

Research Paper

Ammonium sulfate enhances the effectiveness of reactive natural phosphate for fertilizing tropical grasses

Sulfato de amonio como mejorador de la efectividad del fosfato natural reactivo en la fertilización de gramíneas tropicales

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Abstract

Reactive natural phosphate is a slow and gradual solubilizing fertilizer, which makes it difficult to use in neutral to alkaline soils. Nitrogen fertilizers which acidify the soil may increase the possibility of using this phosphate fertilizer commercially. Two greenhouse experiments were conducted to compare responses of Xaraés palisadegrass (*Urochloa brizantha* syn. *Brachiaria brizantha* cv. Xaraés) and Mombasa guineagrass (*Megathyrsus maximus* syn. *Panicum maximum* cv. Mombasa), when different combinations of P and N fertilizers were applied during the establishment phase in non-acidic soils or with corrected acidity. The experiments were carried out in a completely randomized design with 3 fertilizer combinations (simple superphosphate plus urea, SSU; natural reactive phosphate plus urea, RPU; and natural reactive phosphate plus ammonium sulfate, RPAS). There was no difference in tiller density, leaf numbers, forage mass, leaf mass and stem mass for either forage on SSU and RPAS treatments but they exceeded those on RPU. Soil pH was lower in soil fertilized with ammonium sulfate than in soil fertilized with urea. Applying natural reactive phosphate plus ammonium sulfate seems as effective as simple superphosphate plus urea in promoting increased growth in tropical grasses on low-P soils. Longer-term and more extensive field studies are needed to determine if these results can be reproduced in the long term, and the level of soil acidification over time.

Keywords: Ammonium sulfate, establishment fertilization, *Megathyrsus maximus*, phosphorus, soil acidification, urea, *Urochloa brizantha*.

Resumen

El fosfato natural reactivo es un fertilizante que se solubiliza en forma lenta y gradual, lo que dificulta su uso en suelos de reacción neutra a alcalina. Los fertilizantes nitrogenados que acidifican el suelo pueden favorecer el uso del fosfato natural reactivo. Por tanto, el objetivo de este trabajo fue verificar cuál fertilizante nitrogenado favorece el uso de fosfato natural reactivo durante la fase de establecimiento de 2 gramíneas tropicales, en suelo no ácido o con acidez corregida. Para el efecto en condiciones de invernadero se realizaron sendos experimentos con un diseño completamente al azar, con los pastos *Urochloa brizantha* (syn. *Brachiaria brizantha*) cv. Xaraés y *Megathyrsus maximus* (syn. *Panicum maximum*) cv. Mombasa. Los tratamientos consistieron en fertilización con superfosfato simple y urea (SSU), fosfato reactivo natural y urea (RPU) y fosfato reactivo natural y sulfato de amonio (RPAS). No se encontraron diferencias en la densidad de rebrotes, número de hojas, biomasa forrajera, biomasa de hoja y tallo en ambos pastos entre los

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tratamientos de SSU y RPAS, aunque estos parámetros presentaron valores más bajos en el tratamiento RPU. El pH fue más bajo en el suelo fertilizado con sulfato de amonio, en comparación con la urea. El sulfato de amonio, al acidificar el suelo más que la urea, favorece el uso de fosfato natural reactivo en la fertilización de pastos en suelos bajos en fósforo. Se necesitan estudios de campo a plazo más largo y más extensivos para determinar el nivel de acidificación del suelo a lo largo del tiempo y si los resultados de este estudio pueden ser reproducidos a largo plazo.

Palabras clave: Acidificación del suelo, fertilización de establecimiento, fósforo, *Megathyrus maximus*, sulfato de amonio, urea, *Urochloa brizantha*.

Introduction

Phosphorus plays an important role in development of root systems of plants, and concentration of this nutrient in tropical soils is often low ([Marcante et al. 2016](#); [Zambrosi et al. 2017](#)). Deficiency of P during pasture establishment reduces forage photosynthetic activity ([Ghannoum et al. 2008](#)), which has an impact on leaf elongation ([Kavanova et al. 2006](#)) plus forage mass and root production ([Rezende et al. 2011](#); [Waddell et al. 2017](#); [Ros et al. 2018](#)). In P-deficient soils applying P fertilizer is essential to get satisfactory pasture growth and animal performance, which represents a significant cost for cattle farmers.

