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# Enhanced efficiency phosphate fertilizers and phosphorus availability in Acrudox

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## Abstract

The objective of this study was to evaluate the influence on P availability of the application of polymer-coated phosphate and organophosphate fertilizers to the soil under different soil water matric potentials and contact times. The experiment was laid out in a randomized block design and replicated four times, with treatments distributed in a split-plot arrangement. The main plot comprised four phosphate fertilizers (conventional mono-ammonium phosphate, MAP; polymer-coated mono-ammonium phosphate, POL; pelletized mono-ammonium phosphate with filter cake, FC; and granulated mono-ammonium phosphate with swine compost, SC) and two soil water contents corresponding to two matric potentials (-10 and -50 kPa). The subplot comprised six contact times (2, 4, 6, 8, 10 and 14 days after fertilizer addition). P content was determined after extraction with Mehlich-1 or water. The highest available P contents in soil were obtained using MAP (1474.3 mg dm<sup>-3</sup>) followed by POL (1355.7 mg dm<sup>-3</sup>), FC (1235.5 mg dm<sup>-3</sup>) and SC (804.2 mg dm<sup>-3</sup>). The available P contents during the 14 days of the experiment relative to the control (MAP) values ranged from 88.5 to 95.4% for POL, 83.2 to 84.4% for FC and 54.9 to 54.2% for SC. These results evidenced the effects of the organic coating applied to the phosphate fertilizer on fertilizer solubility and the short-term release of P. A decrease in the soil water matric potential decreased P availability in the short term for fertilizers with coating technologies, especially for SC compared to MAP. This result indicates that organic coating technologies may hold promise for maintaining P availability over time.

Keywords: Fertilizer technology, mono-ammonium phosphate, organophosphates, tropical soil.

### Introduction

In tropical regions, where extensive weathering occurs, soils have a high capacity to adsorb phosphate due to the predominance of iron and aluminium oxides, thereby lowering the phosphate ion availability in the soil solution. In addition to mineralogical factors, phosphate ion adsorption is influenced by the soil pH, the volumetric soil water content, the phosphate fertilizer source used and the soil organic matter content (Bhadoria et al., 1991; Villani et al., 1998; Antelo et al., 2005; Pavinato et al., 2009).

Decomposing organic matter releases organic acids that block the adsorption sites of phosphorus (P), reducing the adsorption of this nutrient (Borggaard et al., 2005). These organic acids can also complex iron and aluminium present in the soil solution, reducing the precipitation of P compounds and increasing P availability (Andrade et al., 2013). Thus, phosphate fertilizers associated with organic compounds may benefit from these organic matter characteristics regarding decreased P adsorption by soil and increased P availability to plants.

A reduction in soil water content also affects the P adsorption intensity, increasing P adsorption by bringing the phosphate ion present in the soil solution closer to a colloidal surface (Ruiz et al., 1988). Polymer-coated phosphate fertilizers, which have characteristics that affect

water entry into the microcracks of the fertilizer granules, may offer greater control over P dissolution and possibly over P availability.

Another factor influencing P adsorption is the type of phosphate fertilizer used (Lombi et al., 2004). Those phosphate fertilizers with relatively high solubility (*e.g.*, single and triple superphosphates as well as mono-ammonium and di-ammonium phosphate) release P to the soil solution more rapidly than do those with lower solubility. However, the agronomic efficiency of phosphate fertilizers is reduced with increasing contact time of P with the soil colloids (Laboski and Lamb, 2003), reducing the availability of this nutrient to plants.

Currently, polymer-coated phosphate fertilizers are used in an attempt to increase fertilizer efficiency and lengthen the period during which plant nutrients are available (Trenkel, 2010). For P, polymer coatings not only lead to its gradual release to the soil solution but also reduce the intensity of its adsorption by providing physical protection, minimizing the direct contact of fertilizer with a colloidal surface.

Figueiredo et al. (2012) evaluated the effect on maize production of applying polymer-coated phosphate fertilizer and found that the polymer coating promoted an increase of 3.48 t ha<sup>-1</sup> compared to the uncoated product.

Another formulation technique involves the mixing of phosphate fertilizers with an organic material, such as chicken manure (Castro et al., 2015). This mixing reduces P adsorption, protecting P chemically (via the maintenance of P in the solution around the granules of organic acids that are produced from the organic material mixed with the fertilizer). According to Guppy et al. (2005), organic acids can bind with iron and aluminium in the soil solution or compete for adsorption/precipitation intensity and consequently directly affecting the P availability.

