

GRAIN YIELD OF COFFEE PLANTS FERTILIZED WITH DIFFERENT DOSES OF 20-00-20 NPK FORMULATION UNDER RAINFED CONDITIONS¹

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ABSTRACT - Little is known about the management of high-yield clonal *Coffea canephora* in the Amazonian Region, mainly for nutritional aspects and cultivation system efficiency. This study aimed to evaluate the influence of different nitrogen and potassium fertilization rates on coffee grain yield and fertilizer use efficiency of *C. canephora* trees. An experiment was performed at an experimental field of the *Embrapa Rondônia* in Porto Velho (RO), Brazil. It was carried out in a split-plot scheme with six doses of 20-00-20 NPK formulation (0; 250; 500; 1,000; 2,000; and 3,000 kg ha⁻¹) and three years of evaluation (2014, 2015, and 2016). An interaction between fertilizer dose and crop year was observed. Fertilizer doses showed an exponential behavior, with maximum yields of 51, 114, and 79 bags ha⁻¹ at 3,000 kg ha⁻¹ in the crop years of 2014, 2015, and 2016, respectively. Such a behavior impacted average and accumulated yields in the three harvest seasons. As for crop year effect within each fertilizer dose, the highest yield was reached in the second harvest after pruning for renewal of orthotropic stems. Moreover, fertilizer use efficiency by plants decreased exponentially, with the highest value at the lowest dose. Increasing doses of 20-00-20 formulation promoted an exponential increase in grain yield but decreased its use efficiency by *C. canephora* plants. This management also stimulated a strong biannual production.

Keywords: *Coffea canephora*. Nitrogen. Potassium. Fertilizer use efficiency.

PRODUTIVIDADE DE CAFEEIROS FERTILIZADOS COM DOSES DO FORMULADO 20-00-20 EM CONDIÇÕES DE SEQUEIRO

RESUMO - Informações sobre o manejo do cafeeiro clonais de *Coffea canephora* de alto rendimento agrônomico na Amazônia, ainda são escassas, especialmente no que se refere ao aspecto nutricional e a quantificação da eficiência do sistema de cultivo. Assim, o objetivo neste estudo foi avaliar a influência de doses de adubação nitrogenada e potássica sobre a eficiência do uso de fertilizantes e a produtividade em cafeeiros *C. canephora*. O experimento foi conduzido no campo experimental da EMBRAPA Rondônia em Porto Velho - RO, em esquema de parcelas subdivididas no tempo, composto pela combinação de 6 doses de fertilizantes (0; 250; 500; 1.000; 2.000 e 3.000 kg ha⁻¹ do formulado 20-00-20) e 3 anos de avaliação (safras 2014, 2015 e 2016). Foi observado interação entre os fatores doses e anos de avaliação. Para efeito de dose dentro de cada safra foi evidenciado comportamento exponencial, com produções máximas de 51, 114 e 79 sacas ha⁻¹ na dose de 3.000 kg do formulado em todas as safras avaliadas, respectivamente. Este comportamento foi refletido nas produtividades média e acumulada das três safras. Quanto ao efeito de safras dentro de cada dose, a safra do ano de 2015 apresentou maior produtividade. Para a eficiência do uso dos fertilizantes, o comportamento foi exponencial decrescente apresentando maior eficiência na menor dose. O aumento das doses do formulado promove incremento exponencial da produtividade e decréscimo na eficiência do uso de fertilizantes por cafeeiros *Coffea canephora*, e sob esse manejo ocorre forte bialidade de produção.

Palavras-Chave: *Coffea canephora*. Nitrogênio. Potássio. Eficiência do uso de fertilizantes.

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INTRODUCTION

Together with calcium (Ca), nitrogen (N) and potassium (K) are macronutrients accumulated in large amounts in vegetative shoots of *Coffea canephora* trees (BAZONI et al., 2020). Both are also required in large amounts by coffee plants during reproductive stages, when accumulations may exceed 10 mg per fruit, at the end of its expansion period (DUBBERSTEIN et al., 2016). Therefore, these elements should receive the most attention in nutritional management programs for Conilon coffee production.

Although general knowledge on nutritional requirements indicates that N and K are the most demanded by coffee trees, such demands may vary with genotype (PREZOTTI; BRAGANÇA, 2013; PARTELLI et al., 2014; STARLING et al., 2018) and environmental conditions (COVRE et al., 2016).

