter (OM), nitrogen (N), phosphorus (P), potassium (K) and C/N ratio of poultry litter fertilizer fermented for 60 days.

Tabela 1. Matéria orgânica (OM), nitrogênio (N), fósforo (P), potássio (K) e relação C/N do fertilizante cama de aviário fermentado por 60 dias.

Attributes	Values in the dry mass	Amount
		g dm ⁻³
pH (CaCl ₂)	7.91	–
OM total (%)	57.69	4.322
OM compostable (%)	55.20	4.121
N total (%)	1.40	0.105
P ₂ O ₅ total (%)	2.55	0.191
K ₂ O total (%)	2.05	0.153
C total/N total	23/1	–
C org/ N total	22/1	–

The amount of P₂O₅ adopted for the Arad phosphate treatment (50 mg dm⁻³) was calculated based on the concentration of P₂O₅ fertilizer (approximately 33%) recommended for pastures in the state of Pará (Cravo et al., 2010). The amount

adopted for poultry litter was based on studies by Pitta et al. (2012); these authors found that approximately 15 t ha⁻¹ or 7.5 g dm⁻³ applied to Oxisols promoted adequate availability of P and other nutrients such as nitrogen (N) and potassium (K) (Table 1).

The experimental units consisted of plastic pots with 4 dm³ dried and sieved soil, mixed with the fertilizer employed in each treatment and incubated for a period of 60 days. The incubation time was based on studies that showed greater availability of nutrients in this period (Pitta et al., 2012). To standardize the amount of water used for incubation as well as experimental unit irrigation, the Soil Water Retention (SWR) capability was estimated and water inputs were fabricated according to it.

To estimate SWR, four additional experimental units were prepared by fitting drains at their bases and filling their bottoms with coal. The soil of the experimental units was saturated with water for 24 h, and the excess water was drained by gravity during nighttime for 12 h. The water mass was calculated as the average difference of mass in comparison to the experimental dry units. The water mass drained results were equivalent to the volume of distilled water contained in 100% of the SWR capability. The amount of water used in the incubation and plant irrigation periods was SRW = 80%.

The tropical grasses were seeded directly in the experimental units, after the soil incubation period. After germination, successive thinnings were performed until there were three plants left per pot. Ten days after the plants emerged, uniformity cuts were performed, marking the beginning of the growth period. Plants were left to grow for two 28-day growth periods, and the shoots were cut at five-centimeter-length of soil, separating the material into newly expanded or diagnostic leaves, other leaves, and stems + sheaths, per the procedure described by Silveira & Monteiro (2010). The plant parts were dried in a forced circulation oven at 65 °C for 74 h.

At the end of the growth periods, the total number of leaves per pot and tillers per pot were measured, followed by the cut of the plant shoots. Total dry-matter production of leaves, sheaths + stems, and shoots was determined from the shoots. To evaluate P concentrations in diagnostic leaves, the leaves were ground using a Wiley mill and then submitted to nitric-perchloric digestion, per the procedure described by Sarruge & Haag (1974). P quantifications of the digested extracts were done using spectrophotometry at 420 nm from the standard P curve (Sarruge & Haag, 1974).

Statistical analysis was performed using R software. Initially, ANOVA at 5% significance was performed and, when the F-value became significant at 5%, a Tukey test at 5% was performed for comparison of means.

3 Results and Discussion

At first harvest, the Arad phosphate × poultry litter interaction was significant for number of leaves (Table 2). The application of Arad + poultry litter fertilizer during this harvest resulted in a higher number of forage grass leaves in comparison to the other treatments (Table 2). The number of tillers was not influenced by factor interaction, but only the poultry litter treatment was significant (Table 2), which induced a higher number of tillers in comparison to the control (Table 2).

Table 2. Number of leaves and number of tillers at first harvest, as well as number of tillers at second harvest, for forage grasses fertilized with Arad phosphate and poultry litter in an Amazonian Oxisol¹.

Tabela 2. Número de folhas e número de perfilhos no primeiro corte e número de perfilhos no segundo corte de gramíneas forrageiras fertilizadas com fosfato de Arad e Cama de aviário num Latossolo da Amazônia.

Fertilizers	First harvest		Second harvest
	Number of leaves	Number of tillers	Number of tillers
Control	18.6 c	4.25 b	4.83 c
Arad phosphate	18.1 c	4.83 ^{ns}	4.54 c
Poultry litter	35.5 b	9.91 a	9.50 b
Arad phosphate + poultry litter	42.5 a	10.16 ^{ns}	13.3 a

¹ Lowercase letters in the columns differentiate fertilizations. ^{ns} Not significant.

