Agronomic and economic efficiency of the decanted phosphate as function of the liming in marandu grass (*Brachiaria brizantha*)

Eficiencia agronómica y económica del fosfato decantado como función del encalado en hierba marandu (*Brachiaria brizantha*)

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Abstract

The decanted phosphate (DP) is an environmental liability for the fertilizer industries and its use as a phosphate fertilizer has been suggested in agriculture. However, there are few researches that studies its efficiency. In this sense, this experiment was conducted in a greenhouse with the main objective to evaluate the agronomic efficiency and the relative economic efficiency of decanted phosphate (DP) in the presence and absence of lime during three growth periods of *Brachiaria brizantha* cv. Marandu (marandu grass). In addition, the critical levels of P were determined in soil and shoots of plants. The indices Equivalent Triple Superphosphate medium (EqTS medium) e Relative Economic Efficiency (REE) were calculated in order to evaluate the efficiency of DP and triple superphosphate (TS). The critical levels of P were set when relative production was 90%. The DP efficiency indices were more than 100% when not applied liming. The liming reduces the agronomic and economic efficiency of DP. The P critical levels in soil and shoots of the marandu grass were 15 mg dm^{-3} and 1.2 g kg^{-1}, respectively.

Keywords

pH • phosphorus • residual effect • critical level of P. *Brachiaria brizantha*.

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Resumen

El fosfato decantado (FD) es una responsabilidad ambiental para las industrias de fertilizantes y se ha sugerido su uso como fertilizante de fosfato en la agricultura. Sin embargo, hay pocas investigaciones que estudien su eficacia. En este sentido, este experimento se realizó en un invernadero con el objetivo principal de evaluar la eficiencia agronómica y la eficiencia económica relativa del fosfato decantado (FD) en presencia y ausencia de cal durante tres períodos de crecimiento de *Brachiaria brizantha* cv. Marandu (hierba marandu). Los niveles críticos de P se determinaron en el suelo y los brotes de las plantas. El índice equivalente superfosfato triple medio (EqST medio) y la eficiencia económica relativa (EER) se calcularon para evaluar la eficacia de FD y superfosfato triple (ST). Los niveles críticos de P se establecieron cuando la producción relativa fue del 90%. Los índices de eficiencia del FD fueron más del 100% cuando no se aplicó el encalado. El encalado reduce la eficiencia agronómica y económica de FD. Los niveles críticos de P en el suelo y en la parte aérea de la hierba marandu fueron 15 mg dm^{-3} y 1,2 g kg^{-1}, respectivamente.

Palabras clave

pH • fósforo • efecto residual • nível crítico de P. *Brachiaria brizantha*.

Introduction

Studies suggest the establishment of agronomic and economic indices for the choice of the phosphate fertilizer (3, 8, 10). In this sense, the equivalent triple superphosphate medium (EqTS medium) and Relative Economic Efficiency (REE) are more interesting than other commonly used indices such as Agronomic Efficiency Index (AEI) and triple superphosphate equivalent (EqTS), because it does not suffer the influence of the dose used due to it considers the part of the curves of greater response to the P addition.

Furthermore, the evaluation of P sources should also consider the residual effect of fertilizers, because forms of P may be more or less available for plants over time (11).

The most commonly used P sources are soluble phosphates in water, thermophosphate and natural phosphates. However, these forms have higher prices due to the dependence on imports. In addition, tropical soils are mostly weathered, acidic and with high adsorption of P to oxides and hydroxides of iron (Fe) and aluminum (Al), making it unavailable (2). This combination increases the search for new alternatives to supply the requirement of crops with this nutrient, and increase the sustainability of agricultural systems.

