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Phosphorus use efficiency in maize as a function of different sources

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Abstract

The objective of this study was to evaluate the initial growth of maize plants and phosphorus use efficiency due to phosphate fertilization with or without polymer coating for controlled nutrient release. The experiment was conducted in a greenhouse. Ten treatments were accomplished under a 5 x 2 factorial scheme, with five doses of phosphorus and two types of monoammonium phosphate (MAP), with and without polymer coating. The experimental design consisted of three maize plants grown in a 5 liter plastic pot. The study was conducted for 30 days when the phosphorus content, dry matter production and nutrient use efficiency were measured in the plant. The data obtained were submitted to analysis of variance by the F-test at 5% probability, the quantitative data were submitted to regression analysis according to the doses, and the qualitative data according to the source by the Tukey test. The plants fertilized with conventional MAP had averages higher than the ones fertilized with polymer-coated MAP at 50, 150 and 200 mg doses of P dm^{-3} soil. The initial growth of maize plants was higher when they were fertilized with conventional MAP. The efficiency in P use did not increase with the polymer-coated source, but decreased with doses of both sources

Keywords: *Zea mays* L., monoammonium phosphate, absorption, nutritional efficiency.
Abbreviations: DAE_ days after emergence; DM_ dry matter; MAP_ monoammonium phosphate; NUE_ nutrient use efficiency.

Introduction

Maize (*Zea mays* L.) is one of the most important cereals grown and consumed in the world given its great yield potential, adaptability to different environmental conditions and nutritional value. In Brazil, about 79 million tons of grains are produced with yields reaching 14 tons per hectare in experimental conditions. These results reflect investments in technology combined with the use of cultivars with great potential productive stability (Forsthofer et al., 2006; Cruz, 2013; CONAB, 2012).

One of the determining variables in achieving high yields is the supply of nutrients, among which phosphorus (P) stands out. Phosphorus is essential in the plant for photosynthesis, respiration and energy transfer. Phosphorus use efficiency in maize fields is critically important, since this nutrient constitutes one of the most limiting factors to production (Coelho et al., 2009).

Overall, the soils of tropical regions are characterized by high variation of weather conditions and low levels of phosphorus in the form available to plants (Barroso and Nahas, 2008). In this case, the lack of phosphorus is due to strong interaction of this nutrient with soil colloids, which causes high setting and low availability (Corrêa et al., 2008; Costa et al., 2009). As a result, ensuring proper phosphorus concentration for the development of species grown in weathered soils may be the most important factor contributing to increase in production costs. The high adsorption power of these soils requires a greater amount of nutrient to be applied per unit of dry matter produced, causing the soil to establish strong competition with the plant for the phosphorus available in solution (Corrêa et al., 2008). To improve fertilization efficiency, formulas with gradual nutrient release were developed, which help reduce the losses that normally occur with the use of monoammonium phosphate (MAP), allowing for lower fertilizer dosage without effects on crop yields. Among such formulas is gradual-release polymer coating.

The polymers used in the coating are monomers that have carbon and hydrogen in their chemical structure. Some have their release controlled by humidity, others by temperature. The purpose of adopting this technology is to reduce losses by adsorption, surface runoff, volatilization and leaching, through the gradual release of the element, making the applied phosphorus more available to plants (Withers et al., 2014).

However, in some cases the use of slow release phosphate fertilizer did not yield satisfactory results. Rather, it produced results similar to those with conventional fertilizer (Silva et al., 2012) and impaired the development of some crops (Malhi et al., 2001). Such contrasting information has raised the interest of researchers in polymer-coated fertilizers.

Thus, the objective of this study was to evaluate the initial growth and phosphorus use efficiency by maize plants fertilized with two sources of phosphate, gradual release polymer-coated or conventional.

Results and Discussion

Phosphorus content

The phosphorus content accumulated in the plants was influenced by both the doses and the sources, and significant interaction was observed of the two factors on this variable (Fig.1). The interaction observed indicates that the sources did not perform in the same way according to the phosphorus doses applied. The interaction started from the 150 mg P dm^{-3} dose and the conventional MAP source was higher higher than the polymer-coated MAP. The mean values obtained with conventional MAP were also higher than those of the polymer-coated MAP (Table 1).

