Alternative sources of potassium in coffee plants for better soil fertility, productivity, and beverage quality

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Abstract – The objective of this work was to evaluate alternative sources of potassium for improving soil fertility and coffee productivity and beverage quality. The experiment was conducted in a coffee (*Coffea arabica*) crop, planted in an Oxisol area, in the municipality of Patrocínio, in the state of Minas Gerais, Brazil. The treatments consisted of the K sources TK47 and Super Greensand (SG) – both based on glauconite silicate mineral –, at the following doses: 0 kg ha^{-1} K_2O (control); 42, 84, 168, and 336 kg ha^{-1} K_2O from TK47; 618 kg ha^{-1} K_2O from KCl; and 168 kg ha^{-1} K_2O from SG. A randomized complete block design was used, with four replicates in each treatment. The experimental units consisted of three rows with ten plants each, using the eight central plants as the useful plot. Potassium fertilization with TK47 increased soil fertility, correcting soil acidity and elevating K^+, P, and Ca^{2+} contents, effective cation exchange capacity, and Zn^{2+} and Fe^{2+} levels in the soil. Fertilization with 336 kg ha^{-1} K_2O from TK47, in a single dose, provides grain yield and polyphenol oxidase activity similar to those of fertilization with 618 kg ha^{-1} K_2O from KCl, in a split-dose, but a better sensory analysis of the resultant beverage.

Index terms: *Coffea arabica*, alternative fertilizers, coffee mineral nutrition, glauconite, potassium gradual solubilization, residual effect.

Fontes alternativas de potássio em cafeeiros para melhoria da fertilidade do solo, da produtividade e da qualidade de bebida

Resumo – O objetivo deste trabalho foi avaliar fontes alternativas de potássio para melhoria da fertilidade do solo e da produtividade e da qualidade de bebida do cafeeiro. O experimento foi conduzido em lavoura de café (*Coffea arabica*) plantada em área de Latossolo, no Município de Patrocínio, no Estado de Minas Gerais. Os tratamentos consistiram da aplicação das fontes de K TK47 e Super Greensand (SG) – ambas baseadas no mineral silicatado glauconita –, nas seguintes doses: 0 kg ha^{-1} de K_2O (controle); 42, 84, 168 e 336 kg ha^{-1} de K_2O de TK47; 618 kg ha^{-1} de K_2O de KCl; e 168 kg ha^{-1} de K_2O de SG. Utilizou-se o delineamento de blocos ao acaso, com quatro repetições por tratamento. As unidades experimentais foram constituídas por três linhas de dez plantas cada uma, tendo-se considerado as oito plantas centrais como parcela útil. A adubação potássica com TK47 aumentou a fertilidade do solo, com correção da acidez e com elevação dos teores de K^+, P, Ca^{2+}, da capacidade de troca de cátions efetiva, e dos níveis de Zn^{2+} e Fe^{2+} no solo. A adubação com 336 kg ha^{-1} de K_2O de TK47, em dose única, proporciona produção de grãos e atividade de polifenoloxidase semelhantes às da fertilização com 618 kg ha^{-1} de K_2O de KCl, de forma parcelada, mas melhor análise sensorial da bebida resultante.

Termos para indexação: *Coffea arabica*, fertilizantes alternativos, nutrição mineral do cafeeiro, glauconita, solubilização gradual do potássio, efeito residual.

Introduction

Potassium is required and accumulated in large quantities by the coffee (*Coffea* spp.) plant, and the most common source for fertilization is potassium chloride. Potassium's relationship with coffee production is attributed to its participation in the enzyme activation of several metabolic processes in

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the plant, such as photosynthesis, synthesis of proteins and carbohydrates, and maintenance of cell turgidity (Malavolta, 2006; Ernani et al., 2007). The nutrient has been acknowledged as the “quality element” in plant nutrition, due to its role in metabolic processes and activation of enzymes that influence the chemical composition of coffee beans and, consequently, the quality of the resultant beverage (Guimarães et al., 2011). In contrast, the anion, Cl^-, present in KCl reduces polyphenol oxidase activity, which is related to the quality of the beverage (Silva et al., 2002; Clemente et al., 2015). Therefore, it is essential to devise a K fertilizer that contributes maximally to crop productivity, without compromising any physiological features of the plant.

Brazil imports about 87% of its potassic fertilizers, mainly in the form of KCl (Sumário..., 2014). This low production creates a high dependence on the international market, while increasing production costs due to the high import rates and exchange variation. Therefore, there is a demand for alternative sources of K in order to reduce costs and dependence on the external market.

