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Monoammonium phosphate coated with polymers and magnesium for coffee plants

Monoamônio fosfato revestido com polímeros e magnésio para plantas de café

Douglas Ramos Guelfi[1*], Wantuir Filipe Teixeira Chagas[1], Jordana Reis Lacerda[1], Rafael Mattioli Rezende Chagas[1], Taylor Lima de Souza[1], André Baldansi Andrade[1]

[1]Universidade Federal Lavras/UFLA, Departamento de Ciência do Solo/DCS, Lavras, MG, Brasil
[*]Corresponding author: douglasguelfi@dcs.ufla.br
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ABSTRACT

The coating of phosphate fertilizer granules with polymers and magnesium (Mg) is a technology that can improve phosphorus (P) use efficiency and mitigate problems of low Mg supply in coffee crops. The objective of this work was to evaluate the growth and nutrition characteristics of coffee seedlings and the agronomic efficiency (AE) of monoammonium phosphate (MAP) coated with anionic polymers and Mg in comparison with other phosphate fertilizer technologies. The experiment was carried out in a greenhouse in 20 L pots. Two five-month-old coffee seedlings were transplanted into each pot. The experimental design was completely randomized with three replicates. The following treatments, applied at a dose corresponding to 20 g pot^{-1} of P_2O_5, were carried out: MAP; MAP coated with anionic polymers (Policote Phós®); MAP coated with anionic polymers+Mg (Policote Phós_Mg®); Top-Phós®; and Agrocote®. A control (without P) was prepared. Plant height; leaf area; dry mass of leaves, stems, and roots; total dry mass; shoot/root ratio; specific leaf weight; P and Mg content in plants and their availability in the soil after cultivation and efficiency indicesof the phosphate fertilization treatment were evaluated. The recovery of applied P and the agronomic efficiency of phosphate fertilizers was found to increase in the following order: MAP = Top-Phós® = Agrocote®<MAP+Policote Phós® = MAP+Policote Phós_Mg®. The coating of the MAP+Policote Phós_Mg® granules increased growth, the content and accumulation of P and Mg in coffee seedlings, the availability of these nutrients in the soil after cultivation and the agronomic efficiency of phosphate fertilization.

Index terms: *Coffea arabica*; agronomic efficiency; fertilizer technologies; monoammonium phosphate; synergism.

RESUMO

O revestimento de grânulos de fertilizantes fosfatados com polímeros e magnésio (Mg) é uma tecnologia que pode melhorar a eficiência no uso de fósforo (P) e mitigar os problemas de baixo fornecimento de Mg em lavouras cafeeiras. O objetivo deste trabalho foi avaliar o crescimento e características nutricionais de mudas de café e a eficiência agronômica (EA) de fosfato monoamônico (MAP) revestido com polímeros aniônicos e Mg em comparação com outras tecnologias de fertilizantes fosfatados. O experimento foi conduzido em casa de vegetação em vasos de 20 L. Duas mudas de café com cinco meses de idade foram transplantadas para cada vaso. O delineamento experimental foi completamente casualizado com 3 repetições. Os seguintes tratamentos, aplicados na dose correspondente a 20 g vaso^{-1} de P_2O_5, foram conduzidos: MAP; MAP revestido com polímeros aniônicos (Policote Phós®); MAP revestido com polímeros aniônicos+Mg (Policote Phós_Mg®); Top-Phós®; e Agrocote®. Um controle (sem P) foi preparado. Altura da planta; área foliar; massa seca de folhas, caules, e raízes; massa seca total; razão parte aérea/raíz; peso específico da folha; teores de P e Mg em plantas e suas disponibilidades no solo após o cultivo e índices de eficiência dos tratamentos com adubação fosfatada foram avaliados. A recuperação do P aplicado e a eficiência agronômica dos fertilizantes fosfatados aumentaram na seguinte ordem: MAP = Top-Phós® = Agrocote®<MAP+Policote Phós® = MAP+Policote Phós_Mg®. O revestimento dos grânulos do MAP+Policote Phós_Mg® aumentaram o crescimento, o teor e acúmulo de P e Mg em mudas de café, a disponibilidade destes nutrientes no solo após o cultivo e a eficiência agronômica da adubação fosfatada.

Termos para indexação: *Coffea arabica*; eficiência agronômica; tecnologias de fertilizantes; fosfato monoamônico; sinergismo.

INTRODUCTION

In the main areas of coffee production in Brazil, problems related to the phosphorus (P) and magnesium (Mg) nutrition of plants are reported (Gransee; Fuhrs, 2013; Neto et al., 2016). These problems are due to factors related to soil-climatic conditions and soil fertility management (Guo et al., 2016). In general, Brazilian soils are naturally acidic and have a high retention capacity of P (Lopes; Guilherme, 2016) and a low natural availability of Mg (Melo et al., 2004; 2005).

On most coffee plantations, Mg is supplied by limestone, which has a variable concentration of MgO. Therefore, the choice and correct application of the Mg source is important because its solubility directly affects the efficiency of Mg use by the coffee crop.

