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Soybean and Corn crop response to enhanced efficiency phosphate fertilizer

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***Abstract*— *Many agricultural soils worldwide in their natural state are deficient in phosphorous (P). As P is vital for all living beings, as P fertilizers are manufactured from non-renewable resources and as P fertilizer efficiency is generally low, we need to improve the P use efficiency and minimize P fertilizers usage to ensure the future sustainability of our cropping systems. Enhanced-efficiency fertilizers use is one of the strategies to increase P fertilizer efficiency, but there is no consensus on the effectiveness of this type of technology. 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 fertilizer. Experiments were carried out in greenhouse and field conditions to investigate the effect of P fertilizer coated with anionic polymers (Policote) on corn and soybean crop development and yield, and agronomic P use efficiency. Greenhouse experiments were conducted with corn crop, while field trials were carried out with soybean crop. Greater increases in plant growth parameters, crop yield, soil P content, and fertilizer efficiency use were observed with Policote coated fertilizer than with conventional P fertilizer. The observed changes in P use efficiency among P fertilizers increased our understanding of enhanced efficiency fertilizers. The obtained results demonstrated that Policote coated fertilizer can be used as an enhanced efficiency fertilizer. Results show that Policote coated fertilizer is a more efficient way to deliver required phosphorous to plants than conventional ones.*

***Keywords*— phosphorus, efficiency use, Policote.**

I. INTRODUCTION

Phosphorus (P) is essential to all living beings. It is vital for food production since it is one of three major nutrients used in commercial fertilizer. Many agricultural soils worldwide in their natural state are deficient in P, and the production of healthy crops has required the regular addition of P fertilizers (McLaughlin et al., 2011). This is the reality of many Brazilian soils that have a very high P fixation capacity because of their high content of iron and aluminum oxides and hydroxides. Brazilian soils, especially in tropical savanna (Cerrado), a place where corn and soybean crops are cultivated a lot, have a large affinity for this nutrient. Agricultural production in the Brazilian Cerrado is limited by the low P soil availability, requiring high applications of phosphate fertilizer, which may become more expensive and scarcer in the future. Phosphorous is an essential fertilizer element to maintain or increase the productivity of cropped ecosystems (Condron and Newman, 2011; Johnston et al., 2014). To worst this scenario, it's well known that the low efficiency of P fertilization has been reported several times (Dorahy et al., 2008; Takahashi & Anwar, 2007; Sanders et al., 2012; Dhillon et al., 2017; Dhillon et al., 2019). It is estimated that the plants absorb only 15 to 25% of P applied via fertilizer (Sanders et al., 2012; Zanão Jr et al., 2020). For this reason, much of the input P fertilizer is not used by crops. Modern agriculture is dependent on P derived from phosphate rock. The non-renewable nature of rock phosphate reserves coupled with the low use efficiency of applied P fertilizers in the soil system results in irreversible loss of a huge quantity of P to the environment (Sarkar et al., 2018). While P demand is projected to increase, the expected global peak in P production is predicted to occur around 2030 (Cordell et al. 2009). However, recent and predicted future increases in P fertilizer costs, linked to increasing global P demand and declining reserves of mineable phosphate rock (Cordell et al., 2009; Elser et al., 2014) have raised serious concerns about the efficient use of this non-renewable resource. To reduce the growing pressure on global phosphate rock reserves, fertilizer P must be better managed in agricultural systems (Childers et al., 2011; Withers et al., 2015), especially in emerging economies such as Brazil, where future P demand is expected to be high (Rodrigues et al. 2016). Improving the efficiency of P use in Brazil's cropping systems and reducing dependence on high rates of fertilizer requires a better understanding of how soil, crop, and fertilizer management practices influence long-term P availability in soils.

Improved stewardship of P based on five key R strategies (5R) has been proposed to address these issues: Realign P inputs more precisely to maximize efficiency, Reduce P losses to the oceans, Recycle more P in bioresources, Recover and reuse P from wastes and Redefine P requirements in the food chain (Withers et al. 2015). Enhanced efficiency fertilizer (EEF) can be used to realign P inputs in modern agriculture. This kind of fertilizer contains aggregate technologies that control the release of nutrients or stabilize their chemical transformations in the soil, increasing their availability to the plant (Pelá et al., 2019). Fertilizer additive products have recently been developed to reduce phosphate fixation and improve phosphorus plant availability (Cahill et al., 2013). Polymer coating use is an increasing strategy used to produce EEF. Some polymer coating of P fertilizer granules resulted in a fairly slow, but steady supply of plant-available P as it diffused or leaked through the coating (Nyborg et al., 1995). But, recently, polymer additives with a greater affinity for iron and aluminum than phosphorus have been used to produce EEFs.

Some reports point out the advantages of polymer-coated P fertilizer (Chagas et al., 2015; Chagas et al., 2016; Chagas et al., 2017; Guelfi et al., 2018; Pelá et al., 2018; Pelá et al., 2019; Zanão Jr et al., 2020; and Souza et al., 2020), while others indicate its inefficiency, compared with common fertilizer (Cahill et al., 2013; Degryse et al., 2013; Volf and Rosolem, 2020). Therefore, the type of polymer coating has presumably some effects on crop yield. Validation studies of EEFs with polymer coating are necessary to ensure the economic viability of these fertilizers. 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 fertilizer.