While water-soluble phosphate fertilizers, such as triple and single superphosphate, are most commonly used, a lower-cost alternative is reactive natural phosphate. Reactive natural phosphates come from sedimentary rocks and differ from those from igneous and metamorphic rocks, which have low reactivity and are commonly called 'rock' phosphate ([Corrêa et al. 2005](#)). The lower cost of reactive natural phosphate results from physical processing being all that is involved in manufacture, as opposed to water-soluble fertilizers, which are both milled and chemically ([Ivanova et al. 2006](#)) or thermally solubilized.

Despite its low cost, an obstacle to the use of natural reactive phosphate is that it requires low soil pH, which enables phosphorus in the fertilizer to be converted to a soluble form and enter the soil solution ([Guedes et al. 2009](#)). However, soil acidity also has a negative effect on availability of P in tropical soils, as it increases the adsorption of P by oxides and promotes the precipitation of this nutrient with free aluminum and cationic micro-nutrients ([Souza et al. 2006](#)). Therefore, for productive pastures, correction of soil acidity is an important practice.

Most grass pastures will respond to N fertilizer application and P fertilizer is rarely applied without added N fertilizer. During the nitrification process release of ammonia from nitrogen fertilizers also releases hydrogen in the soil solution, which acidifies the soil by lowering pH ([Schroeder et al. 2011](#); [Bortoluzzi et al. 2017](#); [Cabral et al. 2018](#)).

Urea is the most popular choice of nitrogen fertilizer, due to its high nitrogen concentration and relatively low cost. However, high losses of N can occur through volatilization. Ammonium sulfate is an alternative source of N and is less susceptible to volatilization, but is more expensive than urea per unit of N and has a lower concentration of this nutrient which increases freight costs ([Werneck et al. 2012](#)). Both urea and ammonium sulfate can be applied to enhance the viability of applying natural phosphate to forages ([Nascimento et al. 2002](#)).

This work was designed to determine which nitrogen fertilizer promoted better responses in tropical grasses grown in non-acid or corrected acid soils when applied with reactive natural phosphate.

Materials and Methods

The experiments were performed in a greenhouse at Federal University of Mato Grosso, Cuiabá, MT, in a completely randomized design with 3 treatments.

Treatments consisted of different combinations of nitrogen and phosphorus fertilizers, i.e. simple superphosphate plus urea (SSU), reactive natural phosphate plus urea (RPU) and reactive natural phosphate plus ammonium sulfate (RPAS). The SSU treatment was considered the Control treatment, because it combined a readily available source of P with the N fertilizer most commonly used.

Experiment 1

Experiment 1 was conducted with Xaraés palisadegrass [*Urochloa brizantha* (Hochst. ex A. Rich.) R.D. Webster cv. Xaraés] with 6 replicates of the fertilizer treatments. The soil used was the top 20 cm of an Oxisol, collected in native Cerrado areas, with texture characterized by 57.5% sand, 5.0% silt and 37.5% clay. Chemical composition of the soil was: P = 1.1 mg/dm³; potassium (K) = 47 mg/dm³; calcium (Ca) = 0.2 cmol_c/dm³; magnesium (Mg) = 0.1 cmol_c/dm³; hydrogen and aluminum (H+Al) = 5.7 cmol_c/dm³; cation exchange capacity = 6.1 cmol_c/dm³; base saturation = 6.9%; aluminum saturation = 70.4%; and pH (in calcium chloride) = 4.1. After collection, the

soil was sieved through a 4.0 mm mesh and transferred to pots with 3.5 dm³ volume. Dolomitic limestone was applied to raise base saturation to 50%. After the incorporation, the soil was left for 30 days with soil moisture kept at 80% field capacity for limestone reaction. Thirty days after limestone incorporation, P fertilizer was applied at the rate of 300 mg P₂O₅/dm³ (131 mg P/dm³). Seed was sown after P fertilizer application, and after seedling emergence seedlings were thinned to leave 3 plants per pot. The criteria for thinning were based on seedling vigor and uniformity. After seedling emergence, soil moisture was maintained near field capacity, estimated according to the methodology described by Cabral et al. (2016).