The alternative sources used as fertilizer in the present work are composed essentially of the glauconite silicate mineral with the molecular formula $K_2(MgFe).2Al_6.(Si_4O_{10}).8(OH)_{12}$ (Dana, 1978). Super Greensand consists of 10% K_2O, 1.8% Mg, 27% Si, and 2.7% Fe; and TK47, of 7.0% K_2O, 20% Ca, 17% Si, 3.0% Mg, 0.14% P_2O_5, and 3.5% Fe. The latter source goes through a pyrometallurgical process for greater K solubilization.

Glauconite has been highlighted as an alternative source of K, because it is relatively easy to explore its K_2O contents, which range from 7 to 14% (Lima et al., 2007). Although it is a promising source of K for plants (Martins et al., 2015; Santos et al., 2015), further research is still needed regarding the coffee crop. Moreover, the solubility of potassic minerals present in the rock is low, requiring thermal and chemical processes with limestone addition to increase K solubilization, in order to overcome this obstacle (Silva et al., 2012; Martins et al., 2015).

The objective of this work was to evaluate alternative sources of potassium for improving soil fertility and coffee productivity and beverage quality.

Materials and Methods

The experiment was carried out in a dry coffee (*Coffea arabica* L.) crop of the IBC 12 cultivar, at the experimental farm of Empresa de Pesquisa Agropecuária de Minas Gerais (Epamig), located in the municipality of Patrocínio, in state of Minas Gerais, Brazil (18º57'S, 47º00'W, at an average altitude of 930 m). The climate of the experimental region is tropical, classified as of the Cwa type, according to Köppen, with a cold winter and a rainy summer. The average annual rainfall is 1,620 mm (Silva & Malvino, 2005).

Before the installation of the experiment, soil samples were collected at the 0.00–0.20-m depth, for chemical characterization. The soil was classified as a Latossolo Vermelho-Amarelo (Santos et al., 2013), i.e., a Typic Haplustox, with the following characteristics: 4.5 pH in H_2O, 42.5 mg dm^{-3} K^+, 8.2 mg dm^{-3} P, 7.0 mg dm^{-3} remaining phosphorus (P-rem), 1.8 $cmol_c$ dm^{-3} Ca^{2+}, 1.4 $cmol_c$ dm^{-3} Mg^{2+}, base saturation (BS) of 44.7%, 0.4 $cmol_c$ dm^{-3} Al^{+3}, 4.1 $cmol_c$ dm^{-3} H+Al, aluminum saturation of 5.4%, and 3.1 dag kg^{-1} organic matter.

Based on the soil chemical analysis, 1.4 Mg ha^{-1} calcitic limestone (total neutralizing power = 80%) was applied three months before planting of the coffee seedlings, aiming at BS of 60%. Limestone was applied and incorporated during soil tillage with plowing and harrowing, to a 0.00–0.20-m depth. A total of 300 g m^{-1} simple superphosphate was applied in soil grooves. Soil correction, planting, and post-planting fertilizations during the experimental period were performed based on the soil analysis, according to fertilizer recommendations for the crop in the state of Minas Gerais (Guimarães et al., 1999), except for K.

The coffee seedlings were transplanted, spaced at 3.4x0.7 m, in December 2010. A randomized complete block design was used, with seven treatments and four replicates. Each experimental unit consisted of three rows of ten plants each, with the eight central ones being considered as the useful plot.

The treatments (T1 to T7) consisted of the alternative K sources TK47 and Super Greensand (SG), both based on the glauconite silicate mineral, at the following doses: T1, 0 kg ha^{-1} K_2O (control); T2, T3, T4, and T5, respectively, 42, 84, 168, and 336 kg ha^{-1} K_2O from TK47; T6, 618 kg ha^{-1} K_2O from KCl (half at planting and half during the production phase, at 2.5 years); and T7, 168 kg ha^{-1} K_2O from SG. The recommended dose

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corresponded to 168 kg ha^{-1} K_2O, according to the soil chemical analysis and to fertilizer recommendations for the crop in the state of Minas Gerais (Guimarães et al., 1999). TK47 and SG were applied in the planting pit. KCl was applied after planting, at the dose of 168 kg ha^{-1} K_2O, split into three, at 20-day intervals.