This study aimed to investigate the effect of P fertilizer coated with anionic polymers (Policote) on corn and soybean crop development and yield, soil P content, and agronomic P use efficiency.

II. MATERIALS AND METHODS

Experiments were carried out to evaluate development, yield, and soil P availability in response to P sources (conventional P fertilizer and Policote coated P fertilizer) on corn and soybean crops. Policote, an additive based on water-soluble polymers marketed by Wirstchat Polímeros do Brasil, is an anionic copolymer with iron and aluminum affinity. Policote reduces the contact of the fertilizer with the Al and Fe (Chagas et al., 2017).

Corn Crop

Two experiments were conducted in a controlled environment facility (greenhouse) at the Department of Soil Science at the Federal University of Viçosa, MG, Brazil, between March to April 2011. The soils used in this experiment were a clayed soil (Red Yellow Latosol) and a medium-textured soil (Yellow Latossol), collected in Viçosa, MG, Brazil (20º 45' 17" S, 42º 52' 57" W, altitude 663 m) and Três Marias, MG, Brazil (18º 12' 18" S, 45º 13' 57" W, altitude 569 m), respectively, whose 0-0.2 m layer soil chemical and physical properties, after air drying and screening (4 mm), were: pH (H_2O) = 5.0 and 4.5; organic matter = 11.4 and 14.1 g.dm^{-3}; P-Mehl = 2.3 and 0.4 mg.dm^{-3}; K = 18 and 13 mg.dm^{-3}; Ca = 2.7 and 0.6 mmol$_c$.dm^{-3}; Mg = 0.6 and 0.1 mmol$_c$.dm^{-3}; Al = 1.0 and 4.0 mmol$_c$.dm^{-3}; H+Al = 34 and 43 mmol$_c$.dm^{-3}; CEC = 37.7 and 44.0 mmol$_c$.dm^{-3}; base saturation = 10.1 and 2.3 %; clay = 650 and 280 g.kg^{-1}, respectively. The soil P availability is classified as "Very Low" (CFSEMG, 1999) in both soils. Liming (CFSEMG, 1999) was carried out to correct soil acidity, undergoing 30 days of incubation.

The experimental design was completely randomized with four replications. The treatments were carried out in a (2x4)+1 incomplete factorial experiment, using two P sources [Triple Superphosphate (TSP): 41% P_2O_5 and Policote coated TSP (PTSP): 36% P_2O_5], four P rates, and a control (without application of P fertilizer). The rates used in Viçosa's soil were 100, 200, 400, and 600 mg P.dm^{-3}, while in Três Marias' soil were 50, 100, 200, and 300 mg P.dm^{-3}. The experimental unit consisted of one pot filled with 2.5 dm^3 of soil.

The cultivar AG9010 was sown (four seeds.plot^{-1}), after treatments adding to soil and mixed thoroughly, on March 11th, 2011. Urea (50 mg N.dm^{-3}) was applied weekly after sowing. Thinning was carried out five days after plant emergence, leaving two plants per experimental unit. Boron (0.81 mg.kg^{-1} as H_3BO_3), copper (1.33 mg.kg^{-1}, as $CuCl_2.2H_2O$; iron (1.55 mg.kg^{-1}, as $FeCl_3.6H_2O$), manganese

(3.66 mg.kg^{-1} as $MnCl_2.4H_2O$); zinc (4.0 mg.kg^{-1}, as $ZnCl_2$); and molybdenum (0.15 mg.kg^{-1}, as $(NH_4).6MoO_{27}.4H_2O$) were split in four applications (weekly), after plant emergence. At harvest (45 days after sowing) shoots and roots were packed into paper bags and dried at 75°C to constant weight in a forced-air oven to determine plant dry weight. Plant dry matter was ground in a Wiley mill to determine P content and accumulation. The soil was removed from the plot and homogenized to collect a sample to evaluate P availability (P-Mehlich), and, then, returned to plots. The pots were again sowed (with the same corn cultivar) to evaluate the residual effect of the phosphate fertilization applied to the first crop. Management of the second crop cycle was identical to that described above for the first cycle, except for the absence of the use of phosphate fertilizers. After the second harvest (45 days after sowing), the same variables as in the first crop were evaluated.

Soybean Crop

Field experiments were conducted in Edéia, GO, Brazil (17º 21' 30" S, 49º 56' 11" W, altitude 573 m) and Campinorte, GO, Brazil (14º 18' 50" S, 49º 09' 07" W, altitude 545 m). The fields' climate is classified as Aw (Koppen-Geiser classification), with average temperature of 24.1 and 25.0 °C, respectively, and average precipitation of 1,423 and 1,714 mm, respectively (based on long-term weather data). The experiments were laid out in a Red-Yellow Latosol and in a Red Yellow Argisol (Embrapa, 2006), in Edéia and Campinorte, respectively, whose 0-0.2 m layer soil chemical and physical properties were pH ($CaCl_2$) = 5.0 and 4.6; organic matter = 25.0 and 20.7 g.dm^{-3}; P-Mehl = 3.5 and 1.4 mg.dm^{-3}; K = 30 and 66 mg.dm^{-3}; Ca = 22.0 and 2.7 mmol$_c$.dm^{-3}; Mg = 9.0 and 2.1 mmol$_c$.dm^{-3}; Al = 0.0 and 2.2 mmol$_c$.dm^{-3}; H+Al = 31.0 and 30.2 mmol$_c$.dm^{-3}; CEC = 62.8 and 36.7 mmol$_c$.dm^{-3}; base saturation = 50.6 and 18.0 %; clay = 370 and 345 g.kg^{-1}, respectively. The soil P availability is classified as "Very Low" (CFSEMG, 1999) in both soils.

