

YIELD GAINS OF COFFEE PLANTS FROM PHOSPHORUS FERTILIZATION MAY NOT BE GENERALIZED FOR HIGH DENSITY PLANTING⁽¹⁾

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SUMMARY

Inconclusive responses of the adult coffee plant to phosphorus fertilization have been reported in the literature, especially when dealing with application of this nutrient in high density planting systems. Thus, this study was carried out for the purpose of assessing the response of adult coffee plants at high planting density in full production (in regard to yield and their biennial cycle/stability) to the addition of different sources and application rates of P in the Zona da Mata region of Minas Gerais, Brazil. The experiment with coffee plants of the Catucaí Amarelo 6/30 variety was carried out over four growing seasons. Treatments were arranged in a full factorial design [(4 × 3) + 1] consisting of four P sources (monoammonium phosphate, simple superphosphate, natural reactive rock phosphate from Algeria (Djebel-Onk), and FH 550®), three P rates (100, 200, and 400 kg ha⁻¹ year⁻¹ of P₂O₅), and an additional treatment without application of the nutrient (0 kg ha⁻¹ year⁻¹). A randomized block experimental design was used with three replicates. The four seasons were evaluated as subplots in a split plot experiment. The P contents in soil and leaves increased with increased rates of P application. However, there was no effect from P application on the yield and its biennial cycle/stability regardless of the source used over the four seasons assessed.

Index terms: *Coffea arabica*, mineral nutrition, biennial cycle/stability.

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RESUMO: OS GANHOS DE PRODUTIVIDADE DE CAFEIROS ADULTOS ADENSADOS, COM A FERTILIZAÇÃO FOSFATADA, NÃO PODEM SER GENERALIZADOS

Respostas não conclusivas do cafeeiro adulto à fertilização com fósforo têm sido reportadas na literatura, de modo particular quando se trata da aplicação desse nutriente em sistemas adensados de plantio. Assim, este trabalho foi realizado com o objetivo de avaliar a resposta de cafeeiros adensados adultos, em franca produção, quanto à produtividade e bienalidade, à adição de diferentes fontes e doses de P, na região da Zona da Mata de Minas Gerais. O experimento, com cafeeiros da variedade Catucaí Amarelo 6/30, foi conduzido durante quatro safras. A matriz experimental utilizada foi o fatorial completo [(4 × 3)+1], composto por quatro fontes (fosfato monoamônico, superfosfato simples, fosfato natural reativo da Argélia (Djebel-Onk) e FH 550®), três doses de P (100, 200, e 400 kg ha⁻¹ ano⁻¹ de P₂O₅) e um tratamento adicional, correspondente à dose de 0 kg ha⁻¹ ano⁻¹ de P₂O₅. O delineamento utilizado foi em blocos casualizados, com três repetições. As quatro safras constituíram faixas no tempo. Houve aumento dos teores de P no solo e nas folhas do cafeeiro com o aumento das doses aplicadas. Apesar disso, não houve efeito da adição de P sobre a produtividade e a bienalidade da produção das plantas, independentemente da fonte utilizada ao longo das quatro safras avaliadas.

Termos de indexação: Coffea arabica, nutrição mineral, bienalidade.

INTRODUCTION

The coffee plant (*Coffea arabica*) is among the most highly studied perennial crops in Brazil, which is the largest worldwide exporter of the product, with particular importance for the state of Minas Gerais, where 50 % of Brazilian coffee is produced (CONAB, 2010). Among the traditional coffee-producing mesoregions, the Zona da Mata is responsible for around 21 % of production in the State of Minas Gerais (Emater, 2009). This region is characterized by highly rolling topography and, predominantly, family farms, in contrast with the newer coffee-growing regions in the State, such as the Cerrado (Brazilian tropical savanna) regions, where, in general, the mechanization of production processes and large size of agricultural areas facilitate large scale systems and ensure greater competitiveness in this sector. Even so, the relevance of coffee growing in these more traditional regions is strong, especially for small family farm properties (INAES, 2010).

