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Coffee Orchard Response to Enhanced Efficiency Phosphate Fertilizer

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Abstract

Phosphorus (P) plays a crucial role in plant growth by aiding in the development of strong roots, promoting flower and fruit formation, and aiding in photosynthesis. Studies to improve P fertilizers efficiency in coffee orchards are necessary due to the need for better efficiency and the lack of information on enhanced efficiency P fertilizers. This study aimed to investigate the effect of MAP coated with anionic polymers (Policote) on coffee orchard development. A coffee trial was carried out in a randomized block design with three replications. The treatments, applied at coffee planting, were arranged in an incomplete factorial (2 × 4) + 1, using two P sources (MAP and Policote coated MAP), four P rates (40, 80, 120, and 160 g P_2O_5 plant^{-1}) and control (without application of P fertilizer). Plant height was evaluated in the 2016/2017, 2017/2018, and 2018/2019 seasons, while coffee bean maturation, yield, and agronomic P efficiency use were evaluated in the last two seasons. P fertilization did not affect coffee bean maturation and increased coffee yield in 31-month-old plants when differences among P sources and rates were observed. Using Policote-coated P fertilizer resulted in higher yields at the same P rate, as well as similar yields at a lower P rate, compared to conventional fertilizer. Policote-coated P fertilizer can be used as an enhanced efficiency fertilizer and is an efficient way to deliver required P to plants. The target for reducing farm investment, increasing agricultural profits, preserving phosphatic rock reserves, and avoiding the overuse of phosphate fertilizer could be realized through the rational use of enhanced efficiency fertilizers.

Keywords

Agronomic P Efficiency, Coffee Bean Maturation, Policote

1. Introduction

It is estimated that the world population will increase up to 33% by 2050, from the current 7.2 billion to 9.6 billion people [1]. To provide adequate food, fiber, and renewable energy resources to meet this growth in population, we will need to dramatically increase crop yields [2], requiring, among several strategies, increasing the use of plant nutrients such as phosphorus (P) applied in the form of fertilizers.

Coffee is the second most traded commodity in the world after oil, generating approximately U$ 90 billion per year and involves about 500 million people in its management from cultivation to final product for consumption [3] [4]. With the rise in popularity of coffee among Europeans, Brazil became the world's largest producer in the 1840s and has been ever since. Until the 60s, Brazilian coffee plantations were sited in areas of average to high fertility that were originally forested, but with the tightening of environmental legislation and the increased cost of the most fertile areas, the coffee crop has expanded into areas that were marginal in terms of fertility, where constant soil correction and fertilization are needed [5]. Brazilian coffee-producing areas are concentrated in the tropical regions, whose soils are highly weathered with low plant-available phosphate [6]. This is not just a Brazilian soil problem. Phosphorus is known to be one of the most recognized limiting factors for coffee production in most soils of southwestern Ethiopia, the primary diversity center of this crop [7].

Phosphorus plays a crucial role in plant growth by aiding in the development of strong roots, promoting flower and fruit formation, and aiding in photosynthesis. Phosphorus is one of the important nutrients for coffee because it causes an increase in root development and plant vigor to ensure the formation of crops with high productivity and low rates of replanting [8]. High phosphate fertilizer rates are necessary for coffee planting, but relatively small amounts of P are extracted by the plants, indicating that a large part of the added phosphates would be unavailable to the growing coffee tree [9]. Amelioration attempts by the addition of phosphatic fertilizers are economically and ecologically unsound as the efficiency of added phosphatic fertilizers is very low [10]. Some current issues with commercial P fertilizers include their potential environmental impact through runoff and water pollution, limited availability of phosphate rock reserves, and the high cost of production and transportation. The low efficiency of phosphate fertilizer requires an increase in the amount of P applied to the crops [11]. This scenario increases the pressure to improve P use efficiency. Currently, most commercial P fertilizers are water-soluble and P sorbs rapidly onto soil minerals, causing low P use efficiency and low residual values of these fertilizations [12]. The low efficiency of P fertilization has been reported in different papers [13] [14] [15] [16] [17]. It is estimated that the plants absorb only 15% to 25% of P applied via fertilizer [18] [19] [20]. On weathered and tropical soils, it can be necessary to apply up to five-fold more P as fertilizer than is exported in products [21]. For this reason, much of the input P fertilizer is not used by crops.

