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Enhanced efficiency phosphorous fertilizers on the coffee crop in sandy soil

Douglas R. Guelfi[1], Roberto dos A. Reis Jr[5]* and Wantuir F. T. Chagas[1]

[3]Soil Science, UFLA, Lavras, Brazil
[2]R&D, Wirstchat Polímeros do Brasil, Londrina, Brazil
*Correspondence: roberto@wsct.com.br

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Abstract**—***Crops are generally cultivated in deficient phosphorus soils in the tropics. Phosphorus (P) is essential to crop development and has a low efficient use in fertilizer management. The need to increase P fertilization efficiency justify studies evaluating the performance of enhanced efficiency P fertilizers. A greenhouse experiment was carried out to evaluate coffee growth, plant P contents, and agronomic P fertilization efficiency. The treatments, randomly designed with three replicates, were arranged in a 2x5 factorial scheme: two P sources (Triple Superphosphate – TSP and Policote coated TSP – TSP+Policote) and five P rates (0; 5; 10; 15 and 20 g* $P_2O_5.plot^{-1}$*). The experimental plot was formed by a pot with 14 kg of sandy soil. All treatments were homogenized with the plot's soil. Then, coffee seedlings were transplanted. Coffee growth, plant P content and accumulation, and agronomic P fertilization efficiency were affected by phosphorus fertilization. TSP+Policote promoted higher leaf and plant dry matter yield and P accumulation in coffee than conventional P fertilizer. The higher agronomic efficiency and apparent P recovery efficiency index, observed with TSP+Policote, explain the higher coffee plant growth observed with Policote coated P fertilizer. The obtained results demonstrated that Policote coated P fertilizer can be used as an enhanced efficiency fertilizer. Results show that Policote coated P fertilizer is a more efficient way to deliver the required P to plants.*

Keywords**—*phosphorus, efficiency use, apparent P recovery efficiency.***

I. INTRODUCTION

Plants don't complete their cycle without phosphorus (P), because it is an important nutrient for the energy storage process and to the structural integrity of plants (Taiz & Zeiger, 2009). Tropical soils are deficient in P due to the poor parent material (Raij, 1991; Rosolem& Merlin, 2014; Chagas et al., 2016) and strong P fixation to colloids (Büll et al., 1998; Novais& Smyth, 1999; Chikowo et al., 2010; Rosolem& Merlin, 2014), resulting in low P content available to plants. Therefore, higher P application rates, above plants' needs, is usual in tropical soils to compensate for phosphorus losses. Such losses increase the cost of fertilization programs and severely pollute the environment (Timilsena et al., 2014). Important reasons for these problems are the low use efficiency of fertilizers (Adesemoye & Kloepper, 2009). Low P fertilizer efficiency has been reported in the literature (Dorahy et al., 2008; Takahashi & Anwar, 2007; Murphy & Sanders, 2007; Sanders et al., 2012). P-fertilizer efficiency is generally low, usually sitting around 10–20% in the short term (Chien et al., 2009). Improving P fertilizer efficiency in agriculture is indispensable since P fertilizer depends on non-renewable sources (phosphate rocks) and has a high share of agricultural cost. In a growing world population, increasing the efficiency of phosphate fertilization is also important to meet the growing demands for food production around the world.

Several strategies have been used to increase the efficiency of P fertilization. Among them, the use of enhanced efficiency fertilizers (EEF) 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.

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 an additive capable of inhibiting the transformation of nitrogen into the soil in some undesirable way. A similar strategy could be applied with additives of iron (Fe) and aluminum (Al) affinity (responsible for the fixation of phosphorus in tropical soils) in P fertilizers, increasing its agronomic efficiency. New P fertilizer additives have been recently developed to combat P-limited crop productivity by reducing phosphate fixation in soil (Cahill et al., 2013).

Polymer additives with a higher affinity for Fe and Al than P 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 (Valderrama et al., 2009; Cahill et al., 2013; Gazola et al., 2013;Degryse et al., 2013; Lino et al., 2018; Volf and Rosolem, 2020). The need to increase P fertilization efficiency and the lack of information with enhanced efficiency P fertilizers justify the performance of studies evaluating the performance of this type of fertilizer.

