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Effect of Phosphate Organomineral Fertilization on the Dry Matter Production and Phosphorus Accumulation of Corn

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Abstract

Brazilian soils are typically highly weathered, naturally poor in P, and rich in minerals with high P-adsorbing capacity. The objective of the present study was to evaluate the efficiency of peat-based granulated organomineral phosphate fertilizer (OMF) on the phosphorus supply capacity, shoot dry matter production and P accumulation of corn plants, as well as its residual effect on soil, compared to that of monoammonium phosphate (MAP). The experimental was performed using a randomized block design with a 2 × 5 + 1 factorial scheme (two fertilizer: OMF and MAP; five P doses: 15, 30, 45, 60, and 75 mg P_2O_5 dm^{-3}, and one control treatments (no P fertilizer), and three replicates. Two soils (Ferralsol and Planosol) were used in this study. Soil samples were incubated with limestone for 30 days and then dried, sieved and used to fill plastic pots (3 dm^3 soil per pot). Four successive corn cultivations were evaluated and, at the end of each cultivation period, the shoot dry mass (SDM) and P content of the corn were determined. In addition, soil P was measured at the end of the experiment. OMF and MAP had similar effects on SDM, but MAP provided higher P accumulation (SPA) of the first two cultivations, while OMF had higher soil residual P in Ferralsol. However, considering the total accumulated in four crops, SDM and SPA were statistically similar between the two P sources. SDM and SPA in Ferralsol increased linearly with increasing doses, while in Planosol, SPA increased linearly with increasing P dose, regardless of the P source, but SDM was not affected by increasing P doses. According to the results, OMF composed of chemically activated peat and MAP can replace MAP as phosphate fertilizer and maintain the same agronomic efficiency.

Keywords: organomineral fertilizer, peat, residual effect, *Zea mays*, phosphate fertilization

1. Introduction

As a result of per capita income and population growth, the projections show that feeding a world population of 9.1 billion people in 2050 would require raising overall food production by some 70 % between 2005/07 and 2050. Production in the developing countries would need to almost double (FAO, 2009). However, the generation of such products requires agricultural inputs, including P, because a significant increase in global phosphorus demand is expected if growing prosperity in developing countries leads to more P-rich diets (Helin & Weikard, 2019). In Brazil, most soils are characterized by low pH and high P-retention capacity, which, together, reduce the efficiency of phosphate fertilizers (Lopes & Guilherme, 2016). Thus, in order to maximize phosphate fertilizer efficiency, growers have adopted the use of humic acids, polymer-coated fertilizers, biochar, and seed inoculation (with arbuscular mycorrhizal fungi), among others (Novotny et al., 2012; Heitor et al., 2016; Guelfi et al., 2018; Rosa et al., 2018). Alternative phosphate sources are needed for fertilizer productions since most of the raw materials used today are non-renewable resources and Brazil has great economic and political dependence on the foreign market to obtain phosphate fertilizers (ANDA, 2021; Pantano et al., 2016). Brazil possesses an estimated phosphate mining reserve of about 315 Mt, which corresponds to 2.24% of the world's reserves (ANM, 2018).

Organomineral fertilizers, which are produced by mixing or combining mineral and organic fertilizers (MAPA, 2009), may be efficient, owing to the reduction of P adsorption by the colloidal fraction of the soil. During the mineralization of the organic fraction of organomineral fertilizers, organic acids are formed and released into the soil solution, where they compete for P adsorption sites and form complexes with Al, Fe, and Ca, thereby increasing the bioavailability of P in the soil (Hinsinger et al., 2011). The ability of organic acids to compete for P adsorption sites in the soil is regulated by both their concentration and the incorporation of carboxylic functional groups in their structure (Guppy et al., 2005). Results obtained by Ngo et al. (2022) showed that optimum plant growth does not depend solely on immediately available P, and that timing of nutrient supply to match plant demand is importante.

Peat is a porous and humified material that exhibits high adsorption capacity, especially for transition metals and polar organic molecules (Couillard, 1994), and that contains a large amount of humic substances (*i.e.*, fulvic acid, humic acid, and humine). Humic acid increases P availability in soil by forming variable stability complexes that block P adsorption sites and form complexes with Ca, Fe, and Al, thereby preventing phosphate precipitation (Rosa et al., 2018).

Corn (*Zea mays* L.) is widely cultivated in Brazil, owing to its great economic and social importance, and has many uses, ranging from animal feed to uses in the high-tech industry. The low availability of P in most Brazilian soils is one of the main factors limiting the nation's crop productivity (Fletcher et al., 2008).