At second harvest, the forage × Arad phosphate × poultry litter interaction was significant for number of leaves (Table 3). In comparison to the other treatments, the highest number of leaves was found in *U. brizantha* fertilized with Arad phosphate + poultry litter. We also verified that the Arad phosphate × poultry litter interaction was significant for number of tillers (Table 2). The highest number of tillers at second harvest resulted from the combination of Arad phosphate + poultry litter (Table 2).

Table 3. Number of leaves of forage grasses fertilized with Arad phosphate and poultry litter, at second harvest, in an Amazonian Oxisol¹.

Tabela 3. Número de folhas de gramíneas forrageiras fertilizadas com fosfato de Arad e Cama de aviário no segundo corte num Latossolo da Amazônia.

Forage grass	Control	Arad phosphate	Poultry litter	Arad phosphate + poultry litter
				Number of leaves
<i>U. brizantha</i>	19.3 aB	21.3 aB	37.3 aB	58.0 aA
<i>P. maximum</i>	9.66 bB	28.0 aA	33.0 bA	28.6 bA

¹ Lowercase letters differentiate forage grasses within each fertilization and uppercase letters differentiate fertilization within each forage grass.

At first harvest, the forage × Arad phosphate × poultry litter interaction was significant for the dry-matter production of shoots, leaves, and sheaths + stems. Higher values of these three variables were verified in *P. maximum* cultivated with Arad phosphate + poultry litter in comparison to other combinations (Table 4). Differences in the dry-matter production of shoots, leaves, and sheaths + stems in relation to control treatment were 411, 396, and 454%, respectively, for the *P. maximum*. The *P. maximum* forage grass fertilized with Arad phosphate produced a greater amount of dry-matter leaves than *U. brizantha* plants grown under the same conditions (Table 4). In the presence in the presence of poultry litter, *U. brizantha* plants produced a higher amount of dry-matter sheaths + stems than *P. maximum* plants (Table 4). In the control treatment (absence of fertilizers), *P. maximum* and *U. brizantha* plants produced similar amounts of dry matter (Table 4).

Table 4. Dry-matter production of shoots, leaves, and sheaths + stems in forage grasses fertilized with Arad phosphate and poultry litter, at first harvest, in an Amazonian Oxisol¹.

Tabela 4. Produção de massa seca da parte aérea, produção de massa seca de folhas e produção de massa seca de colmo + bainha de gramíneas forrageiras fertilizadas com fosfato de Arad e Cama de aviário no primeiro corte num Latossolo da Amazônia.

Forage grass	Control	Arad phosphate	Poultry litter	Arad phosphate + poultry litter
Shoots dry-matter production (g per pot)				
<i>U. brizantha</i>	2.26 aC	2.42 bC	4.92 aB	7.56 bA
<i>P. maximum</i>	1.98 aD	3.40 aC	4.56 aB	10.1 aA
Leaves dry-matter production (g per pot)				
<i>U. brizantha</i>	1.38 aC	1.74 bC	3.44 aB	5.22 bA
<i>P. maximum</i>	1.36 aD	2.66 aC	3.66 aB	6.75 aA
Sheaths + stems dry-matter production (g per pot)				
<i>U. brizantha</i>	0.87 aC	0.68 aC	1.48 aB	2.34 bA
<i>P. maximum</i>	0.61 aB	0.74 aB	0.90 bB	3.38 aA

¹ For each variable, lowercase letters differentiate forage grasses within each fertilization and uppercase differentiate fertilization within each forage grass.

At second harvest, the forage × poultry litter interaction was significant for dry-matter production of shoots and sheaths + stems. Higher values were observed in *U. brizantha* cultivated with poultry litter in comparison to other treatments. Increases in the dry-matter production of shoots and sheaths + stems obtained under poultry litter fertilization in comparison to control treatment were 81 and 61% for *P. maximum* and 118 and 194% for *U. brizantha*, respectively (Table 5). The interaction was not significant for dry-matter production of leaves, but the forage grasses and poultry litter factors were the only ones to influence this production (Table 5). Results showed higher values of dry-matter leave production for *U. brizantha* than for *P. maximum*; the same was true for the poultry litter fertilization treatment in comparison to the absence of this fertilizer (Table 5).

At first harvest, the Arad phosphate × poultry litter interaction was significant for P concentration in diagnostic leaves (Table 6), which was higher in the Arad phosphate + poultry litter combination than in the other treatments (Table 6). At second harvest, the interaction was not significant for P concentration, and only the poultry litter fertilization was significant (Table 6). P concentration was higher in diagnostic leaves of the forage grasses fertilized with poultry litter than in unfertilized forage grasses (Table 6).