Various techniques assist farmers in competing in the market. Among them, the high density planting system, characterized by plant population densities from 5,000 to 10,000 plants ha⁻¹, stands out as an alternative for improving the viability of coffee growing (Nacif, 1997), especially on highly rolling land and small properties. This system, when adequately managed, allows intensification in the use of agricultural areas, with greater yields and better efficiency in the use of labor and inputs.

Even without high density planting, the responses of the adult coffee plant to fertilization are highly variable (Prezotti & Rocha, 2004). For this reason, studies have been developed to assess the response of high density coffee planting to fertilization in some producing regions (Pavan et al., 1994; Prezotti & Rocha, 2004; Figueiredo et al., 2006; Bragança et al., 2009).

The coffee plant is considered not very responsive to fertilization with P during the production period. Nevertheless, studies have shown expressive responses to the addition of this nutrient in some producing regions (Gallo et al., 1999; Reis et al., 2011). Even so, it might not be possible to extrapolate the conclusions and/or recommendations obtained to other growing regions, given the diversity of environments and management conditions of the crop. In addition, studies usually do not consider the effect on the biennial production cycle of the coffee plant.

Although it is an important coffee producing region, there is a lack of information for the Zona da Mata of Minas Gerais in regard to phosphate fertilization of coffee plants in high density planting. Thus, the aim of this study was to assess the response of coffee, in high density planting in the production phase, to the addition of different sources and rates of P application, particularly in regard to yield and the biennial production cycle in this region.

MATERIAL AND METHODS

The experiment was carried out in the Centro de Pesquisas Cafeeiras Eloy Carlos Heringer (CEPEC) [Eloy Carlos Heringer Coffee Research Center], located in the municipality of Martins Soares, MG, Brazil (latitude 20° 14' 45" S and longitude 41° 50' 47" E) at 740 m altitude, in an area of Latossolo Vermelho-Amarelo distrófico (Embrapa, 2006) soil [Oxisol]. The chemical characteristics of the soil are shown in table 1. The variety used was Catucaí Amarelo 6/30, at a spacing of 2.5 × 0.6 (population density of 6,666 plants ha⁻¹). Climate in the region, according to the Köppen classification, is mesothermal, with rainy summers (Cwa).

Table 1. Chemical characteristics of the soil used in the experiment (0-20 cm)⁽¹⁾

pH(H ₂ O)	P	K	Ca ²⁺	Mg ²⁺	Al ³⁺	H+Al	OM	P-rem
	mg dm ⁻³		cmol _c dm ⁻³				dag kg ⁻¹	mg L ⁻¹
5.21	6.4	139.8	1.28	0.28	0.24	4.60	1.98	25.7

⁽¹⁾ Mean values obtained in the control treatment in 2008 and 2009. P and K: extractor Mehlich-1; Ca, Mg and Al exchangeable: extractor: 1 mol L⁻¹ KCl; H+Al: extractor 0.5 mol L⁻¹ calcium acetate, pH 7.0; Organic matter (OM): Walkley-Black method; P-rem: Alvarez V. et al. (2000).

Planting was carried out in November 2003, in plant holes of 40 × 40 × 20 cm. Soil samples were collected under the plant canopy in September 2008 and 2009, according to the method proposed by CFSEMG (1999). Three months before planting, soil amendment was performed by the application of 100 g/plant of limestone (relative Total Neutralizing Power [TNP] - 98 %; 38 % of CaO and 12 % of MgO). At planting, 200 g/plant of the phosphate fertilizer FH460[®] (29 % total P₂O₅ and 14 % soluble in citric acid) was applied. After the plantlets were established, three fertilizations were carried out annually, from October to March, each at the rate of 20 g/plant of the formulation (N-P₂O₅-K₂O) 20-00-20, in 2003/2004, and 42 g/plant of the formulation (N-P₂O₅-K₂O) 24-00-12, in 2004/2005. After the beginning of the reproductive period, 280 g/plant of the formulation (N-P₂O₅-K₂O) 20-00-20 + 0.4 % Mn + 0.4 % Zn + 0.1 % B was applied annually in three portions in the rainy period. Leaf applications of Cu, B and Zn were also made, following the recommendations of CFSEMG (1999).