In this context, the decanted phosphate (DP) can be a possible source of P. The DP is a by-product of wastewater treatment of phosphoric acid production (H_3PO_4) and it is obtained by precipitation reaction of H_3PO_4 diluted (contained in the precipitation ponds) with calcium hydroxide or lime, resulting in a powder that is dried and marketed. This product is an environmental liability and it generates costs for the fertilizer manufacturers, which seek an appropriate destination for this material. In addition, there is a growing worldwide concern for the reuse of wastewater from industries, especially when they can provide nutrients such as P to soils, reducing depletion of phosphate reserves and avoiding watercourses contamination (13, 14).

The DP has been indicated by companies mainly for pasture due to its initial and residual effect. It is also known that most of the Brazilian pastures present some degradation, mainly related to the deficiency of P in their soils with little corrected acidity (4). In this sense, liming and phosphate fertilization are the most expensive practices in the implementation of a pasture. However, the efficiency of P sources is influenced by changes in the soil pH value (they modify the adsorption reactions of P) and by the chemical composition, solubility and accompanying cation (they interfere in phosphate solubilization) (2, 12).

Moreover, the critical levels of P in the soil defined for fodder were established on the basis of annual crops, with scarcity of information for crops such as *B. brizantha*, which has been included in various agrosystems either in exclusive cultivation or in a consortium with cereals, grains and forest.

As there are few researches that studied efficiency indices of the DP and their relationship with the soil acidity, the main objective of this study was to evaluate the agronomic and relative economic efficiency of the DP in the presence and absence of lime during three consecutive growths periods of *B. brizantha* cv. Marandu (initial and residual effect).

Furthermore, due to the fact that the soil fertility classes used for fodder had been established for annual crops, the present study also aimed to determine the critical levels of P in soil and shoots of the plants.

Materials and Methods

Location, period and soil characterization

This experiment was conducted in a greenhouse from October 2012 to January 2013 at Sao Paulo State University - Jaboticabal/SP - Brazil in pots containing samples of sandy clay loam Typic Haplustox.

The soil had the following granulometric characteristic:

clay = 260 g kg^{-1}; silt = 30 g kg^{-1} and sand = 710 g kg^{-1}.

The chemical attributes of soil fertility were:

pH ($CaCl_2$) 4.1
MO = 23 g dm^{-3}; missing N content
P (resin) = 4 mg dm^{-3}
K = 0.4 $mmol_c$ dm^{-3}
Ca = 7 $mmol_c$ dm^{-3}
Mg = 3 $mmol_c$ dm^{-3}; S = 4 mg dm^{-3}
H + Al = 58 $mmol_c$ dm^{-3}
CTC = 68 $mmol_c$ dm^{-3} and V = 15%

The experimental design and treatments

The experimental design was completely randomized (with three replications), according to a factorial 6 x 2 x 2 [six doses of P; two sources of P; presence (P/L) and absence of lime (A/L)], totaling 72 experimental units (pot with 2.8 kg of soil).

The doses of P (calculated by total P of the fertilizers) were 0, 30, 60, 90, 120 and 150 mg kg^{-1} of P.

The P sources were decanted phosphate (DP) (P_2O_5 total = 17%; P_2O_5 soluble in neutral ammonium citrate (NAC) + water = 9%; P_2O_5 soluble in citric acid = 12%; Ca = 18%) and triple superphosphate (TS) (P_2O_5 total = 45%, P_2O_5 soluble in water = 37%; P_2O_5 soluble in NAC + water = 43%; Ca = 14%).

Soils with the acidity correction received lime (PRNT = 95%), in a amount calculated to elevate soil base saturation to 60%. The sources of P were applied in powder form in order to avoid the effects of granulometry and facilitate the mixture of them with the soil. The marandu grass (*Brachiaria brizantha* cv. Marandu) was used as test plant.

Experimental conduction

The lime was mixed with the soil in each pot, followed by the addition of distilled water to the soil to reach approximately 80% of the maximum water retention (MWR).

The soil was incubated for 20 days. The soil in each pot was air-dried and it received phosphate fertilizers and basic fertilization.

