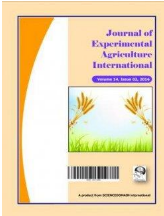

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Solubilization of Phosphorus in Phosphate Fertilizers after Treatment with Different Organic Residues

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Authors' contributions

This work was carried out in collaboration between all authors. Author MOS participated in the idea and management of the experiment, besides writing the article. Author EGFS was responsible for collecting, tabulating and analyzing the data. Author FBSP participated in the management of the experiment from the implantation to the data collection. Author JS participated in the handling of the experiment and writing the article. Author KDSC were responsible for guiding this work. All authors read and approved the final manuscript.

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Short Communication

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ABSTRACT

Phosphorus is an element of low mobility in soil. It is combined with iron compounds, aluminum and calcium, and organic matter. Phosphorus inorganic compounds found in the soil are conditioned by pH, type and quantity of minerals present in the clay fraction. This study aimed to evaluate the influence of three types of organic waste and the incubation time in the solubilization of three sources of P in the soil of the northeastern semi-arid region. The treatments were arranged in a 3 x 3 x 7 factorial arrangement, and a solo, 3 sources of phosphorus (P), 3 organic waste and 7 incubation times. The treatments were arranged in a randomized block design with three replicates. All soil samples were determined: pH, Ca and P concentrations, 10, 20, 30, 40, 50, 70 and 90 days of incubation. Data were submitted to ANOVA and Tukey test to compare the treatment averages.

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For the incubation time factor, regression equations were set at the level of 1% probability. The most efficient organic waste in reducing pH and solubilizing phosphate was Leucaena; The biofertilizer was the most efficient source of phosphate in making phosphorus available for soil.

Keywords: Fertilizer; availability; soil; biofertilizers.

1. INTRODUCTION

The soils of the Brazilian semi-arid region contain low levels of phosphorus (P), one of the elements that most limit productivity in this region. Consequently, to obtain high yields, the addition of phosphate fertilizers is required. It is known that only a fraction of P applied to the soil of which 15 to 25% is used and the rest remains in the soil. Another part is adsorbed by colloids, another part is combined with the soil components, remaining in the insoluble form and also, another part is immobilized by microorganisms [1].

Practically, there are no detailed studies on the desorption of P in soils of the northeastern semi-arid, perhaps as a consequence of the lack of use of fertilizers, since, P is an element whose use is quite expensive in agriculture and presents great power of adsorption to soil colloids, which highlights a need to use alternative sources, such as fertilizers of organic origin, which present costs lower than conventional fertilizers and greater residual effect.

However, since this source of P has low solubility, one of the alternatives for this is to increase the activity of the microbiota that participates in the solubilization of P in the soil. Thus increasing the production of organic acids and other products of microbial metabolism [2,3], which can be increased with the addition of organic compounds to the soil [4].

Through this process, there is a slow but continuous release of phosphorus from phosphate sources (FF), in contrast to soluble fertilizers that provide high content of soluble phosphorus immediately after its application.

In this way, it was tried to evaluate the influence of three types of organic residues and the incubation time in the solubilization of three P sources in the Northeastern semi-arid soil.

2. MATERIALS AND METHODS

The experiment was conducted in the Laboratory of Physics and Soil Management of the Department of Agroecology, of the Federal Institute of Alagoas, Campus Piranhas-AL, in 2016.

The experiment consisted of a 3x3x7 factorial arrangement (phosphate, residue, time), with three replicates, being the treatments were arranged in a randomized block design.

The following materials were selected: a characteristic Luvisolic soil with greater predominance in the region; three sources of phosphorus: rock biofertilizer, natural phosphate (Fertipar), and simple superphosphate; and three organic residues: one legume (*Leucaena leucocephala*), earthworm humus, and tanned bovine manure.

Vegetable residues were ground in forage. Humus and manure were sieved in a 2-milimeter sieve. These materials were applied to soil samples, collected in the 0-20-centimeter layer. After collection, the soil was air-dried, broken down and sieved in a 2-milimeter mesh and submitted to chemical analysis (Table 1), according to [5]. The pH of water was determined in the ratio 1: 2.5 soil: solution.

The available phosphorus was determined by colorimetry using ascorbic acid as a reducing agent after extraction with 0.05 mol L^{-1} HCl solution and 0.025 mol L^{-1} H_2SO_4 solution (Mehlich). Exchangeable potassium and sodium were determined by flame photometry, after extraction with $Mehlich^{-1}$, while calcium, magnesium and exchangeable aluminum were be extracted with 1mol L^{-1} KCl and determined by titrimetry. The potential acidity (Al + H) was evaluated by extraction with 0.5 mol L^{-1} calcium acetate at pH 7.0.