Experiment 2

Experiment 2 was conducted with Mombasa guineagrass [*Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs cv. Mombasa] and involved 5 replicates of the fertilizer treatments. The soil used was the top 20 cm of an Inceptisol from a degraded pasture with texture characterized by 80% sand, 12% silt and 8% clay. Chemical composition of the soil was: P = 22 mg/dm³; potassium (K) = 152 mg/dm³; calcium (Ca) = 7.4 cmol_c/dm³; magnesium (Mg) = 2.0 cmol_c/dm³; hydrogen and aluminum (H+Al) = 1.4 cmol_c/dm³; cation exchange capacity = 11.2 cmol_c/dm³; base saturation = 87%; aluminum saturation = 0%; and pH (in calcium chloride) = 5.9. After collection, the soil was sieved through a 4.0 mm mesh and transferred to 5.0 dm³ pots. Phosphorus fertilizer was applied on the day of sowing at rates of 300 mg P₂O₅/dm³ (131 mg P/dm³). After seedling emergence excess seedlings were removed leaving 3 plants per pot. Criteria for thinning and maintenance of soil moisture were as described in Experiment 1.

For both experiments, fertilizer application after thinning consisted of N fertilizer application (200 mg N/dm³) as urea or ammonium sulfate and potassium fertilizer application (100 mg K₂O/dm³ or 83 mg K/dm³) as potassium chloride.

Measurements

Measurements commenced 30 days after seedling emergence. Estimation of the chlorophyll index of the youngest adult leaf of a representative tiller was performed with a non-destructive method using a Clorofilog (CLF 1030 Falker, Brazil) for Experiment 1 only.

Aerial parts were then cut at 10 and 25 cm above the soil for Xaraés and Mombasa, respectively. Forages were allowed to regrow and evaluated at intervals of 20 days. Four

regrowth cycles were evaluated for Xaraés palisadegrass and 2 regrowth cycles for Mombasa guineagrass.

Plant height was measured with a graduated rule and the numbers of tillers per pot were recorded at the end of each regrowth cycle, before harvest. All leaves present in each pot above the residue height were counted, to obtain leaf numbers (LN). Leaf appearance rate (LAR) was estimated by the ratio of number of leaves per tiller and the interval between cuts. Phyllochron (PHY) was calculated as the inverse of LAR.

At the end of each regrowth period the harvested material was separated into morphological components, i.e. leaf and stem (stem + sheath). These fractions were conditioned in paper bags, then subjected to drying in an air circulation oven at 65 °C for 72 hours and weighed. Forage accumulation rate (FAR) was calculated by dividing forage mass (FM) at each cut by the interval between cuts.

At the final evaluation, plants were harvested at ground level and the stem residue and roots were collected. The root system was washed with running water using a 4 mm mesh sieve. Afterwards, residue and roots were dried in a forced air circulation oven under the same conditions mentioned for FM to obtain dry matter data. Soil pH (in calcium chloride) was determined at this time.

Statistical analysis

Data were submitted to analysis of variance using the general linear mixed model method, using the PROC MIXED command (SAS[®] Institute Inc., Cary, NC, USA). Least squares means of treatments were compared by Tukey test (P≤0.05).

The model was as follows:

$$y_{ijk} = \mu + T_i + e_{ij} + C_k + \varepsilon_{ijk};$$

where:

y_{ijk} = expected response;

μ = average/constant, associated with the experiment;

T_i = treatment effect (different nitrogen fertilizers) i ;

e_{ij} = treatment error i , in repetition j , normally and independently distributed;

C_k = random effect associated with regrowth cycle k , normally distributed; and

ε_{ijk} = experimental error associated with treatment i , in repetition j , in cycle k , normally distributed.

Results

Experiment 1

Fertilizer type had no significant effect (P>0.05) on height, leaf appearance rate, phyllochron or root mass of Xaraés

(Tables 1 and 2). However, forage mass, leaf mass, stem mass, leaf number, tiller density, forage accumulation rate and stem residue for RPAS and SSU treatments were greater ($P < 0.05$; Table 1) than for RPU.

Table 1. Effects of N and P fertilizer combinations on productive and structural characteristics and chlorophyll index of *Urochloa brizantha* cv. Xaraés plus soil pH during establishment.