The basic fertilization was consisted of doses of N, S, K and Zn in mg kg^{-1}: N = 30 and S = 36 (ammonium sulfate), K = 120 (potassium chloride) = 3 and Zn (zinc sulfate). The sources of P were applied only before sowing.

Marandu grass sowing was made with 30 seeds per pot. Seven days after the plant emergence, thinning was done leaving four plants per pot.

After 20 days of plant emergence, a standardization cut to 0.10 m above ground level was done. Then the fertilization was performed with 120 mg kg^{-1} N (ammonium sulfate).

After the standardization, three cuts of the shoot were done at intervals of 30 days, also to 0.10 m. After each cut, fertilization was performed with 150 mg kg^{-1} N (ammonium nitrate) and 80 mg kg^{-1} K (potassium chloride). Daily waterings with distilled water were made to maintain the soil close to 80% of the MWR.

The shoots at each of the three cuts were washed. The plant materials were dried at 65°C in forced-air oven. The plant material was weighed to determine the dry mass of shoots.

Agronomic and economic efficiency

To evaluate the efficiency of P sources was used the response curve of TS Goedert *et al.* (1986).

The response curves were adjusted following the model $y = y_0 + ax^{0,5}$, and the significance of the regressions were verified ($p<0.01$).

The comparative analysis of response curves (EqTS medium) was calculated through the quotient squared of the angular coefficients of the curve, multiplied by a hundred, using the DP as numerator (y_2) and TS as divisor (y_1):

$$EqTS\ medium\,(\%) = \left[\frac{b(y_2)}{b(y_1)}\right]^2 .100$$

The relative economic efficiency (REE) was obtained by division of the price in reais of one kilogram (kg) of P_2O_5 of TS (PTS), reference source, and the cost of a kilogram of P_2O_5 of test source- DP(PDP), multiplied by the agronomic efficiency (EqTS medium) of the test source and by a hundred (6).

The information for calculating the REE were: the price in real of the fertilizer per ton (t) (DP = R$ 320/t; TS = R$ 1,615/t), the total content of P_2O_5 in the fertilizer (DP = 17%; TS = 45%), the PDP = R$ 1.88, the PTS = R$ 3.59 and the ratio PTS/PDP = 1.90. Commercial fertilizer prices were obtained on February 24th, 2016.

$$REE(\%) = (EqTSmedium.\frac{PTS}{PDP}).100$$

P critical level

The P critical levels were set when relative production was 90%. The linear plateau model was performed to determine the P critical level in soil and shoots of marandu grass, which was defined by the intersection of the two lines (1).

Results

The adjusted equations that best described the response curves according to each P source, where x is the dose of P used, and y_1 and y_2 correspond to the dry matter production of marandu grass shoots provided respectively by TS and DP (table 1). Through the EqTS medium (table 2, page 82), it was found that the sum of the growths, the DP was more efficient compared to TS when not applied lime.

On the other hand, the DP was less efficient when the soil received this corrective. In the three growths, the EqTS medium provided by the DP were similar or above those verified for the TS when the treatments did not receive lime (EqTS medium ≥ 100).

When the soils received lime, the EqTS medium for DP in the first growth was the lowest of the experiment. This indice was raised to higher values than the ST in the second growth and again reduced to lower after this growth.

Through the REE (table 2, page 82), it can see that the REE indices obtained for the DP were always higher than 100%, except for the first growth when the DP had REE lower than 100% when applied lime to the soil. However, in the sum of the growth, REE for DP was than 100% even when the soil received lime.

Table 1. Response curves for fertilizers as function of the liming in the three growth periods of *Brachiaria brizantha* cv. Marandu and the sum of the growths.

Tabla 1. Curvas de respuesta para fertilizantes en función del encalado en los tres períodos de crecimiento de *Brachiaria brizantha* cv. Marandu y la suma de los crecimientos.

