Phosphate Efficiency for Corn Following Brachiaria Grass Pasture in the Cerrado Region

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Efficient use of phosphate fertilizers is still a challenge for long-term soil management in the Cerrado region. Corn yields were quite similar in response to different P sources and application methods following Brachiaria grass pasture. There are indications of very different behaviors between first crop and long-term cultivated soils.

Large-scale production of corn and other grains in the Brazilian Cerrado became viable only after the development of technologies to improve the fertility of soils. The requirement of large amounts of phosphates to correct the fertility of these soils justifies studies to optimize fertilization efficiency.

Taking into account the yield accumulated in sequential cultivations, the performance of some rock phosphates (especially the reactive ones) may be comparable to more soluble fertilizers. It happens due to the conversion of the P from soluble sources into less labile forms while the rock phosphates release the nutrient gradually through time (Novais and Smyth, 1999). In Brazil, long-term field experiments are scarce.

The present work compared the agronomic and economic efficiency of P fertilizers and application methods in a clayey dystrophic Red Argisol (Ultisol), considering the cumulative yield of three successive corn crops. The study was carried out in a field formerly cropped and fertilized, which remained covered by a pasture of brachiaria-grass (*Brachiaria brizantha*) for 10 years before the experiment began. The soil had low P availability, determined by Mehlich 1 (2.0 mg/dm^3) and ion exchange resin (7.8 mg/dm^3) tests.

Treatments were arranged in a 4x3+1 factorial scheme, comparing four commercial P sources (**Table 1**) at the rate of 180 kg P_2O_5/ha: triple superphosphate (TS), Yoorin magnesium thermophosphate (MT), Arad reactive rock phosphate (RP), and Araxá rock phosphate (AP). The study compared three P fertilization methods, including: 1) A single pre-plant broadcast of 180 kg P_2O_5/ha. 2) A single band of 180 kg P_2O_5/ha within the sowing furrow. In each crop, corn rows were located exactly on the original location (relative to the first year band) in the plots. Sowing furrows were manually opened. Thus, there was a constant distance between seed rows and band placement. 3) Three annual bands of 60 kg P_2O_5/ha within the sowing furrow. A check plot without P was also included in the study. In the broadcast application, the P sources were manually distributed and incorporated at 10 cm depth. The soil was limed to obtain a water pH value around 5.5. Soil tillage was done only in the first year. Other nutrients were provided for each crop as starter and side-dress fertilizations for yield expectations of 8 t/ha.

The residual effect from past fertilization, the characteristics of previous crop species, and the genotypic P use efficiency may level the corn response to different P fertilization strategies. Long-term results are crucial to assess the agronomic and economic efficiency of phosphates with distinct solubility.

Grain yield and P exportation at harvest were evaluated. After the third harvest, the soil was sampled (0 to 20 cm depth) to determine residual available P extracted with ion exchange resin. Soil cores were taken at aligned points crossing the sowing row (band place). The plot sample was formed from 10 soil cores (single samples) taken at increasing distances from each side of the row (two of them were taken exactly on the furrow location). This procedure was assumed to represent the average P availability of the plot both in broadcast and

Table 1. Chemical and physical characteristics of phosphate fertilizers and cost per ton.

Fertilizer	Total P_2O_5	Soluble P_2O_5	CaO	MgO	SiO_2	$CaCO_3$ equivalent[3]	Texture	Cost, US$/t
	------	------	%	------	------	------		
TS	46.1	38.3[1]	13.0	–	–	–	Granulated	334.44
MT	18.1	17.6[2]	20.0	7.0	25.0	50	Powder	187.69
RP	33.0	10.0[2]	37.0	–	–	–	Coarse	182.58
AP	22.7	4.3[2]	40.0	–	–	–	Powder	64.84

[1]Water soluble P_2O_5. [2]Citric acid soluble P_2O_5. [3]Alkalinizing effect given in kg $CaCO_3$ for each 100 kg of fertilizer.