The objective of this study was to compare the efficiency of peat-based granulated organomineral phosphate fertilizer (OMF) on the phosphorus supply capacity, dry matter production and P accumulation of corn shoots, as well as its residual effect on soil, to that of monoammonium phosphate (MAP).

2. Materials and Methods

2.1. Study Area

The experiment was conducted in a greenhouse, under natural light, in the municipality of Seropédica, Estate of Rio de Janeiro (RJ), Brazil (22°45′33″ S and 43°41′50″ W), with an average altitude of 30 m. The climate of the study region is classified as Aw, by Köppen, characterized by hot and humid summers and dry winters. The average of recent years has a maximum average temperature of 32.2 °C, with a minimum of 20.3 °C. The annual averages of temperature and precipitation of the last 20 years, are, respectively, 23.7 °C, 1,275 mm, with a relative humidity of 69.3%, obtained from the meteorological station of PESAGRO, RJ, the closest to the experiment site.

2.2. Soils Sampling

Samples from two soils, which were classified as Latossolo Vermelho-Amarelo (Ferralsol) and Planossolo Háplico (Planosol) according to Brazilian system of soil classification (Santos et al., 2018), were collected in the municipalities of Paula Cândido, Estate of Minas Gerais, Brazil, and Seropédica, RJ, Brazil, from the upper 20 cm of soil (0-20 cm layer). The soil samples were chemically and physically analyzed (Table 1) following methodologies as described by Teixeira et al. (2017), and the results are presented in Table 1. Soil samples were incubated with limestone for 60 days with humidity maintained around 80% of field capacity and then dried, sieved and used to fill plastic pots (3 dm^3 soil per pot).

Table 1. Physicochemical parameters of experimental soils (0-20 cm depth)

Soil	Parameters														
	Na	Ca	Mg	K	H+ Al	Al	SB	T	V	m	pH H_2O	P$^{1/}$	Clay	O.M.	Bulk Density
	------------------- cmol$_c$ dm^{-3} -------------------								------ % ------			ppm	------ % -----		g cm^{-3}
Planosol	0.0	0.9	0.3	0.1	2.8	0.3	1.3	4.1	32	7	4.6	26	10.0	1.1	1.52
Ferralsol	0.0	0.6	0.3	0.3	3.8	1.0	1.2	5.0	24	20	4.4	4	38.0	2.5	1.03

Note. Analyzes performed following methodologies as described by Teixeira et al. (2017); SB = sum of exchangeable bases (SB = Ca + Mg + K + Na); T= cation exchange capacity [T = SB + (H+Al)]; V = base saturation rate [V = (SB/T) × 100]; m = aluminum saturation rate [m = [Al/(SB + Al)] × 100]; O.M. = organic matter. $^{1/}$ Mehlich-1 extractor.

2.3. Experimental Design

The experimental was performed using a randomized block design with a 2 × 5 + 1 factorial scheme (two fertilizer treatments: OMF or MAP; five P doses: 15, 30, 45, 60, or 75 mg L^{-1} of P_2O_5, and one control treatments (no P fertilizer), and three replicates per treatment for a total of 11 treatments and 33 experimental units for each soil. Two types of soil (Ferralsol and Planosol) were used in the study, each evaluated as a separate experiment. The granulated organomineral fertilizer was primarily composed of chemically activated peat and MAP and had the formulation of 05-26-00 (N-P_2O_5-K_2O) plus 2% Mg and 0.3% Zn. The MAP fertilizer had 54% of P_2O_5 an 10% of N.

2.4. Conducting the Experiment and Plant Phytotechnical Assessments

In the experiment, four successive cultivations of corn (*Zea mays* L. cv Ipanema) were cultivated. Before each cultivation, 0.1 L of a nutrient solution (Table 2) was applied to each pot. The application of the treatments with phosphate fertilizers was done to furrows, just before the first sowing. Between the sequential cultivations, that is between the harvest of the plants and the replanting of others, the soil of the pots remained dry, without water supply.

Table 2. Nutrient solution components

Nutrient	Source	Source concentration (mg L^{-1})
N	$CO(NH_2)_2$	1,330
K	KCl	900
S	$MgSO_4$	9300
B	H_3BO_3	136.9
Cu	$CuSO_4 \cdot 5H_2O$	133.1
Fe	$FeCl_3 \cdot 6H_2O$	224.6
Mn	$MnCl_2 \cdot 4H_2O$	395.2
Mo	$NaMoO_4 \cdot 2H_2O$	10.3
Zn	$ZnSO_4 \cdot 7H_2O$	529.8

Source: Adapted from Furlani et al. (2009).