Coffee is subjected to several processes before it is consumed as a beverage, and several factors contribute to its final quality [22], such as shade level [23] [24] [25], altitude [26] [27] [28], daily temperature [29], amount and distribution of rainfall [30], physical and chemical characteristics of the soil [31], agricultural management [32], genotype and provenance [26] [28] [33] [34] [35] and agronomical measures like pruning and fruit thinning [25] [28] [36]. Recent studies have associated mineral nutrition with the quality of the harvested product [37]. The higher the concentration of available P in relation to soil organic carbon (P:C) or total nitrogen (P:N), the better the cup quality of the coffee, and vice versa [38]. Despite its evident agronomic importance, the effects of P fertilization on the coffee beans' maturation and consequent quality of the product have not been investigated extensively.

Due to the importance of food, economy, and environmental safety, it is necessary to carry out studies aimed at increasing P fertilizer use efficiency in agriculture [19]. Several strategies have been used to increase P fertilization efficiency. Lately, the most frequently used strategy has been the application of increased-efficiency fertilizers. 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 [37]. 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 their agronomic efficiency. References [19] [39]-[44] 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 in several crops. Studies to improve P fertilizers efficiency in coffee orchards are necessary due to the need for better efficiency and the lack of information on enhanced efficiency P fertilizers.

This study aimed to investigate the effect of P fertilizer coated with anionic polymers (Policote) on agronomic P use efficiency and coffee orchard development and yield.

2. Materials and Methods

2.1. Experimental Site and Description

A coffee trial was carried out in Santo Antônio do Amparo, MG, Brazil (20˚53'26"S, 44˚52'04"W and average altitude around 1100 m) along three seasons (2016/2017, 2017/2018 and 2018/2019). According to the Köppen international classification, the climate of the region is Cwa, with an average temperature of 19.6˚C and average precipitation of 1648 mm. The experiment was laid out at a Red Latosol (Oxisol) characterized for pH (H_2O), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), aluminum (Al^{3+}), (H + Al), P, boron (B), iron (Fe), cooper (Cu), manganese (Mn), zinc (Zn) following the methodology described by [45], and Remaining P (P-rem) following the methodology described by [46]. Ca^{2+}, Mg^{2+}, and Al^{3+} were extracted using 1.0 mol·L^{-1} KCl, while Fe, Cu, Zn, Mn, P and K by Mehlich-1, and H + Al by 0.5 mol·L^{-1} calcium acetate. Ca^{2+},

Mg^{2+}, Fe, Cu, Zn and Mn were determined by atomic absorption spectrophotometry, K^+ by flame photometry, P by colorimetry, and Al^{3+} and (H + Al) by volumetry analysis. In the 0 - 0.20 m layer, the soil characteristics were as follows: pH (H_2O), 5.1; organic matter, 3.7 $g \cdot dm^{-3}$; P-rem, 5.95 $mg \cdot L^{-1}$; P-Mehl, 5.0 mg dm^{-3}; K, 160 $mg \cdot dm^{-3}$; Ca, 12 $mmol_c \cdot dm^{-3}$; Mg, 4.0 $mmol_c \cdot dm^{-3}$; Al, 2.0 $mmol_c \cdot dm^{-3}$; H + Al, 54.6 $mmol_c \cdot dm^{-3}$; CEC, 74.7 $mmol_c \cdot dm^{-3}$; base saturation, 26.9%; B, 0.3 $mg \cdot dm^{-3}$; Cu, 4.4 $mg \cdot dm^{-3}$; Fe, 61 $mg \cdot dm^{-3}$; Mn, 6 $mg \cdot dm^{-3}$; Zn, 2.8 $mg \cdot dm^{-3}$; clay, silt, and sand contents of 550, 130, and 325 $g \cdot kg^{-1}$, respectively. The soil P availability used in the experiment was classified as "Very Low" for coffee orchards [47]. The treatments, applied in the planting furrow, were arranged in an incomplete factorial (2 × 4) + 1, using two P sources (MAP: 11% N, 52% P_2O_5 and Policote coated MAP: 10% N, 47% P_2O_5 and 1.9% Mg), four P rates (40, 80, 120 and 160 g P_2O_5 $plant^{-1}$) and control (without P application). Policote is a water-soluble polymer additive distributed by Wirstchat [48]. A randomized block design with three replications was used. Each experimental plot had three rows, with eight plants each. The central row was considered in this experiment and two guard rows were discarded. Weed, pest, and disease controls were made in all seasons.