The present study aimed to evaluate coffee growth (stem diameter, plant height and leaf, stem, and root dry matter), plant P content and accumulation, and agronomic P fertilization efficiency in response to P sources (conventional and enhanced efficiency) and rates on the coffee crop in sandy soil.

II. MATERIALS AND METHODS

Experimental site

The experiment was carried out at the Department of Soil Science/Lavras Federal University, in Minas Gerais/Brazil, under greenhouse conditions, from February to November 2014. A sandy soil, classified as QuartzarenicNeosol (Embrapa, 2013), collected from the 0–20 cm layer, was used. The soil was air-dried, and any clumps were removed. The soil was then passed through a 4 mm sieve and manually homogenized. The soil presented the following chemical characteristics: pH (H_2O) = 4.9; P (Mehlich-1) = 0,84 $mg.dm^{-3}$; K (Mehlich-1) = 34 $mg.dm^{-3}$; Ca = 1.0 $mmol_c.dm^{-3}$; Mg = 1.0 $mmol_c.dm^{-3}$; Al = 4.0 $mmol_c.dm^{-3}$; clay = 230 $g.kg^{-1}$; silt = 170 $g.kg^{-1}$ and sand = 600 $g.kg^{-1}$.

Experimental design

The experimental design was completely randomized, and the treatments were carried out in a 2 x 5 factorial scheme: two P sources [Triple Superphosphate – TSP (46% P_2O_5) and Policote coated TSP – TSP+Policote (43.7% P_2O_5)] and five P rates (0; 5; 10; 15 and 20 g $P_2O_5.plot^{-1}$), with three replications. Each experimental plot consisted of one pot filled with 14 kg of soil in which two plants were grown. The Policote additive, a biodegradable and soluble anionic polymer, was used to coat TSP and to reduce the contact of P fertilizer with Al and Fe (Chagas et al., 2015; Chagas et al., 2016), decreasing Fe^{2+} and Al^{3+} activity near P fertilizer granules and the precipitation reactions of P with these cations (Guelfi et al., 2018).

Crop Management

Nitrogen (5.33 g $N.plot^{-1}$, as ammonium sulfate) and potassium (6.72 g $K_2O.plot^{-1}$, as KCl) fertilization and all treatments were homogenized with the plot's soil on February 15, 2014. Then, five-month-old coffee (*Coffea arabica* L., cultivar Acaiá IAC 474-19) seedlings [produced with Plantmax substrate: N (4.9 $g.kg^{-1}$), P_2O_5 (4.1 $g.kg^{-1}$), K_2O (3.8 $g.kg^{-1}$), Ca (9.0 $g.kg^{-1}$), Mg (17.8 $g.kg^{-1}$), Fe (20 $g.kg^{-1}$), Cu (41.3 $mg.kg^{-1}$), Mn (312 $mg.kg^{-1}$) and B (8.2 $mg.kg^{-1}$)] were transplanted. The seedlings presented five pairs of true leaves and were produced from seeds that had been sown in washed and sieved sand. During the entire experimental period, the soil moisture was maintained at 70% of the total pore volume by weighing the pots and adding deionized water. At 60 days after transplanting, foliar fertilization, with boric acid (0.3% boron) and zinc sulfate (0.3% zinc), was carried out.

Data evaluation

Evaluation of seedling growth occurred in June 2014 (stem diameter and plant height) and in November 2014 (stem diameter; plant height; leaf, stem, and root dry matter, P content and accumulation; agronomic efficiency and apparent P recovery by plants). Plant height was measured from the root crown to the apical bud with a millimeter ruler. Leaf, stems, and root dry matter were determined after incubation in a forced air oven at 75 °C until a constant weight was achieved. Two grams of the samples collected from leaves, stems, and roots were removed for nitric-perchloric acid digestion followed by determination of P content (Malavolta et al., 1997). Leaf, stem and root dry matter and P content were used to calculate P dry matter accumulation. Agronomic efficiency and apparent P recovery by plant index were calculated (Fageria et al., 2010).