Another condition that promotes reduced use of Mg by the coffee crop is application of high amounts of potassium (K) and calcium (Ca). Excess Ca and K promote an imbalance between these cations in the soil, consequently inhibiting Mg uptake due to negative or competitive interactions between these three plant nutrients (Shabala; Hariadi, 2005; Gransee; Fuhrs, 2013; Guo et al., 2016).

There are two types of interactions between nutrients: positive and negative. When the effects are adverse, i.e., in situations with high Ca and K application where Mg uptakeis inhibited, the interaction is called negative, competitive or non-competitive. When the interaction between nutrients improves plant growth, development and nutrition compared with its isolated application, the interaction is considered to be positive, as in the case of synergism between P and Mg. The main changes that nutrient interactions cause in plants occur in respiration, photosynthesis, cell division and growth, translocation of carbohydrates and organic acids and, consequently, crop yield (Fageria, 2001).

The efficient use of P and Mg in Brazilian coffee production is essential for adequate plant nutrition (Neto et al., 2016; Guo et al., 2016). Mg is part of the chlorophyll molecule, participates in the metabolism of carbohydrates and activates several enzymes, some of which are involved in the P-uptake process (Shaul, 2002; Shabala; Hariadi, 2005; Hermans et al., 2005; Cakmak; Kirkby, 2008; Cakmak, 2013; Silva et al., 2014). P is a component of macromolecules such as nucleic acids and is essential for sugar transport, energy storage and cell division and growth processes in plants (Marschner, 2012). Therefore, the positive interaction between P and Mg should be used to benefit plant nutrition to support the development of phosphate fertilizer technologies for coffee production.

The coating of phosphate fertilizers with anionic polymers with affinity for cations such as aluminum and iron may attenuate the adverse effects of soil P precipitation and increase the efficiency of phosphate fertilization (Chagas et al., 2015; 2016a; 2016b). Adding both Mg and anionic polymers to the coating may result in increased P uptake and coffee plant growth compared with other phosphate fertilizer technologies, such as resin-coated fertilizers, which decrease the rate of P released from the fertilizer granule to the soil (Huett; Gogel, 2000; Du; Zhou, 2006; Broschat; Moore, 2007; Sanders et al., 2012; Adams; Frantz; Bugbee, 2013).

The objective of this work was to evaluate the growth and nutrition characteristics of coffee seedlings and the agronomic efficiency of monoammonium phosphate (MAP) coated with anionic polymers and Mg in comparison with other phosphate fertilizer technologies.

MATERIAL AND METHODS

The experiment was carried out in a greenhouse at the Federal University of Lavras (Universidade Federal de Lavras - UFLA) in the Department of Soil Science between June 2015 and July 2016. Samples were collected from the B horizon of a clayey Red Latosol (Oxisol) located in the municipality of Lavras, Minas Gerais, Brazil. The soil collected wasthen air-dried, decanted, passed through a 2-mm mesh sieve, homogenized, characterized chemically and in terms of grain size (Ribeiro; Guimarães; Alvarez, 1999) (Table 1) and placed in plastic pots.

Table 1: Chemical and grain size characteristics of the soil.

pH	O.M.	P-rem	P	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H+Al	SB	BS
(H_2O)	gkg^{-1}	mgL^{-1}	---- $mgdm^{-3}$ ----		---------------- $cmol_cdm^{-3}$ ----------------					%
5.0	1.6	2.6	0.8	10	0.9	0.1	0.1	4.04	1.03	20.2
m	t	T	B	Cu	Fe	Mn	Zn	Clay	Silt	Sand
%	$cmol_cdm^{-3}$		-------------------- $mgdm^{-3}$ ------------------					--------- % -----------		
9.0	1.13	5.07	0.1	2.2	25.01	4.0	0.5	67	14	19

pH_{H2O} (ratio 1:2.5); organicmatter (O.M.): oxidation $Na_2Cr_2O_7$ 0.67 mol L^{-1} + H_2SO_4 5 mol L^{-1}; P-rem: Alvarez et al. (2000); P, K, Zn, Mn and Cu: extractant Mehlich-1; Ca^{2+}, Mg^{2+}, Al^{3+}: extractant KCl 1 mol L^{-1}; B: extractant hot water; (H+Al): extractant SMP; Sand, silt, clay: pipette method."T" is the potential cation exchange capacityat pH7; "t" is the effective cation exchange capacity (CEC_e); 'm' is aluminum saturation at CEC_e; and "BS" is base saturation. The values for an effective CEC (t), CEC at pH 7.0 (T) and the base saturation (BS %) and aluminum (m) rates were indirectly obtained using potential acidity, exchangeable bases and exchangeable aluminum values.

Before the coffee seedlings were transplanted, liming was carried out to raise the base saturation by 70% using acalcium carbonate and Mg mixture (analytical grade) with a Ca/Mg ratio of 4:1. The following doses were applied: 4.56 g Ca per pot and 1.11 g Mg per pot.