A complete block design, with four replications, was used. The treatments were arranged in an incomplete factorial (2x4)+1, using two P sources [Monoammonium phosphate (MAP): 11% N and 52% P_2O_5 and Policote coated MAP: 10% N and 49% P_2O_5], four P rates (Edéia: 60, 80, 120 and 150 kg P_2O_5.ha^{-1}; Campinorte: 40, 80, 120 and 160 kg P_2O_5.ha^{-1}) and control (without P application). Campinorte's rates were higher than Edeia's rate because its soil had lower P content than Edeia's. Each experimental plot had five rows, spaced 0.5 m, and seven meters long. Potassium fertilizer (170 kg KCl.ha^{-1} in Edéia and 200 kg KCl.ha^{-1} in Campinorte) was applied before soybean sowing. The NS7670 RR and M8466 IPRO cultivars were sown, after treatment applications in the sowing furrow, on December, 11th, 2016 (Edéia) and on December, 21th, 2017 (Campinorte), respectively. Weed, pest, and disease controls were made. Total precipitations observed throughout the experiments were 819.2 and 1,259.0 mm in Edéia and Campinorte, respectively. Foliar sampling (3rd trifolium plus petiole) was carried out at the flowering (R1 stage) to evaluate P content. Plant height was measured 50 days after plant emergence in Edéia and on harvest in Campinorte. Soybean yield was evaluated on harvest on March, 24th, 2017 (Edéia) and April, 25th, 2018 (Campinorte).

Statistical analysis

Data, from each experiment, were submitted to analysis of variance and regression, at a 0.05 probability level. Agronomic P efficiency (Fageria et al., 2010) was calculated with average soybean yields. Expected soybean yields for the phosphorus recommendation rate based on soil analysis (CFSEMG, 1999) were determined.

III. RESULTS AND DISCUSSION

Greenhouse studies: Corn Crop in clayed soil

Phosphorus fertilization produced significant differences in plant dry matter ($p<0.01$), plant P content ($p<0.01$) and accumulation ($p<0.01$), and soil P content ($p<0.01$) in the 1st and the 2nd crop.

Increasing P rates boosted plant dry matter (Figure 1), P content (Figure 2) and accumulation (Figure 3), and soil P content (Figure 4) in the 1st and the 2nd crop, but differences of plant dry matter ($p<0.05$), P accumulation ($p<0.05$), and P soil content ($p<0.05$) between P sources were only found in the 1st crop. Plant dry matter increased up to 21.1 and 25.5 g.plant^{-1}, with 444.4 and 469.3 mg P.dm^{-3}, and TSP and PTSP, respectively, in the 1st crop. But, in the 2nd crop, plant dry matter increased up to 11.1 g plant^{-1}, with 400.8 mg P.dm^{-3}. Plant P content increased up to 1.67 and 4.19 g.kg^{-1} in the 1st and the 2nd crop, respectively. Plant P content was lower in the 1st crop than in the 2nd crop, probably as a result of the dilution effect, because the 1st crop had a higher plant dry matter yield than the 2nd crop. Plant P accumulation increased up to 36.5 and 42.7 mg.plant^{-1}, with TSP and PTSP, respectively, in the 1st crop. But, in the 2nd crop, plant P accumulation increased up to 41.9 g.plant^{-1}, with 600 mg P.dm^{-3}. Policote coated fertilizer improved soil P content only in the 1st crop. Soil P content increased linearly up to 190.0 and 246.1 mg.dm^{-3}, with TSP and PTSP, respectively, in the 1st crop. But, in the 2nd crop, soil P content increased up to 144.6 mg.dm^{-3}, with 600 mg P.dm^{-3}. Probably soil removing from the plot, followed by homogenizing practice before return to plot to carry out the 2nd crop reduced the residual effect of Policote P fertilizer because new contact between residual P and Al/Fe colloids were promoted.