2.2. 2016/2017 Season

The experiment with Arabica coffee (Coffea arabica L.), cultivar Catuaí Amarelo, was planted in November 2016, in 3.00 × 1.00 m spacing, with one plant per hole. The fertilization conducted at planting was composed of the treatments, 4.0 $Mg \cdot ha^{-1}$ poultry manure and 4.0 $Mg \cdot ha^{-1}$ organic compost (44% wet coffee husk, 28% dry coffee husk, 20% coal grinder, and 8% soil). Nitrogen and potassium applications (15 g N + 30 g K_2O $plant^{-1}$; ammonium nitrate and KCl) were parceled out in three applications (December 2016, January 2017, and February 2017). Plant height was evaluated in the six central plants of each plot in December 2016 and June 2017.

2.3. 2017/2018 Season

Nitrogen application (30 g N $plant^{-1}$; ammonium nitrate) was parceled out in three applications (November 2017, December 2017, and January 2018). Plant height and coffee yield were evaluated in the six central plants of each plot in April 2018 and June 2018 (18-month-old coffee plants), respectively. All coffee fruits were hand-harvested to estimate the percentages of immature, ripe, overripe, and dry beans. After sun drying, the fruits were weighed, and their moisture content was adjusted to 12% (w/w). Thus, the final yield was expressed in $kg \cdot ha^{-1}$ of air-dried fruits.

2.4. 2018/2019 Season

Nitrogen and potassium applications (60 g N + 60 g K_2O $plant^{-1}$; ammonium nitrate and KCl) were parceled out in three applications (November 2018, January 2018, and February 2018). Plant height and coffee yield were evaluated, as described above, in November 2018 and June 2019 (30-month-old coffee plants), respectively. Agronomic P efficiency use index [(coffee yield with P—coffee yield without P)/ applied P rate] was calculated [49] with average coffee yields.

2.5. Data Analysis

All of the statistical procedures were performed with the R Studio software. Normality and homoscedasticity of variances were tested before performing an analysis of variance. Regression analysis was used, when necessary. Qualitative treatment means were compared using the F test ($p \leq 0.05$).

3. Results

3.1. Plant Height

P fertilization only increased plant height in April 2018 (**Table 1**), and it was not different with or without P fertilization in all other time evaluations. There were no differences among P sources in April 2018, but increasing P rates increased plant height ($p < 0.05$; **Figure 1**).

Table 1. Plant height in response to phosphorus (P) fertilization.

	Plant Height (cm)			
	Dec 2016 (01 month old)	Jun 2017 (07 months old)	Apr 2018 (17 months old)	Nov 2018 (24 months old)
Control	20.8	35.9	63.6	85.6
P fertilization	21.1^{ns}	37.2^{ns}	71.3*	93,7^{ns}

ns—statistically insignificant. *—statistically significant ($p < 0.05$).

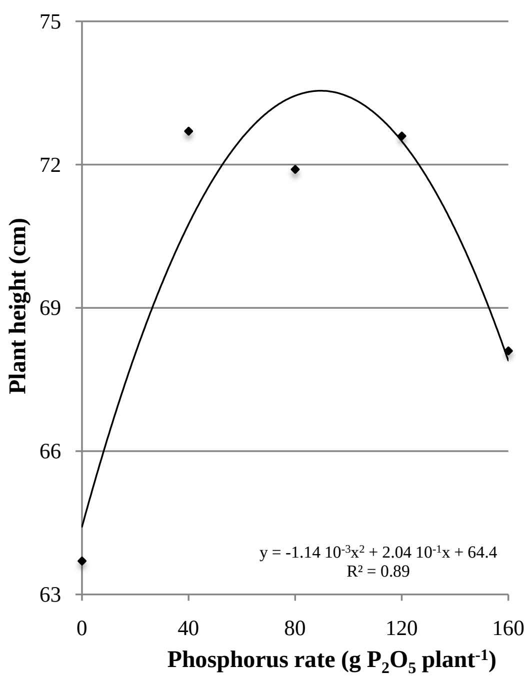

Figure 1. Plant height in response to P rates (April 2018).

3.2. Coffee Yield

P fertilization did not affect coffee bean maturation because the percentages of immature, ripe, overripe, and dry beans were not different among treatments in the 2017/2018 (18-month-old coffee plants) and 2018/2019 (30-month-old coffee plants) seasons. Average observed percentages of immature, ripe, overripe, and dry beans in the 2017/2018 season were 14.58%, 66.21%, 12.71%, and 6.50%, respectively. In the 2018/2019 season, the percentages were 8.01%, 65.29%, 15.69%, and 11.01%, respectively.

P fertilization increased coffee yield only in the 2018/2019 season ($p < 0.01$; Table 2) when differences among P sources ($p < 0.01$) and rates ($p < 0.01$) were observed (Figure 2). Average coffee yield in 2017/2018 season was 156.6 kg·ha^{-1}.