After the soil was incubated for 30 days, five-month-old coffee seedlings (*Coffea arabica* L., cultivar Acaiá IAC 474-19) were transplanted. The seedlings presented the third pair of true leaves and were produced from seeds that had been sown in washed and sieved sand.

The experimental plots consisted of pots containing 14 kg of soil and two coffee seedlings. The experiment was carried out with five phosphate fertilizers applied at doses of 20 g pot^{-1} of P_2O_5: MAP (11% N and 52% P_2O_5), MAP coated with Policote Phós® (10% N and 49% P_2O_5), MAP coated with Policote Phós_Mg® (9% N, 46% P_2O_5 and 1.6% Mg) Top-Phós® (3% N, 28% P_2O_5, 10% Ca and 6% S) and Agrocote® (9% N and 47% P_2O_5). A control treatment without P was included.

Two of the treatments consisted of MAP coated with Policote®, a product that is composed of soluble anionic polymers with 93.7% biodegradability. The function of Policote® is to decrease the activity of Fe^{2+} and Al^{3+}near the MAP granules and decrease the precipitation reactions of P with these cations. Another purpose of Policote® is to improve the physical and physicochemical characteristics of fertilizers by increasing hardness and reducing free acidity, hygroscopicity and the tendency of the fertilizer to form dust (Reis Junior; Silva, 2013).

All of the phosphate fertilizers were homogenized with the soil for the experimental plots on June 26, 2015. Maintenance fertilization was performed with 5.3 g of N+5.6 g of K per pot divided into three applications using ammonium sulfate and potassium chloride as the N and K sources, respectively.

During the entire experimental period, the soil moisture was maintained at 60% of the total pore volume (TPV) by weighing the pots and adding deionized water.

At 60 days after transplanting, foliar fertilization with 0.3% B and 0.3% Zn, applied in the form of boric acid and zinc sulfate, was carried out.

Evaluation of seedling growth occurred at 392 days after transplanting (July 22, 2016) by determining the following characteristics: A) leaf area (cm^2) estimated with a LI-COR leaf area meter, model LI-3000; B) shoot height (cm) measured from the root crown to the apical bud with a millimeter ruler; C) dry masses of leaves, stems and roots (g pot^{-1}) determined after incubation in a forced air oven at 75 °C until a constant weight was achieved; D) total dry mass (g pot^{-1}) obtained by summing the dry masses of leaves, stems and roots; E) ratio between shoot dry mass and root dry mass; and F) specific leaf weight, which is the ratio of total dry mass to leaf area expressed in mg cm^{-2}.

Two grams of the samples collected from leaves, stems and roots were removed for nitric-perchloric acid digestion followed by determination of the P and Mg contents (Malavolta; Vitti; Oliveira, 1997).

After removal of the coffee plants from each experimental plot, soil composite samples were collected from the whole pot with the aid of a sampler specific for pots (five simple samples per pot) to determine the availability of P (Mehlich-1) and exchangeable magnesium (Mg^{2+}) after cultivation of the coffee plants according to the methodology proposed in Ribeiro, Guimarães and Alvarez (1999).

The dry weights of the leaves, stems and roots and the P and Mg contents were used to calculate P and Mg accumulation with the following equation: Nutrient accumulation (g pot^{-1}) = Dry weight (g pot^{-1}) x Nutrient content (g kg^{-1}).

To calculate the efficiency of phosphate fertilization, the following index was used: Agronomic Efficiency (AE) = (Dry mass of the plants after treatment “x” (g pot^{-1}) - Dry mass of the plants in the control treatment)/Applied dose of P (g pot^{-1}) (Fageria; Santos; Moraes, 2010).

The experimental design was completely randomized with three replicates. The results were subjected to analysis of variance and regression when necessary, and treatment (fixed effect) means were compared using Tukey’s test ($p \leq 0.05$). All of the statistical procedures were performed with the SISVAR 5.3® software (Ferreira, 2011).

RESULTS AND DISCUSSION

The growth characteristics of coffee plants were influenced ($p \leq 0.05$) by phosphate fertilizers. The coating of the MAP with Policote Phós_Mg® increased the height, leaf area, dry mass of shoots and dry mass of roots of the coffee seedlings by 12.2 cm, 671.4 mm^2, 17.3 g and 6.5 g, respectively, when compared with MAP (Figure 1). For coffee seedlings that grew without P and Mg supplied by fertilizers, a decrease in growth was observed. In the control treatment, plant height, leaf area and total dry mass were reduced by 5.0 cm, 1018.9 mm^2 and 12.6 g, respectively, compared with seedlings fertilized with MAP (Figure 1).

The Top-Phós® and Agrocote® fertilizers did not promote improvements in the growth and development of coffee seedlings compared with MAP.