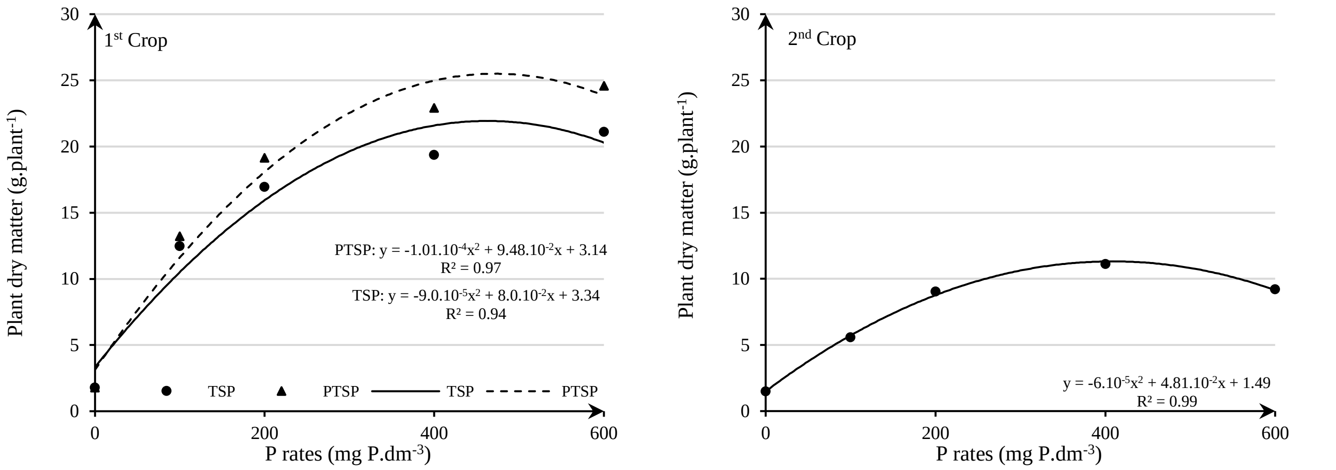

Fig.1: Plant dry matter in response to P rates and sources (TSP: Triple Superphosphate; PTSP: Policote coated Triple Superphosphate) in the 1st and the 2nd corn crop on clayed soil.

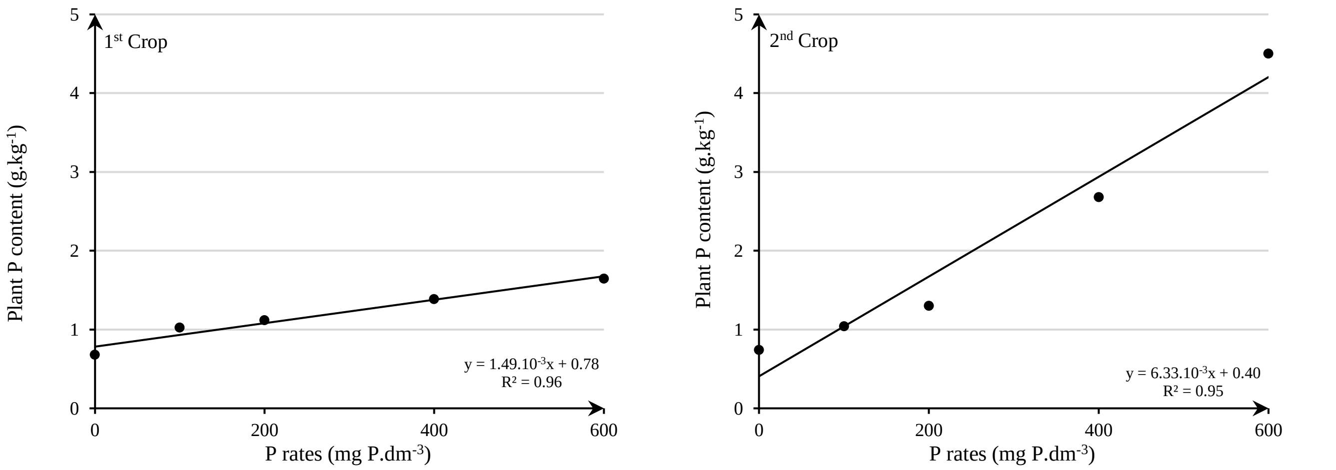

Fig.2: Plant P content in response to P rates in the 1st and the 2nd corn crop on clayed soil.

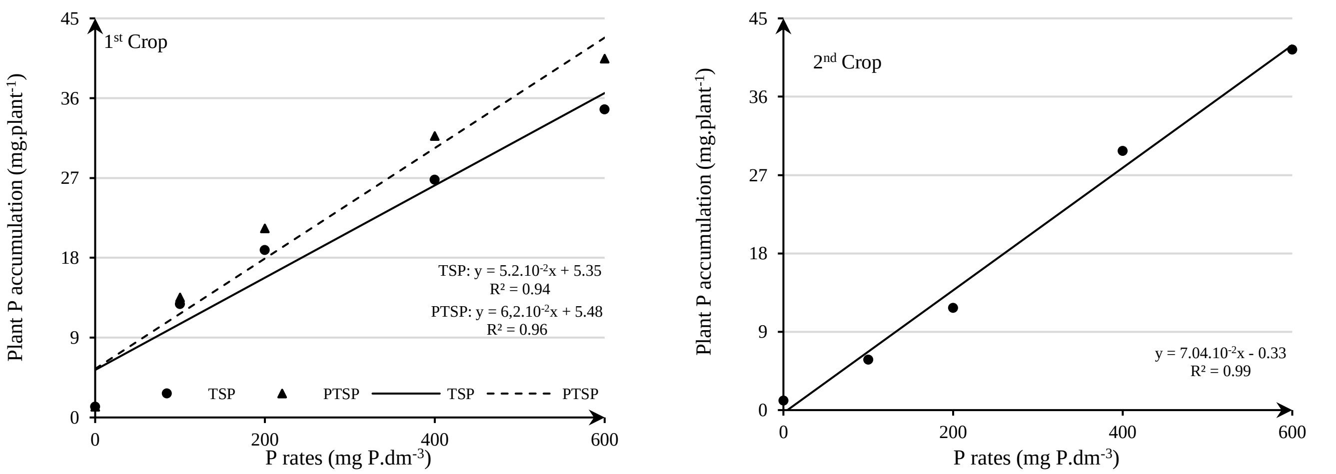

Fig.3: Plant P accumulation in response to P rates and sources (TSP: Triple Superphosphate; PTSP: Policote coated Triple Superphosphate) in the 1st and the 2nd corn crop on clayed soil.