These results may be related to the fact that when the uncoated source is added to the soil, it makes nutrients available more quickly, increasing the concentration and facilitating nutrient absorption by the root system. In this case, the speed in releasing phosphorus occurs because the conventional MAP is more soluble compared to the slow release polymer-coated MAP, which is less soluble. Furthermore, the greater the amount of phosphorus available in the soil, the higher the element concentration gradient, which saturates the adsorption surfaces thus increasing P content in the plant (Bastos et al., 2010). Another explanation would be the increase in base saturation after soil incubation with treatment. The pre-liming of acidic soils, besides providing an increase in pH and base saturation, promotes the neutralization of aluminum and a great amount of iron and manganese, reducing the phosphorus setting capacity and providing increased fertilizer efficiency (Prochnow et al., 2004). Gazola et al. (2013) points out that in the case of phosphorus, a simple practice such as liming would be effective in reducing its problem of high soil adsorption and slow release fertilizer would not be required for this nutrient. For Jarosiewicz and Tomaszewska (2003) the efficacy of coated fertilizers relies on the solubility of the polymer that coats the granules. Moreover, the thickness and chemical nature of the coating resin, number of surface microcracks and fertilizer granule size determine the rate of nutrient release over time (Girardi and Mourão Filho, 2003).

Corroborating Jarosiewicz and Tomaszewska (2003), the study by Chagas et al. (2016) reported that higher phosphorus accumulation in onion bulb was obtained with the use of polymer-coated triple superphosphate. The source KIM COAT (LGP) presented no difference compared to conventional MAP. However, in the study by Gazola et al. (2013), MAP coated forms did not differ from conventional MAP in phosphorus release efficiency and levels of this nutrient in maize plants.

In maize cultivation, Valderrama et al. (2011) observed that increasing doses influenced the phosphorus content in the plant, fitting the quadratic equation and peaking at the application of 127 kg ha^{-1} de P_2O_5. Prado et al. (2001), worked with increasing doses of phosphorus up to 135 kg ha^{-1} de P_2O_5 and also found positive effect for the phosphorus levels in maize plants.

Dry matter production

In the dry matter accumulation by the maize plants, there was no difference between the use of MAP with and without polymer coating (Fig. 2). The plants fertilized with conventional MAP had averages higher than the ones fertilized with polymer-coated MAP at 50, 150 and 200 mg doses of P dm^{-3} soil. The mean DM values obtained with conventional MAP, 6.31 g $plant^{-1}$, were also higher than the polymer-coated MAP, 2.81 g $plant^{-1}$ (Table 1). The data were adjusted linearly, indicating that the doses tested in the two sources were not sufficient to meet the demand of the plants (Fig. 2). The increased phosphorus absorption by the plants fertilized with conventional MAP (Fig. 1) may have been responsible for better nutrition, ensuring higher initial growth of maize plants (Fig. 2). However, Gazola et al. (2013) found that the polymer-coated MAP showed the same residual effect as the conventional MAP, because they provided results similar to the evaluations of irrigated maize. Regarding phosphorus levels, the maize crop responses are generally positive with respect to increase in dosage. Silva el al. (2014) observed linear increase in grain productivity up to the 120 kg ha^{-1} P_2O_5 dose. Veloso et al. (2005) found response in shoot dry matter up to the 150 mg kg^{-1} P dose in all the studied maize cultivars.

Brasil et al. (2007), while studying the influence of phosphorus in nutrient solution on dry matter in eight maize genotypes, also found that higher phosphorus concentration promoted higher dry matter accumulation. Corrêa et al. (2008) and Bastos et al. (2010) obtained similar results; the increase in doses of phosphate fertilizers caused proportional increase in dry matter production by maize plants. In the study by Cruz et al. (2009), the increase in dry matter production by sorghum plants was due to the increase in phosphorus levels.