Given the above observations, the objective of the present study was to evaluate P availability as influenced by a polymer-coated phosphate fertilizer and organophosphate fertilizers applied to the soil under conditions of different soil matric potentials and contact times.

## Results

The P contents presented similar patterns regardless of whether P was extracted by Mehlich-1 or water; however, their magnitudes differed (Table 1). The phosphate fertilizers influenced the P content extracted from the soil samples by Mehlich-1 and by water regardless of the matric potential, distance or contact time (Figures 1 and 2).

For Mehlich-1 extraction, the P levels available in the soil relative to the MAP values at the different contact times ranged from 88.5 to 95.4% for POL, 83.2 to 84.4% for FC and 54.9 to 54.2% for SC (Figure 1). A similar pattern among the treatments was observed for water extraction, but the magnitudes differed (Figure 2).

The P contents following extraction by Mehlich-1 or water were higher for the conventional fertilizer (MAP) than for the coated fertilizers (C1, Table 2). When comparing POL with the organophosphate fertilizers (FC + SC), POL showed higher P contents after both Mehlich-1 and water extraction (C2, Table 2). FC application provided higher soil levels of P than did SC application for both Mehlich-1 extraction and water extraction (C3, Table 2).

At the distances of 0-0.5, 0.5-1.0 and 1.0-1.5 cm from the phosphate fertilizer granules, MAP presented higher values for P than did the other fertilizers following Mehlich-1 extraction; however, no difference among the fertilizers was observed at the distances of 1.5 to 2.0 cm (C4, Table 3), evidencing limited P movement.

The P contents were higher for POL than for FC + SC at the distances of 0-0.5, 0.5-1.0 and 1.0-1.5 cm from the phosphate fertilizer granules following Mehlich-1 extraction (C5, Table 3). Comparing FC and SC (C6, Table 3), higher P values were observed for FC at distances of 0-0.5 and 0.5-1.0 cm from the phosphate fertilizer granules following Mehlich-1 extraction.

Regarding the contents of P extracted by water, a pattern similar to that observed for Mehlich-1 was observed at distances of 0-0.5 and 0.5-1.0 cm from the phosphate fertilizer granules (C4, C5 and C6; Table 3). However, at the distances of 1.0-1.5 and 1.5-2.0 cm, no significant differences among the fertilizers were observed following water extraction, which can be attributed to the lower power of water than of Mehlich-1 for extracting P for quantification in soil.

In the C7 contrast (Table 4), a similar pattern of P content for Mehlich-1 and water extraction was generally observed at

the 0.0- to 0.5-cm distance for all fertilizers, with higher P values for the matric potential of -50 kPa.

For the 0.5-1.0 cm distance, a pattern opposite to that observed for the first distance (0.0-0.5 cm) was observed regarding the P contents for the different fertilizers and extractors (C7, Table 4), with higher P values observed for the matric potential of -10 kPa.

At distances of 1.0-1.5 and 1.5-2.0 cm, no significant contrast values were found for FC or SC between the matric potentials (C7, Table 4) for either extractor.

## Discussion

As expected, higher P contents were obtained with Mehlich-1 extraction than with water extraction, since Mehlich-1, in addition to extracting P from solution, extracts some of the P from the soil colloids by acid dissolution and quantifies the forms precipitated with Ca, Al and Fe (Schlindwein and Gianello, 2008; Oliveira et al., 2014). Thus, Mehlich-1 might be less effective than water for revealing changes in P content after the application of phosphate fertilizers. Therefore, a water extractor, which quantifies the P that is in the soil solution alone and thus has greater accuracy for revealing changes in the P of the soil solution after the application of phosphate fertilizers, was also used.

The addition of MAP to the soil rapidly increased the P concentration of the soil solution, consistent with the results of Chien et al. (2011). However, when applying a source of soluble P soluble to soil, more than 90% is typically adsorbed in the first hour of contact with the soil (Gonçalves et al., 1985), thereby reducing the availability of P (Rheinheimer et al., 2002). Thus, it can be hypothesized that the use of fertilizers of greater efficiency may be an alternative to the use of sources of soluble P, such as MAP, to maintain P availability in the soil over time.