Abbreviations and notes for this article:
P = phosphorus;
mg/dm^3 = parts per million;
cm = centimeters;
t/ha = metric tons per hectare;
kg = kilograms

band treatments. The agronomic efficiency index was determined by deducting the check yield and considering TS as a reference for each application method (efficiency = 100%). The economic efficiency of the different fertilization strategies was evaluated by benefit/cost ratio according to the respective yield responses obtained. Calculation was made according to the yield increment of each P treatment relative to check treatment, the cost of P fertilizers, and corn price, regardless of cost differences due to application methods. Other cropping-related costs were assumed as constant.

Using a corn price of US$106.99/t, the benefit/cost ratio was determined as:

(YI x CP) / FP, where:

YI = yield increment, t/ha

CP = corn price, US$/t

FP = fertilizer price, US$/ha (**Table 1**)

Grain Yield and P Exportation

Yield differences were not observed for one-time, first-year broadcast or band applications. When the band application was annually split, AP produced lower yields compared to RP, but neither of them was different from TS or MT (**Table 2**). Apparently, RP solubilization and plant availability was not compromised under the annual band application strategy. The lower yield obtained with AP suggests that it is less suited to a band application at lower rates. Indeed, the yield obtained with AP was similar in all application methods. The low solubility of the product is the biggest restriction to its use efficiency, regardless of the method of application.

The yield responses in this study were not as large as those obtained in earlier P fertilization studies established on previously uncropped Cerrado soils. Usually, yields from check treatments are extremely low (Sousa and Lobato, 2004). Despite anticipated contrasts in P supply between treatments, the cumulative effects of the various P sources tended to equalize after the study's three harvests (**Table 2**).

Table 2. Corn yield and P exportation according to P sources and application methods (total of three crops).

	Application method		
P source	Broadcast	Band	Annually split band
	Grain yield, t/ha		
TS	18.0 a A	18.4 a A	17.8 ab A
MT	18.1 a A	19.2 a A	17.6 ab A
RP	16.5 a B	17.9 a AB	19.4 a A
AP	16.9 a A	17.2 a A	15.8 b A
Check		12.5 **	
	P exportation, kg/ha		
TS	79.6 a A	73.5 ab A	79.3 a A
MT	83.3 a A	86.2 a A	73.9 a A
RP	76.5 ab AB	64.8 b B	81.5 a A
AP	63.7 b A	65.0 b A	67.5 a A
Check		44.4 **	

Averages followed by same small letters in columns or capital letters in rows do not differ through the Tukey test ($p<0,05$).

**Average of the check treatment (-P) differs in relation to the average of the factorial (+P) through the F Test ($p<0.01$).

Residual P fertility resulting from past P application would be a strong candidate for masking the treatment effects at this site. The check treatment produced a considerable yield, which would only be possible given access to a significant source of available P—a condition not detected by Mehlich 1 or ion exchange resin extractants (Resende et al., 2006). This scenario has been associated with the influence of brachiaria-grass, a plant considered quite efficient in P uptake (Sousa and Lobato, 2004). Despite low soil test P levels, a significant amount of P could be present within brachiaria residues, providing a readily bioavailable source capable of supporting the unexpected yields achieved in the check plots.

Generally, when the total P rate was entirely broadcast or banded in the first year, the most soluble TS and MT sources provided for higher P removal by corn. Since the yields obtained with these two application methods were not significantly different among the four P sources, one may suppose that conditions of luxury consumption (excess supply) were created in the case of these highly soluble sources.