Variable	SSU	RPU	RPAS	s.e.m.	P-value
Height (cm)	48	50	49	1.14	0.53
FM (g DM/pot)	19.5a	11.1b	19.1a	0.59	<0.01
FAR (g/d)	0.89a	0.52b	0.89a	0.02	<0.01
LM (g DM/pot)	15.9a	9.0b	15.6a	0.49	<0.01
SM (g DM/pot)	3.6a	2.1b	3.5a	0.19	<0.01
LN (No./pot)	83a	50b	80a	2.66	<0.01
TD (No./pot)	32a	19b	33a	0.84	<0.01
LAR (No./tiller/d)	0.12	0.12	0.11	0.003	0.38
PHY (No. of days/leaf)	8.6	8.8	9.0	0.27	0.50
Soil pH	4.14b	4.66a	3.56c	0.04	<0.01
Chlorophyll index	52.7a	45.7b	53.0a	0.82	<0.01

Means within rows with different letters differ ($P < 0.05$) by Tukey's test.

SSU = simple superphosphate plus urea; RPU = reactive natural phosphate plus urea; RPAS = reactive natural phosphate plus ammonium sulfate.

FM = forage mass; FAR = forage accumulation rate; LM = leaf mass; SM = stem mass; LN = leaf number; TD = tiller density; LAR = leaf appearance rate; PHY = phyllochron.

Table 2. Effects of N and P fertilizer combinations on stem residue and root mass (g DM/pot) of *Urochloa brizantha* cv. Xaraés (Experiment 1) and *Megathyrsus maximus* (syn. *Panicum maximum*) cv. Mombasa (Experiment 2) during establishment.

Treatment	Xaraés		Mombasa	
	Residue mass	Root mass	Residue mass	Root mass
SSU	17.6a	67.1	13.0	4.8
RPU	9.8b	49.7	7.1	2.9
RPAS	18.2a	58.6	9.6	4.5
P-value	<0.01	0.15	0.05	0.43
s.e.m.	0.83	5.88	1.68	1.21

Means within columns with different letters differ ($P < 0.05$) by Tukey's test.

SSU = simple superphosphate plus urea; RPU = reactive natural phosphate plus urea; RPAS = reactive natural phosphate plus ammonium sulfate.

Chlorophyll index for RPAS and SSU was greater ($P < 0.05$) than for RPU (Table 1).

Final soil pH had the pattern RPU > SSU > RPAS ($P < 0.05$) with RPU being greater than the original pH and RPAS lower than the original.

Experiment 2

As for Experiment 1, fertilizer combination had no significant effect ($P > 0.05$) on leaf appearance rate, phyllochron, stem residue or root mass of Mombasa guineagrass (Tables 3 and 2). However, plant height, forage mass, leaf mass, stem mass and forage accumulation rate were greater ($P < 0.05$) for RPAS and SSU than for RPU. Leaf number followed the pattern SSU > RPAS > RPU, while tiller density for SSU exceeded that for RPAS and RPU ($P < 0.05$).

Table 3. Effects of N and P fertilizer combinations on productive and structural characteristics of *Megathyrsus maximus* (syn. *Panicum maximum*) cv. Mombasa plus soil pH during establishment.

Variable	SSU	RPU	RPAS	s.e.m.	P-value
Height (cm)	62a	56b	64a	1.04	<0.01
FM (g DM/pot)	9.00a	5.23b	8.44a	0.62	<0.01
FAR (g/d)	0.30a	0.17b	0.28a	0.02	<0.01
LM (g DM/pot)	8.68a	5.13b	8.14a	0.59	<0.01
SM (g DM/pot)	0.32a	0.09b	0.29a	0.04	<0.01
LN (No./pot)	35a	22c	28b	5.26	<0.01
TD (No./pot)	11a	7b	9b	0.57	<0.01
LAR (No./tiller/d)	0.10	0.11	0.11	0.005	0.80
PHY (No. of days/leaf)	9.7	10.0	9.5	0.44	0.71
Soil pH	7.89a	7.91a	6.12b	0.10	<0.01

Means within rows with different letters differ ($P < 0.05$) by Tukey's test.

SSU = simple superphosphate plus urea; RPU = reactive natural phosphate plus urea; RPAS = reactive natural phosphate plus ammonium sulfate.

FM = forage mass; FAR = forage accumulation rate; LM = leaf mass; SM = stem mass; LN = leaf number; TD = tiller density; LAR = leaf appearance rate; PHY = phyllochron.