The technologies applied to create the enhanced-efficiency fertilizers used in this experiment are intended to increase the agronomic efficiency of the fertilizers. The polymer coating is expected to control the inflow of water and therefore the dissolution of P within the coating capsule, thus decreasing the contact time of P with the solid phase. In addition, the organic acids released from the decomposition of organic material coatings can increase agronomic efficiency via competition for the adsorption sites of P and the complexation of iron and aluminium.

The FC + SC fertilizers yielded lower P availability in the soil under the different experimental conditions of this study (temperature, soil water content and soil type). This suggests greater control of P release by these fertilizers than the other fertilizers because the same dose and P source were used. These fertilizers might increase P availability over time due to the more gradual release of P in soil (Figures 1 and 2).

This difference in P release (POL vs. FC and SC) may be related to the maintenance of a constant volumetric soil water content throughout the experiment, providing a greater release of P from the POL fertilizer (C2, Table 2). Polymer-coated fertilizers exhibit increased nutrient release with increased moisture (Du et al., 2006). The effects of the gradual release of enhanced-efficiency fertilizers can be better visualized under experimental conditions showing soil

<b>Table 1.</b> Mean P content (mg dm <sup>-3</sup> ) extracted by Mehlich-1 and by water for the different matric potentials ( $\Psi$ m), d	listances and
phosphate fertilizers independent of contact times.	

Extractor	Ψm (kPa)	Distance (cm)	MAP	POL	FC	SC
		0.0-0.5	4704.25	4215.40	4225.22	2926.72
	10	0.5-1.0	1095.22	921.15	647.70	304.83
	-10	1.0-1.5	96.87	80.12	32.62	6.98
Mahliah 1		1.5-2.0	1.53	1.43	1.15	0.98
weniich-1		0.0-0.5	5039.97	4875.98	4548.67	2999.02
	EO	0.5-1.0	825.28	729.62	419.10	191.10
	-50	1.0-1.5	30.40	20.67	8.52	3.05
		1.5-2.0	1.17	1.18	1.03	0.90
		0.0-0.5	1883.68	1621.23	1559.65	1150.83
	10	0.5-1.0	349.60	274.67	221.35	89.85
	-10	1.0-1.5	12.07	9.42	2.47	0.48
Wator		1.5-2.0	0.25	0.27	0.18	0.20
water -		0.0-0.5	2041.52	1872.08	1723.77	1169.33
	EO	0.5-1.0	246.93	234.93	124.07	32.80
	-50	1.0-1.5	1.17	0.80	0.55	0.22
		1 5-2 0	0.18	0.18	0.18	0 18

MAP = conventional monoammonium phosphate, POL = polymer coated monoammonium phosphate, FC = pelletized monoammonium phosphate with filter cake, and SC = granulated monoammonium phosphate with swine compost.



**Fig 1.** Soil P extractable with Mehlich-1 over time by phosphate fertilizer at two matric potentials and four sampling distances. MAP = conventional mono-ammonium phosphate, POL = polymer-coated mono-ammonium phosphate, FC = pelletized mono-ammonium phosphate with filter cake, and SC = granulated mono-ammonium phosphate with swine compost.

Table 2. Orthogonal contrasts (C) for the P con	ents (mg dm <sup>-3</sup> ) extracted b	by Mehlich-1 and by water f	or the different phosphate
fertilizers.			

Variables	C1	C2	C3
P Mehlich-1	342.55**	335.85**	431.30**
P Water	146.52**	121.94**	148.54**

C1: MAP vs. POL + FC + SC (3+,--). C2: POL vs. FC + SC (2+,--). C3: FC vs. SC (+,-). \*\*Significant at 1% probability by the F test. MAP = conventional mono-ammonium phosphate, POL = polymer coated mono-ammonium phosphate, FC = pelletized mono-ammonium phosphate with filter cake, and SC = granulated mono-ammonium phosphate with swine compost.



**Fig 2.** Soil P extractable with water over time by phosphate fertilizer at two matric potentials and four sampling distances. MAP = conventional mono-ammonium phosphate, POL = polymer-coated mono-ammonium phosphate, FC = pelletized mono-ammonium phosphate with filter cake, and SC = granulated mono-ammonium phosphate with swine compost.

**Table 3.** Orthogonal contrasts (C) for the P contents (mg dm<sup>-3</sup>) extracted by Mehlich-1 and by water considering the distances for the different phosphate fertilizers.