Statistical analysis

All data were analyzed by analysis of variance, and the F-test was used to determine treatment significance. Appropriate regression equations were also used to further analyze relations between evaluated parameters and P rates. All of the statistical procedures were performed with Assistat software (Silva & Azevedo, 2016).

III. RESULTS AND DISCUSSION

Statistical results are reported in Table 1. Stem diameter and plant height, after four months of transplanting, were not influenced by P fertilization, with average values of 4.77 cm and 46.41 cm, respectively. Probably there wasn't enough time to difference among treatments appear. Melo et al. (2005) also did not observe differences in coffee plant height and stem diameter fertilized with different P sources. However, at harvest, these characteristics were significantly influenced only by P rates, increasing up to 9.68 cm and 73.8 cm, respectively, with 20.0 and 19.1 g P_2O_5.plot^{-1}, respectively (Figure 1). Chagas et al. (2016), evaluating coffee plants of the same age, found plant height equal to 75.1 cm, using TSP at the rate of 20 P_2O_5.plot^{-1}, in clay soil. That result is similar to that observed in this experiment.

Leaf and plant dry matter were significantly influenced by P rates and sources, while the stem and root dry matter were significantly influenced only by P rates (Figure 1). Stem and root dry matter yield increased linearly up to 72.0 and 29.6 g.plot^{-1}, respectively, with 20 g P_2O_5.plot^{-1}. Higher leaf and plant dry matter production were observed with TSP+Policote. Leaf and plant dry matter increased up to 85.8 and 188.3 g.plot^{-1}, respectively, using TSP+Policote at rates of 16.6 and 20.0 g P_2O_5.plot^{-1}. Chagas et al. (2016), evaluating coffee plants of the same age, found a dry matter yield of 233.8 g.plot^{-1}, with 18.9 g P_2O_5.plot^{-1}, in clay soil.

Foliar and stem P contents were significantly influenced by P sources ($p<0.05$) and rates ($p<0.01$), but root P content was significantly influenced only by P rates ($p<0.01$) (Figure 2). Root P content increased up to 1.45 g.kg^{-1}, with 16.9 g P_2O_5.plot^{-1}. Higher leaf and stemP content were observed with TSP+Policote.Stem P content increased up to 1.57 and 1.89 g.kg^{-1} with 20 g P_2O_5.plot^{-1} of TSP and TSP+Policote, respectively. Foliar P content increased with P fertilization up to 1.61 g.kg^{-1}, with 20.0 g P_2O_5.plot^{-1} of TSP and up to 1.74 g.kg^{-1} with 19.4 g P_2O_5.plot^{-1} of TSP+Policote. Increasing foliar P content with P fertilization in the coffee crop was also reported by Vilela et al. (2017).

Table 1: Stem diameter after four months of transplanting and at harvest (SD4 and SDh, respectively), plant height after four months of transplanting and at harvest (PH4 and PHh, respectively), leaf (LDM), stem (SDM), root (RDM) and plant (PDM) dry matter, leaf (LPC), stem (SPC) and root (RPC) P contents, P accumulation in leaves (PAL), stem (PAS) and roots (PAR), agronomic P efficiency (APE) and apparent P recovery (APR) indexes.