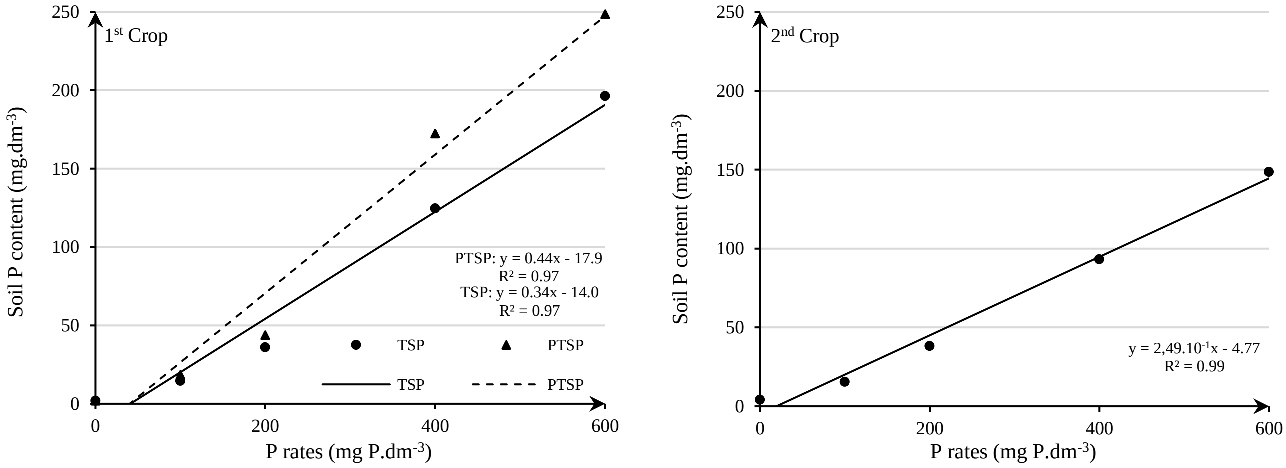

Fig.4: Soil P content in response to P rates and sources (TSP: Triple Superphosphate; PTSP: Policote coated Triple Superphosphate) in the 1st and the 2nd corn crop on clayed soil.

Greenhouse studies: Corn Crop in medium-textured soil

Phosphorus fertilization produced significant differences in plant dry matter ($p<0.01$), P content ($p<0.01$) and accumulation ($p<0.01$), and in soil P content ($p<0.05$) in the 1st and the 2nd crop.

Increasing P rates boosted plant dry matter (Figure 5), P content (Figure 5), and accumulation (Figure 6), and soil P content (Figure 6) in the 1st and the 2nd crop, but no differences between P sources were found. Plant dry matter increased up to 18.6 and 10.4 $g.plant^{-1}$, with 224.3 and 230,5 mg $P.dm^{-3}$, respectively, in the 1st and the 2nd crop, respectively. Plant P content increased linearly up to 2.26 and 2.71 $g.kg^{-1}$, with 300 mg $P.dm^{-3}$, in the 1st and the 2nd crop, respectively. Plant P accumulation increased up to 34.2 and 23.6 $mg.plant^{-1}$, with 300 mg $P.dm^{-3}$, in the 1st and the 2nd crop, respectively. Soil P content increased linearly up to 134.1 and 94.6 $mg.dm^{-3}$ with 300 mg $P.dm^{-3}$, in the 1st and the 2nd crop, respectively.