After the first harvest, only the conventional source (KCl) was reapplied, in the amount of 450 kg ha^{-1} K_2O, also divided into three, at 20-day intervals. This amount of K was used due to the high production expectation for the first harvest, 2.5 years after planting, considering the high K drainage in this stage (Guimarães et al., 1999). The alternative sources of K from glauconite were not reapplied in order to evaluate their residual effects. SG has about 10% total K_2O, 1.8% Mg, 27% total Si, and 2.7% Fe; while TK47, which goes through the pyrometallurgical proprietary process to enhance K solubility, has about 7% total K_2O, 20% Ca, 17% total Si, 3.0% Mg, 0.14% P_2O_5, and 3.5% Fe.

In December 2012, soil samples were collected at the 0.00–0.20-m depth, where fertilization was performed, for chemical characterization (Silva, 2009). The analyzes were carried out at the laboratory of soils and plant nutrition of Epamig, in the municipality of Lavras, also in the state of Minas Gerais.

To evaluate the nutritional status of the plants, 50 pairs of leaves (third or fourth pairs counted from the tip of the branch) were collected from plants within the useful area, at the beginning of January 2013. Coffee bean samples were then collected, washed, placed in paper bags, and dried in an oven until they reached constant weight (Malavolta et al., 1997).

Grain production was evaluated in June 2013, in the useful plots. A total of 5 L cherry coffee per plot were collected, and then pulped and dried separately in individual suspended sieves. After drying and benefiting, samples were coded and sent for the quality analysis of the beverage. The sensorial analysis of coffee was carried out by three specialist tasters of Brazil Specialty Coffee Association at Cooperativa Regional de Cafeicultores em Guaxupé Ltda., located in the municipality of Guaxupé, in the state of Minas Gerais. The enzymatic activity of polyphenol oxidase was determined according to Ponting & Joslyng (1948), using the sample extract without L-3,4-dihydroxyphenylalanine (L-DOPA).

Data were subjected to the analysis of variance, and means were compared by the Scott-Knott test, at 5% probability, using the Sisvar statistical software (Ferreira, 2014).

Results and Discussion

The dose of 336 kg ha^{-1} K_2O from TK47, applied in treatment T5, promoted a significant elevation in pH, BS, P-rem, and P, K^+, Ca^{2+}, effective cation exchange capacity (ECEC), Zn^{2+}, and Fe^{2+} levels, compared with the control and the other treatments (Table 1). Soil pH was 6.33 in T5, within the ideal range for the coffee crop (Guimarães et al., 1999); however, in the other treatments, pH values were between 4.2 and 5.2, below the ideal.

The ability of TK47 to correct soil acidity is due to the presence of silicate and carbonate anions. Ions including Ca^{2+} and K^+ displace Al^{3+} from the exchange complex, while SiO_3 neutralizes the H^+ ions in the soil solution and converts them to H_2SiO_3 (Sarto et al., 2014). Due to the tendency of silicate to neutralize acidic components, mainly as Ca^{2+} and K^+ ions, TK47 also promotes an increase in BS. This corrective effect

Table 1. Soil chemical analysis as a function of fertilization with different K sources and doses(1).

Treatment(2)	pH (H_2O)	P-rem (g L^{-1})	P (mg dm^{-3})	K^+ (mg dm^{-3})	Ca^{2+} ($cmol_c$ dm^{-3})	Mg^{2+} ($cmol_c$ dm^{-3})	ECEC ($cmol_c$ dm^{-3})	BS (%)	Zn^{2+} (mg dm^{-3})	Cu^{2+} (mg dm^{-3})	Fe^{2+} (mg dm^{-3})	Mn^{2+} (mg dm^{-3})	B (mg dm^{-3})
T1	4.5b	9.7c	10.6b	44.6c	1.8c	1.5a	3.8c	47c	5.1b	11.7a	34.5c	12.8a	1.15a
T2	4.4b	9.9c	17.8b	92.3c	1.8c	1.0a	3.9c	35d	5.2b	7.30a	38.3c	14.8a	1.16a
T3	4.7b	9.6c	11.5b	186b	2.5c	1.3a	4.7c	51c	4.7b	12.2a	40.4c	13.6a	1.18a
T4	5.2b	11.6b	19.2b	226b	4.0b	1.2a	5.9b	65b	8.0b	10.7a	66.9b	19.7a	1.41a
T5	6.3a	13.5a	89.7a	875a	8.4a	1.1a	11.8a	89a	12.1a	9.80a	98.8a	18.7a	1.28a
T6	4.5b	10.9b	13.5b	114b	2.0c	1.3a	3.9c	46c	4.2b	8.10a	36.8c	14.1a	1.09a
T7	4.2b	10.9b	18.6b	70.3c	2.4c	1.3a	4.3c	44c	6.4b	14.5a	37.6c	15.4a	1.11a

