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Enhanced efficiency of phosphorus fertilizer in soybean and maize

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Abstract

Soybeans and maize are the most cultivated crops in tropical soils and require large amounts of phosphate fertilizers. The use of enhanced-efficiency fertilizers is a promising technology to minimize losses of P by fixation in highly weathered tropical soils. The objectives of this study were to evaluate morphological characteristics, soybean P and boron foliar content, yield and agronomic efficiency of P fertilizer in response to P rates and sources in maize and soybean crops. Two P fertilization experiments with the sources Mono-ammonium Phosphate (MAP) and Policote coated MAP were carried out, one in maize (0, 20, 40, 80, 120 and 160 kg P_2O_5 ha^{-1}) and another in soybean crop (0, 20, 40, 80 and 120 kg P_2O_5 ha^{-1}). The morphological characteristics, soybean P and boron foliar content, yield and agronomic P fertilizer efficiency were evaluated. The results showed that maize and soybean morphological characteristics, as well as soybean foliar P and boron contents were not influenced by fertilization. P fertilization increased soybean yield. Policote coated MAP was more efficient than MAP (conventional fertilizer) to produce higher maize and soybean yields and higher agronomic efficiency of P use. For higher productivity, we recommend the dose of 102.9 kg P_2O_5 ha^{-1} of Policote coated MAP for soybean and 97.6 kg P_2O_5 ha^{-1} for maize.

Keywords: Enhanced efficiency fertilizers, *Glycine max*, *Zea mays* L., Policote.
Abbreviations: MAP_Monoammonium Phosphate; APE_Agronomic P Efficiency.

Introduction

Plants do not complete their productive cycle without phosphorus (P) because P is an important nutrient for plant energy storage process and for structural integrity (nucleic acids, phospholipids) (Taiz and Zeiger, 2010). It is common to use high doses of P in tropical soils such as Brazil, because they have high sorption capacity of phosphate. Most of the fertilizer-derived phosphorus either becomes fixed, or unavailable to the plants (Kochian, 2012). Less than 0.1% of total P is found in the soil solution as free orthophosphate ion (Fardeau, 1996). The intense P fixation into the soil results in low P content available to plants, especially in the soils with sesquioxides minerals (Büll et al., 1998; Novais and Smyth, 1999).
Low P availability in agriculture on tropical soils is a strong impediment to achieve high yields. Due to the low natural P availability in tropical soils and the plants' need for P, the use of P fertilizers is an important tool for achieving high yields. However, P fertilizer is dependent on non-renewable sources (phosphate rocks), represents an increasing percentage of agricultural cost production and has low use efficiency in agriculture, an unsustainable situation.
Low P fertilizer efficiency has been reported (Dorahy et al., 2008; Takashi and Anwar, 2007; Murphy and Sanders, 2007). According to Shen et al. (2011), the low availability of P is due to slow diffusion and high fixation in soils. The adsorption/ desorption and precipitation/dissolution equilibria control the concentration of P in the soil solution and, consequently, the bioavailability and chemical mobility (Hinsinger, 2001). This low P fertilizer efficiency is common in Brazilian Cerrado savanna, whose soils have high acidity, high aluminum saturation and low bases saturation.
The United Nations estimates that global population will increase 33% by 2050, from 7.2 billion today to 9.6 billion people (Nalley et al., 2017). Therefore, improving the fertilizer use efficiency is important to increase food supply, economy and environment safety, justifying the need for further studies in the area of agricultural systems.
Several strategies have been used to increase the efficiency of P fertilization. Among them, the use of enhanced efficiency P fertilizers has been studied more often recently. Those fertilizers contain aggregate technologies that control the release of nutrients or stabilize their chemical transformations in the soil, increasing their availability to the plant. Such characteristics minimize the potential for nutrient losses to the environment when compared to conventional fertilizers (Urrutia et al., 2014; Giroto et al., 2017).
This type of technology has long been used in nitrogen fertilizers, but its use in P fertilizers is small. One of the strategies used in enhanced efficiency nitrogen fertilizers is the use of inhibitors such as NBPT (*N*- (*n*-butyl) thiophosphoric triamide) to control the hydrolysis of urea to

ammonia gas in the soil (San Francisco et al., 2011). A similar strategy could be applied with additives of iron and aluminum affinity (responsible for the fixation of phosphorus in the soil) in P fertilizers, increasing its agronomic efficiency. Reis Jr and Silva (2012), Chagas et al. (2015), Chagas et al. (2016) carried out studies on P fertilizer coated with anionic polymers (Policote) that reduce the activity of iron and aluminum to evaluate the efficiency of P fertilization. The need to increase the efficiency of P fertilization and the lack of information about enhanced efficiency P fertilizer justifies studies to evaluate the performance of this kind of fertilizers.
The aims of this study were to investigate the effect of the Mono-ammonium Phosphate coated with anionic polymers (Policote) over the nutrition, agronomic efficiency, production and yield components of the maize and soybean crops and P fertilizer as a function of fertilizer doses.

