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Chickpea production and soil chemical attributes after phosphorus and molybdenum fertilization

Produção de grão-de-bico e atributos químicos do solo após a adubação fosfatada e molíbdica

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ABSTRACT

Chickpea is the third most cultivated legume in the world. In Brazil, cropping of this legume is recent and definitions of fertilizer management techniques are scarce. In this study, the objective was to evaluate chickpea (BRS Aleppo) production and soil chemical attributes with and without phosphorus fertilization and leaf-applied molybdenum. A randomized block experimental design was used, with four replications. A 2 x 5 factorial arrangement was used to evaluate production, consisting of two molybdenum fertilization management practices (with and without molybdenum) and five application rates of P_2O_5 (0, 60, 120, 180, and 240 kg ha^{-1}) in the form of single superphosphate. Soil sampling for evaluation of soil chemical attributes in the crop row and between rows was also considered. Molybdenum fertilization brought about greater stem and aboveground dry matter. Phosphorus fertilization increased stem, leaf, and seed yield, yielding a maximum of 2.83 t ha^{-1} seed at the rate of 200 kg ha^{-1} P_2O_5. However, maximum agronomic efficiency (8.30) was observed with the addition of 150 kg ha^{-1} P. Soil in the crop row attained higher concentrations of P, K, H+Al, and P-rem and reduction in pH, Ca concentration, SB, T, and V compared to between rows. Phosphorus rates reduced soil pH and increased T and the P concentrations, though only in the plant row. Between the rows, no changes were observed in soil chemical attributes, indicating low mobility of P and the acidification capacity of superphosphate in alkaline soils.

Index terms: *Cicer arietinum* L.; single superphosphate; seed yield.

RESUMO

O grão-de-bico é a terceira leguminosa mais cultivada no mundo. No Brasil cultivos com essa leguminosa são recentes e definições de técnicas de manejo de fertilizantes são escassas. Objetivou-se avaliar a produção de grão-de-bico (BRS Aleppo) e os atributos químicos do solo sob doses de fósforo e molibdênio foliar. O delineamento utilizado foi em blocos ao acaso, com quatro repetições. Para avaliação da produção, adotou-se o esquema fatorial 2 x 5, consistindo de dois manejos da adubação, com ou sem molibdênio e cinco doses de P_2O_5 (0, 60, 120, 180 e 240 kg ha^{-1}). Para avaliação dos atributos químicos do solo, considerou-se também a amostragem na linha e entre linha de semeadura. A adubação molíbdica propiciou maior massa seca de ramos e da parte aérea. As doses de fósforo aumentaram a massa seca de ramos, folhas e grãos, obtendo-se a produção máxima de 2,83 t ha^{-1} de grãos na dose 200 kg ha^{-1} de P_2O_5. Entretanto a máxima eficiência agronômica (8,30) foi observada com a adição de 150 kg ha^{-1}de P. No solo da linha de cultivo obteve-se maiores teores de P, K, H+Al e P-rem, e diminuição do pH, teor de Ca, SB, T e V, em comparação àquele da entre linha. As doses de fósforo reduziram o pH do solo, aumentaram a T e os teores de P, somente na linha de cultivo, indicando a baixa mobilidade do P e a capacidade de acidificação do superfosfato em solos alcalinos.

Termos para indexação: *Cicer arietinum* L.; superfosfato simples; produção de grãos.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is the third most cultivated legume in the world. India stands out as one of the largest producers and consumers of its seeds (or seed); however, its production is insufficient to meet the needs of the internal market, and chickpea imported (Bidyarani et al., 2016). It is recognized as a legume with high concentrations of proteins, nutrients, and carbohydrates (Laranjo; Alexandre; Oliveira, 2014). It is adaptable to wide climatic variation, has low production cost, and promotes biological fixation of atmospheric nitrogen (Nascimento, 2016; Artiaga et al., 2015; Balai et al., 2017). In Brazil, the semi-arid region has high production potential; however, this production is limited by lack of knowledge of adequate crop management conditions.

Phosphorus fertilization is among the main practices of crop management; yet, it is considered complex in tropical soils because of the high capacity of phosphorus for covalent adsorption to soil oxides (Gazola et al., 2013) and because of low natural availability of P to plants. In chickpea, balanced phosphorus nutrition is fundamental for establishing symbiosis with N_2 fixing rhizobacteria, and it stimulates nodulation, initial development of roots, plant growth, and seed yield and quality, among other aspects (Balai et al., 2017). Neenu et al. (2014) affirm that fertilization with 60 kg $ha^{-1}$of P_2O_5 is sufficient for maximum production of chickpea seeds in a *Vertisols* in India. Das et al. (2008) also reported a positive effect on relative growth rate, dry matter accumulation, nodulation, yield, and harvest index with application of 60 kg ha^{-1} of P_2O_5. Economical efficiency and high degree of protein are reported by Singh and Singh (2012) using this same phosphorus application rate.