(1)Means followed by equal letters, in the columns, do not differ significantly by the Scott-Knott test, at 5% probability. (2)T1, 0 kg ha^{-1} K_2O (control); T2, T3, T4, and T5, 42, 84, 168, and 336 kg ha^{-1} K_2O from TK47, respectively; T6, 618 kg ha^{-1} K_2O from KCl; and T7, 168 kg ha^{-1} K_2O from Super Greensand. ECEC, effective cation exchange capacity; and BS, base saturation.

in acidity with the application of silica rocks was also observed in works by von Wilpert & Lukes (2003), using phonolite, and by Moreira et al. (2006), with volcanic sandstone rocks.

The greater P availability in the soil of treatment T5 was mainly caused by the increase in pH (Sandim et al., 2014), due to the desorption and saturation of P adsorption sites by Si when TK47 was used (Carvalho et al., 2000; Pozza et al., 2007; Sandim et al., 2014). Pulz et al. (2008) observed an increased desorption and uptake of P by the potato (*Solanum tuberosum* L.) crop, when subjected to excessive use of calcium and magnesium silicate.

Treatment T5 also showed a significant increase in K^+ content in the soil, which reached 875 mg dm^{-3}, whereas in T6, with the dose of 618 kg ha^{-1} K_2O from KCl, the obtained value was 114 mg dm^{-3}. This was attributed to the more gradual release of nutrients with TK47 use, due to its lower solubility, which reduces losses by leaching and increases residual effect (Melamed et al., 2009).

Duarte et al. (2013) reported higher K^+ leaching when KCl was used, compared with thermopotash. In the present study, when comparing the equivalent doses of 168 kg ha^{-1} K_2O, from TK47 and SG, applied in T4 and T7, respectively, it was observed that the former provided K^+ contents in the topsoil more than three times greater than that of the latter. This result confirms the efficiency of TK47 in enhancing K^+ solubilization due to the pyrometallurgical process it undergoes. Calcination, grinding, melting with other materials, and acid solubilization are commonly used to solubilize rocks; these techniques are based on physicochemical principles and alter the crystalline structure of minerals, increasing the release of K^+ (Silva et al., 2012).

The dose of 336 kg ha^{-1} K_2O used in treatment T5 added about 991 kg ha^{-1} Ca to the soil, justifying the highest Ca^{2+} contents observed with this treatment. However, the contents of Mg^{2+} in the soil were, in general, similar between treatments and above the level of 0.8 $cmol_c$ dm^3 considered critical for coffee (Guimarães et al., 1999). It should be pointed out that, even with the elevation of pH, T5 still provided the highest levels of Zn^{2+} and Fe^{2+}, which is justified by the presence of these elements in glauconite (Toledo Piza et al., 2011; Santos et al., 2015).

It is important to note that the results of the soil chemical analysis were obtained after two years of providing nutrients to the coffee tree, through the treatments, since the beginning of the crop, which was harvested after six months of this evaluation. These results show that TK47, due to its more gradual solubility, was able to raise pH, BS, P-rem, and P, K^+, Ca^{2+}, ECEC, Zn^{2+}, and Fe^{2+} levels even after the coffee crop absorbed nutrients during both years.

The treatments resulted in significant differences in the leaf contents of N, K, Ca, Mg, Cu, Mn, and Zn, whereas those of P, B, and Fe did not differ (Table 2).

Nitrogen contents were higher for T3, but lower for T5. Treatment T6, with the conventional source KCl, provided the highest foliar content of K, followed by T5 using TK47, which presented higher K contents than the control and the other treatments. Although T5 provided the highest availability of K in the soil, it had the highest harvest forecast, indicating that there was a K drain for the coffee fruits. T6 was the only treatment that received cover fertilization in the second year after planting, which justifies the obtained result.

Table 2. Foliar nutrient contents in coffee (*Coffea arabica*) subjected to fertilization with different K sources and doses(1).