Results and discussion

Development and production components of maize crop

Stalk diameter, plant and ear height, ear diameter and length, number of row/ear ratio, number of grain/row ratio, number of grains/ear ratio, mass of 1000 grains and plant shoot fresh and dry mass were not significantly influenced by P fertilization, whose average values were 1.86 m, 2.35 m, 1.26 m, 50.8 mm, 16.2 cm, 15.3, 499.3, 32.9, 321.9 g, 45,900 kg ha^{-1} and 37,800 kg ha^{-1}, respectively. For this same maize hybrid, Vieira et al. (2015) reported plant height (2.85 m) higher than that found in this study.
Maize yield was significantly influenced by treatments ($p <0.01$), P rates ($p <0.01$) and P sources ($p <0.01$). Maize yield increased from 5,736 kg ha^{-1}, without P fertilization, up to 8,730 kg ha^{-1}, using the MAP at 104.0 kg P_2O_5 ha^{-1}, while the use of Policote coated MAP presented the maximum yield of 11,370 kg ha^{-1}, with 97.6 kg P_2O_5 ha^{-1} (Fig 1a). The maximum yield that obtained using Policote coated MAP was 30.2% higher than that obtained with MAP. Phosphorus rate recommended for maize in this experiment was 100 kg ha^{-1} of P_2O_5 for an expected yield about 8,000 kg ha^{-1} (CFSEMG, 1999). A yield of 8,726 kg ha^{-1} was obtained using 100 kg ha^{-1} of P_2O_5 and MAP, while using the same P rate and Policote coated MAP produced 11,367 kg ha^{-1}, an increase of 30.2%. Better results for plant height and wheat yield with polymers coated fertilizers were also reported by Zhang et al. (2006) and Ali et al. (2017). To obtain 8,730 kg maize ha^{-1}, 104 kg P_2O_5 ha^{-1} (MAP) or 29.8 kg P_2O_5 ha^{-1} of Policote coated MAP were necessary. Lower P rates using polymer coated P fertilizer than conventional P fertilizer were also reported by Ali et al. (2017) to achieve the same yield.
Agronomic P Efficiency (APE) was also significantly influenced by P fertilization ($p <0.01$). Increasing P rates reduced APE (Fig 1b). Average APE with Policote coated MAP was 70.0% higher than that observed using MAP. Higher APE with Policote coated MAP explains higher yields obtained with this enhanced efficiency P fertilizer.

Development and production components of soybean crop

Leaf P and boron contents, plant height, number of internodes/plant ratio, number of pod/plant ratio, mass of 1000 grains and plant shoot dry mass were not significantly influenced by P fertilization, whose average values were 3.21 g kg^{-1}, 51,9 mg kg^{-1}, 59.4 cm, 15.3, 51.7, 175.5 g and 14.688 kg ha^{-1}, respectively. These average leaf P and boron contents are classified as "sufficient" and "high", respectively (Embrapa Soja, 2013).
Soybean yield was significantly influenced by treatments ($p <0.01$), P rates ($p <0.01$) and P sources ($p <0.01$). Soybean yield was increased from 2277 kg ha^{-1}, without P fertilization, up to 3038 kg ha^{-1}, using the MAP at 120 kg P_2O_5 ha^{-1}. Application of Policote coated MAP presented the maximum yield of 3611 kg ha^{-1}, with 102.9 kg P_2O_5 ha^{-1} (Fig 2a). The maximum yield was obtained using Policote coated MAP, which was 18.8% higher than that obtained with MAP. Phosphorus rate recommended for soybean crop in this experiment was 90 kg P_2O_5 ha^{-1} (Embrapa Soja, 2013). Soybean yield with 90 kg P_2O_5 ha^{-1} and MAP was 2,968 kg ha^{-1}, while using the same P rate and Policote coated MAP it was 3595 kg ha^{-1}, an increase of 21.1%
To obtain 3038 kg soybean ha^{-1}, 120 kg P_2O_5 ha^{-1} was necessary using MAP or 28.3 kg P_2O_5 ha^{-1} using Policote coated MAP. Lower P rates using polymer coated P fertilizer than P rates using conventional P fertilizer achieved the same yield (Ali et al., 2017).
Agronomic P Efficiency (APE) was also significantly influenced by P fertilization ($p <0.01$). Increasing P rates reduced APE (Fig 2b). Higher APE with Policote coated MAP explained higher yields obtained with this enhanced efficiency P fertilizer. The APE increase by applying Policote coated P fertilizer was also observed by Chagas et al. (2015), Chagas et al. (2016) and Guelfi et al. (2018), in lettuce and coffee crops, respectively.