The dose of 600 kg ha^{-1} of P_2O_5 was applied. Organic residues were submitted to nitric-perchloric digestion for subsequent determination of Ca and Mg contents by complexometry, P by colorimetry, and K by flame emission photometry [5]. Total organic carbon was determined by the method of [6]. N content was determined in 100 mg of sample digested with sulfuric acid in the presence of a mixture of copper sulfate and potassium sulfate, by the Kjeldahl method [5]

Table 1. Chemical characteristics of the soil used in the experiment. Piranhas. IFAL, 2016

pH	P	Ca^{2+}	Mg^{2+}	Al^{3+}	Na^{+}	K^{+}	H+Al
	mg dm^{-3}	------------	------------	------------$cmol_c$ dm^{-3}------------	------------	------------	
6.90	11.00	12.50	3.20	0.00	0.07	0.85	1.65

Table 2. Main characteristics of the organic residues used in the experiment. Piranhas. IFAL, 2016

Residues organic [1]	Parameters						
	K	Mg	Ca	P_2O_5	C	N	C/N
	------------	------------	------------	g kg^{-1}	------------	------------	
Leucena	3.60	18.10	38.50	4.50	500.00	26.00	19
Humus	12.80	3.88	5.80	8.70	190.00	15.00	12
Bovine manure	14.28	4.65	9.35	5.75	315.50	21.10	15

Table 3. Principal characteristics of the phosphate fertilizers used in the experiment. Piranhas. IFAL, 2016

Phosphate fertilizers[1/]	Parameters						
	P_2O_5 total	P_2O_5 sol.água	P_2O_5 ác. cítrico	P_2O_5 CNA+ water	MgO	CaO	SiO_2
	------------	------------	------------	------------%------------	------------	------------	
SS	18.7	-	10.3	-	-	12.0	-
RBF	25.6	-	16.6	-	5.0	15.0	-
FNP	27.7	-	19.0	-	-	22.8	12.3

[1/] SS = Simple Superphosphate; RBF = Rock Biofertilizer; FNP = Fertipar Natural Phosphate

(Table 2). Fertilizers were characterized according to methodology described in [5] (Table 3).

As an experimental unit, plastic bags with a capacity of 500 ml with 100 g of soil were used. After mixing the phosphates, residues and soils, these will be maintained in the field capacity, using distilled water, and will be incubated for 90 days. Up to 50 days of incubation, samples were taken every 10 days. After 50 days, the samples were taken at intervals of 20 days, completing 90 days of incubation. Immediately after the withdrawal of samples, they were submitted to pH and P analysis according to [5]. Available P was extracted with 0.5 mol L^{-1} sodium bicarbonate solution, with pH adjusted to 8.5 at 1:10 ratio (soil: solution) [7]. The obtained extract was purified with activated charcoal, filtered and an aliquot of clarified extract was used for determination of P by colorimetry, using the phospho-molybdic complex method according to [8].

Data were submitted to analysis of variance and, afterwards, the Tukey test was applied to compare the means of the treatments. For the incubation time factor, regression equations were adjusted at a 1% probability level.

3. RESULTS AND DISCUSSION

The analysis of variance indicated a difference (P = 0.01) for the pH value and Ca and P contents as a function of the factors studied and for all interactions tested (Table 4).

Table 4. Test F in function of the effects of the following factors: organic residues (R), phosphorus sources (PS) and incubation times (T) for the variables pH, contents of P and Ca. Piranhas. IFAL, 2016

FV	Parameters	
	pH	P
Organic Residues (R)	46.65**	5.58**
Phosphorus Sources (PS)	53.85**	19.43**
Incubation Time (T)	14.53**	145.54**
R x FPS	8.41**	14.32**
T x R	13.08**	70.64**
T x PS	3.78**	67.62**
R x PS x T	3.02**	148.29**
CV (%)	1.96	3.55

*** significant at 1% probability level.*

Of the added residues, those of leucine resulted in lower mean pH values relative to the phosphorus sources (PS) used (Table 5). This behavior may be a reflection of increased

Table 5. Mean of incubation times of pH values, P content for the type of residue applied and the source of P used. Piranhas. IFAL, 2016