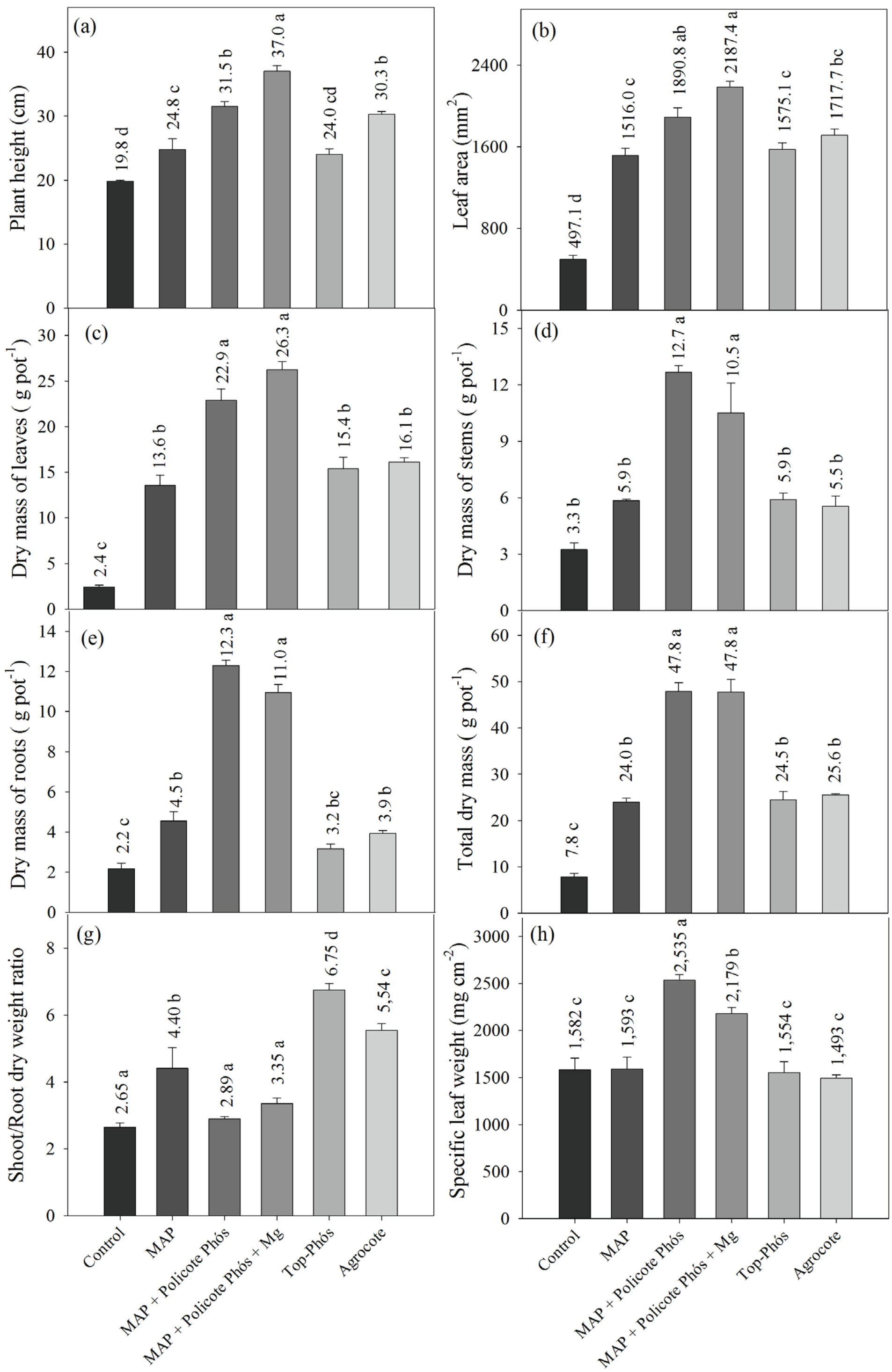

Figure 1: Plant height (a), leaf area (b), dry mass of leaves (c), stems (d) and roots (e), total dry mass (f), shoot/root ratio (g) and specific leaf height (h) of coffee seedlings fertilized with phosphate fertilizers. Bars marked with the same letters do not differ from one another by Tukey's test at the 5% significance level. The vertical bars represent the standard errors of the means (n = 3).

Chagas et al. (2016b) found that adding a coating composed of anionic polymers with Al^{3+} and Fe^{2+} retention capacity for decreasing P precipitation in the dissolution zone of the triple superphosphate granules promoted increased plant height, total dry mass and leaf area in coffee plants. The adequate P supply associated with the Mg in the MAP+Policote Phós_Mg® granules increased the plant height, total dry mass, leaf area, the shoot/root ratio and the specific weight of the coffee seedlings. This increase was likely caused by the synergism between P and Mg; P uptake is increased in the presence of Mg because Mg participates in phosphorylation (Vitti; Lima; Cicarone, 2006). Positive interactions between P and Mg are expected because Mg activates enzymes related to P uptake (Cakmak, 2013).Therefore, an adequate Mg supply is important for improving the efficiency of P used by coffee crops.