Nutrient utilization efficiency

No differences were observed for nutrient utilization efficiency (NUE) among the tested sources and between the phosphorus concentrations in the soil (Table 1), i.e. even with increasing phosphorus availability and regardless of the source, the maize reduced linearly the efficiency rate, from 0.7 to 0.4 g DM per mg phosphorus (Fig. 3). These results agree with those of Corrêa et al. (2008) in maize crops and Chagas et al. (2015) in two lettuce crops, who observed a reduction in phosphorus use efficiency with dosage increases. However, Chagas et al. (2015) found increased phosphate efficiency with polymer-coated MAP fertilizer in both lettuce crops, improving residual phosphorus used, but not for onions (Chagas et al., 2016). However, increased nutrient availability and the source used are not the only factors that can alter the efficiency rate. Another important factor would be the cultivar intrinsic characteristics. According to DoVale and Fritsche-Neto (2013) and Chen et al. (2009), maize cultivars show variation in the phosphorus use efficiency rate in tests conducted both in nutrient solution and in the field.

Materials and Methods

Experimental site

The experiment was conducted in a greenhouse at Goiás State University (UEG), Ipameri Campus, Municipality of Ipameri, GO, Brazil. The soil was classified as Red Yellow Latossol (Ferralsol) (EMBRAPA, 2013), with average texture. Soil samples were collected which were used for the chemical characterisation (Table 2).

Experimental procedure and treatments

There were ten treatments in 5 x 2 factorial scheme with five P doses (0, 50, 100, 150 and 200 mg P dm^{-3} soil) and two types of monoammonium phosphate (MAP), with and without polymer coating, in a total of 30 plots. The experimental

Table 1. Phosphorus content, dry matter (DM) and nutrient utilization efficiency (NUE) by maize plants at 30 days after emergence (DAE), fertilized with polymer-coated MAP or conventional MAP.

Treatments	P Content	Dry Matter	NUE
	___mg plant^{-1}___	___g plant^{-1}___	___g DM mg P^{-1}___
A - Polymer-coated MAP	5.34 b	2.81 b	0.62 a
B - Conventional MAP	12.66 a	6.31 a	0.57 a
DMS	2.53	1.10	0.06
C.V. %	36.9	31.7	13.0

Means followed by the same letters do not differ by Tukey's test ($p<0.05$).

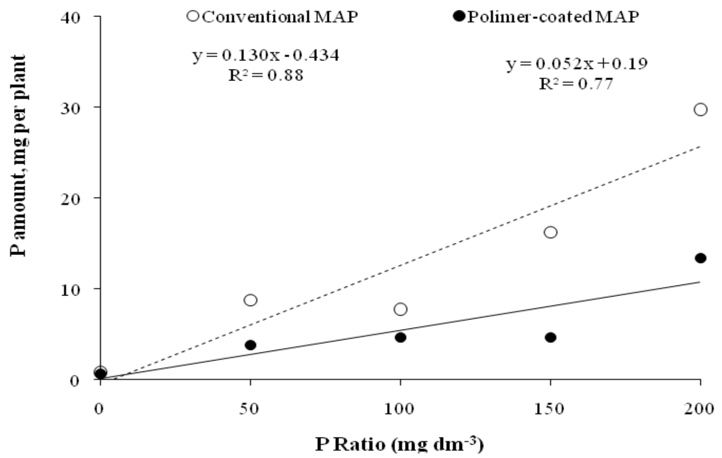

Fig 1. Phosphorus content accumulated by maize plants at 30 days after emergence (DAE), fertilized with polymer-coated MAP or conventional MAP.

Table 2. Chemical attributes of the soil used in the study.

pH ($CaCl_2$)	V	OM	P (Mel.)	S	Ca	Mg	K	T
	%	______mg dm^{-3}	_______		___________	cmol$_c$ dm^{-3}	___________	
4.4	28	17.0	1.5	2.8	0.8	0.6	0.22	5.8

V –Base saturation; OM –Organic matter; Mel. – Extractor Mehlich-1; T –Cation exchange capacity.