		SD4 (cm)	PH4 (cm)	SDh (mm)	PHh (cm)	LDM (g.plot^{-1})	SDM (g.plot^{-1})	RDM (g.plot^{-1})	PDM (g.plot^{-1})	LPC (g.kg^{-1})	SPC (g.kg^{-1})	RPC (g.kg^{-1})	PAL (mg.plot^{-1})	PAS (mg.plot^{-1})	PAR (mg.plot^{-1})	APE (g MS.g $P_2O_5^{-1}$)	APR (g P/g P_2O_5)
Average	TSP (00 g P_2O_5.plot^{-1})	4.74	46.75	5.78	44.1	36.2	33.7	12.2	82.2	0.56	0.67	0.79	20.12	22.45	9.64	9.78	-
	TSP (05 g P_2O_5.plot^{-1})	4.29	41.50	6.76	55.3	51.5	40.2	16.9	108.7	0.79	0.74	0.84	41.50	30.42	14.20	14.1	5.29
	TSP (10 g P_2O_5.plot^{-1})	4.56	42.58	8.47	64.7	62.4	50.3	19.9	132.7	1.13	0.83	1.34	70.70	41.14	26.67	26.7	5.04
	TSP (15 g P_2O_5.plot^{-1})	4.95	49.16	9.91	74.0	73.5	71.8	33.2	178.6	1.37	1.49	1.54	101.2	106.88	51.13	50.9	6.42
	TSP (20 g P_2O_5.vaso^{-1})	5.15	49.16	9.27	73.5	74.0	65.9	29.6	169.6	1.59	1.57	1.18	117.3	103.33	34.93	34.8	4.37
	TSP+Policote (00 g P_2O_5.plot^{-1})	4.51	45.25	5.78	44.1	36.2	33.7	12.2	82.2	0.56	0.67	0.79	20.12	22.45	9.64	9.78	-
	TSP+Policote (05 g P_2O_5.plot^{-1})	4.83	45.33	8.02	63.8	59.0	45.7	20.4	125.1	1.30	0.86	0.97	75.12	39.27	19.79	19.64	8.57
	TSP+Policote (10 g P_2O_5. plot^{-1})	4.67	45.66	8.40	68.1	78.3	59.1	29.9	166.6	1.42	1.11	1.22	110.91	65.58	36.48	34.70	8.44
	TSP+Policote (15 g P_2O_5. plot^{-1})	4.79	46.50	9.12	69.8	86.8	57.6	25.9	170.2	1.59	1.82	1.84	137.9	105.39	47.66	45.95	5.86
	TSP+Policote (20 g P_2O_5. plot^{-1})	5.26	51.25	9.98	75.0	83.0	73.6	34.9	191.5	1.79	1.79	1.46	149.4	131.51	50.95	50.63	5.46