The fertilizers MAP+Policote®Phós and MAP+Policote Phós_Mg® promoted higher growth of the root system (Figure 1e) and a consequent decrease in the shoot/root ratio (Figure 1g) of coffee seedlings compared with MAP, Phós® and Agrocote® treatments. Coffee seedlings receiving P in the form of MAP, Top-Phós® and Agrocote® grew under greater limitation sin Mg availability compared with seedlings receiving MAP+Policote Phós_Mg®, resulting in an increase in their shoot/root ratios.

One of the initial effects of Mg deficiency in plants is an increased shoot/root ratio due to greater carbohydrate accumulation in the leaves. The photosynthesis rate is reduced, and the carbohydrates produced, even in reduced amounts, remain in the leaves and are not translocated to the root system, which promotes an increaseds hoot/root ratio due to reduced root growth and, consequently, less water and nutrient use (Cakmak; Kirby, 2008; Cakmak, 2013; Verbrugge; Hermans, 2013). In coffee seedlings of the Acaiá and Catuaí cultivars, higher shoot/root ratios were reported under Mg deficiency (Silva et al., 2014).

The specific leaf weight showed the following decreasing trend: MAP+Policote Phós®>MAP+Policote Phós_Mg®> MAP = Control = Top-Phós® = Agrocote® (Figure 2).

Specific leaf weight is related to the ability to translocate photoassimilates from the shoot to the rest of the plant (Scalon et al., 2006). A higher specific weight results in a more efficient translocation and greater seedling growth. Our results indicate the importance of taking advantage of the synergism that likely occurred between P and Mgin this study. These results may guide the phosphate fertilizer industry in producing new technologies.

The Mg content in the leaves, stems and roots was unaffected ($p> 0.05$) by the phosphate fertilizers (Figure 2). The Mg contentin the coffee seedlings' leaves, stems and root sranged from 2.00 to 3.09 g kg^{-1}, 3.50 to 3.70 g kg^{-1} and 1.60 to 2.67 g kg^{-1}, respectively (Figure 2).

When Mg was supplied together with P in the MAP, the coffee seedlings produced more dry mass (Figure 1) and had a greater accumulation of Mg (Figure 2) and P (Figure 3) in leaves, stems and roots.

The values of Mg and P accumulation in the plants fertilized with MAP+Policote Phós+Mg® were 128.0 mg pot^{-1} for Mg and 34.3 mg pot^{-1} for P; these values were 106% and 138% higher than MAP, respectively, and 474% and 535% higher than the control, respectively.

The P levels in the leaves, stems and roots were not influenced ($p> 0.05$) by the phosphate fertilizers (Figure3).

The P content in the coffee plants, leaves, stems and root sranged from 0.53 to 0.64 g kg^{-1}, 0.67 to 0.75 g $kg^{-1}$and 0.67 to 0.94 g kg^{-1}, respectively (Figure 3).

The Top-Phós® and Agrocote® fertilizers promoted Mg and P accumulation to similar levels as MAP but to lower levels than MAP+Policote Phós® and MAP+Policote Phós_Mg®.

In another work on soils with low P availability (8 mg dm^{-3}), P levels in the new and old leaves, stems and roots in 21 *Coffea Arabica* cultivars were 1.06, 0.74, 0.49 and 0.53 g kg^{-1}, respectively. Under high P availability (120 mg dm^{-3}), these values were 1.93, 1.46, 0.99 and 0.84 g kg^{-1} for the new leaves, old leaves, stems and roots, respectively (Neto et al., 2016). Chagas et al. (2016b) found that leaf P content varied between 0.7 and 1.3 g kg^{-1} after applying P_2O_5 doses (0 to 20 g pot^{-1}) in the forms of triple superphosphate (TSP) and anionic polymer-coated TSP to coffee seedlings.

The availability of $P_{Mehlich-1}$ and Mg^{2+}in the soil after harvesting the coffee seedlings was influenced by the phosphate fertilizer technologies used (Figure 4).

The initial availability of $P_{Mehlich-1}$ and Mg^{2+}in the soil was 0.8 mg dm^{-3} and 0.1 $cmol_c dm^{-3}$, respectively (Table 1). After application of phosphate fertilizers and cultivation of coffee seedlings, there was an increased availability of these nutrients in the soil (Figure 4). The greater P availability after cultivation occurred with all of the phosphate fertilizers applied.

Improvement in the efficiency of P use with the application of Policote Phós_Mg® (Figure 5) promoted greater availability of $P_{Mehlich-1}$ (61.3 mg dm^{-3}) and Mg^{2+} (0.37 $cmol_c$ dm^{-3}) in the soil after cultivation of coffee seedlings.