Ten corn seeds were sown in each pot, and at 8 days after emergence (DAE), the seedlings were thinned to three per pot. At 21 DAE, the plant shoots were collected. Plant harvesting was performed close to the ground. The collected shoots were placed in paper bags and dried in a forced air oven at 65 °C until constant weight was reached. The first cultivation cycle was shorter than the others due to electrical problems in the greenhouse that compromised the maintenance of the experiment for a longer time.

After the first plant harvest, the pots were re-fertilized using 70% of original dose of nutrient solution, and P fertilizer was not re-applied. For the second planting, sowing and thinning were performed as described above. However, cover fertilization was applied at 20 DAE by applying urea (120 mg N pot^{-1}), and the plants were harvested at 54 DAE. As described above, the collected shoots were dried to constant weight.

Meanwhile, the third and fourth cultivation periods were performed using the same procedures used for the second planting, except that the corn shoots were harvested at 46 and 51 DAE, respectively.

The dried shoots from all four cultivation periods were weighed, ground using a Wiley mill, and then subjected to P measurement using a sulfuric digestive solution and spectrophotometry, as described by Tedesco et al. (1995).

After the last cultivation period, a sample of soil was collected from each pot, and P was extracted from each sample, in order to measure residual P content, using Mehlich-1 extractor, as described by Teixeira et al. (2017).

2.5 Statistical Analysis

The normality of the data was verified using the Shapiro-Wilk test and the homogeneity of variances was verified using the Bartlett test. Then the data were submitted to analysis of variance using the R program (R Core Team, 2021). When the F-test indicated significant differences, the data were subjected to regression analysis.

3. Results and Discussion

In the first crop, P source failed to affect shoot dry matter production, regardless of soil type (Table 3), but did affect the P accumulation of plants grown in the Ferralsol, with MAP treatment yielding greater P content. In addition, both dry matter production and P accumulation increased linearly with increasing P, regardless of soil type (Figures 1 and 2).

Table 3. Effect of phosphorus source and dose on the shoot dry mass (SDM) and phosphorus accumulation (SPA) of corn plants grown in two Brazilian soils and four successive cultivations

		Mean square			
Source of variation	DF	Ferralsol		Planosol	
		SDM	SPA	SDM	SPA
First cultivation					
Block	2	1.26^{ns}	43.55^{*}	0.92^{ns}	85.13^{o}
Source	1	0.12^{ns}	38.92^{o}	0.01^{ns}	28.82^{ns}
Dose	4	32.98^{**}	348.05^{**}	4.86^{*}	393.02^{**}
Source*dose	4	1.28ns	40.77^{*}	1.38^{ns}	47.85^{ns}
Control *vs*. Factorial	1	68.18^{**}	627.27^{**}	52.49^{**}	861.66^{**}
Residue	20	0.66	9.59	1.32	26.47
Coefficient of variation (%)		14.1	17.76	16.49	20.21
Second cultivation					
Block	2	21.94^{ns}	36.93^{ns}	56.80^{**}	289.61^{**}
Source	1	68.07^{ns}	51.08^{ns}	11.38^{ns}	14.37^{ns}
Dose	4	178.01^{*}	179.87^{*}	17.99^{ns}	37.31^{ns}
Source*dose	4	111.51^{ns}	148.39^{o}	10.06^{ns}	61.37^{ns}
Control *vs*. Factorial	1	403.47^{*}	535.58^{**}	0.07^{ns}	86.92^{ns}
Residue	20	51.06	57.35	8.94	35.58
Coefficient of variation (%)		58.26	53.1	14.65	20.73
Third cultivation					
Block	2	1.78^{ns}	9.05^{ns}	2.33^{*}	10.95^{ns}
Source	1	2.02^{ns}	0.00^{ns}	0.57^{ns}	6.56^{ns}
Dose	4	7.42^{ns}	19.43^{ns}	2.03^{*}	26.28^{o}
Source*dose	4	3.97^{ns}	13.63^{ns}	0.16^{ns}	2.24^{ns}
Control *vs*. Factorial	1	11.56^{ns}	29.09^{ns}	0.88^{ns}	43.03^{*}
Residue	20	4.01	11.3	0.57	9.46
Coefficient of variation (%)		30.64	31.46	11.3	20.08
Fourth cultivation					
Block	2	1.34^{ns}	2.01^{ns}	1.74^{ns}	14.50^{ns}
Source	1	2.66^{ns}	13.54^{ns}	0.13^{ns}	0.90^{ns}
Dose	4	0.27^{ns}	16.15^{*}	0.56^{ns}	26.12^{ns}
Source*dose	4	2.50^{ns}	8.13^{ns}	0.49^{ns}	34.06^{ns}
Control *vs*. Factorial	1	14.60^{**}	1.05^{ns}	0.02^{ns}	48.53^{ns}
Residue	20	1.63	4.85	1.18	18.43
Coefficient of variation (%)		25.34	24.09	30.79	29.27
Total accumulated in four cultivation cycles					
Block	2	5.49^{ns}	26.88^{ns}	24.93^{ns}	18.06^{ns}
Source	1	30.68^{ns}	95.02^{ns}	14.60^{ns}	3.74^{ns}
Dose	4	394.08^{**}	1430.79^{**}	26.56^{ns}	1109.89^{**}
Source*dose	4	64.50^{ns}	73.84^{ns}	12.23^{ns}	126.43^{ns}
Control *vs*. Factorial	1	779.67^{**}	2981.76^{**}	64.85^{*}	2725.16^{**}
Residue	20	46.37	53.86	12.22	105.81
Coefficient of variation (%)		23.00	14.24	9.30	12.21