Phosphate fertilization, together with other nutrients such as molybdenum (Mo), can maximize legume yield. Bhuiyan et al (2008) and Togay, Togay and Dogan (2008a) obtained maximum seed yield and aboveground biomass production of mung bean and lentils, respectively, after using phosphorus application rates associated with molybdenum fertilization. Fertilization with P and Mo also had a positive effect on edible bean and soybean yield in areas of the Brazilian *Cerrado* (Araújo et al., 2009; Matoso; Kusdra, 2014; Vieira et al., 2016; Oliveira et al., 2017).

Molybdenum favors agricultural production by acting in plants as a cofactor of enzymes that participate in nitrogen metabolism, and participates as a constituent of the enzymes nitrogenase and nitrate reductase (Taiz; Zeiger, 2013), essential in assimilation of N by plants, indicating their potential as fertilizers for chickpea crops.

In light of the above, studies that seek to understand the yield capacity of chickpea in tropical soils fertilized with P and Mo are indispensable for definition of adequate management techniques. The aim of this study was to evaluate chickpea yield and soil chemical attributes under different application rates of phosphorus and molybdenum.

MATERIAL AND METHODS

The experiment was conducted from April to August 2016 in an area in the municipality of Montes Claros, MG, Brazil, located at 16°40’S and 43°50’W, characterized as As semiarid tropical by the Köppen classification, with a dry summer (Alvares et al., 2013). The climate data during the time of the experiment are represented in Figure 1. The soil of the area is classified as a *Haplic Cambisol*, with medium texture. In the initial phase of the study, soil samples were collected from the 0-20 cm depth layer for chemical characterization, with the following results – organic matter (OC): 3.08 dag kg^{-1}; pH (H_2O): 7.5; P (Mehlich 1): 3.51 mg dm^{-3}; K(Mehlich 1): 142 mg dm^{-3}; Ca: 7.6 $cmol_c$ dm^{-3}; Al (KCl): 0.0 $cmol_c$ dm^{-3};H+Al: 0.78 $cmol_c$ dm^{-3}; SB: 10.36 $cmol_c$ dm^{-3}; t: 10.36 $cmol_c$ dm^{-3}; base saturation (V%): 93%; and T: 11.14 $cmol_c$ dm^{-3}.

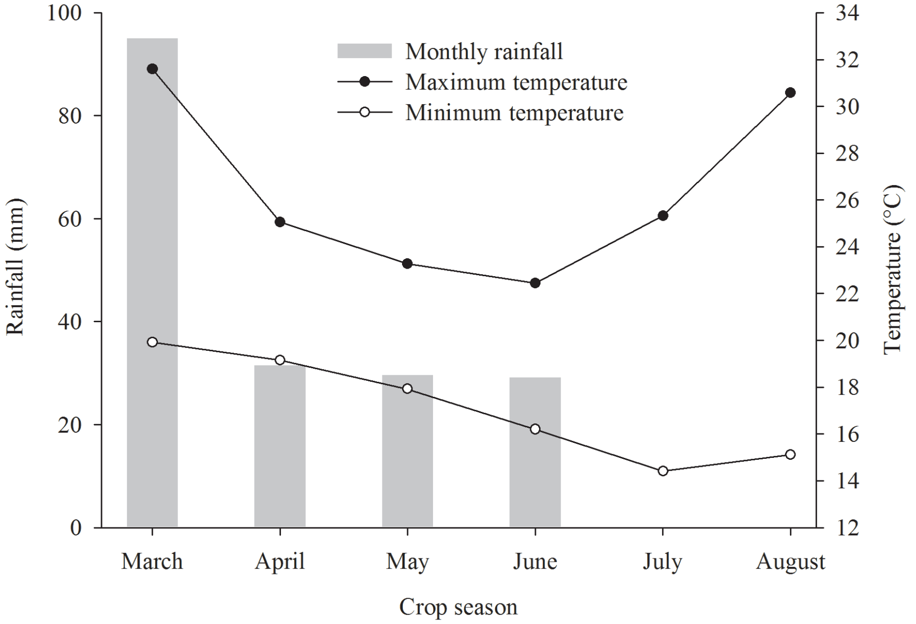

Figure 1: Rainfall, maximum and minimum temperature in the month in the chickpea crop season.