Treatment(2)	N	P	K	Ca	Mg	Cu	B	Fe	Mn	Zn
	(g kg^{-1})					(mg kg^{-1})				
T1	33c	1.4a	10c	17a	8.4a	15b	104a	97a	218b	12c
T2	36b	1.4a	10c	15b	7.1b	16b	107a	91a	250b	12c
T3	39a	1.3a	10c	15b	6.9b	17b	102a	102a	249b	23a
T4	36b	1.2a	11c	15b	6.3c	16b	97a	95a	246b	15b
T5	31d	1.3a	12b	16a	6.5c	14b	104a	101a	217b	14b
T6	35b	1.2a	15a	14b	4.1d	22a	102a	102a	380a	13c
T7	35b	1.2a	11c	14b	6.2c	21a	106a	100a	314a	14b

(1)Means followed by equal letters, in the columns, do not differ significantly by the Scott-Knott test, at 5% probability. (2)T1, 0 kg ha^{-1} K_2O (control); T2, T3, T4, and T5, 42, 84, 168, and 336 kg ha^{-1} K_2O from TK47, respectively; T6, 618 kg ha^{-1} K_2O from KCl; and T7, 168 kg ha^{-1} K_2O from Super Greensand.

Foliar Ca content was higher in the control (T1) and in the treatment with a higher dose of TK47 (T5). Two factors may have contributed to these results: the low fruit load in the plants in T1; and the high availability of Ca^{2+} in the soil in T5.

The treatments with potassic fertilizations showed lower Mg leaf contents, compared with the control (T1). This could be explained by the competitive inhibition in the absorption of this nutrient due to the presence of K and Ca (Ding et al., 2006), since the contents of Mg^{2+} in the soil did not differ. The contents of Cu and Mn in the leaves showed a similar behavior, being higher in T6 and T7, in comparison with the control and the other treatments. The content of Zn (23 mg kg^{-1}) was higher in T3, ranging from 12 to 15 mg kg^{-1} in the other treatments. The main factors that caused the changes observed in macro- and micronutrient levels in the leaf analysis are production load, soil pH, soil nutrient balance, type of K source, and doses of K_2O applied in the treatments.

Treatments T5 and T6 had similar and significantly higher productivity, compared with the control and the other treatments (Figure 1). This result is explained by the higher doses of K_2O used. The amount of K_2O in T6 was established as a function of the high production expectation, common for the first harvest. In this case, production fertilizations are recommended as K drainage in the fruits is high (Guimarães et al., 1999).

TK47 was able to supply the coffee crop with K more gradually than KCl, since the application of approximately 54% K_2O in T5 resulted in productivities similar to those of T6. It was verified that the SG source also has potential to supply K to plants, considering productivity was superior to that of the control and statistically similar to that of the TK47 source at 186 kg ha^{-1} K_2O.

The addition of crushed rocks to the soil, especially of mafic ones, has shown good results for some crops (Silverol & Machado Filho, 2007; Silva et al., 2008; Prates et al., 2015). According to Theodoro & Leonardos (2006), rock application allowed corn (*Zea mays* L.), rice (*Oryza sativa* L.), cassava (*Manihot esculenta* Crantz), sugarcane (*Saccharum officinarum* L.), and similar crops to be maintained at conventional fertilization levels. However, a lack of yield responses has also been observed in some works, which may be associated to: the short cycle of the crops used as test plants, short evaluation periods, unfavorable climatic conditions, use of sterile soils with low microbial activity, or the agromineral used as a nutrient source (Silva et al., 2008; Prates et al., 2012).

The quality of the coffee beverage and polyphenol oxidase activity were significantly affected by the

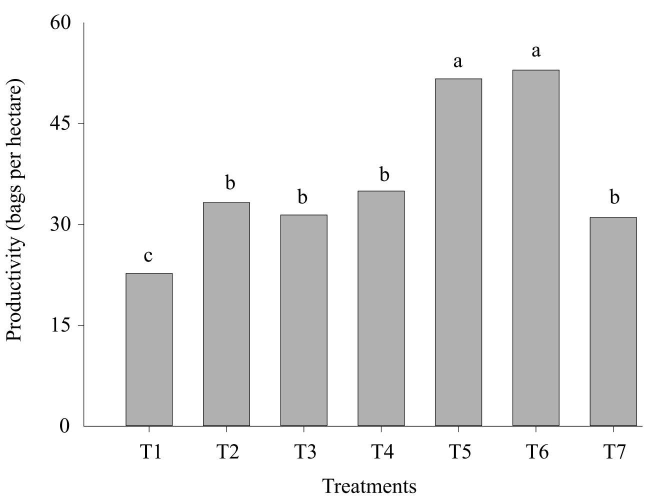

Figure 1. Productivity of coffee (*Coffea arabica*) plants subjected to fertilization with different K sources and doses. Means followed by equal letters, in the columns, do not differ significantly by the Scott-Knott test, at 5% probability. T1, 0 kg ha^{-1} K_2O (control); T2, T3, T4, and T5, 42, 84, 168, and 336 kg ha^{-1} K_2O from TK47, respectively; T6, 618 kg ha^{-1} K_2O from KCl; and T7, 168 kg ha^{-1} K_2O from Super Greensand.