	TSP	4.74	45.83	8.04	62.3	59.6b	52.4	22.4	134.3b	1.09b	1.06b	1.14	70.0b	60.8 b	27.31	27.3b	5.28b
	TSP+Policote	4.81	47.00	8.26	64.2	68.7a	54.0	24.4	147.1a	1.33a	1.25a	1.26	98.7a	72.8 a	32.90	32.1a	7.08a
	00 g P_2O_5.plot^{-1}	4.63	46.00	5.78	44.1	36.2	33.7	12.2	82.2	0.56	0.67	0.79	20.12	22.4	9.64	9.78	-
	05 g P_2O_5.plot^{-1}	4.56	43.41	7.39	59.6	55.3	43.0	18.6	116.9	1.04	0.80	0.90	58.31	34.8	16.99	16.9	6.93
	10 g P_2O_5.plot^{-1}	4.62	44.12	8.44	66.4	70.4	54.8	24.4	149.7	1.27	0.97	1.28	90.81	53.3	31.57	30.7	6.74
	15 g P_2O_5.plot^{-1}	4.87	48.33	9.52	71.9	80.2	64.7	29.6	174.4	1.48	1.65	1.69	119.53	106.1	49.39	48.4	6.14
	20 g P_2O_5.plot^{-1}	5.20	50.21	9.63	74.2	78.5	69.8	32.3	180.5	1.75	1.68	1.32	133.34	117.4	42.94	42.7	4.91
	Average	4.77	46.41	8.15	63.2	64.1	53.2	23.4	140.7	1.21	1.15	1.20	84.42	66.8	30.11	29.7	6.18
CV (%)		13.12	13.57	11.2	10.7	10.4	12.7	13.9	7.54	20.10	16.0	19.91	22.47	19.21	13.5	15.2	25.0
F value (ANOVA)	Source	0.11^{ns}	0.26^{ns}	0.44^{ns}	0.56^{ns}	14.0**	0.42^{ns}	2.96^{ns}	10.8**	7.42*	7.75*	1.95^{ns}	16.95**	6.54*	8.7**	8.65**	8.12*
	Rate	1.09^{ns}	1.23^{ns}	18.7**	18.9**	46.0**	29.2**	37.3**	90.3**	19.45**	40.37**	13.63**	35.37**	66.21**	25.0**	79.42**	2.07^{ns}
	Source*Rate	0.35^{ns}	0.25^{ns}	1.17^{ns}	0.70^{ns}	1.25^{ns}	2.96*	5.35**	3.83*	0.83^{ns}	0.76^{ns}	0.87^{ns}	1.10^{ns}	1.71^{ns}	1.54^{ns}	4.56**	2.25^{ns}
	Rate/TSP	-	-	-	-	-	17.3**	21.8**	47.8**	-	-	-	-	-	-	40.13**	-
	Rate/TSP+Policote	-	-	-	-	-	14.8**	20.9**	50.4**	-	-	-	-	-	-	43.86**	-