A randomized block experimental design was used, with four replications, in a 2 x 5 factorial arrangement. The first factor represented the absence and presence of molybdenum at the rate of 80 g ha^{-1} (ammonium molybdate); and the second factor consisted of the five phosphorus application rates: 0, 60, 120, 180, and 240 kg ha^{-1} P_2O_5 (single superphosphate). The phosphorus reference dose corresponded to 120 kg ha^{-1}, recommended for the highest technological level (NT_4) in bean cultivation, according to Chagas et al. (1999), since there are no consolidated studies indicating the recommended dose of P_2O_5 in Brazilian tropical soils for the cultivation of chickpea. The soil chemical attributes were analyzed at the end of the harvest as a factorial; soil samples were collected in the row and between the plant rows, and then the interactions among molybdenum application, soil sample location, and phosphorus application rates (2 x 2 x 5) were examined.

Soil conventional tillage was performed by plowing and disking. Seeding was done with the application of 15 seeds per meter, with a 0.5 m spacing between plant rows. Thereafter was kept only 10 plants per meter, totalizing 200,000 plants ha^{-1}. Before sowing, the seeds were inoculated with commercial peat material for edible bean at a concentration of 1 x 10^9 CFU of *Rhizobium tropici*, under the recommendation for use of 4 g of the material for every 1 kg of seeds. The cultivar used was BRS Aleppo of the kabuli group, with semi-upright growth habit, recommended for growing in the dry season (Nascimento et al., 2014).

Fertilization with P was carried out one week before sowing, in accordance with each established application rate. Fertilizer was applied in topdressing near the plant row (approximately 5 cm distant from the plants) at 20 days after emergence (DAE) with 65 kg ha^{1} of N, 20 kg ha^{-1} K, and 10 kg ha^{-1} Mg, using urea, potassium chloride, and magnesium sulfate as sources, respectively. The fertilization used in the cultivation of chickpea followed the recommendation proposed by Chagas et al. (1999) for bean culture. In addition, in this period, 80 g ha^{-1} of molybdenum was applied to the leaves in the form of ammonium molybdate. The molybdenum foliar application was performed with a coastal sprayer, using a spray volume equivalent to 200 L ha^{-1}. The micronutrients B, Cu, Fe, and Zn were applied to leaves at 30 and 50 DAE at the proportion of 0.2% boric acid (0.34 g L^{-1} B), 0.2% copper sulfate (0.26 g L^{-1} Cu), 0.2% ferrous sulfate (0.38 g L^{-1} Fe), and 0.2% zinc sulfate (0.40 g L^{-1} B), respectively.

Plant health treatments and irrigation were carried out according to crop needs and technical recommendations for the crop in the region, as indicated by Nascimento (2016). A micro-spray irrigation system was used, with irrigation frequency of every four days. When necessary, weed growth was controlled manually.

At the end of the crop cycle, the twelve central plants in each plot were evaluated in regard to dry matter weight of plant parts: leaves, stems, seeds (corrected humidity in 13%), and shoot plant parts), 100 seed weight, number of seed per plant, and Agronomic efficiency, expressed by the following Equation 1:

$$AE = \frac{\text{YFT} - \text{YCT}}{\text{ARFT}} \tag{1}$$

in which,

RAE = Agronomic efficiency in kg of seeds per kg of nutrient applied;

YFT = Yield in treatment fertilized with P, kg ha^{-1};

YCT = Yield in control treatment, kg ha^{-1};

ARFT = Application rate in treatment fertilized with P, kg ha^{-1}.

The harvest index in % ((seeds weight/shoot biomass weight) x 100) was also evaluated; the results were adjusted to the Gaussian model.

The data were subjected to analysis of variance. After that, depending on significance, the T test at 5% probability was used for the qualitative factors; and, for quantitative factors, adjustments of the regression model were made, which were chosen based on significance of the regression coefficients and on the potential to explain the biological phenomenon in question. Statistical analysis was made with the SISVAR 5.3 statistical software (Ferreira, 2011).

RESULTS AND DISCUSSION

The production characteristics of stem, leaf, and shoot dry matter and 100 seed weight were influenced ($p<0.05$) by the molybdenum application factor (Table 1). Isolated application of phosphorus (P) rates significantly affected the characteristics of stem, seed, and shoot dry matter and number of seed per plant. Significant interaction ($p>0.05$) was not found between the factors of molybdenum application x phosphorus application rates for the chickpea production characteristics.