During the 2010/2011 crop season, leaves were sampled in the middle section of the plants in the third or fourth pairs of leaves of the plagiotropic branches when the fruits were in the initial growth stage (CFSEMG, 1999) and the N, P, K, Ca, Mg, S, Zn, Cu, B, Fe and Mn contents were determined according to the method described by Malavolta et al. (1997).

Sources and application rates of P were assessed. Treatments were arranged in a full factorial design with an additional treatment [(4 × 3) + 1] composed of four sources of P [monoammonium phosphate (48 % of P₂O₅), simple superphosphate (18 % of P₂O₅), natural reactive rock phosphate from Algeria (29 % of total P₂O₅ and 9 % soluble in citric acid), and FH 550[®] (24 % of total P₂O₅ and 14 % soluble in citric acid)], three application rates of P (100, 200, and 400 kg ha⁻¹ year⁻¹ of total P₂O₅); and an additional treatment, without application of the nutrient (0 kg ha⁻¹ year⁻¹ of total P₂O₅). The experimental unit was composed of three rows of 10 plants, in which the eight central plants were assessed. A randomized block experimental design was used with three replicates. The four seasons were evaluated as subplots in a split plot experiment.

The P application rates, for all the sources, were calculated based on the total P₂O₅ content and applied annually in October through broadcasting on the soil surface under the plant canopy, without incorporation.

The following items were assessed: yield data obtained in the 2007/2008, 2008/2009, 2009/2010 and 2010/2011 crop years; P content in the soil in 2008 and 2009; and nutrient content in the leaf tissue in reference to the 2010/2011 crop year. The biennial production cycle was assessed by calculation of the coefficients of variation of the yield data at the plot level for the four crop seasons assessed. The data were subjected to analysis of variance and regression models were fitted so as to relate the dependent variables to the application rates of P₂O₅. Models were chosen whose regression coefficients were significant up to the 5 % level of probability and which exhibited the greatest adjusted coefficient of determination.

RESULTS AND DISCUSSION

There was an increase in P availability in the soil with the application of this nutrient through its various sources (Figure 1). The greater contents observed in the treatments with sources of lower solubility (FNR and FH550[®]) are associated with solubilization of P-Ca by the Mehlich-1 extractor (Novais & Smyth, 1999).

Although the P contents in the soil used were low (mean of 6.4 mg dm⁻³ of P-Mehlich-1, with mean residual P of 25.7 mg L⁻¹ in the 0-20 cm layer in the control treatment), there was no effect of the addition of this nutrient on coffee yield (Tables 2 and 3). This may be attributed to the lack of uptake of P by the plants as a result of surface application of the fertilizer; nevertheless, there was an increase in the leaf contents of this nutrient in response to the rates applied (Figure 2).

The leaf contents of P, estimated by the regression equation shown in figure 2, ranged from 1.1 to 1.48 g kg⁻¹ of P. These values are near or within the range considered adequate for the region of Manhuaçu (which includes the experimental area), which is 1.2 to 1.7 g kg⁻¹ of P (Martinez et al., 2003). The high yields obtained may also be considered (mean yield of the four crop seasons of 64 bags/ha of hulled coffee, 2.7 times greater than the mean value of the Zona da Mata of the State of Minas Gerais), a strong indication that P was not a limiting factor under these conditions.

Although some studies report an effect of phosphate fertilization applied during the production period on coffee yield (Prezotti & Rocha, 2004; Reis et al., 2011), in general, a large increase in the yield of adult woody

plants is not expected as a result of P supply in this phase (Novais et al., 1982), as observed in this study and in the studies of Figueiredo et al. (2006) in the south of Minas Gerais.