Considering the average of all application methods, the use of TS, MT, RP, and AP corresponded to the recovery of 49, 54, 46, and 33% of the applied P, respectively (Resende et al., 2006). These recovery values are not low, given the remarkable P-fixing character of soils from the Cerrado region. Sousa and Lobato (2004) reported that a clayey Latosol (Oxisol) receiving 100 to 800 kg P_2O_5/ha as single superphosphate had average P recoveries after 17 years of cultivation of 36 and 61%, respectively, under an exclusive grain crop system versus a system with *Brachiaria humidicola* during 9 of the 17 years. Such information reinforces the influence of Brachiaria on enhancing soil P availability as well as the dependence of this study's corn responses on its field cropping history.

Agronomic and Economic Efficiency, and Residual Effect of Treatments

The agronomic efficiency index (**Table 3**) indicates that the least soluble AP and RP sources are very distinct products in relation to their P supplying potential. If broadcast, both sources showed similar behavior. If banded, RP was shown to be more plant available. The annual band application of RP produced a significant corn response, but the same was not observed for AP. The more soluble TS and MT sources showed similar use efficiency, and were less influenced by the application method.

The annual band application resulted in higher residual P availability with all sources except AP. For the three most soluble sources, this parceled fertilization method appears to prevent both P luxury consumption by corn and P fixation by soil. The method also provided higher residual effects along with good grain yields, a result of an intermediate P release rate, which did not compromise P uptake by corn. According to Rajan et al. (1996), reactive rock phosphates are the

Table 3. Agronomic efficiency and soil residual available P of sources and application methods of P in corn (after three crops).

P source	Application method: Broadcast			Band			Annually split band		
	- - - - - - - - - - - - -			Agronomic efficiency[1], %			- - - - - - - - - - - - -		
TS	100	a	A	100	a	A	100	ab	A
MT	104	a	A	114	a	A	98	ab	A
RP	74	a	B	94	a	B	133	a	A
AP	79	a	A	79	a	A	62	b	A
	- - - - - - - - - - -			Residual available P[2], mg/dm^3			- - - - - - - - - - - -		
TS	10.0	a	B	10.2	a	B	17.1	b	A
MT	9.7	a	B	10.5	a	B	16.3	bc	A
RP	12.1	a	B	13.2	a	B	24.9	a	A
AP	9.8	a	A	11.1	a	A	12.0	c	A
Check				8.7 **					

[1]Treatment with triple superphosphate as reference (in each application method, efficiency = 100%).
[2]Extracted with ion exchange resin.
Averages followed by same small letters in columns or capital letters in rows do not differ through the Tukey test (p<0,05).
**Average of the check treatment (-P) differs in relation to the average of the factorial (+P) through the F Test (p<0.01).

ideal sources for long-term soil management, if they can achieve a controlled P release. In the present study conditions, the advantage of adopting the annual band application method in order to optimize soil fertility is clear. Annual application of 60 kg P_2O_5/ha was sufficient to assure yield gains, replace P removed in harvested grain, and improve fertility for following crops by providing a P surplus.

It is also important to realize that the most suitable treatments in agronomic terms (**Tables 2 and 3**) do not necessarily correspond to those economically more viable (**Table 4**). Longer-term economic evaluation should be made since the P treatments appeared to have distinct residual soil effects at the end of 3 years. The evaluation of yield accumulated from a number of successive crops, field history, and corn genotypic P efficiency have minimized differences between treatments, favoring those with lower P supply potential. Thus, RP and

Table 4. Benefit /cost ratio of sources and application methods of P in corn (total of three crops).

P source	Application method: Broadcast	Band	Annually split band	Average
TS	4.5	4.8	4.3	4.5
MT	3.2	3.8	2.9	3.3
RP	4.2	5.8	7.4	5.8
AP	9.1	9.7	6.9	8.6
Average	5.3	6.0	5.4	5.6

AP, the less soluble but lower cost P sources, provide better cost/benefit ratios. Results showed similar efficiency of different P sources and application methods for corn following Brachiaria grass pasture. Probably, the Brachiaria strongly influences the soil P dynamics in the formerly-fertilized soil, converting residual P into organic, readily-available forms enough to attend a significant part of the corn demand. BC

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