Leaf fertilization with molybdenum led to higher production of stems and shoot dry matter compared to plants that did not receive molybdenum through fertilization (Table 2). Such results indicate greater mineral nutritional balance with molybdenum in cultivation of chickpea, after fertilization, especially since it is a nutrient responsible for an increase in activity of the enzymes nitrogenase and nitrate reductase, which are involved in biological fixation and assimilation of N, increasing the production of photoassimilates and the accumulation of shoot biomass. In the edible bean crop, leaf application of molybdenum also had a positive effect on shoot dry matter and productivity, which can be attributed to greater enzyme activity that strengthens nitrate assimilation by plants (Nascimento et al., 2009; Lopes et al., 2014; Lopes et al., 2016).

The use of molybdenum on edible bean seeds (3 g kg^{-1} seeds), also increased shoot dry matter production by 3.91 g (Matoso; Kusdra, 2014). Oliveira et al. (2017), in the soybean crop, concluded that application rates of Mo from 25 to 50 g ha^{-1} through the leaves are sufficient to increase yield. However, fertilization with molybdenum did not change dry matter production of leaves and seeds or seeds per plant (Table 2), indicating lower demand of molybdenum for chickpea production or adequate natural supply of this nutrient via soil. Fertilization with nitrogen in the crop may have contributed to obtain this result because the way of supplying nitrogen changes molybdenum uptake by plants. For Araujo et al. (2009), under conditions of good N availability, both in sowing and in topdressing, the application rate of Mo necessary to obtain maximum production of pods per edible bean plant was lower, indicating lower response from molybdenum fertilization. The application of Mo combined with rhizobia inoculation can be used as a solution for making Mo available to plants (Marschner, 2012).

However, only the 100 seed weight variable was higher in the absence of application of leaf molybdenum. In studies with edible bean (BRSMG Majestoso), Vieira et al. (2016) concluded that molybdenum is more effective when applied in the pod formation phase, resulting in higher results in content for the seed. In the present study, molybdenum fertilization was carried out near 20 DAE and did not contribute to the increase of the seeds weight. Molybdenum leaf fertilization contributed to higher production of stems and shoot dry matter,

Table 1: Summary of analysis of variance for stem dry matter, leaf dry matter, seed yield (Yeld), shoot dry matter (Shoot), 100 seeds weight (W100), and number of seeds per plant of chickpea after application of phosphorus rates and leaf application of molybdenum.

S.V.	DF	Mean square					
		Stems	Leaves	Yield	Shoot	W100	Seeds/plant
Block	3	0.56^{ns}	0.02^{ns}	0.76^{ns}	2.85*	5.44^{ns}	19.16^{ns}
Molybdenum (M)	1	4.13*	0.15*	0.00^{ns}	6.06*	27.85*	0.06^{ns}
P Rates (P)	4	3.25*	0.07^{ns}	2.63*	11.88*	2.98^{ns}	65.85*
M *x* P	4	0.64^{ns}	0.05^{ns}	0.25^{ns}	0.58^{ns}	10.33^{ns}	6.47^{ns}
Residue	27	0.56	0.03	0.38	0.85	4.11	9.56
Mean		5.43	1.24	2.48	9.15	32.73	12.40
CV (%)		13.82	15.75	24.95	10.09	6.20	24.95

^{ns,*}: not significant and significant at 5% by the F test, respectively. S.V.: Source of variation; DF: degrees of freedom; C.V.: coefficient of variation in percentage.

Table 2: Stem dry matter (Stems), leaf dry matter (Leaves), seed yield (Seeds), shoot dry matter (Shoot), 100 seed weight (W100), and seed per plant (Seeds/plant) of chickpea, without or with leaf application of molybdenum.

Molybdenum	Stems	Leaves	Seeds	Shoot	W100	Seeds/plant
	-------------------------t ha^{-1}---------------------				-----g-----	------g------
Without	5.11b	1.18a	2.47a	8.76b	33.57a	12.36a
With	5.75a	1.30a	2.49a	9.54a	31.90b	12.44a

Mean values followed by the same letter in the column do not differ among themselves by the t test (p<0.05).

indicating the greater allocation of photoassimilates in vegetative organs of the chickpea in detriment to the 100 seed weight. Qin et al. (2017) mention that Mo plays important roles in the growth and metabolism of plants as a constituent of various enzymes, such as nitrate reductase, sulfite oxidase, xanthine dehydrogenase, aldehyde oxidase, and the mitochondrial amidoxime reductase, in these enzymes Mo is directly involved in nitrate assimilation, sulfite detoxification, purine degradation and synthesis of abscisic acid (ABA).