	Distance (cm)							
С	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	0.0-0.5	0.5-1.0	1.0-1.5	1.5-2.0
Mehlich-1			Water					
C4	907.0**	424.6**	38.3**	0.24 <sup>ns</sup>	446.5**	135.3**	4.3 <sup>ns</sup>	0.02 <sup>ns</sup>
C5	870.8**	434.7**	37.6**	0.28 <sup>ns</sup>	345.9**	137.8**	4.2 <sup>ns</sup>	0.04 <sup>ns</sup>
C6	1424.1**	285.4**	15.6 <sup>ns</sup>	0.14 <sup>ns</sup>	481.6**	111.4**	1.1 <sup>ns</sup>	0.01 <sup>ns</sup>

C4: MAP vs. POL + FC + SC d/Distances (3+,--). C5: POL vs. FC + SC d/Distances (2+,--). C6: FC vs. SC d/Distances (+,-). \*\*Significant at 1% probability by the F test; <sup>no</sup>not significant. MAP = conventional monoammonium phosphate, POL = polymer coated monoammonium phosphate, FC = pelletized monoammonium phosphate with filter cake, and SC = granulated monoammonium phosphate with swine compost.



**Fig 3.** Scheme of soil sampling of the rectangular sections at distances (cm) of 0.0-0.5 (A); 0.5-1.0 (B); 1.0-1.5 (C) and 1.5-2.0 (D) from the granules of the phosphate fertilizer, starting from the central region.

Table 4. Orthogonal contrasts (C) for the P contents (mg dm <sup>-3</sup> ) extracted by Mehlich-1 and by water considering the distances and
matric potentials for the different phosphate fertilizers.

Fortilizor	Distance (am)	C7			
Fertilizer	Distance (cm)	Mehlich-1	Water		
	0.0-0.5	-335.72**	-157.83**		
	0.5-1.0	269.92**	102.67**		
WAP	1.0-1.5	66.46**	10.89 <sup>ns</sup>		
	1.5-2.0	0.37 <sup>ns</sup>	0.04 <sup>ns</sup>		
	0.0-0.5	-660.59**	-250.87**		
DOI	0.5-1.0	191.53**	39.72**		
POL	1.0-1.5	59.45**	8.59 <sup>ns</sup>		
	1.5-2.0	0.24 <sup>ns</sup>	0.03 <sup>ns</sup>		
	0.0-0.5	-323.44**	-164.11**		
50	0.5-1.0	228.64**	97.29**		
FC	1.0-1.5	24.09 <sup>ns</sup>	1.93 <sup>ns</sup>		
	1.5-2.0	0.14 <sup>ns</sup>	0.02 <sup>ns</sup>		
	0.0-0.5	-72.32**	-18.51 <sup>ns</sup>		
50	0.5-1.0	113.74**	57.02**		
SC	1.0-1.5	3.96 <sup>ns</sup>	0.26 <sup>ns</sup>		
	1.5-2.0	0.11 <sup>ns</sup>	0.03 <sup>ns</sup>		

C7: matric potential of -10 kPa vs. matric potential of -50 kPa d/Fertilizers d/Distances (+,-). \*\*Significant at 1% probability by the F test; <sup>16</sup> not significant. MAP = conventional monoammonium phosphate, POL = polymer coated monoammonium phosphate, FC = pelletized monoammonium phosphate with filter cake, and SC = granulated monoammonium phosphate with swine compost.

 Table 5. Physical and chemical characterization of the Acrudox.

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Characteristic	Acrudox
Clay (kg kg <sup>-1</sup> ) <sup>/a</sup>	0.437
Soil density (kg dm <sup>-3</sup> ) <sup>/b</sup>	1.10
Water retention (kg kg <sup>-1</sup> ) $^{/c}$	
-10 kPa	0.281
-50 kPa	0.232
- 500 kPa	0.166
pH-H <sub>2</sub> O <sup>/d</sup>	4.96
$Al^{3+}$ (cmolc dm <sup>-3</sup> ) <sup>/e</sup>	0.80
$Ca^{2+}$ (cmolc dm <sup>-3</sup> )/ <sup>e</sup>	0.45
$Mg^{2+}$ (cmolc dm <sup>-3</sup> ) <sup>/e</sup>	0.32
H+AI (cmolc dm <sup>-3</sup> ) <sup>/f</sup>	5.70
CEC (cmolc dm <sup>-3</sup> ) <sup>/g</sup>	6.55
K (mg dm <sup>-3</sup> ) <sup>/h</sup>	20.50
P (mg dm <sup>-3</sup> ) <sup>/h</sup>	0.61
P-rem (mg $L^{-1}$ ) <sup>/i</sup>	14.30
MPAC (mg cm <sup>-3</sup> ) $^{/j}$	1.60