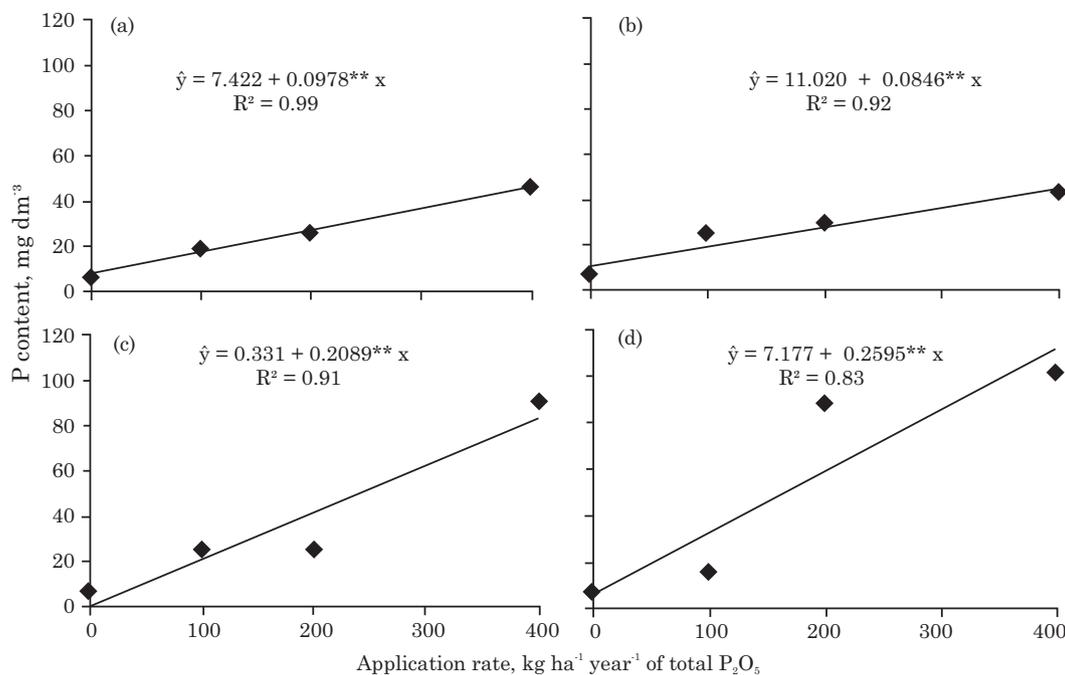


Figure 1. Content of P-Mehlich-1 in the soil, collected under the canopy of the coffee plants in September in the 0-20 cm layer in 2008 and 2009, as a function of the rates of P_2O_5 applied under the forms of simple superphosphate (a), monoammonium phosphate (b), FH 550® (55 % natural reactive rock phosphate from Algeria (Djebel-Onk) and 45 % simple superphosphate) (c), and natural reactive rock phosphate from Algeria (Djebel-Onk) (d). ** significant at 1 %.

Table 2. Coffee yield as a function of different sources and application rates of P over a period of four crop seasons

Crop season	Application rate	MAP ⁽¹⁾	bag ha ⁻¹			
			SS ⁽²⁾	FRA ⁽³⁾	FH550 ⁽⁴⁾	
	g ha ⁻¹ of total P ₂ O ₅					
2007/2008	0.0	77.8	77.8	77.8	77.8	
	100.0	88.2	89.1	83.3	70.6	
	200.0	75.4	78.3	77.4	74.6	
	400.0	70.2	76.4	82.3	66.1	
2008/2009	0.0	74.8	74.8	74.8	74.8	
	100.0	57.1	49.4	80.0	58.6	
	200.0	84.6	72.3	73.6	67.5	
	400.0	80.8	59.7	64.3	89.5	
2009/2010	0.0	23.6	23.6	23.6	23.6	
	100.0	35.5	56.0	23.4	39.6	
	200.0	25.2	32.4	15.2	21.6	
	400.0	17.0	23.4	25.7	17.0	
2010/2011	0.0	73.2	73.2	73.2	73.2	
	100.0	71.0	61.2	83.3	69.4	
	200.0	73.0	73.0	75.6	80.8	
	400.0	62.8	85.9	78.7	86.4	