Growths	P sources	Liming	Adjusted equations	R^2
1ST Growth	Triple superphosphate	Ausence	$y_1 = 0.9947 + 0.5562x^{0.5}$	0.81**
		Presence	$y_1 = 0.0023 + 0.4141x^{0.5}$	0.87**
	Decanted phosphate	Ausence	$y_2 = 1.0186 + 0.5597x^{0.5}$	0.68**
		Presence	$y_2 = -0.1830 + 0.2626x^{0.5}$	0.46**
2ND Growth	Triple superphosphate	Ausence	$y_1 = 2.1772 + 0.7493x^{0.5}$	0.75**
		Presence	$y_1 = 1.8723 + 0.8825x^{0.5}$	0.80**
	Decanted phosphate	Ausence	$y_2 = 1.8821 + 0.8226x^{0.5}$	0.80**
		Presence	$y_2 = 0.9461 + 0.8956x^{0.5}$	0.89**
3RD Growth	Triple superphosphate	Ausence	$y_1 = 0.1660 + 0.4467x^{0.5}$	0.90**
		Presence	$y_1 = 0.3223 + 0.6234x^{0.5}$	0.76**
	Decanted phosphate	Ausence	$y_2 = 0.9486 + 0.4471x^{0.5}$	0.78**
		Presence	$y_2 = 0.1048 + 0.4746x^{0.5}$	0.79**
Sum of the growths	Triple superphosphate	Ausence	$y_1 = 3.3380 + 1.7521x^{0.5}$	0.87**
		Presence	$y_1 = 2.1969 + 1.9200x^{0.5}$	0.91**
	Decanted phosphate	Ausence	$y_2 = 3.8494 + 1.8295x^{0.5}$	0.83**
		Presence	$y_2 = 0.8679 + 1.6364x^{0.5}$	0.91**

** significant at 1% probability. / ** significativo al 1% de probabilidad.

Table 2. The equivalent triple superphosphate medium (EqTS medium) and relative economic efficiency (REE) for the three growth periods and sum of the growths of *Brachiaria brizantha* cv. Marandu.

Tabla 2. El equivalente superfosfato triple medio (medio EqTS) y la eficiencia económica relativa (REE) para los tres períodos de crecimiento y la suma de los crecimientos de *Brachiaria brizantha* cv. Marandu.

P source	1ST Growth		2ND Growth		3RD Growth		Sum of growths	
	Liming		Liming		Liming		Liming	
	Ausence	Presence	Ausence	Presence	Ausence	Presence	Ausence	Presence
	---------------Equivalent triple superphosphate medium (%) -------------							
Decanted phosphate	101	40	120	103	100	58	109	73
Triple superphosphate	100	100	100	100	100	100	100	100
	------------------------- Relative economic efficiency (%) ----------------------							
Decanted phosphate	192	76	228	196	190	110	207	139
Triple superphosphate	100	100	100	100	100	100	100	100

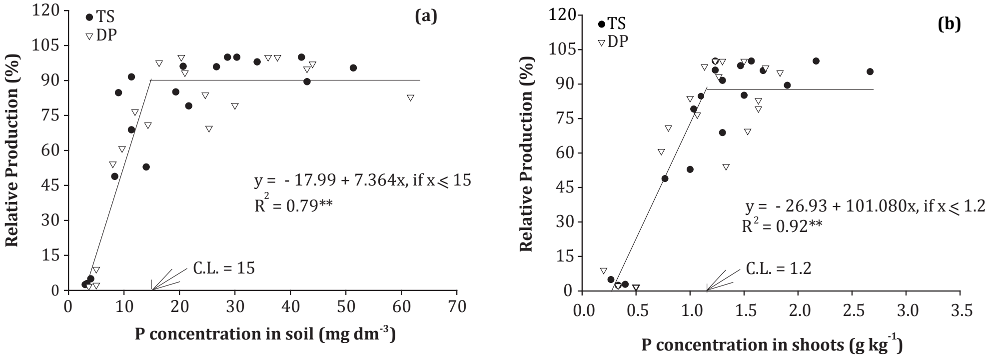

Figure 1. Critical levels of P in soil (a) and shoots of *Brachiaria brizantha* cv. Marandu (b).