<sup>a</sup>Pipette method. <sup>b</sup>Test tube method. <sup>c</sup>Porous plate extractor. <sup>d</sup>Soil-water ratio 1:2.5. <sup>e</sup>Potassium chloride 1 mol L<sup>-1</sup> extractor. <sup>f</sup>Calcium acetate 0.5 mol L<sup>-1</sup> pH 7.0 extractor. <sup>g</sup>CEC at pH 7.0. <sup>h</sup>Mehlich-1 extractor. <sup>i</sup>Remaining phosphorus (Alvarez V. et al., 2000). <sup>j</sup>Maximum phosphorus adsorption capacity (Olsen and Watanabe, 1957).

**Table 6.** Chemical characterization of phosphate fertilizers.

Fertilizer	N <sup>/a</sup>	$P_2O_5^{/b}$	K <sub>2</sub> O <sup>/c</sup>	C <sup>/d</sup>	CEC <sup>/e</sup>	C/D	nu <sup>/f</sup>
		% mmol <sub>c</sub> kg				C/P	μп
MAP	11.0	46.2	0	-	-	-	4.1
POL	9.0	44.3	0	-	-	-	3.7
FC	6.0	30.0	0	8.0	80.0	0.3	5.1
SC	6.9	26.0	1.6	12.7	339.1	0.5	4.9
<sup>a</sup> Total nitrogon (Mana 2014)	Total P (Mana 2014)	<sup>c</sup> K = water coluble peter	cium (Mana 2014) d	C = total organic ca	rhon (Mana 2014) <sup>e</sup> CEC = cat	ion ovchange canacity	(Mana 2014) <sup>f</sup> nH in

rotal introgen (wapa, 2014). Total P (wapa, 2014). K = water-soluble polassium (wapa, 2014). C = total organic carbon (wapa, 2014). CEC = cation exchange capacity (wapa, 2014). Ph in calcium chioride (Mapa, 2014). MAP = conventional monoammonium phosphate, POL = polymer coated monoammonium phosphate, FC = pelletized monoammonium phosphate with filter cake, and SC = granulated monoammonium phosphate with swine compost.

wetting and drying cycles than under relatively constant moisture conditions.

Experimental temperature is another factor that may have contributed to the above-described difference in P release. According to Shaviv (2005), the release of nutrients through a polymer membrane is not significantly affected by soil properties, such as the pH, texture, microbial activity and ionic strength of the soil solution, but is influenced by temperature, moisture and the permeability of the polymer coating. An increase in temperature can promote the expansion of the polymer layer, causing an increase in its permeability to water and, consequently, greater P release.

The type of organic material (filter cake and swine compost) used in the coating influences the P release from the fertilizer and consequently the availability of soil P. The P release difference between these organophosphate fertilizers is related to their different characteristics, including differences in the manufacturing process (granulation or pelletisation), quality and thickness of the coating, degree of hardness, degree of surface micro-cracking and cation exchange capacity of the fertilizers.

The greater P movement in the MAP treatment than in the other treatments at the distances of 0-0.5, 0.5-1.0 and 1.0-1.5 cm is related to the higher P concentration in the soil, resulting in an increased P concentration gradient that favours P movement (Figures 1 and 2).

The higher P contents following Mehlich-1 extraction for POL than for FC and SC at the distances of 0-0.5, 0.5-1.0 and 1.0-1.5 cm from the phosphate fertilizer granules occurred because of the greater P release from POL than from the other two fertilizers (Table 1), increasing the P contents at these distances and providing greater P movement.

The increase in P diffusion may have been provided by the heightened soil water content at the matric potential of -10 kPa and/or by the relatively high initial P concentration at the first distance (0-0.5 cm) provided by the heightened P availability in the soil solution at this potential. Thus, an increase occurred in the P concentration gradient, facilitating the distance movement of this nutrient.

An increase in soil water content increases P movement because this water is the medium in which diffusion occurs. The soil water content is directly related to the level of P diffusion, as the moisture determines the fraction of the area or the volume of soil in which diffusion occurs. Additionally, the soil water content indirectly influences the transport of this nutrient by promoting changes in the impedance factor, which varies with the amount of water in the soil (Costa et al., 2009). In evaluating the effect of P dose on diffusion, Costa et al. (2006) observed that higher P doses increased diffusion, which they attributed to an increased concentration gradient caused by the increased P in the soil. In addition, the soil water content may be more important than the applied P dose for regulating P diffusion in tropical soils (Ruiz et al., 1988).