Regarding genotype influence, studies have shown that varieties of *C. canephora* or populations distributed worldwide are genetically distinct (MONTAGNON; CUBRY; LEROY, 2012). Even within the same country, as in Brazil, there is high genetic variability among genotypes grown commercially in different Conilon coffee producing regions (FERRÃO et al., 2013; SOUZA et al., 2013). Thus, nutrient calibration studies for this crop should consider agronomic traits of genotypes grown in each region.

As for environmental conditions, factors such as water availability (DAMATTA et al., 2018) and sub- or supra-optimal temperatures (RODRIGUES et al., 2018; RAMALHO et al., 2018) may change coffee metabolism and hence agronomic performance. Climatic conditions in the Brazilian Amazon, in particular high temperatures associated with severe droughts from June to September (ALVARES et al., 2013), may influence plant

development, limiting growth period to months with the highest rainfall intensities and lowest temperatures (DUBBERSTEIN et al., 2017). Thus, in this region, nutrient supply is restricted from May to October, mainly in rainfed crops.

To deal with climate and peculiarities of the Amazon region, the Brazilian Agricultural Research Corporation (Embrapa) has developed a clonal variety of Conilon coffee, known as 'BRS Ouro Preto'. It is adapted to cultivation conditions in the Brazilian Southwestern Amazon (RAMALHO et al., 2014). However, little is known about its responses to fertilizers throughout its growth cycle.

In this sense, this study aimed to evaluate the influence of different nitrogen and potassium fertilization rates on yield and fertilizer use efficiency of *C. canephora* plants variety 'BRS Ouro Preto' under rainfed conditions in the Western Amazon.

MATERIAL AND METHODS

The experiment was carried out at an experimental field of the *Embrapa Rondônia*, in the city of Porto Velho (RO) Brazil (8°53'20" S and 63°06'40" W). It was performed from September 2012 to August 2016. According to Köppen, the local climate is classified as *Am* type, which stands for rainy tropical with rainy summers (October to May) and dry winters (June to September). Average temperatures range from 26.3 °C in the summer to 25.9 °C in the winter. Average annual rainfall is 2,200 mm (ALVARES et al., 2013). Data on rainfall, temperature, and air relative humidity during the experimental period were obtained from a weather station of the Rondônia State Secretariat of Environmental Development (SEDAM, 2020) (Figure 1).

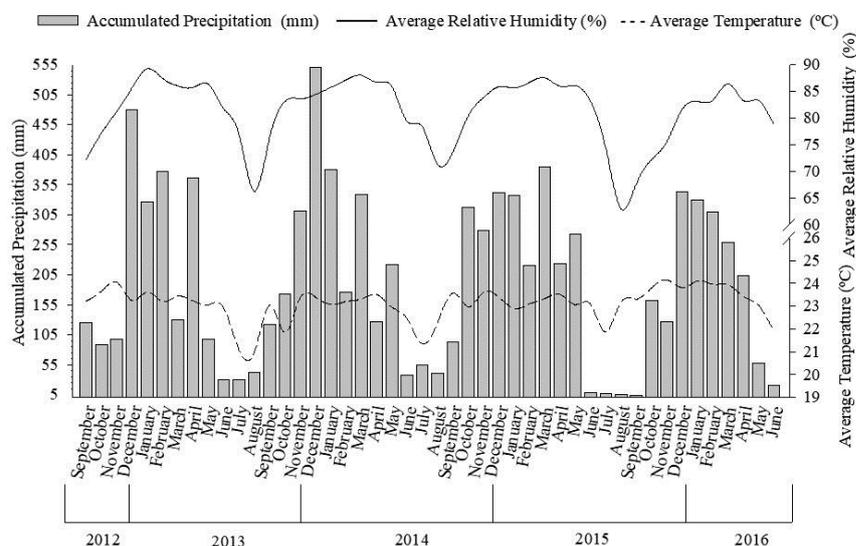


Figure 1. Averages of accumulated rainfall (mm), air relative humidity (%), and temperature (°C) for the years 2012, 2013, 2014, 2015, and 2016. Source: SEDAM (2020). Porto Velho - RO, Brazil.

Coffea canephora plants of the clonal variety ‘Conilon - BRS Ouro Preto’, which is composed of 15 genotypes (clones) of intermediate ripening (May), were grown in the experimental area. These genotypes show typical phenotypic characteristics of plants of the Conilon botanical group. The variety was developed under rainfed conditions (RAMALHO et al., 2014) and has been recommended for cultivation in the Southwestern Amazon.