Residues	SS	BFR	FNP
pH			
Leucine	7.18 b	6.79 b	7.20 a
Humus	7.56 a	7.25 a	7.21 a
Bovine manure	7.62 a	7.28 a	7.33 a
DMS	0.14		
Standard error	0.04		
CV (%)	2.79		
General average	7.27		
P (mg dm^{-3})			
Leucine	27.51 a	32.83 a	32.02 a
Humus	26.56 a	23.12 b	26.18 b
Bovine manure	27.15 a	31.30 a	19.56 c
DMS	3.93		
Standard error	1.17		
CV (%)	19.68		
General average	27.36		

Means followed by the same lowercase letter in the line do not differ from each other by the Tukey test at 5% probability level. SS = Simple Superphosphate; RBF = Rock Biofertilizer; FNP = Fertipar Natural Phosphate. MSD = Minimum significant difference; CV = Coefficient of variation

microbial metabolism with production of acidifying compounds [9]. Leucine residues present higher C/N ratio [10,11] compared to other residues and, therefore, greater resistance to decomposition [12].

This higher resistance to decomposition, besides a higher content of N, resulted in a greater decrease of soil pH because of humus and bovine manure residues. A higher acidity observed in treatments with leucine residue had a higher available content of P only when associated to the biofertilizer (Table 5). However, the availability of P must be related to other parameters, because the higher acidity will not result in higher P, since Al^{3+}, Fe^{3+} and Mn^{3+} were more available in acid soil. Having these minerals more positive charges, although there are negative and positive sites, the predominance of positive charges attracts $H_2PO_4^-$ easily. Therefore, phosphate ions absorb the oxide surface of Al, Fe and Mn by changing with OH and OH^{2+}. With respect to bovine manure, it is possible to observe that it provided, on average, lower release of P, showing differences of the other residues in the phosphates of simple superphosphate and natural phosphate.

The content of P made available by the other phosphates is dependent on the type of residue used. In addition, one of the conditions for the solubilization of phosphates is the existence of acidic soil conditions [13,14,15].

The greater decrease in soil pH and increase in P availability of the phosphates when in the presence of leguminous residues, may be due to their higher ammoniacal N content. Organic waste has a higher concentration of N [16], which produces acidification of the environment after oxidation due to the transformation of ammonium into nitrate. Acidification is one of the necessary conditions for increased solubilization of phosphates [13]. Solubilization of P may also result, of the production of CO_2 and organic acids from the mineralization of C-organic and the production of enzymes and chelating and complexing compounds by the microbiota [17]. These factors may exert direct solubilizing action on phosphates [18]. The reaction of CO_2 with water, in basic medium, releases H^+ and HCO_3^- ions being able to solubilize Ca and Mg carbonates and phosphates [19,20].

As for P, there is a great fluctuation in the levels released, in relation to incubation time. For the three sources used, a slow release of P was initially observed in the first 10 days, occurring, from that point, a great increase in the available P content, reaching the maximum value between 30 and 50 days of incubation (Fig. 1). Some researchers, studying the kinetics of P release by phosphate solubilizing microorganisms, observed

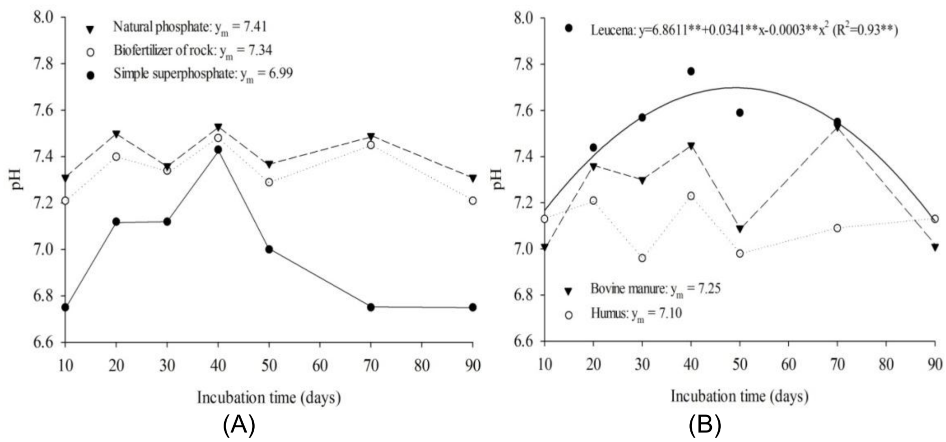

Fig. 1. Application of biofertilizer phosphorus sources, natural phosphate and simple superphosphate (A); and leucine residues, humus and bovine manure (B) on pH change as a function of incubation time