Note. **, *, and ^{o}: Significant at the 1, 5, and 10% probability, respectively (F-test); ns: not significant at 10% probability.

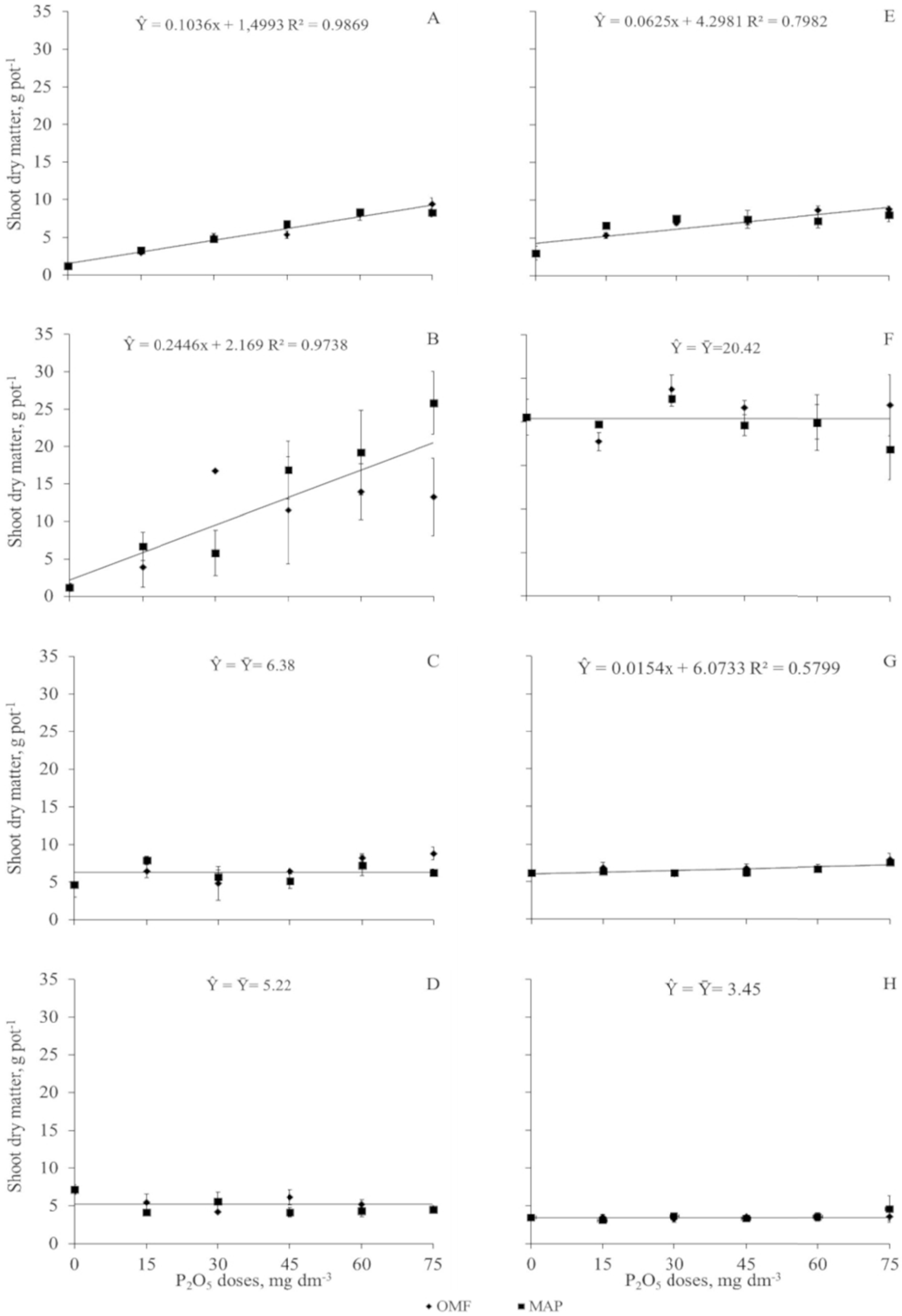

Figure 1. Shoot dry mass of corn plants grown in two Brazilian soils (Ferralsol: A, B, C, and D and Planosol: E, F, G, and H) and four successive cultivations (A and E; B and F; C and G; and D and H) in response to the application of different doses of P as organomineral phosphate fertilizer (OMF) or monoammonium phosphate (MAP). Note. Values and error bars represent mean±MSE (mean standard error)