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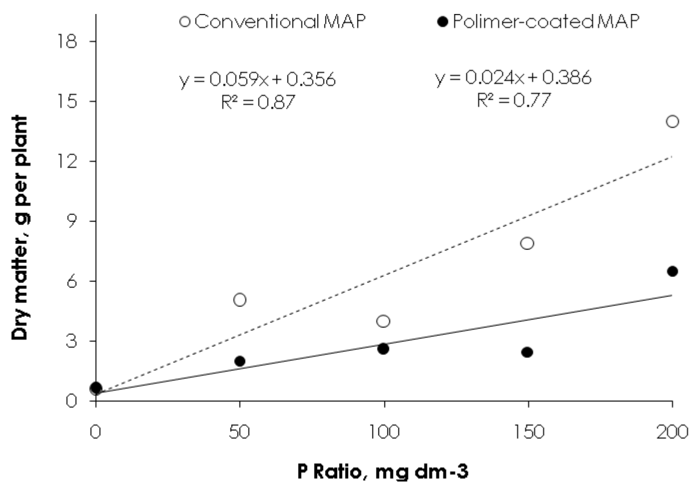

Fig 2. Dry matter accumulated by maize plants at 30 days after emergence (DAE), fertilized with two sources of MAP with and without polymer coating.

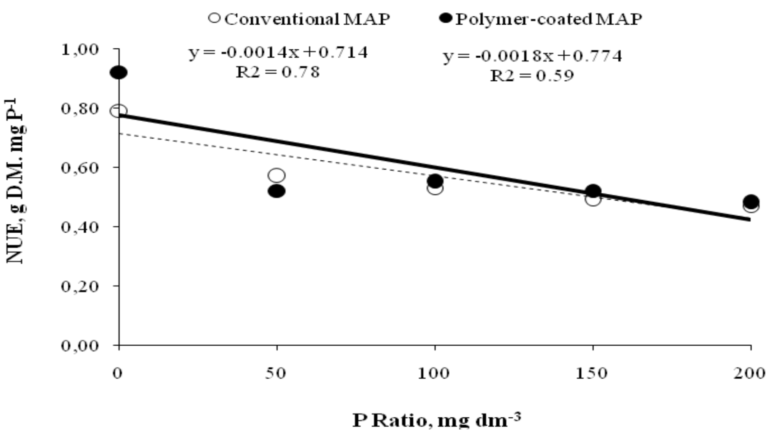

Fig 3. Nutrient utilization efficiency (NUE) rate by maize plants 30 days after emergence (DAE), fertilized with two sources of MAP, with and without polymer coating. D.M.= Dry matter.

experimental plot was made up of three maize plants grown in a plastic pot with 5.0 dm^3 soil capacity. The soil acidity was corrected, by incubating for 30 days in plastic pots with the respective $CaCO_3$ dose, and moisture was corrected to 32%. This moisture level was maintained throughout the experimental period. The nitrogen (N) content was adjusted taking into consideration the amount provided by MAP so that all the treatments had the equivalent of applying 120 mg N dm^{-3} soil, using urea. For potassium (K) a dose of 120 mg K_2O dm^{-3} soil was applied, and potassium chloride was used as a K source. The NPK doses were incorporated into the soil and then maize was sown, six seeds per pot, on 10 October 2012. After seedling emergence, the plants were thinned and only 3 seedlings per pot were left.

Measurements

The experiment was conducted for 30 days, when the plants were evaluated for phosphorus content, dry matter production (DM), and nutrient use efficiency (NUE). For this purpose, the three plants that formed the plot were collected. Then the plant material (root + shoot) was chopped, weighed and dried in an oven with forced ventilation at 65ºC for 72 hours. After determining the dry matter mass per plant, the plants were ground, and the quantity of phosphorus in the dry matter was measured after nitric-perchloric digestion by metavanadate colorimetrics (Malavolta et al., 1989). The phosphorus use efficiency was determined by the NUE index given by the ratio between the amount of dry matter and nutrient content accumulated in the tissues (g DM mg^{-1} P).

Data analysis

The data were submitted to analysis of variance by the F test at 5% probability, the qualitative data according to the source by the Tukey test, and the quantitative data were submitted to regression analysis in relation to dosage. The model with the greatest regression coefficient, significant at 5% probability by the F-test, was chosen from among the linear and quadratic models.

Conclusion

The initial growth of the maize plants was higher when they were fertilized with MAP without polymer coating (conventional). P use efficiency did not increase with polymer-coated source, but decreased with doses of both sources.

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