The coffee trees were implanted in December 2008 and were fertilized to produce 70 bags per hectare during the 2009, 2010, 2011 and 2012 crop years, as recommended by MARCOLAN et al. (2009). In September 2012, their orthotropic branches were drastically pruned to standardize canopy size. After pruning, only 6 branches were maintained per plant (10,000 stems per hectare, 3 × 2m spacing). Before experiment installation, from

September 2012 to May 2013, plants received 50 kg P₂O₅ (as triple superphosphate), 50 kg urea nitrogen, 100 kg ammonium sulfate, 60 kg K₂O (as potassium chloride), and 30 kg FTE BR-12 fertilizer per hectare. Other treatments were carried out following the technical recommendations for the growing of this crop in the region (MARCOLAN et al., 2015).

The soil of the area was classified as Red-Yellow Latosol (Oxisol) with clayey texture (SANTOS et al., 2018), and its chemical and physical properties were determined for the depth layers of 0-10, 10-20, and 20-40 cm in July 2013 (Table 1). Before treatment, in August 2013, four tons of dolomitic limestone (with 76% PRNT) per hectare were applied onto the soil surface, without incorporation. In September 2014, two more tons were applied onto the surface, also without incorporation.

Table 1. Chemical and physical properties at the 0-10, 10-20 and 20-40 cm depth layers of the Red-Yellow Latosol in the *Embrapa Rondônia* experimental station, Porto Velho - RO, Brazil.

Depth layer (cm)	pH	P	K	Ca	Mg	Al+H	Al	CEC	OM	m	V
	H ₂ O	mg dm ⁻³	-----cmol _c dm ⁻³ -----						g kg ⁻¹	-----%---	
0-10	5.6	9,73	0,77	2,6	1,98	11,75	1,01	17,19	58,8	16	29
10-20	5.4	3.11	0.38	1.64	1.31	11.89	1.32	15.22	53.2	29	20
20-40	5.4	4.97	0.35	1.38	1.10	11.57	0.96	14.40	45.6	26	20
Density		Porosity			Water content (m ³ m ⁻³)						
Soil (apparent)	Particle (real)	Micro	Macro	Total	6	10	30 ²	100	1,500 ³		
-----g cm ³ -----		-----m ³ m ⁻³ -----			-----Tensions (kPa)-----						
1.03	2.33	0.42	0.08	0.50	0.42	0.41	0.37	0.34	0.27		

pH in water (1: 2.5); O.M. by wet digestion; P and K by the Mehlich I method; exchangeable Ca, Mg, and Al using 1 mol KCl.

The experiment was conducted in a split-plot scheme, combining 6 fertilizer doses and three years of evaluation. The main plots consisted of six doses of the NPK formulation 20-00-20 as production fertilization (0; 250; 500; 1,000; 2,000; and 3,000 kg ha⁻¹). The subplots comprised the evaluation years of 2014, 2015, and 2016, which are equivalent to the first, second, and third harvest seasons after pruning of orthotropic stems.

The experimental design was fully randomized with 15 replications. Each repetition was composed of one clone of the variety ‘Conilon - BRS Ouro Preto’. Each experimental plot consisted of 10 plants continuously arranged in a planting row, spaced 3 m between rows and 2 m between plants, totaling 1,667 plants per ha⁻¹. The useful plot was the

8 central plants of each experimental plot.

Fertilizer doses were staggered throughout the rainy season of each year, from October 2013 to March 2016, totaling four fertilization cycles. In each year, doses were divided into four applications (October, December, January, and March). Plants were only rainfed without the use of any supplemental irrigation, and crop treatments followed recommendations for the Amazon region.

Phosphorus was supplied twice a year (in October and March) by applying 100 kg P₂O₅ per hectare, as simple superphosphate. In October of each year, 50 kg FTE BR-12 complex fertilizer was applied per hectare for micronutrient supply. In November and March of each year, 20 kg zinc sulfate, 15 kg boric acid, and 20 kg magnesium

sulfate were also applied.

All plants within the useful area were harvested, and fruits were dried and then benefited for dry grain mass determinations. Based on these, annual, accumulated, and average yields for three years were estimated for the three crop years and expressed in bags per hectare at 12% humidity.