The P applied at different rates increased stem and seed yield (Figure 2). The application of 160 and 200 kg ha^{-1} P_2O_5 brought about accumulation of 5.91 t ha^{-1} of stem dry matter and 2.71 t ha^{-1}of seeds, respectively (Figure 2). This seed yield was considered high, compared to other countries, such as India and Pakistan, with mean yields of 912 and 471 kg ha^{-1}, respectively (Rani; Krishna, 2016; Nawaz et al., 2017). This indicates that the semi-arid region of the north of the state of Minas Gerais, Brazil, has high yield potential for irrigated chickpea.

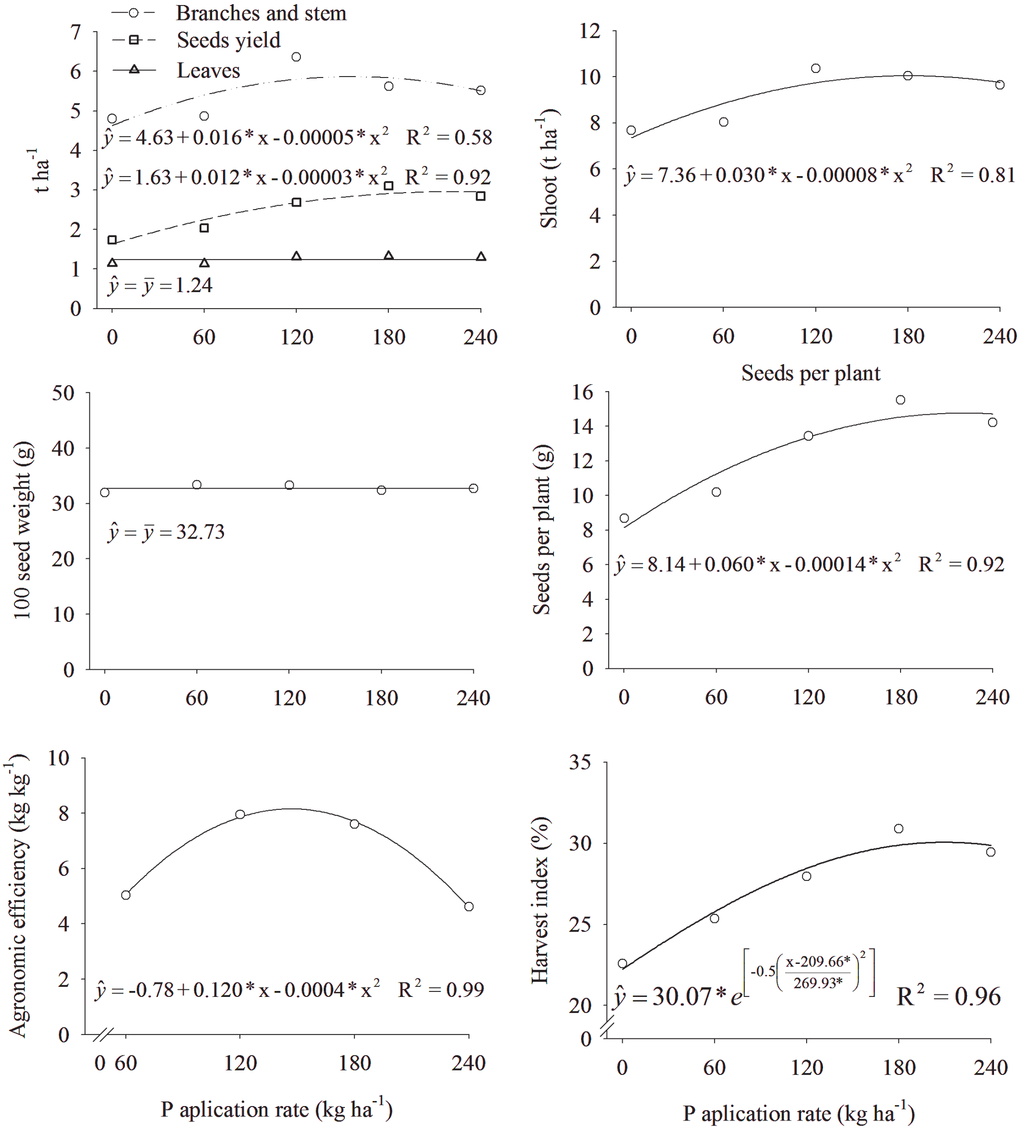

Figure 2: Stem dry matter, leaf dry matter, seed yield, shoot dry matter, 100 seed weight (W100), and seed per plant, agronomic efficiency, and harvest index of chickpea after fertilization at different rates of phosphorus. *, significant at 5% by the t test.