Figura 1. Niveles críticos de P en el suelo (a) y brotes de *Brachiaria brizantha* cv. Marandu (b).

The relation between the relative production and the P levels in the soil and shoots of marandu grass is presented (figure 1). The determined critical levels of this nutrient in soil and shoots of the plant were 15 mg dm^{-3} and 1.2 g kg^{-1}, respectively.

Discussion

The P solubilization from the DP had been favored by the higher acidity of the soil, which it was possibly increased throughout the experiment due to nitrogen fertilization performed in each marandu grass cut. In this sense, other authors verified the efficiency of partially acidulated phosphate was directly proportional to the acidification rate (7).

The values of EqTS medium for DP are higher than those verified by other researchers in field condition for two years for P sources such as magnesium thermophosphate and Gafsa phosphate (90% and 48%, 91% and 88%, respectively) (3).

Moreover, the phosphate fertilizers were applied in powder form, which may also have reduced faster the efficiency of TS (more soluble source in water) after the first growth due to greater surface contact and adsorption P to the soil, reducing the availability of this nutrient.

These results suggest that DP efficiency can be reduced in soils with lower acidity due to the smaller supply of protons H^+ for the solubilization of P from this source and it can be increased in soils with higher acidity. On the other hand, although the increase in acidity could result in better utilization of P from DP, it can also enhance adsorption reactions of this nutrient to the soil that make the EqTS medium had been reduced after the second growth. In acidic soil conditions, positive charges are generated which increase adsorption the phosphate anions to adsorbent soil surface.

In addition, precipitation reactions of P can also occur with ionic forms of Al and Fe in acidic soils (2). Although the EqTS medium indice is obtained by the curves of responses as a function of the doses of P, the higher concentration of Ca in the DP compared to the TS may have provided greater amount of this nutrient to plants, which can have increased the efficiency of this by-product (DP = 18% Ca; TS = 14% Ca).

However, the EqTS medium was better than other indices such as Agronomic Efficiency Index (AEI), and equivalent triple superphosphate (EqTS), because it did not suffer the influence of the dose used because it considers the part of the curves of greater response to the P addition.

The REE indices showed that studies about effects of P sources must consider the initial effect of the fertilizer but also the residual effect. The treatments without lime had the highest REE indices compared to those in which the corrective was applied.

The high REE achieved for DP is due to good agronomic efficiency indices associated with high PTS/PDP ratio = 1.90 (price of one kilogram of P_2O_5 of TS/price of one kilogram of P_2O_5 of DP). The results of this experiment for EqTS medium and REE suggest generally efficiencies of DP similar or above those of the TS, especially when not applied lime. At the same time, REE were not considered transportation and operation costs, which possibly were higher for DP due to be more the necessary quantity of this product, when compared to TS, to apply the same quantity of P.

On the other hand, these same results can direct field studies about the efficiency and use of DP in agriculture, assisting in the reduction of the national dependence on the import of phosphate fertilizers and the environmental liabilities of the fertilizer manufacturers.

The critical level values of P in soil falls within the range of P levels of the low soil fertility class (7 to 15 mg dm^{-3}) (9), which was established for annual crops, but is used for fodder species.

In the shoots of the plant, the critical level value is within the range suggested by some authors for *B. brizantha* (0.8 to 3.0 g kg^{-1} of P) (15).

Conclusions

In the conditions of this experiment under greenhouse, it was concluded that the DP could be a good P source because it had high EqTS medium and REE, especially in acid soils and after the first growth period (residual effect).

The use of DP should consider that the liming reduces its agronomic and economic efficiency. For improving the management of DP in agriculture, new studies in the field conditions should be performed.

Furthermore, the critical levels of P in the soil and shoots of the marandu grass were 15 mg dm^{-3} and 1.2 g kg^{-1}, respectively.

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