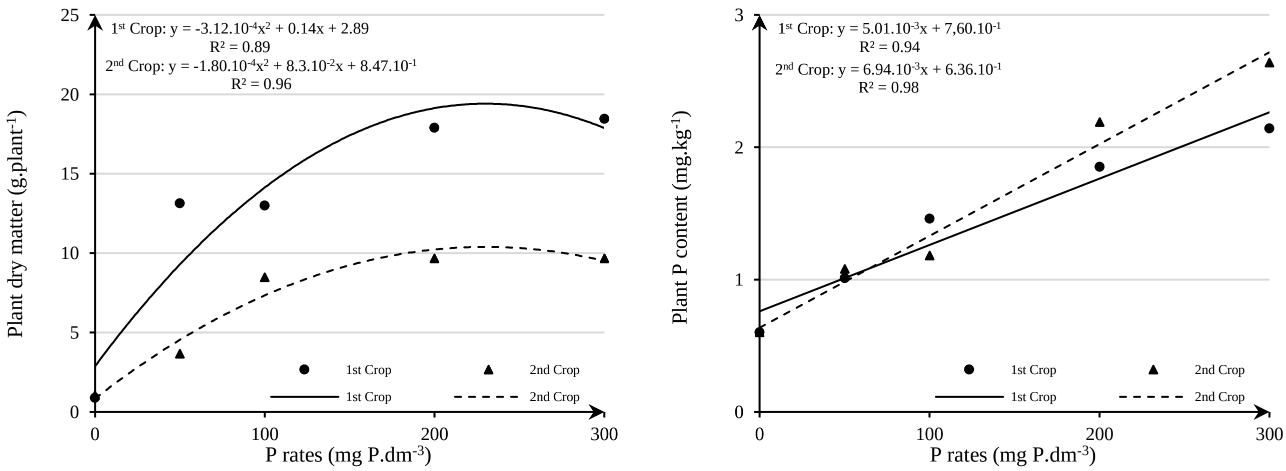

Fig.5: Plant dry matter and P content in response to P rates in the 1st and the 2nd corn crop on medium-textured soil.

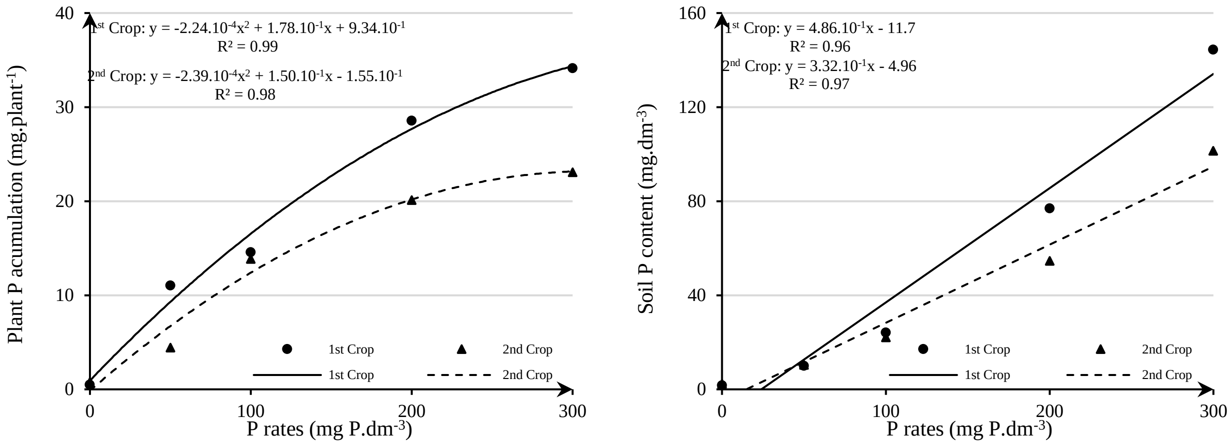

Fig.6: Plant P accumulation and soil P content in response to P rates in the 1st and the 2nd corn crop on medium-textured soil.

Corn development and soil P content were higher in the 1st crop than in the 2nd crop (in both soils). It may be explained by P aging in the soil. Enwezor (1977) reported corn response reduction with P aging in the soil. Gonçalves et al. (1989) reported a decrease of the extractable P and the plant absorbed P with increasing contact time between P fertilizer and soil. Jalali and Ranjbar (2010) reported the transformation of soil P soluble forms into more stable fractions with time.

Differences between P sources were only observed in clayed soil (high P adsorption capacity). Policote coated TSP resulted in higher plant dry matter, plant P accumulation, and P soil content than those observed with TSP in clayed soil. It can be explained by greater soil P availability with Policote coated TSP than that provided by conventional P fertilizer. Although both soils had a "very low" P availability, the clayey soil normally has a higher P sorbing capacity than a medium-textured one. As Policote coating is used to reduce the negative effects of soil P fixation, its benefits will appear when the soil has a significant P adsorption, explaining the results. The phosphate fertilizer action pattern and P availability were influenced by Policote coating, which was more effective in soils with high P adsorption capacity. Understanding and measuring soil P adsorption capacity is important to improve the positioning of this technology.

Field studies: Soybean Crop (Edéia)

Phosphorus fertilization significantly increased soybean plant height ($p<0.01$), P foliar content ($p<0.01$), and grain yield ($p<0.05$). Significantly differences between P sources were also found ($p<0.05$).

Plant height increased linearly up to 73.0 and 76.0 cm, with MAP and PMAP, respectively (Figure 7). The addition of MAP and PMAP resulted in significant P foliar increases up to 1.72 and 2.06 g.kg^{-1}, respectively (Figure 8). Soybean yield increased linearly up to 3,560.3 kg.ha^{-1} using the MAP, while using Policote coated MAP, the maximum yield was 3,757.0 kg.ha^{-1} (Figure 9), an increase of 5.52%.

Effects of Policote coated MAP on agronomic P efficiency use (APEU) are reported in Table 1. Increasing P rates with MAP increased APEU while increasing P rates with Policote coated MAP reduced APEU. The increasing P fertilization rate normally results in lower APUE, which is associated with the "decreasing increments law", where the successive nutrient supply results in decreasing increments of productivity.