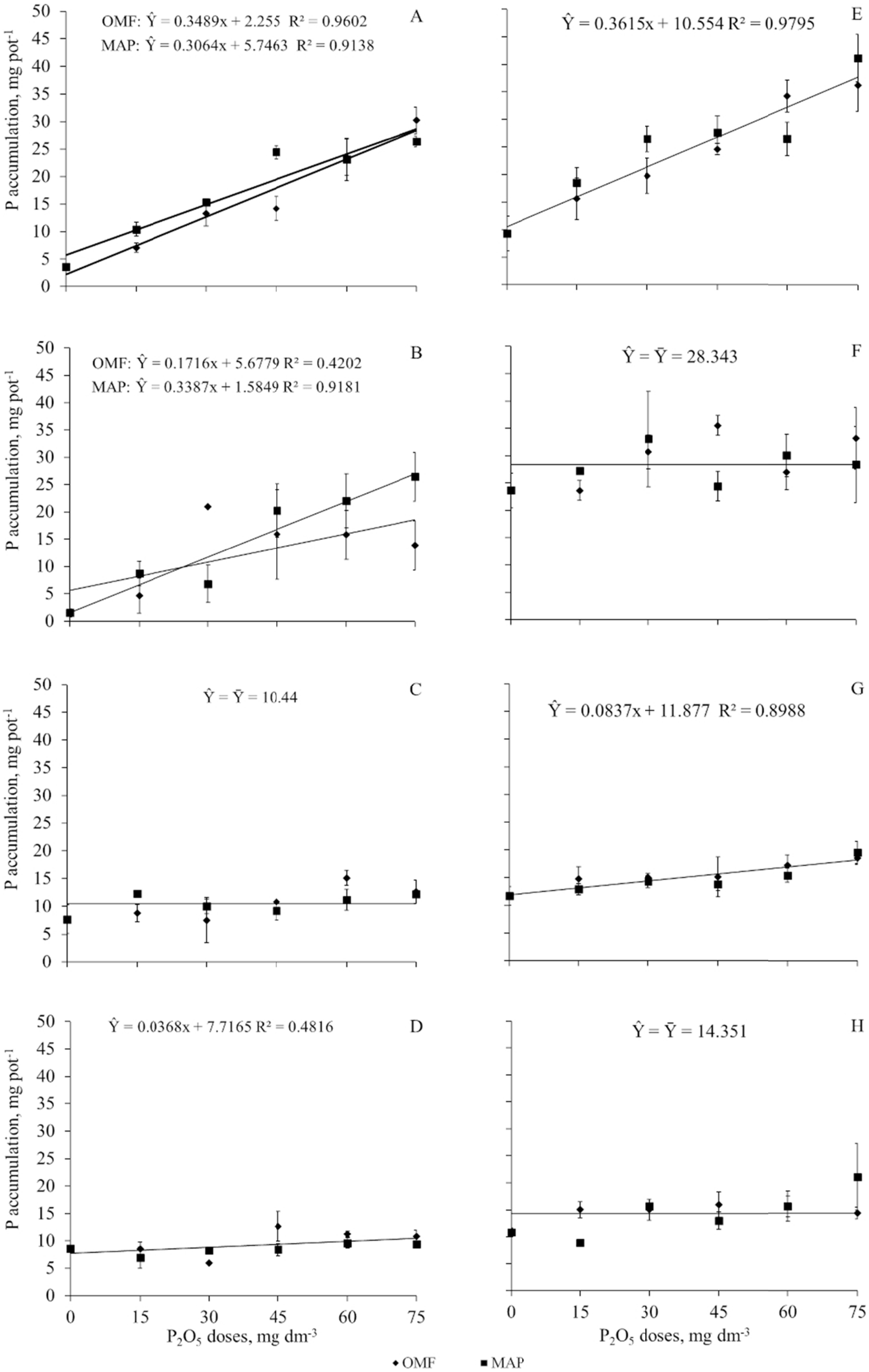

Figure 2. Phosphorus accumulation in corn plants grown in two Brazilian soils (Ferralsol: A, B, C, and D and Planosol: E, F, G, and H) and four successive cultivations (A and E; B and F; C and G; and D and H) in response to the application of different doses of P as organomineral phosphate fertilizer (OMF) or monoammonium phosphate (MAP). Note. Values and error bars represent mean±MSE (mean standard error)