⁽¹⁾ Monoammonium phosphate; ⁽²⁾ Simple superphosphate; ⁽³⁾ Natural reactive rock phosphate from Algeria (Djebel-Onk); ⁽⁴⁾ Mixture of 55 % natural reactive rock phosphate from Algeria (Djebel-Onk) and 45 % simple superphosphate.

Table 3. Coffee yield (\hat{y} , bag ha⁻¹), as dependent variable of different sources and application rates of P (kg ha⁻¹ of P₂O₅) over the period of four crop seasons

Crop season	Equation / Yield
2007/2008	$\hat{y} = \bar{y} = 77.7$
2008/2009	$\hat{y} = \bar{y} = 71.0$
2009/2010	$\hat{y} = \bar{y} = 26.7$
2010/2011	$\hat{y} = \bar{y} = 74.6$

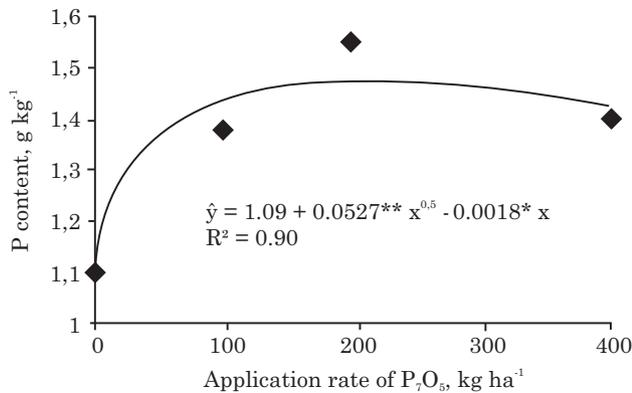


Figure 2. Mean leaf content of P as a function of rates of P₂O₅ applied as a mean value for the four sources of P used in the 2010/2011 crop season. ** and *: significant at 1 and 5 %, respectively.

The nutrient, P, is one of the macronutrients least accumulated by the coffee plant (Corrêa et al., 1986). Thus, responses of this plant to phosphate fertilization, when they occur, are due to the low availability of this nutrient in the soil, and may furthermore vary as a result of greater or lesser uptake efficiency and/or efficiency in utilization of the nutrient by the plant, regulated by genetic and environmental factors (Novais & Smyth, 1999; Pozza et al., 2009; Amaral et al., 2011). In spite of the complexity of these relationships, normally, critical levels of P decrease with the age of the plant (Novais et al., 1982). This occurs because, as the plant grows and develops, it increases its efficiency in acquiring and using nutrients, associated with an increase in the surface area of roots, with an increase of mycorrhizal associations over time, and with changes in its metabolism which, in essence, are connected with intensification of biochemical and biogeochemical cycling of the nutrient (Thinker & Nye, 2000). In other words, the tendency is for the plant to require less P, in relative terms, over time.

An example of how positive responses of the adult coffee plant to the addition of P are often due to the limited availability of the nutrient in the soil is the study of Gallo et al. (1999), carried out in two soils in the state of São Paulo. In their study, P addition

resulted in an increase of 16 % in the yield of coffee plants grown in the soil that had lower availability of the nutrient (13 mg dm⁻³ of P resin) but no response in the soil with the greater availability (22 mg dm⁻³ of P resin), in spite of both being included in the same class of P availability according to Raij et al. (1997).