Materials and methods

Two field experiments were carried out in 2014 using a randomized block design, with four replications, one in the maize crop and the other in the soybean crop.

Maize crop, site description and soil classification

The experiments were laid out at experimental farm of State University of Goiás (Ipameri, GO, Brazil) at a Red-Yellow Dystrophic Latosol (Embrapa, 2006), with 575 g kg^{-1} clay, 75 g kg^{-1} silt and 350 g kg^{-1} sand.
Soil from the upper 20 cm in the experiment area were collected before sowing the crop, at 20 points to form a composite sample (Table 1). The soil P availability used in the maize experiment was classified as "Medium", according to CFSEMG (1999) standards.
Each experimental plot had four rows, spaced 0.5 m, and five meters long. Two central rows were considered in this experiment and two guard rows were discarded. 70,000 plants ha^{-1} was sown on 07 November 2014, after applying KCl (60 kg K_2O ha^{-1}) and a total of 34 kg N ha^{-1} (N from treatments plus urea) application in the sowing furrow. Ammonium sulphate (150 kg N ha^{-1}) and KCl (60 kg K_2O^{-1}) were applied on soil surface when plants were in the V3 stage (three fully expanded leaves). Weed, pest and disease controls were made. Stalk diameter, plant and ear height, ear diameter and length, number of row/ear ratio, number of grain/row ratio, number of grains/ear ratio, mass of 1000 grains, yield, and plant shoot fresh and dry mass were evaluated at harvest (10 may 2015). Plant shoot dry mass was obtained by oven drying it (70^{o}C) until constant weight. Agronomic P efficiency was calculated (Fageria et al., 2010).

Table 1. Chemical attributes of the Red-Yellow Dystrophic Latosol before maize crop (Ipameri, GO, Brazil).

pH	P (Mehlich-1)	O.M.	K^+	Ca^{2+}	Mg^{2+}	H+Al	CEC	V
$CaCl_2$	mg dm^{-3}	g dm^{-3}	mg dm^{-3}	----------------mmol$_c$ dm^{-3}	----------------			%
6.4	15.9	7.0	94	28	13	12	55.4	78.3

Zn	Cu	Fe	Mn	B
	---	mg dm^{-3}	---	
0.9	0.7	13	2.2	0.73

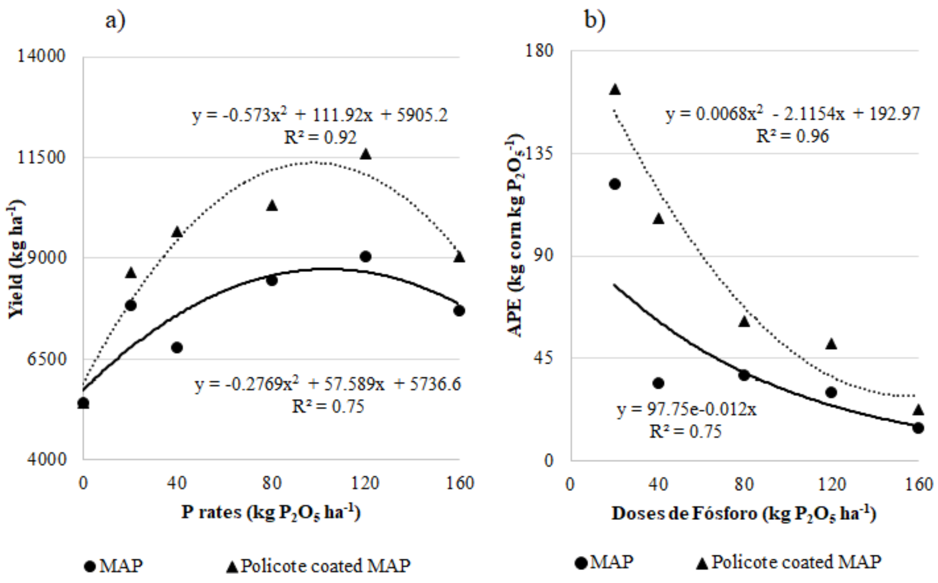

Fig 1. Maize yield (a) and Agronomic Phosphorus Efficiency (b) in maize crop with phosphorus rates and sources.