Phosphorus mainly moves from where it is applied *via* diffusive flow into the soil solution, until it contacts roots and is absorbed (Santner et al., 2015). Diffusive flow and, consequently, P availability are affected by soil moisture, density, clay content, mineralogy, and P source and concentration (Hinsinger et al., 2011). Therefore, in the Planosol, the response of shoot dry matter production to dose increase was not pronounced, most likely because the initial available P content was much higher than that of the Ferralsol (Table 1) and because the Planosol possessed a lower clay content than the Ferralsol. These properties (*i.e.*, high available P content and low clay content) facilitate P diffusion, thereby favoring P absorption, even in treatments that received little or no P_2O_5.

In the more clayey soil (Ferralsol), which exhibited a relatively high P adsorption capacity and relatively low available initial P concentration, the rate of phosphate diffusion is usually lower than that of the Planosol (Valladares et al., 2003). Because the solubility of OMF is lower than that of MAP (Frazão et al., 2019), diffusion may have been greater when MAP, rather than OMF, was applied to the Ferralsol, thereby reflecting the higher P content of the MAP-fertilized plants.

The diffusion of P in the soil solution differed according to the solubility of the P source. When using more-soluble sources, diffusion tends to stabilize more rapidly, owing to the saturation of sorption sites that limit the additional movement of P in the soil. In contrast, phosphate diffusion from less-soluble sources occurs more slowly and gradually. However, the radius of the P diffusion zone tends to be similar for different phosphate sources, regardless of solubility (Lustosa Filho et al., 2019). Because corn grows rapidly, the lower solubility of OMF may been responsible for the relatively low P content compared of the OMF-fertilized plants.

In the second crop, P dose and the interaction between P source and dose were observed to affect shoot dry matter production and P accumulation, respectively (Table 3). Indeed, in the Ferralsol, the shoot dry matter production of MAP-fertilized plants increased linearly with increasing P dose (Figure 1), and the response of P accumulation to increasing P dose was more pronounced in the MAP-fertilized plants than in the OMF-fertilized plants (Figure 2).

In the third cultivation, P source failed to affect either dry matter or P accumulation in the Ferralsol (Table 3), whereas the dry matter production of plants grown in the Planosol responded to increases in P dose (Figure 1). Costa et al. (2011), who evaluated soil attributes and corn yield under different management and fertilization systems, reported that, during the first year of cultivation, mineral fertilization promoted greater crop yields than organomineral fertilization. However, no statistical differences were observed during the second year, thereby highlighting the need for longer studies.

In the fourth cultivation, P source failed to affect either dry matter or P accumulation in the Planosol (Table 3), whereas the P accumulation of plants grown in the Ferralsol responded linearly to increased P dose P dose (Figure 2). Because P fertilizer was only applied before the first planting and the supply of P to subsequent crops was derived from native and residual P, it is likely that the initial properties of the Ferralsol (e.g., relatively high P adsorption capacity and low available P content) were responsible for the more apparent responses of shoot P content to increases in P dose.

The dry matter production and P accumulation of the four sequential cultivations (Table 3 and Figure 3) were statistically similar, regardless of P source. The dry matter production and P accumulation of shoots in the Ferralsol increased linearly with increasing in P dose, while for Planosol, only the P accumulation increased linearly with increasing P dose, regardless of P source (Figure 3). In relation to the production of shoot dry matter in the Planosol, there was an effect of the application of P in relation to the control treatment, but the responses were the same regardless of the applied dose. Ferralsol proved to be a soil more responsive to P application because it had much lower initial P levels and due to its higher capacity for P adsorption, while in Planosol, due to its higher initial P level, P application had less influence on dry matter accumulation in the four cultivations. Regardless of the type of soil, under the conditions studied, it can be said that, in the accumulated of the four cultivations, the relative efficiency of the OMF in relation to the MAP was 100% both for the production of dry matter and for the accumulation of P.