(**) significant at 1% probability by the "F" test. (*) significant at 5% probability by the "F" test. Means followed by the same letter lowercase in the column do not differ from each other by the Tukey test at 5%.

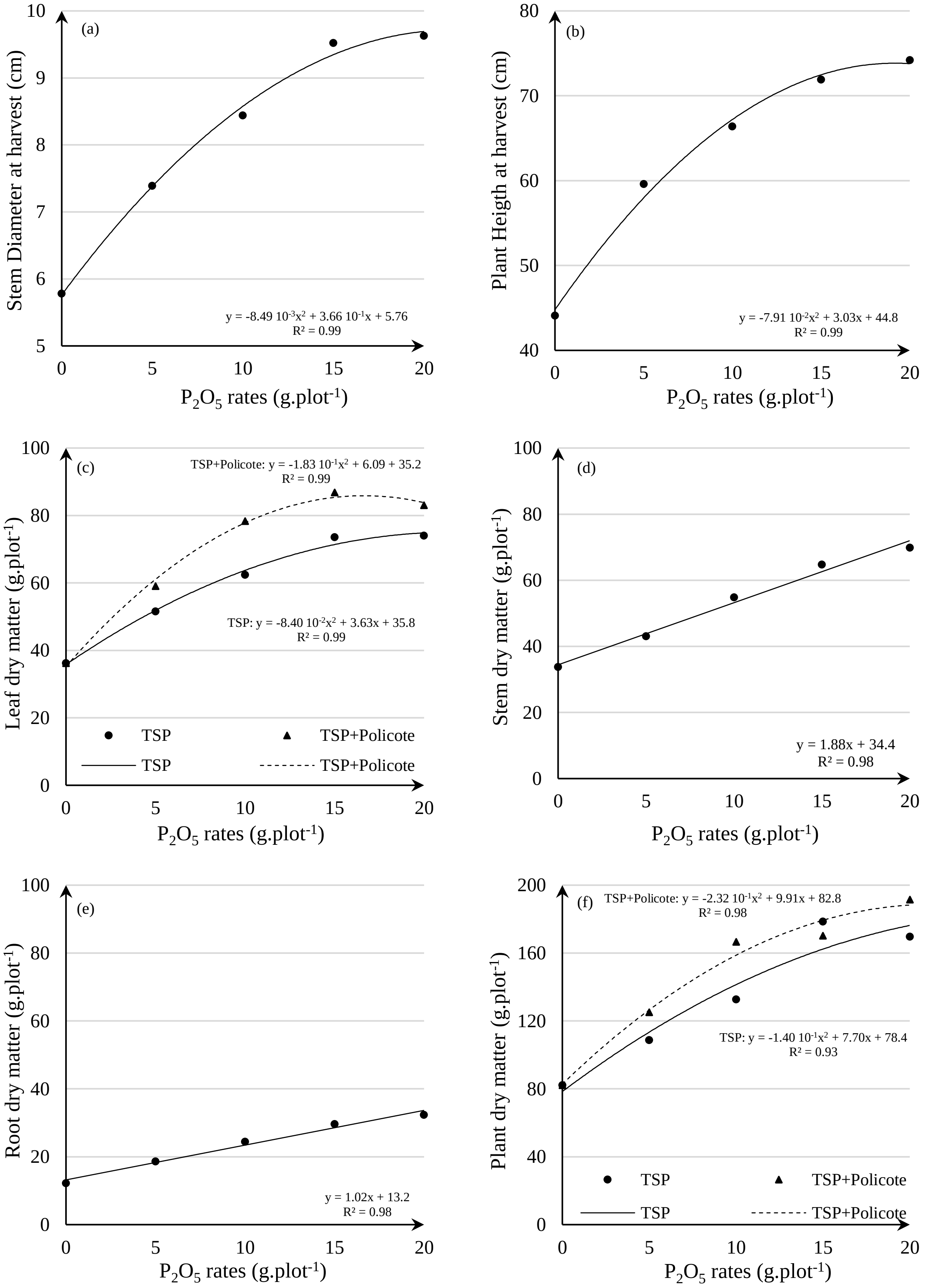

Fig. 1: Relationship between stem diameter (a), plant height (b) and leaf (c), stem (d), root (e) and plant (f) dry matter and P sources (Triple Superphosphate – TSP and Policote coated TSP – TSP+Policote) and rates.