Fertilizer use efficiency (FUE) for grain production was also evaluated. To this end, we considered the accumulated yield (sum of the three evaluated years) and total amounts of fertilizer applied in the three harvests (2013/14, 2014/15, and 2015/16). The total amounts of fertilizer used were 750; 1,500; 3,000; 6,000; and 9,000 kg per hectare for the doses of 250; 500; 1,000; 2,000; and 3,000 kg 20-00-20 formulation ha⁻¹, respectively. FUE was calculated as the difference between treatment and control yields, then divided by the amount of fertilizer applied to the soil (GOOD; SHRAWAT; MUENCH, 2004), as follows:

$$\text{FUE (kg grain per kg fertilizer)} = \frac{\text{Treatment grain yield (kg ha}^{-1}) - \text{Control grain yield (kg ha}^{-1})}{\text{Amount of fertilizer applied (kg ha}^{-1})}$$

The data were subjected to analysis of

variance. Annual averages within each fertilizer dose were compared by the Tukey's test ($p \leq 0.05$), using the Genes software (version 2016.6.9) (CRUZ, 2017). Fertilizer dose effects in each year were evaluated by regression analysis, both for average and accumulated yields, as well as for fertilizer use efficiency, using the SigmaPlot® software version 10 (SYSTAT SOFTWARE Inc, 2006).

RESULTS AND DISCUSSION

Fertilizer doses and evaluation years showed a significant interaction. Dose effects within years had an increasing exponential trend. This indicates that lower doses of 20-00-20 formulation had a more pronounced effect on yield than did the higher ones, tending to stabilize at doses above 2,000 kg ha⁻¹ (Figure 2). For instance, by using the equation for 2015, a 2,000 kg application would yield 103.86 bags ha⁻¹, whereas 3,000 kg would produce 111.74 bags ha⁻¹, that is, around 7.8 extra bags ha⁻¹ by adding 1,000 kg fertilizer. Yet, if a 4,000 kg dose is used, the estimated yield would reach 115.28 bags ha⁻¹.

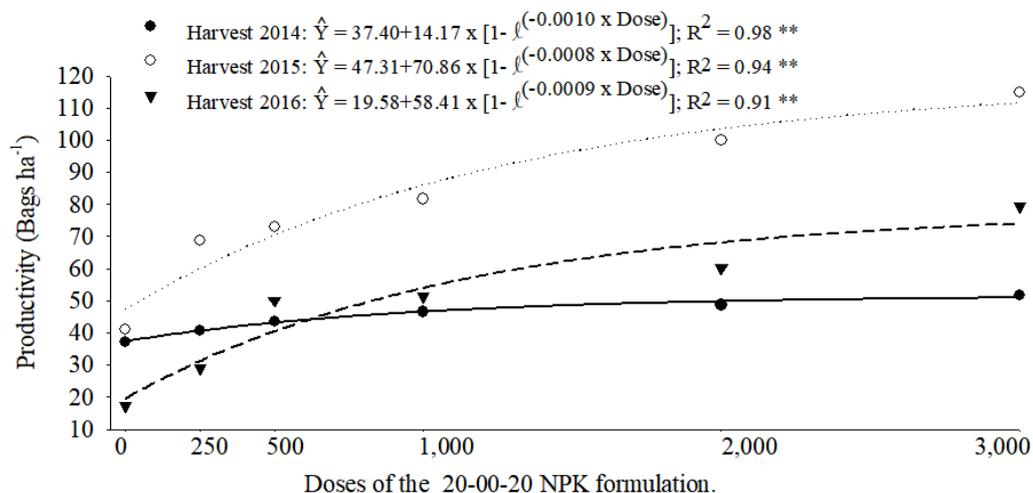


Figure 2. Yield of *Coffea canephora* 'Conilon - BRS Ouro Preto' coffee trees fertilized with six different doses of the 20-00-20 formulation in three harvests (2014, 2015, and 2016), after pruning of orthotropic stems.

The exponential behavior observed in the three harvests promoted an increase in both average and accumulated yields. Accumulated yields ranged from 104 bags at zero dose to 237 bags at 3,000 kg fertilizer, while average yield ranged from 34 to 79 bags ha⁻¹, respectively (Figure 3).

Grain yield exponential behavior in the three harvests, as well as average and accumulated yields (Figures 2 and 3), may be related to biological limitations and agronomic traits of this Conilon variety. Such factors influence plant response to high

fertilizer doses.

Biological limitations are related to the genetic potential of the 'Conilon - BRS Ouro Preto' variety, as it is composed of 15 genotypes with different morphological characteristics and productive potentials (RAMALHO et al., 2014). Such diversity ensures improved production stability under several Amazonian conditions but also limits plant responses to fertilizers. This is because genotypes more efficient under nutritional stress may not respond well to fertilization.