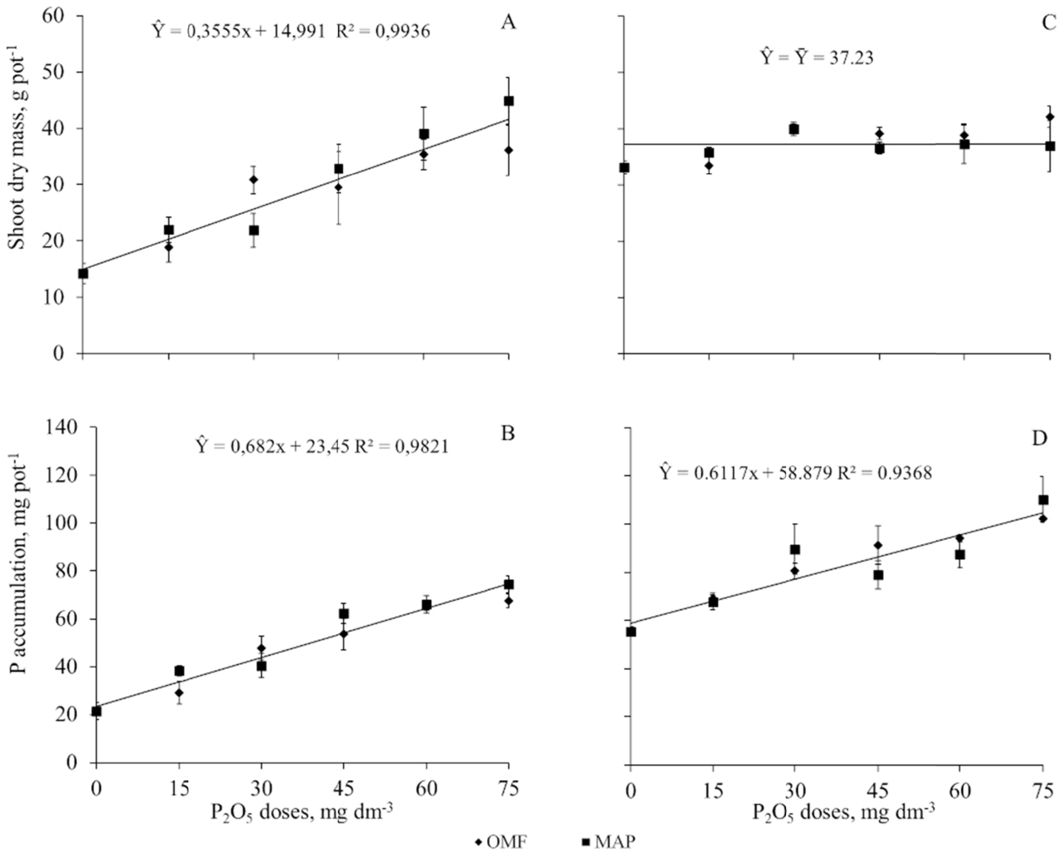

Figure 3. Effect of soil type, and phosphorus source and dose on the shoot dry mass (A and C) and phosphorus accumulation (B and D) of corn plants accumulated in four successive cultivation cycles in two Brazilian soils (Ferralsol: A and B and Planosol: C and D). Note. Values and error bars represent mean±MSE (mean standard error); OMF: organomineral fertilizer

Table 4 summarizes the analysis of variance for soil P content after the four successive crops. For Ferralsol, there was a significant effect for source, dose and source × dose interaction while for Planosol there was only significant effect for doses. The residual P content of the Ferralsol responded more dramatically increasing OMF rate than to increasing MAP rate (Figure 4), whereas that of the Planosol was unaffected by P source, although the available P increases with increasing dose. According to Sá et al. (2017), OMF from poltry litter had a greater immediate effect and promoted a higher dry matter yield in the first cultivation; however, the residual effects of the fertilizers did not differ in the other cultivations.

Table 4. Effect of phosphorus source and dose on the phosphorus contents of two soils after four sequential corn cultivations

Source of variation	DF	Medium square	
		Ferralsol	Planosol
Block	2	10.82^{**}	85.13^{o}
Source	1	27.15^{**}	28.82^{ns}
Dose	4	12.70^{**}	393.02^{**}
Source*dose	4	7.70^{**}	47.85^{ns}
Controls vs Factorial	1	4.23^{ns}	861.66^{**}
Residue	20	1.62	26.47
Coefficient of variation (%)		13.21	20.21

Note. **, * and ^{o}: significant at 1, 5 and 10% probability, respectively (F-test); ns: not significant at 5% probability.