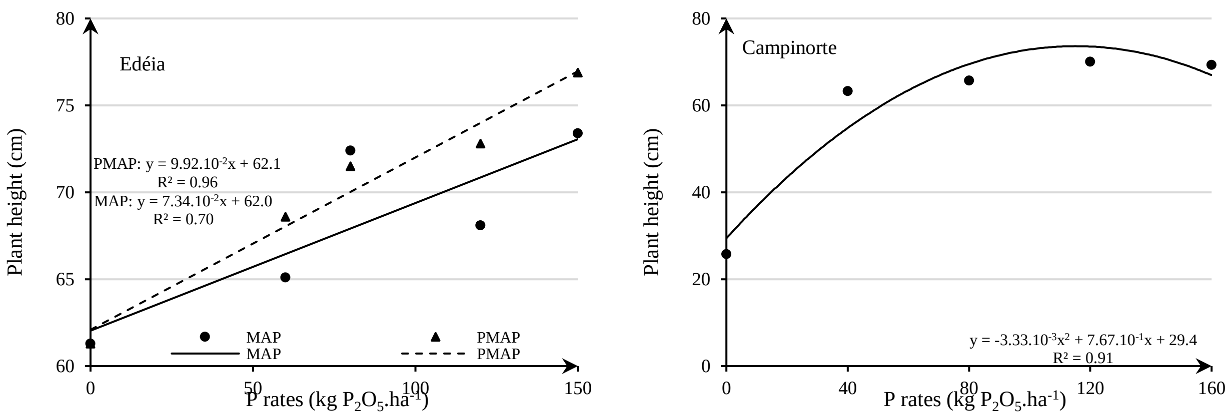

Fig.7: Plant height in response to P sources [MAP and Policote coated MAP (PMAP)] and rates in Edéia and Campinorte.

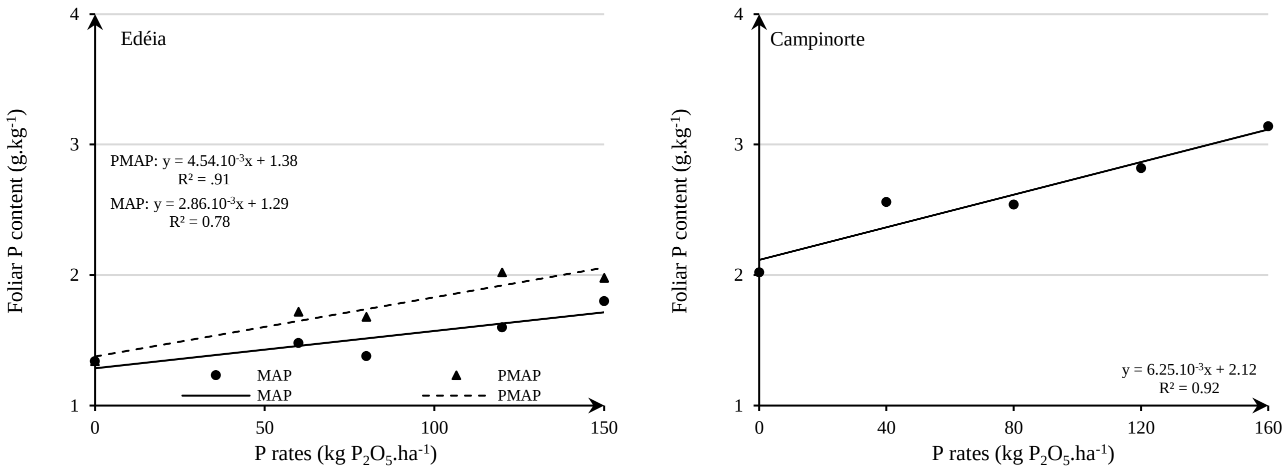

Fig.8: Foliar P content in response to P sources and rates in Edéia and Campinorte.

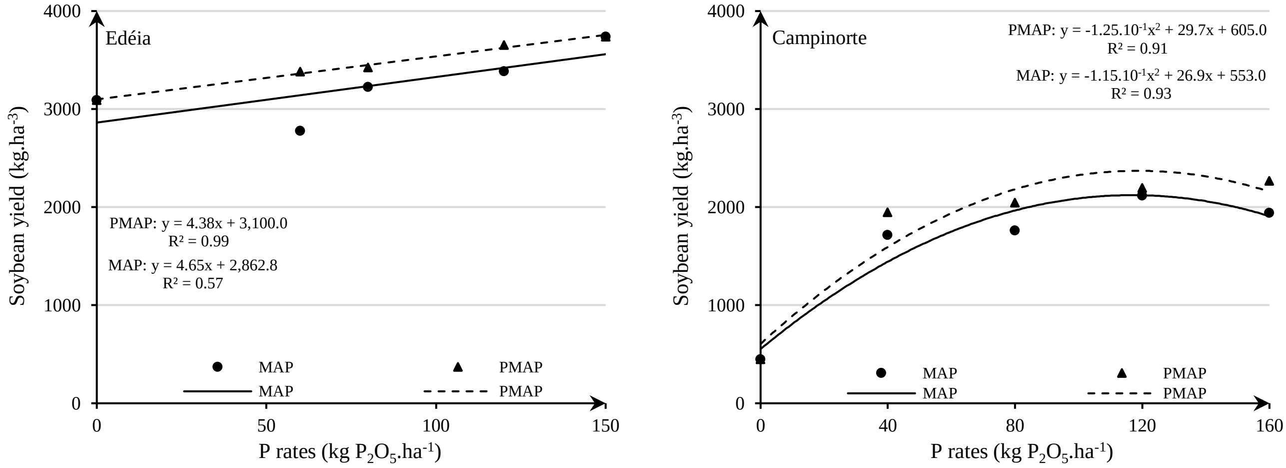

Fig.9: Soybean yield in response to P sources and rates in Edéia and Campinorte.