The phosphorus application rate found in this study to obtain maximum yield was also considered high (200 kg ha^{-1}) compared to the results found in the literature. Neenu et al. (2014) studied the response of chickpea genotypes under P application rates and reported that rates from 60 to 90 kg ha^{-1} P_2O_5 are favorable to root development and, consequently, to biological nitrogen fixation. Gulpadiya et al. (2014) and Pingoliya et al. (2014) also obtained higher growth and seed yield after application of 60 to 90 kg ha^{-1}of P_2O_5. This difference in the P rate may have occurred because Brazilian soils are oxidic, exhibiting high capacity for specific adsorption of P, a phenomenon exacerbated by mineral fractions of clay in the soil (Vilar et al., 2010; Novais; Smyth, 1999).

Dry matter of the shoot part increased (10.17 t ha^{-1}) up to a rate of 187.5 kg ha^{-1} P_2O_5 (Figure 2). Mean production of leaf dry matter and 100 seed weight was 1.24 t ha^{-1} and 32.73 g (Figure 2), and neither was affected by differing P application rates. Nevertheless, phosphorus application increased seed weight from 7.36 g per plant at the zero rate to 14.56 g per plant with the application of 214.28 kg ha^{-1} of P_2O_5. This indicates that phosphorus fertilization was fundamental for obtaining a higher number of seeds per plant and higher yield of chickpea.

Maximum agronomic efficiency of 8,3 kg seeds per kg of nutrient applied was obtained after application of 150 kg ha^{-1} P_2O_5 (Figure 2), indicating that application rates of 150 kg ha^{-1} P_2O_5 may be recommended for growing irrigated chickpea in the Brazilian semi-arid region, because this rate led to expressive results in dry matter and yield, with greater efficiency in P use. In contrast, the maximum harvest index of 30.07 was obtained at the application rate of 209.66 kg ha^{-1} P_2O_5, a rate higher than that found for maximum agronomic efficiency. This harvest index was near that found by Gulpadiya et al. (2014), 30.68, at a much lower application rate (90 kg ha^{-1} P_2O_5) than the rate reported in this study (209.66 kg ha^{-1}). Yet, at the application rate of 150 kg ha^{-1} P_2O_5, there is also a high harvest index, which can ensure the profitability of chickpea.

In general, P_2O_5 application rates from 150 to 200 kg ha^{-1} made it possible to obtain high agronomic indices in chickpea. Neenu et al. (2014) found that when they applied 90 kg ha^{-1} P_2O_5 on a Vertisols, P uptake by seeds was high, corroborating data of Singh and Singh (2012). Togay et al. (2008b) also evaluated the response of chickpea under P application rates and found rates lower than those reported in the present study, perhaps because this study works with tropical soils, and phosphorus is more adsorbed to clay complexes. Results may also be related to the level of technology and the cultivar used by the authors.

After fertilizations with phosphorus and molybdenum, at the end of growing chickpea, soil samples were collected in the row and between plant rows for evaluation of soil chemical attributes (Table 3). Significant changes ($p<0.05$) were found in most of the chemical attributes of the soil collected in the crop row compared to those found between the rows. The phosphorus application rates brought about changes in pH and concentrations of P and Ca in the soil in the crop row; however, the use of Mo did not affect soil attributes.

In the soil in the crop row, higher concentrations were obtained of P, K, H+Al, and Prem, and reduction in pH(H_2O) and Ca concentration, SB, t, and V compared to the soil between the rows (Table 4). Such results were attributed to biological rhizosphere phenomena and to localized fertilization with single superphosphate, potassium chloride, and urea. Greater biological activity of the plant root system and of rhizospheric microorganisms may have contributed to release of organic (low molecular weight organic acids) and inorganic (H^+) compounds able to reduce pH, V, Ca concentrations, and SB, and increase potential acidity of the soil located in the plant row.

Chickpea plants have high cation uptake capacity and acidification of the rhizosphere, decreasing pH from 5 to 4.3, compared to the rhizosphere condition of other plant species, such as wheat and pea (Wang et al., 2016). In soils with pH above 7.3, application of single superphosphate ($Ca(H_2PO_4)_2.H_2O + CaSO_4.2H_2O$) leads to their acidification (Ali et al., 2014), due to dissociation reactions of $H_2PO_4^-$to HPO_4^{2-}, releasing H^+ ions in the soil solution. Acidification is also an indirect consequence of the increase in the concentration of sulfate in the soil solution (Rosado et al., 2014). Oliveira et al. (2014) found decrease in the pH of electronegative soils up to 10 cm from the location of potassium chloride (KCl) granules; this decrease in pH was mainly attributed to increase in the density of electric charges at the surface of the electronegative colloids of the soils, due to the increase in electrolytic concentration, releasing ions of an acidic nature to the soil solution.