3.3. Agronomic P Efficiency Use

Agronomic P efficiency use (APEU) was different between treatments in the 2018/2019 season. The effects of P sources and rates on the APEU are shown in Table 3.

Table 2. Coffee yield in response to phosphorus (P) fertilization.

	Coffee yield (kg·ha^{-1})	
	2017/2018 Season (18 months old)	2018/2019 Season (30 months old)
Control	154.2	355.8
P fertilization	154.8^{ns}	621.3**

ns—statistically insignificant. **—statistically significant ($p < 0.01$).

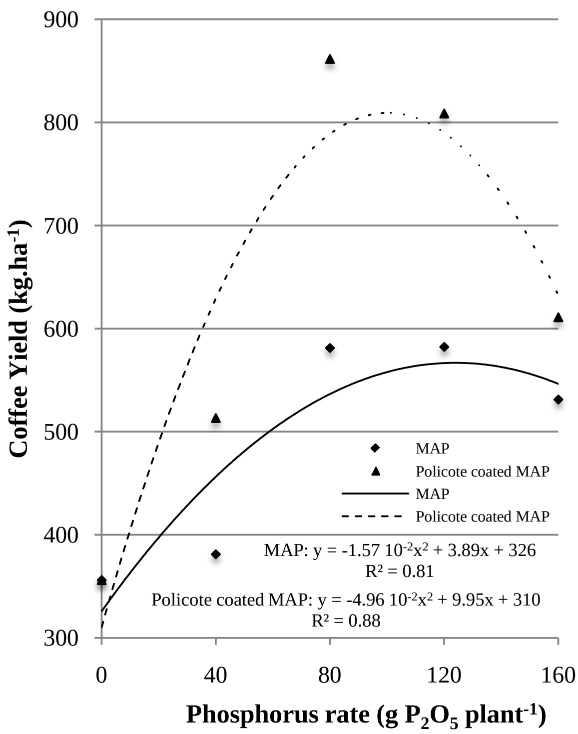

Figure 2. Coffee yield in response to P sources and rates (2018/2019 season).

Table 3. Agronomic P efficiency use in response to P sources and rates (2018/2019 season).

	Agronomic P efficiency use (kg of coffee kg $P_2O_5^{-1}$)	
	MAP	Policote Coated MAP
40	0.63	3.93
80	2.82	6.32
120	1.89	3.77
120	1.09	1.60
Average	1.61	3.90

4. Discussion

4.1. Plant Height

P fertilization increased plant height up to 73.5 cm, with 89.5 g P_2O_5 plant^{-1} in April 2018 (17-month-old plants). Higher plants (105 - 109 cm in 24-month-old plants) were reported by [50] on slow-release fertilizer evaluation on the coffee cultivar Topaz. Probably the differences concerning the cultivar and age might explain this.

Plant height reduction is a typical result of P nutrition lack, but this happened only in the Apr/2018 evaluation. Other manuscripts report similar facts. Reference [51] also did not find plant height differences evaluating growth and nutritional disorders of coffee cultivated in nutrient solutions with suppressed phosphorus. Reference [9] did not find plant height differences among P fertilizers in 30-month-old coffee plants, but in 41-month-old coffee plants, P fertilization increased coffee plant height. Probably, with aging, plant height differences between P fertilizer managements could be easily detected.

The first evidence of phosphorus absence is plant growth reduction and dark green color in old leaves in the coffee crop. Neither plant height reduction (except in the April 2018 evaluation), nor dark green color in old leaves were observed without P fertilization in this experiment. Probably visual symptoms will appear with coffee orchard aging.

4.2. Coffee Yield

Estimated coffee yields (2018/2019 season) with different P sources and rates are described in **Table 4**. The highest coffee yield achieved with MAP application was 566.9 kg·ha^{-1}, which occurred at a rate of 123.9 g P_2O_5 plant^{-1}. The same yield was obtained with Policote-coated MAP at a rate of 30.4 g P_2O_5 plant^{-1}. The P rate used to reach maximum coffee yield with MAP (123.9 g P_2O_5 plant^{-1}) resulted in 37.8% increase in coffee yield with Policote coated MAP (566.9 × 781.4 kg·ha^{-1}). The maximum coffee yield using MAP (566.9 kg·ha^{-1}) was lower than the maximum yield using Policote coated MAP (781.4 kg·ha^{-1}), which used a lower P rate (123.9 × 100.3 g P_2O_5 plant^{-1}, respectively).

Table 4. Estimated coffee yield in response to P sources and rates (2018/2019 season).