The Arad phosphate × poultry litter interaction induced the highest production of dry-matter shoots by forage grasses, due to promoting a greater concentration of P in the diagnostic leaves, especially at first harvest. This indicates that in this treatment there was greater uptake by the roots of forage grasses of the P contained in both the poultry litter and Arad phosphate fertilizers. The additive effects of poultry litter in the

Arad phosphate solution are probably related to the action of organic acids, such as citric, oxalic, fulvic, and humic acids that are released during poultry litter decomposition, contributing to temporary soil acidification, solubilization, and release of P contained in Arad phosphate (Ivanova et al., 2006; Kifuko et al., 2007). Imran et al. (2011) confirmed this hypothesis for livestock manure and waste fruit by demonstrating that organic acids released through decomposition of these materials increased availability of P from natural phosphate, leading to higher corn growth and yield.

Table 5. Shoots, sheaths + stems and leaves dry-matter production in forage grasses fertilized with poultry litter, at second harvest, in an Amazonian Oxisol¹.

Tabela 5. Produção de massa seca da parte aérea, produção de massa seca de colmo + bainha e produção de massa seca de folhas de gramíneas forrageiras fertilizadas com Cama de aviário no segundo corte num Latossolo da Amazônia.

Productive attributes (g per pot)	<i>U. brizantha</i>		<i>P. maximum</i>	
	Control	Poultry litter	Control	Poultry litter
Shoots dry-matter	1.69 c	3.69 a	1.65 c	2.99 b
Sheaths + stems dry-matter	0.35 c	1.03 a	0.39 c	0.63 b
Leaves dry-matter	<i>U. brizantha</i> solely		<i>P. maximum</i> solely	
	2.01 a		1.81 b	
	Without poultry litter		With poultry litter	
	1.30 b		2.51 a	

¹ Lowercase letters in each sub-column differentiate productive attributes.

Table 6. P concentration in diagnostic leaves of forage grasses fertilized with Arad phosphate and poultry litter at first and second harvests in an Amazonian Oxisol¹.

Tabela 6. Concentração de P nas folhas diagnósticas de gramíneas forrageiras fertilizadas com fosfato de Arad e Cama de aviário no primeiro e segundo corte num Latossolo da Amazônia.

Fertilizers	First harvest	Second harvest
	P concentration in leaves (mg kg ⁻¹)	
Control	0.75 c	1.01 b
Arad phosphate	1.71 c	1.02 ^{ns}
Poultry litter	2.98 b	2.15 a
Arad phosphate + poultry litter	3.35 a	1.84 ^{ns}

¹ Lowercase letters in the columns differentiate fertilizations in each harvest. ^{ns} Not significant.

The release of P in the natural phosphate occurs via chemical weathering, and organic acids released by organic matter can contribute significantly to this process. In chemical weathering, H⁺ protons from organic sources in the soil solution attack the natural phosphate, solubilizing P bounded to calcium into a more soluble form, predominantly orthophosphate H₂PO₄⁻ ion,

the main form of plant root uptake (Imran et al. 2011). The availability of P in these phosphates for the establishment of pastures is limited to the effective use of the natural phosphates, since the time until the effective availability of this nutrient to the plants is relatively high (Castellanos González et al., 2014). However, organic sources associated with rock phosphates can serve as catalysts, accelerating the process.

Rossi & Monteiro (1999b) and Martins et al. (2014) found P concentrations in diagnostic leaves of approximately 2.3 and 3.6 g kg⁻¹ in *U. brizantha* plants, respectively, that were properly fertilized with soluble P. Based on the concentration of P in the diagnostic leaves found by our study, it is possible that the release of organic acids from poultry litter may accelerate the release process of rock phosphates, being at least as effective as soluble fertilizers, considering that the concentrations seen here were greater than or equal to those found by Rossi & Monteiro (1999b) and Martins et al. (2014). This effect is particularly important in Amazonian soils, which are often sandy-textured. The application of organic fertilizers with high soil conditioning power, like poultry litter, can promote, in the long term, a higher pasture productivity when compared to soluble fertilizers, since organic sources also increase the soil organic carbon and improve the quality of sandy soil.

According to Araujo (2011), an Ultisol fertilized with tannery sludge and phosphorite showed higher accumulation of P in leaves and higher corn dry-matter after application of a sludge and phosphorite association in comparison to a mineral fertilizer containing 50, 100, and 20 kg ha⁻¹ of N, P₂O₅, and K₂O, respectively. This was possibly due to tannery sludge favoring the P solubility of phosphorite, based on the release of organic acids that can solubilize natural phosphates. Billah & Bano (2015) also found greater growth and accumulation of P in shoots and grains of wheat (*Triticum aestivum*) under Arad phosphate + poultry litter fertilization. However, the authors associated phosphate solubilization with the release of organic acids by microorganisms present in poultry litter organic fertilizer. Thus, it is possible that in our study microorganisms also acted as phosphate solubilizers, another advantage of using poultry litter as a fertilizer for the establishment of forages in weathered Amazonian soils.