For the various fertilizers and extractors (C7, Table 4), the P contents at the 0.5-1.0-cm distance indicated that P had moved the farthest from the granule at the matric potential of -10 kPa, possibly due to the higher volumetric water content and concentration gradient at this potential.

The persistence of P close to the location of the organophosphate fertilizers granules is associated with the slow P release provided by these fertilizers, resulting in a relatively low P concentration gradient in the soil solution in the short term.

### Materials and methods

#### Soil sample preparation and experimental design

Sub-surface samples (0.2-0.4 m) of an Acrudox, collected in Alegre, Espírito Santo, Brazil, were used to conduct the experiment. The soil samples were dried and passed through a 2-mm sieve to obtain fine air-dried soil; subsequently, chemical and physical (Table 5) soil characterizations were performed.

After the chemical characterization, the pH of the soil samples was adjusted to 6.0 (via 2.25 t ha<sup>-1</sup> of calcium carbonate) using the standard method to neutralize soil acidity based on an incubation curve generated with calcium carbonate.

The experiment was conducted under laboratory conditions at a controlled temperature of 25 ± 2 °C. The experiment followed a complete randomized block design with four replicates distributed in a split-plot arrangement. The main plot comprised four phosphate fertilizers (conventional mono-ammonium phosphate, MAP; polymer-coated monoammonium phosphate, POL; pelletized mono-ammonium phosphate with filter cake, FC; and granulated monoammonium phosphate with swine compost, SC) and two soil water contents corresponding to two matric potentials (-10 and -50 kPa). The subplot consisted of six contact times (2, 4, 6, 8, 10 and 14 days after fertilizer addition), totalling 192 experimental units. These contact times were selected since the adsorption of P added as soluble fertilizer occurs very rapidly in soil (Barrow, 1985; Harvey and Rhue, 2008; Fink et al., 2015).

The soil samples (100 cm<sup>3</sup>) were added to plastic boxes (11 cm length by 11 cm width by 3 cm height), which served as the experimental units. Then, the amount of water required to reach the desired matric potential was added to each box.

#### Fertilizers and analyzed variables

A chemical characterization of the phosphate fertilizers is presented in Table 6. The FC fertilizer was produced by

pelletisation after mixing the filter cake, mono-ammonium phosphate and a biodegradable organic polymer. The filter cake was used after composting.

The SC fertilizer was produced by granulation after mixing the swine compost (swine manure composted with grass) with mono-ammonium phosphate. The SC was manufactured in the proportion of 48.75% swine compost, 48.75% mono-ammonium phosphate and 2.5% sodium silicate (a binder used to increase the resistance of the granules to breakage or abrasion).

The fertilizer granules were added to the centre of each plastic box. A 320 mg dm<sup>-3</sup> dose of P, corresponding to 20% of the maximum P adsorption capacity (MPAC), was applied. Because the fertilizers had different P contents, granules whose weight corresponded to the desired amount of P were selected for each experimental unit. The grain size of the applied phosphate fertilizers was standardized using 2-to 4-mm sieves.

At the end of each contact time, the granules were removed. Subsequently, rectangular soil samples were collected at distances of 0.0-0.5, 0.5-1.0, 1.0-1.5 and 1.5-2.0 cm from the phosphate fertilizer granules, starting from the central region (Figure 3). The collected subsamples were dried at 40 °C to constant weight, and P extraction with Mehlich-1 (Embrapa, 1997) or with water was performed for the subsequent determination of P concentration by colourimetry.

## Statistical analysis

The data were subjected to analysis of variance using the SISVAR program (Ferreira, 2011). The treatments were evaluated by comparing the means using orthogonal contrasts and applying the F test at the 1 and 5% probability levels. In addition, the contact times were evaluated by regression analysis.

### Conclusion

Enhanced efficiency phosphate fertilizers altered the P availability in the soil solution, which increased in the order SC < FC < POL. MAP resulted in the highest soil available P contents. The soil content of available P was lowest for SC and decreased over the contact time, demonstrating the importance of the organic material, which coated the soluble phosphate fertilizers and affected the short-term availability of P. A reduction in matric potential was associated with a reduction in the short-term P availability among the fertilizers with coating technologies, especially SC; this result may be relevant for maintaining the P availability over time.

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