Table 3. Quality of the coffee (*Coffea arabica*) beverage as a function of fertilization with different K sources and doses(1).

Treatment(2)	Sensory analysis	PPO activity
	Score	(U min^{-1} g^{-1})
T1	73b	41d
T2	64c	43c
T3	69b	44b
T4	71b	46a
T5	84a	45a
T6	70b	43c
T7	71b	44b

(1)Means followed by equal letters, in the columns, do not differ significantly by the Scott-Knott test, at 5% probability. (2)T1, 0 kg ha^{-1} K_2O (control); T2, T3, T4, and T5, 42, 84, 168, and 336 kg ha^{-1} K_2O from TK47, respectively; T6, 618 kg ha^{-1} K_2O from KCl; and T7, 168 kg ha^{-1} K_2O from Super Greensand. PPO, polyphenol oxidase.

K sources and doses (Table 3). The source TK47, with the highest dose of K_2O in T5, showed the best score for the sensorial analysis, indicating that the quality of the resultant beverage was superior to that of the other treatments. This result is justified by the greater soil availability of K in T5, together with the absence of Cl^- in the applied source, i.e., TK47. As previously highlighted, K is considered to be the nutrient of quality due to its influence on the chemical composition of coffee beans (Guimarães et al., 2011). According to Martinez et al. (2014), in K-deficient plants, the accumulation of soluble carbohydrates, the decrease in starch content, the accumulation of soluble N compounds, and the changes observed in the plant metabolism are related to the high K requirement for the functioning of regulatory enzymes, mainly pyruvate kinase and phosphofructokinase (Martinez et al., 2014). In addition to acting on the carbohydrate metabolism, which affects beverage quality, severe K deficiency in plant tissues leads to the synthesis of toxic amines, such as putrescine and agmatine, which are dreadfully harmful to the quality of the drink (Guimarães et al., 2011). Some authors attribute a decrease in the quality of the beverage to the Cl^- anion, which comes with the application of KCl (Carvalho et al., 1994; Silva et al., 2002).

Polyphenol oxidase activity was higher in T4 and T5 – which received 168 and 336 kg ha^{-1} K_2O from TK47, respectively –, compared with the other treatments. According to Martinez et al. (2014), polyphenol oxidase is a cupric enzyme linked to cell membranes. In adverse conditions or when the fruit cells are damaged, polyphenol oxidase acts on intra- and extracellular polyphenols, promoting the hydroxylation of monophenols to o-diphenols, which undergo H^+ removal and give rise to o-quinones that inhibit polyphenol oxidase. Therefore, the polyphenol oxidase activity, which is strongly influenced by the metabolism of phenols, correlates significantly with the quality of the beverage, decreasing from the best to the worst quality.

However, these results did not corroborate those of Carvalho et al. (1994), who related polyphenol oxidase activity to different classes of drink: “riado” and “rio”, <55.99 U m^{-1} g^{-1}; “hard”, 55.99 to 62.99 U m^{-1} g^{-1}; “soft”, 62.99 to 67.66 U m^{-1} g^{-1}; and “strictly soft”, >67.66 U m^{-1} g^{-1}. In the present study, the polyphenol oxidase activity for T5 was 45 U m^{-1} g^{-1}, which, according to those authors, would be classified as “riado” or “rio”; however, the sample received 84 points in the sensorial analysis, which corresponds to a soft drink, as described by Dalvi (2011).

In view of the overall results, the regional use of TK47 is a good alternative source for supplying K and other nutrients in the initial phase of coffee production. However, there is a need for more studies on different crops and soils, with longer periods of evaluation, in order to verify the behavior of the tested sources and doses.

Conclusions

1. Potassium fertilization with TK47 increases soil fertility, corrects soil acidity, and elevates K^+, P, Ca^{2+}, effective cation exchange capacity, Zn^{2+}, and Fe^{2+} contents in the soil.
2. Fertilization with 336 kg ha^{-1} K_2O from TK47, in a single dose, provides coffee (*Coffea arabica*) grain yield and polyphenol oxidase activity similar to those of fertilization with 618 kg ha^{-1} K_2O from KCl, in a split dose, but a better sensory analysis of the resultant beverage.

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