Another example is the study of Reis et al. (2011), in which there was a great response of the adult irrigated coffee plant to the addition of P. In that study, P availability was very low and the soil showed high capacity for fixing this element (P-Mehlich-1 was 3.3 and 1.4 mg dm⁻³, and residual P was 4.5 and 4.3 mg L⁻¹ in the 0-10 and 10-20 cm layers, respectively). Moreover, for comparison to this study, the effect of irrigation and the fact of the crop being in different climate conditions from those of the Zona da Mata of the State of Minas Gerais should be taken into consideration. The greater leaf contents of P obtained under those conditions (leaf critical level of 1.98 g kg⁻¹ of P) in relation to those obtained in this study (in which maximum leaf content was 1.48 g kg⁻¹ of P) indicate changes in P demand in the plants, which, among other factors, must be associated with better transport of the nutrient in the soil in which there is a supplemental water supply. That way, even a clayey soil, with low residual P, may behave as a soil with a lower capacity factor, conditions in which the critical level of P in the plant is greater (Novais & Smyth, 1999).

The results also generate questions in regard to the use of critical levels in the soil obtained in coffee fields with normal plant density for coffee plants in production in fields with high plant density. This hypothesis corroborates the proposition of Malavolta & Moreira (1997) that the increase in root area and greater input of organic matter in high density cropping favor P uptake by the crop, in detriment to its fixation in the soil. This was also shown in the study of Prezotti & Rocha (2004), in which higher leaf contents of P were observed in plants grown in a high plant density system compared to those grown in a conventional system.

There was no effect of P application rates on the biennial cycle of coffee yield for any of the sources assessed (Figure 3). The biennial cycle was more intense between the 2009/2010 and 2010/2011 crop seasons as a function of the prolonged drought which occurred in 2010 (Table 3).

Multiple factors may alter the biennial yield cycle of coffee plants, which, basically, is associated with the lack of synchronism between their vegetative and reproductive growth (Da Matta et al., 2007). Mineral nutrition stands out in this respect (Valadares et al., 2013). A large part of the nutrients taken up by the plant are directed to the coffee fruits during the reproductive period, including P (Cannell, 1985). In addition, during this period, P uptake is reduced (Lima Filho & Malavolta, 2003) due to lower supply of carbohydrates to the root system, which hurts the

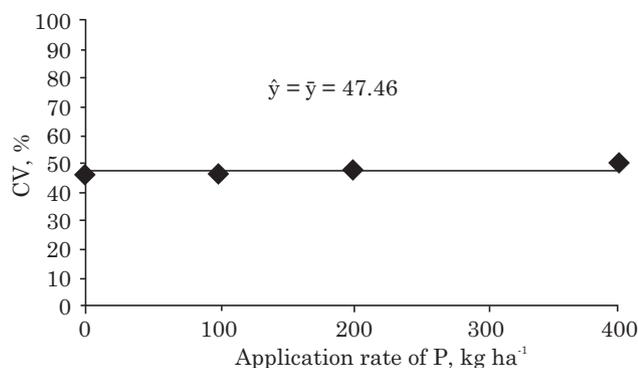


Figure 3. Mean coefficients of variation of yield in high plant density coffee as a function of rates of P₂O₅ applied for the four sources of P used over the period of four crop seasons.

vegetative growth of the crop and, as a consequence, the yield in the following year (Da Matta & Rena, 2002; Rena & Carvalho, 2003; Chaves, 2009). Using the same method of assessment of the biennial nature of yield applied in this study, under similar growing conditions, a positive effect was seen from nutrition with N (especially) and K on the yield stability of high plant density coffee in two field experiments (Valadares et al., 2013). The results reinforce the observation that P was not limiting to coffee production in this study and indicate that it is necessary to establish more adequate criteria for recommendation of this nutrient for the coffee crop and that the responses to phosphate fertilization obtained under some specific growing conditions may not be generalized.

CONCLUSIONS

1. The positive responses of coffee yield to P fertilization obtained in some growing conditions may not be generalized.

2. The biennial nature of coffee production is not necessarily affected by the addition of P.

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