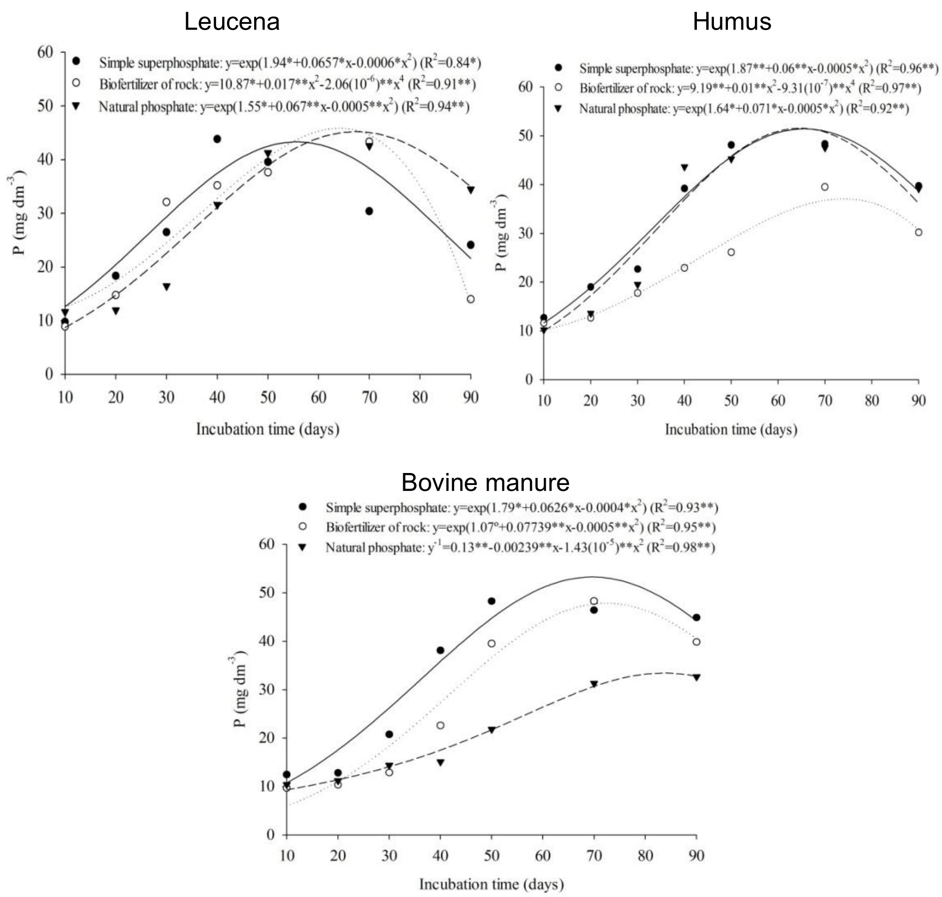

Fig. 2. Application of legume residues, humus and bovine manure in the availability of P as a function of incubation time

variations in solubilized P contents giving rise to several peaks of maximum concentration [21,22,23,24]. These changes in P concentration may be a consequence of their precipitation with organic metabolites [21,24] and/or of the formation of compounds with the excreted organic acids, which are subsequently used as energy source or nutrient, which can occur several times in the medium [22]. Another alternative to explain this behavior is the difference between the release and the assimilation of P by microorganisms.

The upward trend observed at the beginning of the incubation may reflect a microbial solubilization of the added phosphate, while the subsequent drop may reflect microbial immobilization in response to increased microbial metabolism. Similar results were observed by [4], using as carbon source soybean straw, corn and sugarcane bagasse, and [25] afterwards, addition of glucose. In addition, the decrease in P concentration in the solution may be associated with its attachment to the colloidal particles [13].

Regression equations were adjusted using dependent variables, pH (Fig. 1) and P (Fig. 2), and the incubation time as an independent variable. Quadratic equations were fitted for most treatments. In relation to soil pH, their values remained constant throughout the incubation time for all treatments.

4. CONCLUSION

The most efficient organic residue in reducing pH and solubilizing phosphate was leucine. However, other factors also alter the availability of P.

Natural phosphate and simple superphosphate showed very similar pH at all incubation times. All the materials used showed a certain pH instability during the incubation time. Nevertheless, studies with a greater time of incubation, with the exception of the biofertilizer of rock that stabilized around pH 6.7 at 70 days, are still necessary.

In the first 10 days, it was found that the release of P was slow for the three sources of P. From that point, we observed an increase in the P content available, having reached peaks of availability from 40 to 50 days for legume residues, humus and bovine manure.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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