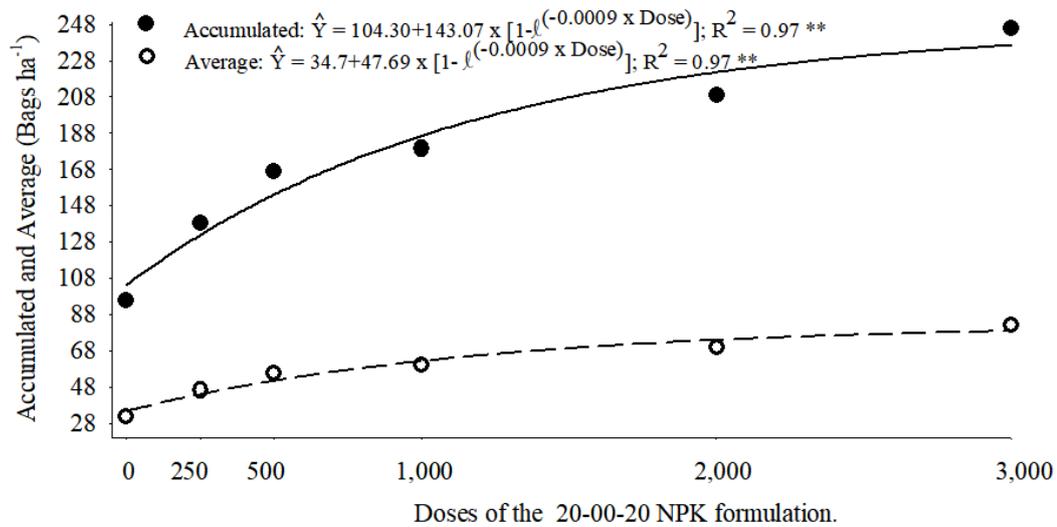


Figure 3. Average and accumulated yields for three crop seasons (2014, 2015, and 2016) of *Coffea canephora* 'Conilon - BRS Ouro Preto' plants fertilized with six different doses of the 20-00-20 formulation.

Agronomic limitations are mainly related to planting density and rainfed systems. In commercial Conilon coffee crops, planting density is about 3,300 plants per hectare, associated with 3 to 4 stems per plant, which increases yield per area (VERDIN FILHO et al., 2014; SAKAI et al., 2015; SILVEIRA et al., 2018) when compared to old practices (1,600 plants per hectare and about six stems per plant). This is because plant expansion influences root system distribution, promoting elongation of the main roots and increasing plant efficiency in nutrient and water uptake from the soil. If associated with a programmed pruning, this plant growth per area may

reduce self-overgrowth and hence metabolic wear (VERDIN FILHO et al., 2016; SILVA et al., 2019).

As for harvest season effects within each dose, grain yield in 2015 was higher than in 2014 and 2016 for all tested doses but the control (zero dose), for which no difference was seen between 2014 and 2015, which were in turn higher than 2016 (Table 2). For the doses of 250; 500; 1,000; and 2,000 kg 20-00-20, no difference was observed between the first and last production in 2014 and 2016 harvests. However, for the highest dose (3,000 kg ha⁻¹), production in 2016 was higher than in 2014 (Table 2).

Table 2. Grain yield of *Coffea canephora* trees, variety 'Conilon - BRS Ouro Preto', fertilized with six doses of the 20-00-20 formulation in three harvests after orthotropic stem renewal pruning.

Year	Dose of 20-00-20 formulation (kg ha ⁻¹ year ⁻¹)					
	00	250	500	1,000	2,000	3,000
2014	37.11 a*	40.78 b	43.58 b	46.57 b	48.71 b	51.68 c
2015	40.98 a	68.76 a	72.86 a	81.65 a	99.84 a	114.92 a
2016	17.37 b	28.86 b	50.15 b	51.25 b	60.38 b	79.39 b
Average	31.86	46.13	58.86	59.82	69.64	81.99
CV (%)	16.3					

*Means followed by the same letter in the column does not differ from each other by the Tukey's test at 5% significance.

Low yield in the first year of evaluation is related to vegetative limitations after drastic pruning (Table 2). This is because orthotropic stems and plagiotropic branches were only 10 months old to develop until subsequent flowering (from September

2012 to July 2013). In other words, short growth time associated with a slow initial growth after drastic pruning reduced numbers of nodes (rosettes) with productive buds. In this sense, when treatments began in October 2013, productive potential in the

2014 harvest had already been defined by the flowering in July and August. Thus, yield increase due to a rise in the amount of fertilizer may be related to grain expansion and not to an increase in the number of produced grains.