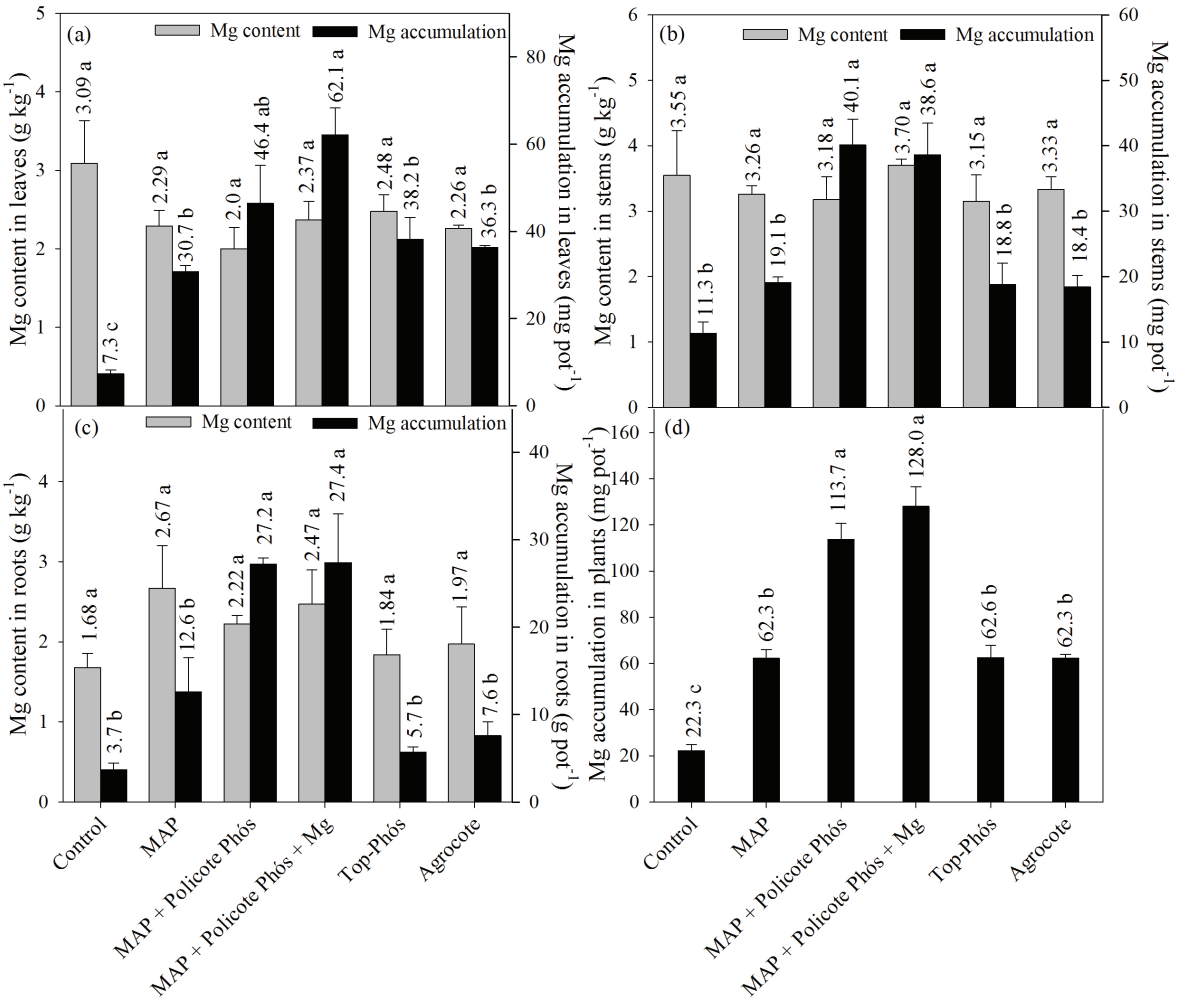

Figure 2: Mg content and accumulation in leaves (a), stems (b), roots (c) and plants (d) in coffee seedlings fertilized with phosphate fertilizers. Bars marked with the same letters do not differ from one another by Tukey's test at the 5% significance level. The vertical bars represent the standard errors of the means (n = 3).

Precovery (PR) and AE of phosphate fertilization followed the same increasing trend: MAP (10.2% and 0.81 g dry mass per g applied P, respectively) = Top-Phós® (12% and 0.83 g dry mass g^{-1} applied P, respectively) = Agrocote ® (14.2% and 0.89 g dry mass g^{-1} applied P, respectively)>MAP+Policote Phós® (30.0% and 2.0 g dry mass g^{-1} applied P, respectively) = MAP+Policote Phós_ Mg® (32.9% and 2.0 g dry mass g^{-1} applied P, respectively).

The increased growth of the root systems of the coffee plants fertilized with MAP+Policote Phós® and MAP+Policote Phós_Mg® (Figure 1e) was also important for improving the efficiency of P use. Adequate Mg supply in the MAP coating helps to reduce the limitations related to low Mg availability that can occurin soils worldwide, which may increase the efficiency of P use in agriculture.