Final pH for SSU and RPU exceeded that for RPAS ($P < 0.05$) with that for RPAS being similar to the original pH while those for SSU and RPU were higher than the original.

Discussion

The similar results found for the productive and structural variables for the RPAS and SSU treatments suggest that reactions between natural phosphate and ammonium sulfate produced sufficient P in a soluble form to meet the growth requirements of a high nutrient extraction grass (Galindo et al. 2018). This synergistic effect between natural reactive phosphate and ammonium sulfate is due to the reduction in soil pH, which promotes the conversion of phosphorus present in natural phosphate

into a soluble form (Degryse et al. 2017). Costa et al. (2008) and Vitti et al. (2002) showed reduction in soil pH of up to 1.1 units when ammonium sulfate was applied as fertilizer. An additional factor which could have contributed to forage growth was the sulfur content of ammonium sulfate, which can increase growth of tropical forages (Miranda et al. 2017; Santos et al. 2019), when available sulfur levels in soil are limiting. According to Artur and Monteiro (2014) sulfur has a greater impact on regrowth than on establishment.

In the case of natural phosphate plus urea, growth of forage was restricted relative to that with SSU and RPAS (Tables 1 and 3). This is probably a function of the lesser effect of urea in lowering soil pH as observed in Tables 1 and 3 to promote solubilization of natural reactive phosphate. Lower acidification of the soil by urea compared with ammonium sulfate is due to hydrolysis that occurs soon after the application of urea to the soil, which consumes protons from the soil (Fageria et al. 2010). In the hydrolysis of urea, hydrogen ions in soil are combined with N to produce ammonia, which temporarily increases soil pH around the urea granule. This increase in pH promotes ammonia volatilization, which reduces the amount of ammonia to be nitrified and/or supplied to plants (Lara Cabezas and Souza 2008). In addition to this increase in pH around the urea granule, when part of the nitrogen is lost by volatilization, less nitrogen remains in soil to be oxidized to nitrate in the nitrification process, which is one of the factors that contributes to soil acidification (Isobe et al. 2011), the main factor that promotes the solubilization of the phosphorus present in natural phosphate. Plants on this treatment would have less available N and P for growth. With SSU, it is important to note that most of the phosphorus in simple superphosphate is water soluble, and is readily available to be absorbed by the plant as well as to be adsorbed on soil. In very adsorptive soils, P can become bound and not available to seedlings, which may impair forage establishment.

Oxidized soils in the Brazilian Cerrado have a high capacity for P fixation and precipitation, which can rapidly reduce availability of this nutrient in a short period. In the case of Latosols, a soil class that predominates in the Cerrado, as much as 30–97% of the soluble P added to soil as fertilizer in readily soluble form can be withdrawn from the soil solution within 24 hours of application (Santos et al. 2011). Therefore, it is important to apply soluble phosphate fertilizers to soil as close to sowing as possible.

Phosphorus is essential to the initial establishment of forages, because it enhances root development (Merlin et al. 2016; Waddell et al. 2017). While root weight in RPU

was lower than in the other treatments, differences were not large enough to be considered significant. On the other hand residue weights (residual stem weights) were higher in the SSU and RPAS treatments than in RPU. The combination of lower root development in RPU combined with lower levels of available N and P in the soil solution plus lower residual stem weight from which to regrow would have contributed to reduced growth of forage on this treatment. Benot et al. (2019) indicated that the stem base, which is present in the residue mass, accumulates non-structural total carbohydrates, which are important for regrowth of forages under conditions of lower photosynthetic activity, such as water deficit, shading and after defoliation.

Commonly, chlorophyll index is a variable used to verify the nitrogen fertilizer efficiency of crops (Cardoso et al. 2011). However, in this study, a phosphate fertilizer effect was observed, as chlorophyll index for Xaraés grass fertilized with RPAS and SSU exceeded that for RPU.

Conclusions

Applying ammonium sulfate as N fertilizer in conjunction with natural reactive phosphate on low-P soils should give similar growth responses in grass pastures as simple superphosphate and urea. Field studies are needed to verify these greenhouse results and determine rate of reactive natural phosphate solubilization, as well as cost-of-production, since ammonium sulfate is more expensive per unit of N than urea, and requires correction of soil acidity, which may increase pasture fertilization costs.

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(Note of the editors: All hyperlinks were verified 21 April 2020.)

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