Enzymatic reactions related to transformation of the N derived from urea bring about soil acidification (Ghimire et al., 2017). In initial periods after fertilization (first 15 days), the ammonium (NH_4^+) mineralization process causes a small increase in soil pH. This alkaline reaction is rapidly suppressed by nitrification (oxidation of the ammonium to nitrate), leading to release of a greater proportion of H^+ and increase in the concentration of Al^{3+} in the soil solution (Mehmood et al. 2017), ions responsible for acidification of the pH.

Table 3: Summary of analysis of variance obtained for the chemical attributes of soil from the crop row and between the rows (A), after leaf application of molybdenum (Mo) (with and without molybdenum) and phosphorus application rates (PAR) in chickpea.

S.V.	DF	Mean square					
		pH	OC	P	K	Ca	Mg
Block	3	0.06*	1.37*	665.78^{ns}	1056.84^{ns}	0.32^{ns}	1.90^{ns}
Sampling (A)	1	0.06*	0.04^{ns}	76020.61*	2773.01*	0.93*	0.31^{ns}
Molybdenum (Mo)	1	0.00^{ns}	0.14^{ns}	554.19^{ns}	1.51^{ns}	0.10^{ns}	0.09^{ns}
P rates (P)	4	0.03*	0.02^{ns}	11252.01*	50.01^{ns}	0.06^{ns}	0.12^{ns}
Mo x A	1	0.05*	0.00^{ns}	2497.61*	365.51^{ns}	0.01^{ns}	0.16^{ns}
Mo x P	4	0.01^{ns}	0.02^{ns}	205.81^{ns}	476.04^{ns}	0.27^{ns}	0.23^{ns}
A x P	4	0.04*	0.02^{ns}	8964.65*	408.16^{ns}	0.13^{ns}	0.25^{ns}
Mo x A x P	4	0.01^{ns}	0.05^{ns}	148.48^{ns}	173.41^{ns}	0.12^{ns}	0.16^{ns}
Residue	57	0.01	0.05	415.51	591.91	0.16	0.19
Mean		7.56	1.93	51.36	186.71	8.64	1.83
CV (%)		1.56	11.81	39.59	13.03	4.66	24.00
		H+Al	SB	t	T	V	Prem
Block	3	2.65*	2.55*	2.55*	1.40*	170.32*	106.74*
Sampling (A)	1	0.88*	1.95*	1.95*	0.21^{ns}	59.53*	50.46*
Molybdenum (Mo)	1	0.03^{ns}	0.01^{ns}	0.01^{ns}	0.02^{ns}	1.76^{ns}	1.65^{ns}
P rates (P)	4	0.07^{ns}	0.28^{ns}	0.28^{ns}	0.42^{ns}	3.90^{ns}	6.80^{ns}
Mo x A	1	0.00^{ns}	0.05^{ns}	0.05^{ns}	0.04^{ns}	0.09^{ns}	5.59^{ns}
Mo x P	4	0.04^{ns}	0.39^{ns}	0.39^{ns}	0.53^{ns}	2.01^{ns}	8.46^{ns}
A x P	4	0.04^{ns}	0.58^{ns}	0.58^{ns}	0.64*	2.80^{ns}	3.95^{ns}
Mo x A x PAR	4	0.02^{ns}	0.11^{ns}	0.11^{ns}	0.13^{ns}	1.52^{ns}	2.68^{ns}
Residue	57	0.03	0.23	0.23	0.21	2.56	5.31
Mean		1.11	10.95	10.95	12.06	90.78	30.91
CV(%)		17.35	4.47	4.47	3.88	1.96	7.46

^{ns,*,**}: not significant and significant at 5% by the F test, respectively. SV: Source of variation; DF: degrees of freedom; C.V.: coefficient of variation in percentage.

Table 4: Chemical attributes of the soil collected in the crop row and between the rows and after harvest of chickpea.

Sampling	pH	OC	P	K	Ca	Mg
	H_2O	dag kg^{-1}	--------mg dm^{-3}--------		------cmol$_c$ dm^{-3}------	
Row	7.53b	1.90a	82.18a	192.60a	8.53b	1.76a
Between rows	7.59a	1.95a	20.53b	180.83b	8.75a	1.89a
	H+Al	SB	t	T	V	Prem
	--------------------cmol$_c$ dm^{-3}--------------------				%	mg L^{-1}
Row	1.22a	10.79b	10.79b	12.01a	89.91b	31.70a
Between rows	1.01b	11.10a	11.10a	12.11a	91.64a	30.12b

Mean values followed by the same letter in the column do not differ among themselves by the F test ($p<0.05$).