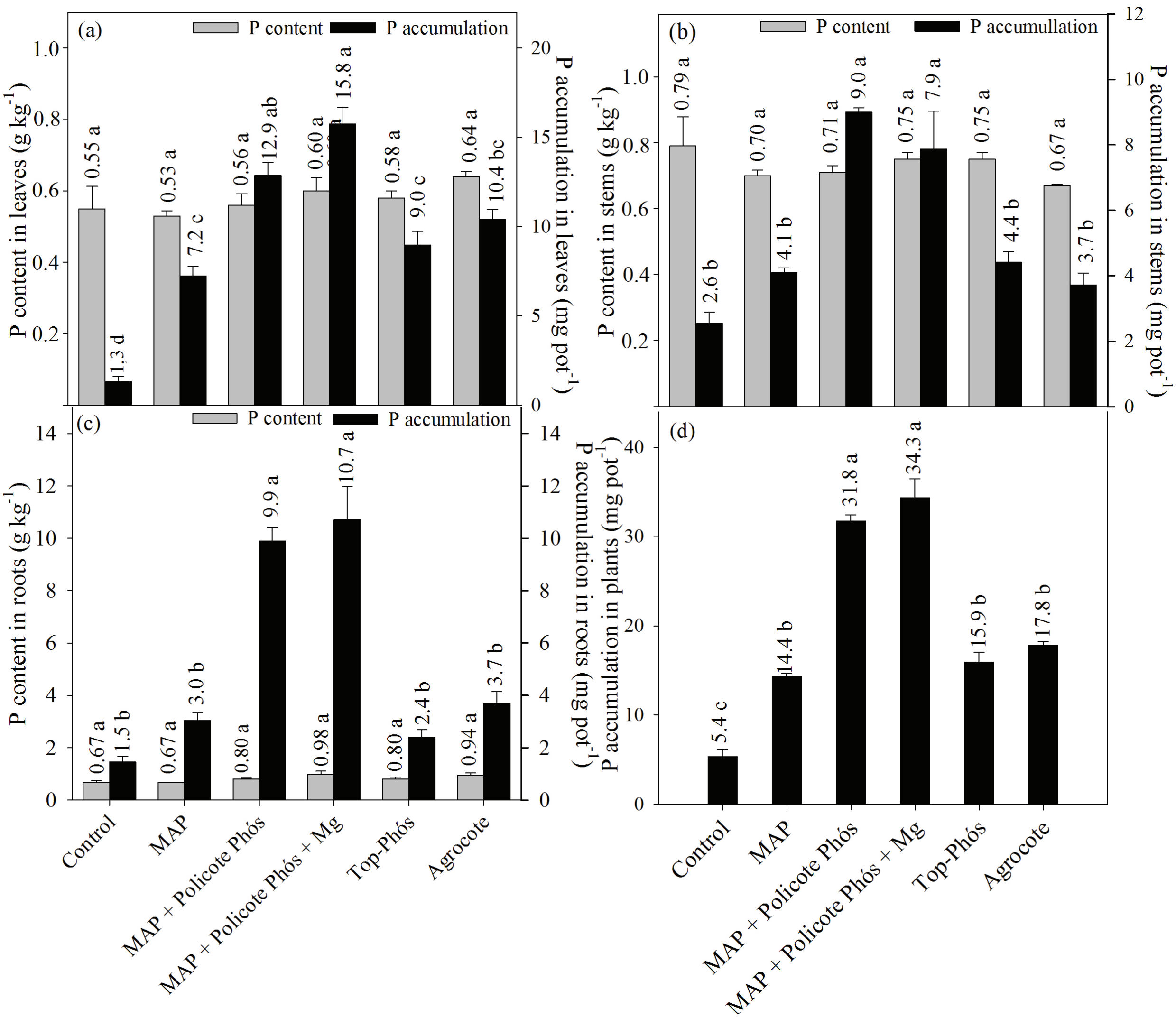

Figure 3: P content and accumulation in leaves (a), stems (b), roots (c) and plants (d) in coffee seedlings fertilized with phosphate fertilizers. Bars marked with the same letters do not differ from one another by Tukey's test at the 5% significance level. The vertical bars represent the standard errors of the means (n = 3).