Table 1. Agronomic phosphorus use index in response to P sources and rates.

P_2O_5 (kg.ha^{-1})	Edéia Trial (kg soybean.kg $P_2O_5^{-1}$)		*P_2O_5 (kg.ha^{-1})*	Campinorte Trial (kg soybean.kg $P_2O_5^{-1}$)	
	MAP	Policote Coated MAP		MAP	Policote Coated MAP
60	-5.20	4.90	40	31.6	37.5
80	1.72	4.20	80	16.4	19.9
120	2.45	4.70	120	13.9	14.4
150	4.32	4.32	160	9.3	11.3
Mean	0.82	4.53		17.8	20.7

Field studies: Soybean Crop (Campinorte)

Phosphorus fertilization significantly increased soybean plant height ($p<0.01$), P foliar content ($p<0.01$), and yield ($p<0.01$), but significant differences between P sources were only observed for soybean yield ($p<0.05$).

Phosphorus rates increased plant height up to 73.5 cm, with 115.1 kg P_2O_5.ha^{-1} (Figure 7). Increasing P rates boosted P foliar content (Figure 8) up to 3.12 g.plant^{-1}. Based on regression equations, the maximum yield of 2126.0 and 2369.2 kg.ha^{-1} were found at 116.9 and 118.8 kg P_2O_5.ha^{-1}, respectively, applied through MAP and Policote coated MAP, respectively (Figure 9), an increase of 11.4%.

Effects of Policote coated MAP on agronomic P efficiency use (APEU) are reported in Table 1. Increasing P rates reduced APEU. Policote coated MAP resulted in higher APEU than conventional P fertilizer.

Phosphate fertilization increased all evaluated soybean parameters. Phosphorus rates and sources resulted in significant differences in soybean yield in both trials.

Foliar P content in the Edéia trial was classified as “Low”, while in Campinorte was classified as “Adequate” according to Embrapa (2013) parameters.

Campinorte's soybean yield was lower than that observed in Edeia's trial because soybean was grown in Campinorte's soil for the first time, while soybean was grown in Edeia's soil many times before. Soybean yields from places never been cropped before initially are low and, subsequently tend to increase.

The phosphorus rate recommendation for Edéia’s and Campinorte’s soil is 120 kg P_2O_5.ha^{-1} (CFSEMG, 1999). Soybean yields of 3,420.8 and 2,125.0 kg.ha^{-1} were found using 120 kg P_2O_5.ha^{-1} and MAP in Edéia and Campinorte, respectively. But soybean yields increased 5.98% (3,625.6 kg.ha^{-1}) and 11.4% (2,369 kg.ha^{-1}) with the same P rate (120 kg P_2O_5.ha^{-1}) and Policote coated MAP in Edéia and Campinorte, respectively. Soybean yield obtained with the recommended P rate based on soil analysis (120 kg P_2O_5. ha^{-1}) and MAP was found with Policote coated MAP and 73.2 and 74.6 kg P_2O_5.ha^{-1} in Edéia and Campinorte, respectively. Crop yield maintenance with lower P rates and enhanced-efficiency P fertilizer, when compared to conventional P fertilizers, was also reported by Ali et al (2017), Noor et al. (2017), Pelá et al (2018), Pelá et al (2019), and Zanão Jr et al (2020). Reduced P rate using allows reducing farm investment, increasing agricultural profits, preserve phosphatic rock reserves, and avoid the overuse of phosphate fertilizer.

Results showed that APEU was higher with Policote coated MAP than with conventional MAP. Higher APEU with Policote coated MAP explains higher yields obtained with this enhanced efficiency P fertilizer when compared to MAP. The APEU increase by applying Policote coated MAP was also observed by Chagas et al. (2015), Chagas et al. (2016), Guelfi et al. (2018), Pelá et al. (2019), and Zanão Jr et al. (2020). Coating phosphate fertilizers with polymer is an innovative option (Noor et al., 2017) and an emerging technology to improve phosphorus use efficiency.

IV. CONCLUSION

Phosphate fertilization increased plant development, crop yield, and soil P content. Greater increases in plant growth parameters, crop yield, soil P content, and fertilizer efficiency use were observed with Policote coated fertilizer than with conventional P fertilizer.

Policote coated P fertilizer can be used as a tool to increase the residual effect of phosphate fertilization, increasing the levels of phosphorus in the soil.

The availability pattern from phosphate fertilizer was influenced by Policote coating, which was effective to increase crop development, and its yield. The observed changes in P use efficiency among P fertilizers increased our understanding of enhanced efficiency fertilizers.

The obtained results demonstrated that Policote coated fertilizer can be used as an enhanced efficiency fertilizer. Results show that Policote coated fertilizer is a more efficient way to deliver required phosphorous to plants than conventional ones.

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