The high supply of P due to the poultry litter + Arad phosphate association, indicated by high concentrations of P in diagnostic leaves, caused higher numbers of tillers, which explains the higher dry-matter production of *P. maximum* shoots at first harvest. Studies show that this result may be linked to *P. maximum*'s higher responsiveness to nutrient supplies when compared to *U. brizantha* (Santos et al., 2002, 2012; Machado & Assis, 2010). Therefore, *U. brizantha* at the second harvest was capable of accumulating more dry mass in relation to *P. maximum* because *U. brizantha*, under certain conditions, is better adapted to lower supplies of nutrients (Machado & Assis, 2010).

The effects of poultry litter on plant growth have been shown to result mainly from the supply of P (Ranatunga et al., 2013), which comes from the mineralization action of acid and basic phosphatases present in organic matter-decomposing micro-organisms (Gatiboni et al., 2008; Pitta et al., 2012; Scherer & Nesi, 2012). In this study, we demonstrated that

even fertilization with poultry litter alone had a marked effect, increasing P concentration in diagnostic leaves of the forage grasses, in turn leading to an increase in the number of leaves, tillers, and dry-matter production of shoots. Belated P utilization also demonstrates clearly that poultry litter can be a source of P for forage grasses during plant establishment, also pointing to a significant residual effect in subsequent growths. This effect has significant importance for Amazonian pastures: the region's soils are poor in P, while forage grasses have high phosphorus demands in their establishment phase—hence, fertilizers that adequately supply this nutrient can improve forage grass production.

The results found for the increased concentration of P and plant production as a function of poultry litter fertilization suggest it is an excellent source of P for tropical forage grasses cultivated in Amazonian soils. These results are complementary to those reported by other authors, who indicated the importance of this fertilizer as a means of increasing availability of P to the soil solution (Pitta et al., 2012; Ranatunga et al., 2013), and in the production of other forage grasses such as ryegrass (*Lolium multiflorum*) and bermuda grass (*Cynodon dactylon*) (Read et al., 2009). Orrico Júnior et al. (2013) found similar results to our study, showing that a 8.2 t ha⁻¹ (4.1 g dm⁻³) poultry litter fertilization in an Oxisol increased the growth and production of *U. brizantha*. However, those authors did not associate that result to the supply of P, but rather to the N present in poultry litter fertilizer. Similar to observations by Ranatunga et al. (2013), our results show that poultry litter is adequate mostly as a P source for forage grasses grown under Amazonia's edaphoclimatic conditions—especially those with high demand for P during initial growth, such as tropical forages.

P. maximum was the forage grass species best able to utilize the P contained in the fertilizer sources, especially Arad phosphate, which resulted in improved dry-matter output. This result suggests higher usage efficiency of P by *P. maximum* when fertilized from organic sources associated with natural reactive phosphate. *U. brizantha*'s production, although lower than *P. maximum*'s during initial growth, was satisfactory and indicated that poultry litter fertilizer served to activate the solubilization of P from Arad phosphate fertilizer, probably due to the interaction between the previously cited mechanisms of acid solubilization and the different root system activities of the studied forage grasses (Kifuko et al., 2007; Guedes et al., 2012; Billah & Bano, 2015).

Arad phosphate allowed increased production and concentration of P in the diagnosed leaves, especially during initial growth. This was due to the higher reactivity of the Arad phosphate when compared to other natural phosphates, demonstrating greater efficiency by *P. maximum* in converting the P from the Arad phosphate into biomass. When applying up to 150 mg dm⁻³ P₂O₅ of Arad phosphate to a sandy Oxisol, Guedes et al. (2012) observed there was an increase in the dry-matter production of shoots and also in the concentration of P in *P. maximum* and *U. brizantha* diagnostic leaves. These authors attributed the result to the capacity of the forage grass to acidify the rhizosphere and solubilize the provided P, without considering the higher reactivity of Arad phosphate compared to other natural phosphates.

4 Conclusions

The interaction of poultry litter and Arad phosphate promotes greater growth, production, and P concentration in diagnostic leaves of forage grasses, especially *Panicum maximum*, which had higher development. The association of poultry litter and Arad phosphate is a potential tool for the establishment of tropical forage grasses in the nutrient-poor Oxisols of Eastern Amazonia.

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