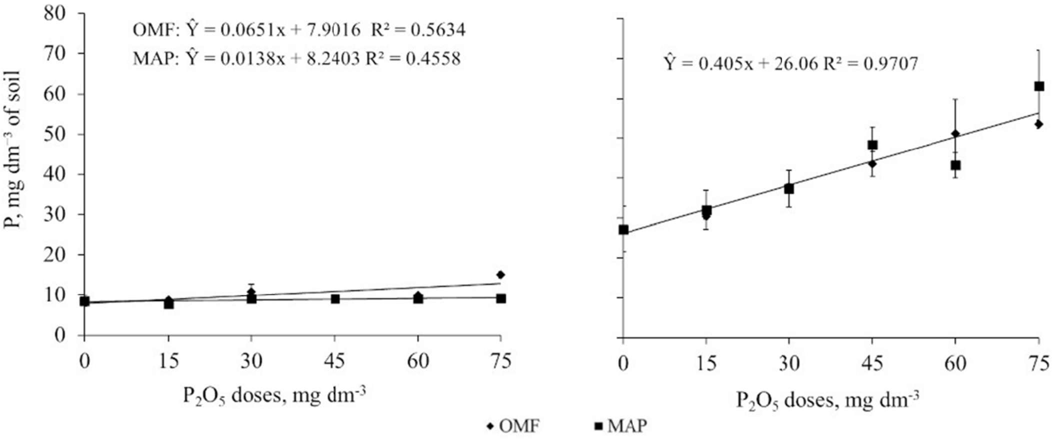

Figure 4. Effect of soil type and phosphorus source and dose on the accumulation of phosphorus in the soils (Ferralsol: left and Planosol: right) after four successive cultivation cycles of corn. Note. Values and error bars represent mean±MSE (mean standard error); OMF: organomineral fertilizer

Granular organomineral fertilizers contain large amounts of organic anions that could eventually compete for soil P colloid adsorption sites, which are abundant in tropical soils, especially those with clayey textures (Schmitt et al., 2018), and such competition can momentarily reduce P fixation. Since the P content of the Planosol used in the present study was initially much higher than that of the Ferralsol, this property may explain why statistical differences were only observed for P source in the Ferralsol.

Humic substances form most of the organic components of peat (Vasilevich et al., 2018) and are traditionally classified as highly stability and high-molecular-weight compounds (Wu et al., 2019). Thus, the P content of the OMF-fertilized soils may have reached their maximum after the four successive crop cycles because the P fraction of the OMF bound to organic matter and solubilized gradually, thereby yielding relatively lower soil P contents after the first two crop cycles.

Frazão et al. (2019) reported that, in highly weathered soils with high P adsorption capacities, OMF is as efficient as conventional soluble mineral fertilizers. However, in sandy soils with low P adsorption capacity, more-soluble sources tend to be more effective. In fact, Frazão et al. (2019) reported that there were no differences in the shoot dry matter production of corn plants fertilized with either OMF (produced with poultry litter) or triple superphosphate, when plants were grown in a clayey soil with high P-adsorption capacity. When the plants were cultivated in P-poor sandy soil, the dry matter production obtained by triple superphosphate fertilization (50 mg P kg^{-1} soil) was greater.

Carvalho et al. (2015), who evaluated the effect of organomineral and mineral fertilizers on the nutrition of olive trees, reported that fertilizer source failed to affect either leaf or soil nutrient content, and Benedito et al. (2010), who investigated the agronomic efficiency of various organomineral compounds in successive plantings of *Brachiaria*, found that plants that were only fertilized using peat did not develop well, owing to severe P deficiency during the second cultivation cycle. Thus, the enrichment of this organic source with P is very important for OMF production. Crusciol et al. (2020) concluded that OMF is suitable to supply sugarcane requirements and can completely replace mineral fertilizer. However, its influence on sugar yield is lower than on stalks yield. In addition, organomineral fertilizer efficiency in stalks and sugar yield is more pronounced in plant cane, being, on average, 96 and 113% more efficient than mineral fertilizer, respectively. Benites et al. (2022) showed that OMF is an efficient farm input that can be used for residue destination and nutrient recycling, especially in acid tropical soils.

4. Conclusions

The OMF and MAP fertilizers exerted similar effects on the dry matter production of corn shoots. However, the responses of dry matter production and P accumulation to increases in P dose were more pronounced in the Ferralsol, and when compared to OMF-fertilization. MAP-fertilization promoted higher P accumulation, but not dry matter production, in the first two crops of the Ferralsol. The OMF yielded greater residual effects on the soil P content of the Ferralsol, when compared to MAP. The OMF composed of chemically activated peat and MAP can replace MAP as phosphate fertilizer and maintain the same agronomic efficiency.

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