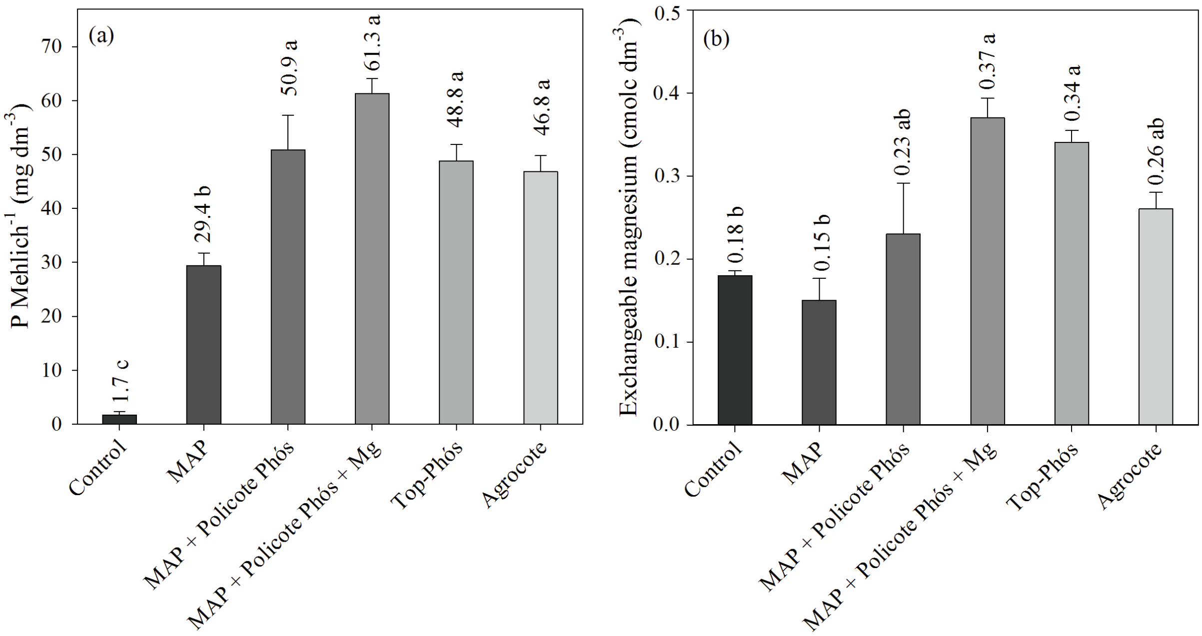

Figure 4: Available $P_{Mehlich-1}$ (mg dm^{-3}) (a) and Mg^{2+}in the soil (cmolc dm^{-3}) (b) after cultivating the coffee seedlings fertilized with phosphate fertilizers. Bars marked with the same letters do not differ by Tukey's test at the 5% significance level. The vertical bars represent the standard errors of the means (n = 3).

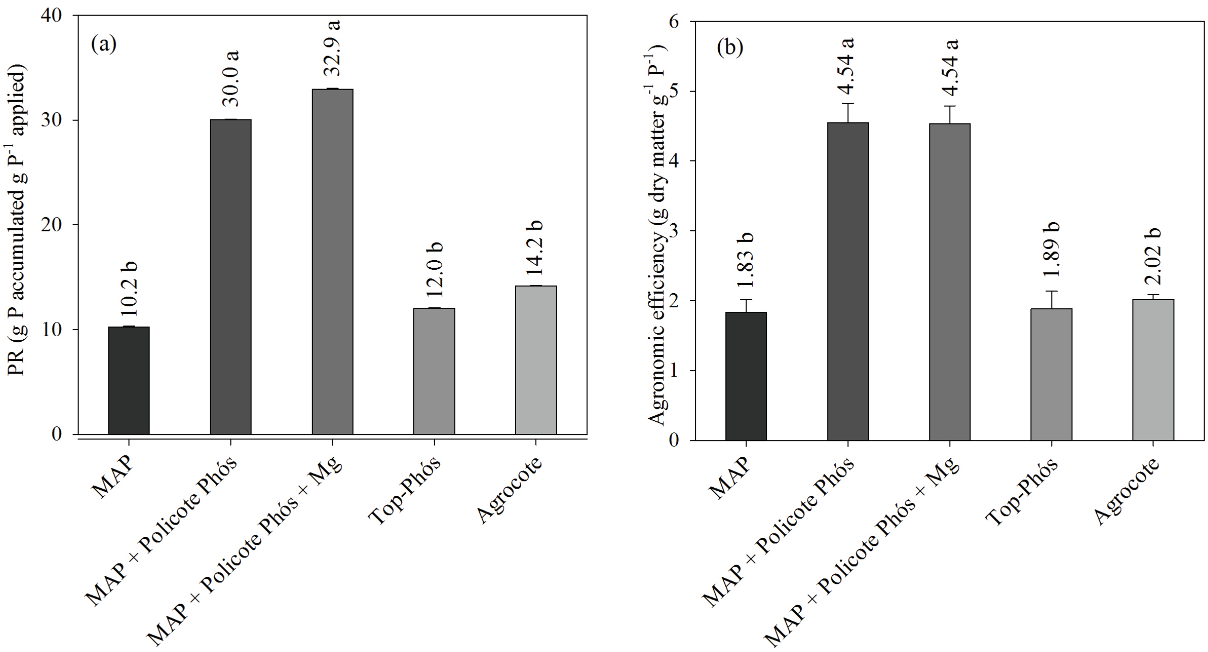

Figure 5: P recovery (PR) (a) and AE (b) of phosphate fertilizers applied to coffee seedlings. Bars marked with the same letters do not differ by Tukey's test at the 5% significance level. The vertical bars represent the standard errors of the means (n = 3).

CONCLUSIONS

The P recovery and AE of the phosphate fertilizers increased in the following order: MAP = Top-Phós® = Agrocote®<MAP+Policote Phós® = MAP+Policote Phós_Mg®. The coating of MAP with Policote Phós® or Policote Phós_Mg® promotes improvement in the growth, nutritional characteristics and efficiency of P use in coffee seedlings.

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