Yield levels and their increases due to fertilizer doses in the second crop year, 2015 (Table 2), are related to effects of fertilizer added in the 2013/2014 harvest on the 2014/2015 cycle. As the number of fruits was limited in the previous harvest (2014), N and K were reallocated to vegetative parts of plants, increasing their vegetative growth and hence production potential in the subsequent crop year (2015). These results confirm biennial bearing,

which is a common phenomenon in plants of the genus *Coffea* (VALADARES et al., 2013; PINTO et al., 2014). Conversely, this biennial behavior promoted a reduction in yield in the subsequent harvest of 2016 (Table 2). Accordingly, since there was a high fruit production in the 2015 harvest, these drained resources and reduced vegetative growth, which compromised the 2016 harvest.

Fertilizer use efficiency (FUE) decreased exponentially with increasing fertilizer doses. It decreased from 3.4 kg grains kg⁻¹ fertilizer at the dose of 750 kg to 1.0 kg kg⁻¹ at the dose of 9,000 kg of the formulation (Figure 4).

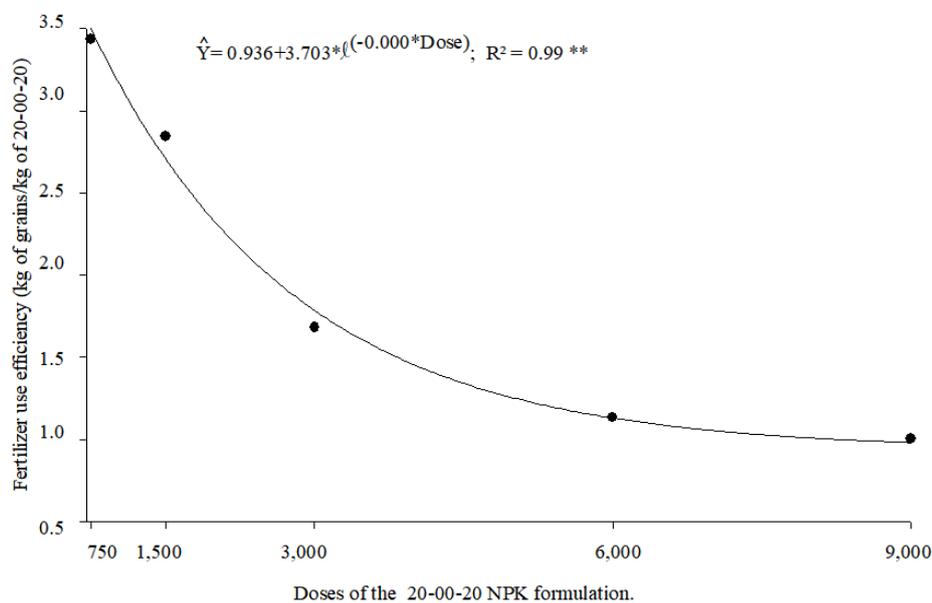


Figure 4. Fertilizer use efficiency (FUE, in kg of grains per kg of 20-00-20) in *Coffea canephora* plants of the variety 'Conilon - BRS Ouro Preto' fertilized with six doses of the 20-00-20 formulation.

The decreasing exponential behavior of FUE (Figure 4) seems to be related to the residual effect of nutrients in the soil (Table 1). This may have ensured fruit yield at low or even at zero fertilizer doses. Moreover, FUE decrease with increasing fertilizer doses indicates that plants did not metabolize all the applied nutrients. Part of the nutrients was lost due to leaching to subsurface layers, runoff, or even ammonia volatilization (ESPINDULA et al., 2021). Whereas the other portion may have been immobilized in plant litter on the soil surface (REICHARDT et al., 2009).

CONCLUSIONS

In Western Amazon under rainfed conditions, *Coffea canephora* trees of the variety 'Conilon - BRS Ouro Preto' respond exponentially to an increase in doses of the 20-00-20 formulation,

showing significant increases up to the dose of 2,000 kg ha⁻¹. The coffee plants also show a seasonal behavior, with maximum yields in the second crop year after drastic pruning for orthotropic stem renewal. Fertilizer use efficiency by this Conilon variety under rainfed conditions decreases exponentially with increasing doses of the 20-00-20 formulation.

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