Table 2. Chemical attributes of the Red-Yellow Dystrophic Latosol before soybean crop (Ipameri, GO, Brazil).

pH	P (Mehlich-1)	O.M.	K^+	Ca^{2+}	Mg^{2+}	H+Al	CEC	V
$CaCl_2$	mg dm^{-3}	g dm^{-3}	mg dm^{-3}	----------------mmol$_c$ dm^{-3}	----------------			%
5.2	1.2	20.6	38	7	2	28	38.0	26.3

Zn	Cu	Fe	Mn	B
	---	mg dm^{-3}	---	
0.2	0.5	20	1.3	0.33

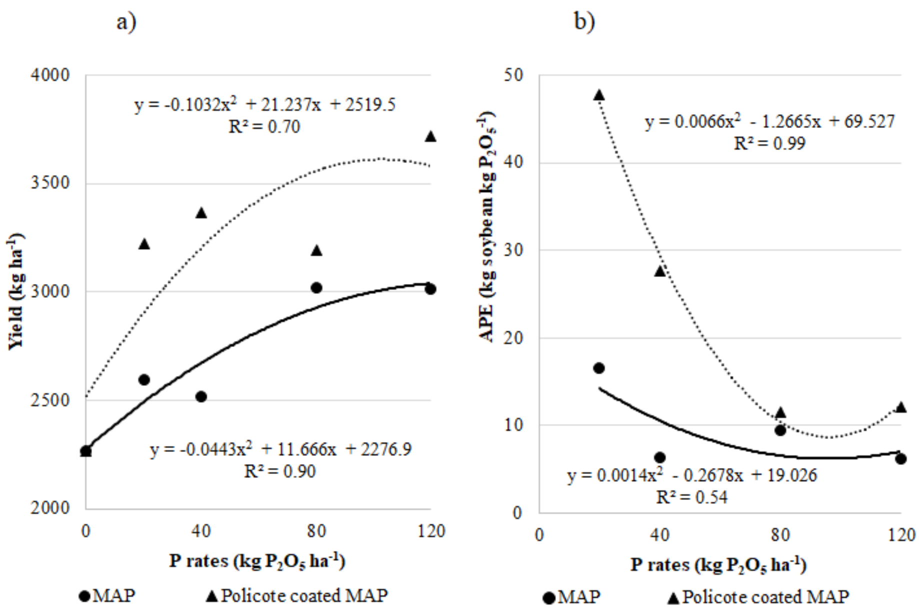

Fig 2. Soybean yield (a) and Agronomic Phosphorus Efficiency (b) in soybean crop with phosphorus rates and sources.

Soybean crop, site description and soil classification

Before sowing the crop, soil samples were collected in the 0 to 20 cm layer at 20 points to form a composite sample (Table 2). The soil P availability used in the soybean experiment was classified as "Very Low", according to CFSEMG (1999) standards.

Soil liming was used to raise the base saturation up to 60%, with application and incorporation of dolomitic limestone (1.7 t ha^{-1}) on 17 October 2014.

Each experimental plot had four rows, spaced 0.5 m and five meters long. Two central rows were considered in this experiment and two guard rows were discarded. The cultivar NS 3730 IPRO (240.000 pls ha^{-1}) was sown on 07 November 2014, after treatments, KCl (60 kg K_2O ha^{-1}) and a total of 25 kg N ha^{-1} (N from treatments plus urea) application in the sowing furrow. Weed, pest and disease controls were made accordingly. Foliar sampling (3rd trifolium plus petiole) was carried out at flowering (R1 stage) to evaluate P and boron content. Plant height, number of internodes/plant ratio, number of pod/plant ratio, mass of 1000 grains, yield and plant shoot dry mass were evaluated at harvest (12 march 2015). Plant shoot dry mass was obtained by oven drying at (70 ^{o}C) until constant weight. Agronomic P efficiency was calculated (Fageria et al., 2010).

Plant materials

In the first experiment the hybrid 30F53H (single hybrid) with high productive potential, super early maturity cycle was used. It also contained herculex® gene (Bt Cry1F) for insect control.

In the second experiment the soybean variety NS 3730 IPRO was used, using super early maturity cycle, indeterminate growth habit, glyphosate resistant and insect resistant genotype.

Experimental design

For maize crop, the experiment was carried out in an incomplete factorial (5x2)+1, five P rates (20, 40, 80, 120 and 160 kg P_2O_5 ha^{-1}), two P sources (MAP: 11% N, 52% P_2O_5; and Policote coated MAP: 10% N, 47% P_2O_5, 0.07% B, 0.38% Zn) and Control (without P). Policote® is an additive based on anionic water-soluble polymers marketed by Wirstchat Polímeros do Brasil.

For soybean crop, the experiment was carried out in an incomplete factorial (4x2)+1 with four P rates (20, 40, 80 and 120 kg P_2O_5 ha^{-1}), two P sources (MAP and Policote coated MAP: 10% N, 47% P_2O_5, 0.2% B) and Control (without P).

Statistical analysis

Data were submitted to analysis of variance and regression, at 0.05 probability level.

Conclusion

Maize and soybean morphological characteristics, as well soybean foliar P and boron contents were not influenced by fertilization. Phosphorus fertilization increased maize and soybean yields. Policote coated MAP was more efficient than MAP (conventional fertilizer) to produce higher maize and soybean yields and higher agronomic efficiency of P use.

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