	Yield ($kg \cdot ha^{-1}$)
Control	326.0
MAP (123.9 g P_2O_5 plant^{-1})	566.9
Policote coated MAP (123.9 g P_2O_5 plant^{-1})	781.4
Policote coated MAP (100.3 g P_2O_5 plant^{-1})	809.0
Policote coated MAP (030.4 g P_2O_5 plant^{-1})	566.9

Phosphorus fertilization did not affect coffee bean ripening. No significant effects of P treatment on the biochemical composition of coffee beans were reported by [52]. Agricultural management is one of the key factors in determining coffee quality [32]. P fertilization plays an important role in agricultural management. But probably, P fertilization affects coffee quality in other criteria than coffee bean maturation.

Inconclusive responses of the adult coffee plant to P fertilization have been reported in the literature [53] [54] because the coffee plant is considered not very responsive to fertilization with P during the production period [54]. So, P fertilization studies at coffee planting are important to develop healthy and productive orchards.

P fertilization increased coffee yield. Similar results were also reported by [5] [9] [53] [55] [56]. Reference [9] applied P fertilization at coffee planting, while [53] and [55] applied it in a one-year-old coffee orchard and [5] applied it in a 5-years-old coffee orchard.

Reference [9] reported a maximum coffee yield (2243.8 $kg \cdot ha^{-1}$) with the application of 620.7 g P_2O_5 m^{-1}, in a 30-month-old coffee plant. It is higher than the maximum yield observed in this experiment (809.0 $kg \cdot ha^{-1}$). This divergence may be explained by cultivar (Acaiá Cerrado × Catuaí Amarelo) and plant density divergences (4081.6 plants ha^{-1} × 3,333.3 plants ha^{-1}).

The observed yields in the 2017/2018 and 2018/2019 seasons were low because they were the 1st and 2nd crop yields, which will increase with age. The results obtained in studies like this highlights the importance of phosphate fertilization at the planting time of coffee orchard.

The recommended P rate for coffee orchards for the used soil in this experiment is 80 g P_2O_5 plant^{-1} [47]. Estimated coffee yields (2018/2019 season) with 80 g P_2O_5 plant^{-1} are described in **Table 5**. P fertilization with Policote-coated MAP increased coffee yield by 46.9% at the recommended P rate.

Increasing crop yields with polymer-coated fertilizers were also reported by [18] [20] [42] [43] [44] [57] [58] [59] and [60]. Higher yield with the same P rate as well same yield with a lower P rate was observed with Policote coated fertilizer. Similar results (fertilizer rate reduction) were also observed by [19] [44] [61] and [62]. This strategy can be used to reduce farm investment, increase agricultural profits, preserve phosphatic rock reserves, and avoid the overuse of phosphate fertilizer.

Table 5. Estimated coffee yield in response to P sources and soil-based P recommendation (2018/2019 season).

	Yield ($kg \cdot ha^{-1}$)
MAP (80.0 g P_2O_5 plant^{-1})	536.7
Policote coated MAP (80.0 g P_2O_5 plant^{-1})	788.5

4.3. Agronomic P Efficiency Use

APEU in the range of 0.13 - 1.28 kg coffee kg $P_2O_5^{-1}$ for 30-month-old coffee plants was reported by [9], while [5] reported APEU in the range of 1.38 - 2.58 kg coffee kg $P_2O_5^{-1}$ for five-year-old coffee plants.

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 [19] [39] [42] [44] and [63], in lettuce, coffee and soybean crops, respectively. Coating phosphate fertilizers with polymer is an innovative option [18] and an emerging technology to improve phosphorus use efficiency. The observed changes in P use efficiency among P fertilizers increased our understanding of enhanced efficiency fertilizers. The obtained results demonstrated that Policote-coated MAP can be used as an enhanced efficiency fertilizer. Results show that Policote-coated fertilizer is a more efficient way to deliver required phosphorus to plants than conventional fertilizer.

4.4. Final Considerations

Phosphorus fertilization did not affect coffee bean maturation.

Phosphorus fertilization increased coffee yield in 31-month-old plants when differences among P sources and rates were observed. Higher yield with the same P rate as well as the same yield with a lower P rate was observed with Policote coated fertilizer concerning conventional fertilizer.

Policote-coated MAP can be used as an enhanced efficiency fertilizer and is a more efficient way to deliver required phosphorus to plants than MAP.

The target for reducing farm investment, increasing agricultural profits, preserving phosphatic rock reserves, and avoiding the overuse of phosphate fertilizer could be realized through the rational use of enhanced efficiency fertilizers and fertilizer rate use reduction towards 4R's stewardship.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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