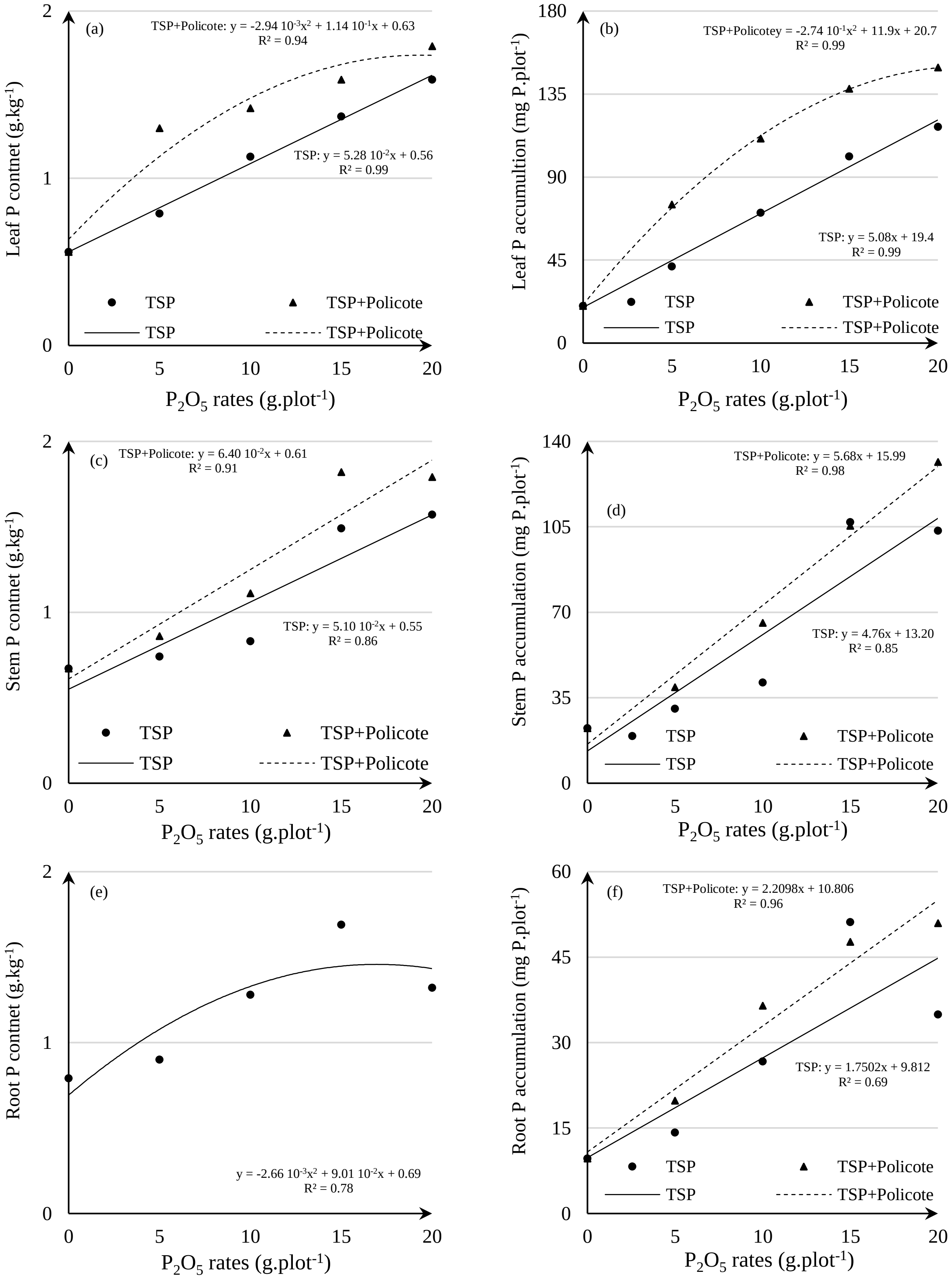

Fig. 2: Relationship between leaf P content (a) and accumulation (b), stem P content (c) and accumulation (d) and root P content (e) and accumulation (f) and P sources (Triple Superphosphate – TSP and Policote coated TSP – TSP+Policote) and rates.

Coffee P accumulation increased with P fertilization. P rates and sources significantly influenced P accumulation in leaves ($p < 0.01$), stem ($p < 0.01$ and $p < 0.05$, respectively), and roots ($p < 0.01$) (Figure 2). The higher P accumulation was observed with 20 g $P_2O_5.plot^{-1}$. Higher leaf, stem, and rootP accumulation were observed with TSP+Policote.When using

TSP, the maximum values of P accumulation in leaves, stem, and roots were 121.1; 108.1, and 44.6 mg.plot^{-1}, respectively. These values were lower than the maximum values found when using the TSP+Policote, which were 149.2; 129.7, and 53.7 mg.plot^{-1}, respectively. Higher P accumulation in coffee leaves with the use of Policote coated P fertilizer was also observed by Chagas et al. (2016).

Agronomic efficiency (APE; $p<0.05$) and apparent P recovery (APR; $p<0.01$) indexes were significantly influenced only by P sources (Figure 3). TSP+Policote resulted in higher APE (+34,1%) and APR (+57,1%) than TSP. Chagas et al. (2016) also observed higher agronomic efficiency when using Policote coated P in coffee seedlings. The higher dry matter production, under the same supply of phosphorus, explains the same growth of plants with lower P rate when using TSP + Policote.

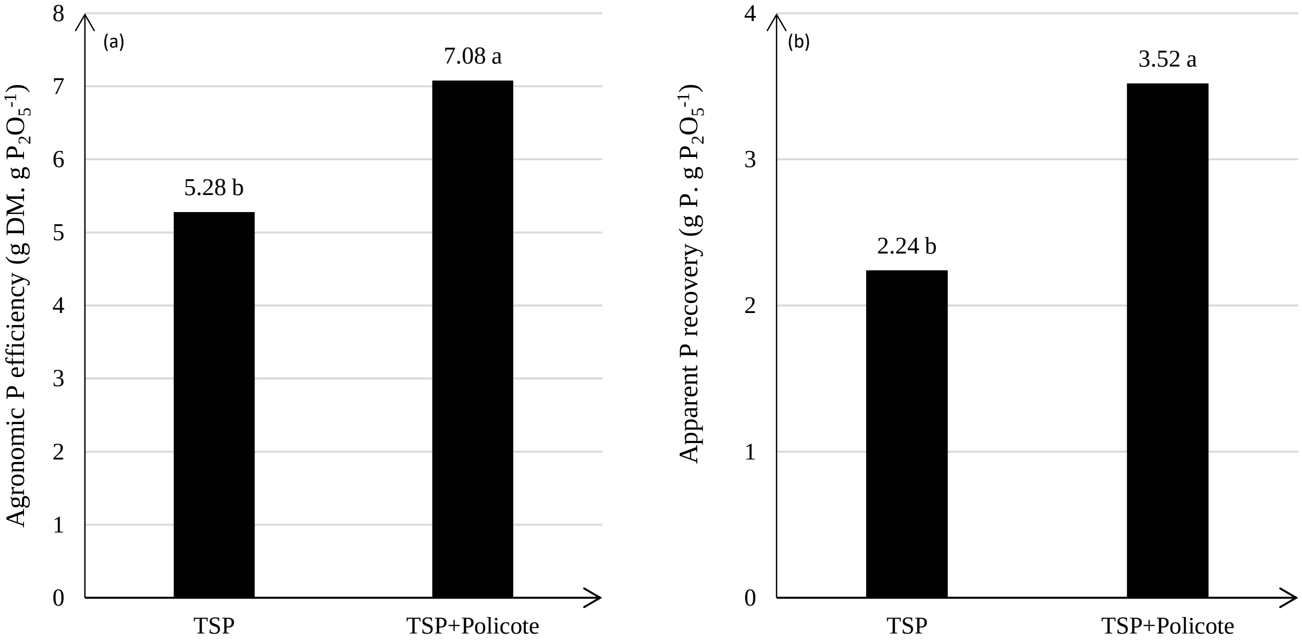

Fig. 3: Relationship between average agronomic efficiency index (a) and apparent P recovery index (b) and P sources (Triple Superphosphate – TSP and Policote coated TSP – TSP+Policote). Bars marked with the same letters do not differ from one another ($p<0.05$).

Among all plant maronutrients, phosphorus (P) is arguably the one presenting the lowest use efficiency in terms of crop production (Borges et al., 2019). As most of the applied P (>90%) can be fixed in the soil after its application (Rajput et al., 2014), it's important to understand its sorption process and to promote ways to reduce it. The fate of fertilizer P in soilis controlled by adsorption and precipitation reactions. So, it's important to intervene in P (from the fertilizer) and Al/Fe (from the soil) reactions, to increase P fertilizer use and crop yields. ThePolicote's ability to decrease Fe/Al activity near P fertilizer granules (Guelfi et al., 2018) could be used to promote P bioavailability. Souza et al. (2020), after 60 days of P fertilizer incubation (with and without Policote coating), reported higher phosphorus diffusion with Policote coated P fertilizer than with conventional phosphorus fertilizer.

Our results suggest that replacement of conventional mineral fertilizer with enhanced efficiency fertilizer improved crop growth and nutrition. In this study, higher leaf and plant dry matter, leaf and stem P content, plant P accumulation, agronomic efficiency, and apparent P recovery indexes were observed with enhanced efficiency P fertilizer (Policote coated P fertilizer). The higher agronomic efficiency and apparent P recovery indexes when using the Policote coated P fertilizer explain the higher observed results for dry matter production and P accumulation in the plant with this enhanced efficiency P fertilizer. This was consistent with previous results reporting in lettuce (Chagas et al., 2015; Chagas et al., 2017), coffee (Guelfi et al., 2018), soybean (Pelá et al., 2019; Zanão Jr et al., 2020), maize (Pelá et al., 2019; Souza et al., 2020; Zanão Jr et al., 2020), carrot (Pelá et al., 2019) and common beans (Souza et al., 2020).

IV. CONCLUSION

Coffee growth, plant P contents, and accumulation and agronomic P fertilization efficiency were affected by phosphorus fertilization.

TSP+Policote promoted higher leaf and plant dry matter yield, P accumulation and agronomic efficiency use in coffee crop than conventional P fertilizer.

The higher agronomic efficiency and apparent P recovery efficiency index, observed with TSP+Policote, explain the higher coffee plant growth observed with Policote coating.

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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