The changes observed in the soil chemical attributes in the crop row can be summed up in the following factors: i) high capacity of cation uptake by plants over the chickpea growing season; ii) greater movement of cations in the soil profile due to formation of ionic complexes with sulfate coming from fertilization with single superphosphate; iii) soil acidification; and iv) formation of precipitates with other soil anions.

The formation of calcium phosphate precipitates may also have contributed to decrease in pH, V, Ca concentration, and SB and an increase in potential acidity in the soil of the crop row, due to the precipitation reaction described by Ernani (2016): $3Ca^{2+} + 2H_2PO_4^{-} => Ca_3(PO_4)^{2+}\ 4H^+$. The product of this reaction releases $4H^+$ to the soil solution and temporarily reduces availability of Ca and P to plants.

P application in the crop row increased P concentration and T in a linear manner, and reduced soil pH (Figure 3). For each 100 kg of phosphorus added, a reduction of 0.09 units of pH in the soil were obtained. In the soil from between the crop rows, phosphorus fertilization did not change these attributes. Ali et al. (2014) showed that rates of application of single superphosphate (from zero to 150 kg ha^{-1} P_2O_5) in soil with $pH(H_2O)$ of 7.73 brought about a reduction of 0.17 units of pH for every 100 kg P_2O_5 applied. The reduction in soil pH was attributed to release of H^+ ions derived from the chemical equilibrium reaction between the two main soluble forms of phosphate ($H_2PO_4^{-} + H_2O = HPO_4^{2-} + H^+$), whose acid dissociation constant is 6.2×10^{-8}, which results in a pK_a (potential of the dissociation constant) of 7.21 (Oliveira et al., 2014). In our study, soil pH was greater than 7.21 (Figure 3); thus, the equilibrium reaction brings about predominance of HPO_4^{2-} and the release of H^+ ions in the soil solution after fertilization with single superphosphate. This reaction was considered positive for plant development, due to reduction in soil alkalinity.

The increase in the application rates of single superphosphate also increased total cation exchange capacity (T) in the soil located in the crop row (Figure 3), exhibiting maximum T of 11.11 $cmol_c\ dm^{-3}$ at the rate of 240 kg ha^{-1} P_2O_5. This result was attributed to the buffering effect of the fertilizer, contributing to an increase in the presence/manifestation of variable charges, dependent on pH, which is very common in soils of tropical origin.

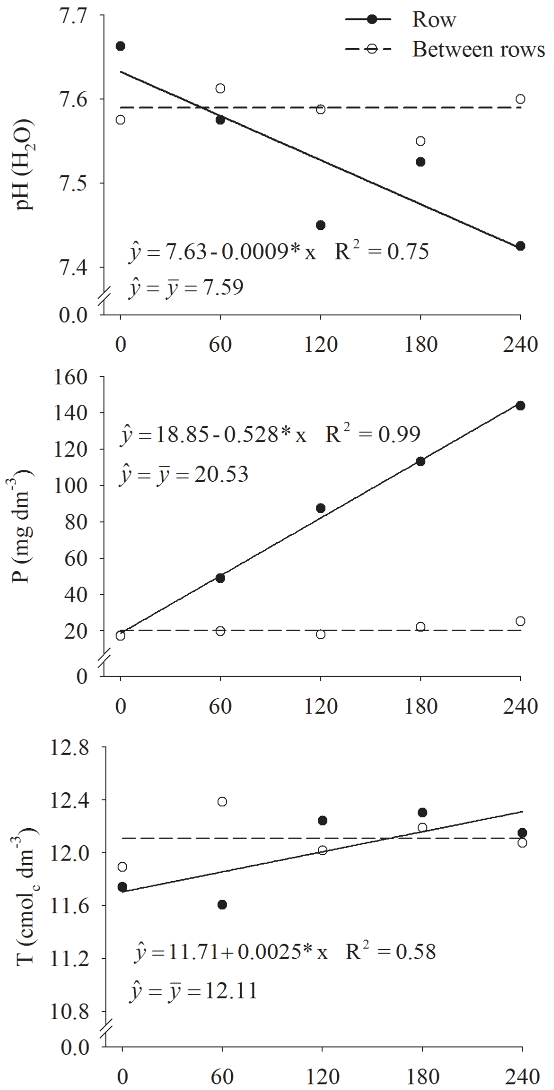

Figure 3: Chemical characteristics, pH (H_2O), P, and total cation exchange capacity (T) obtained in soil from the crop row and between crop rows of chickpea, after fertilization with different rates of P in the form of single superphosphate. *, significant at 5% by the t test.

CONCLUSIONS

The yield of 2.71 t ha^{-1} chickpea is obtained from fertilization of 200 kg ha^{-1} P_2O_5. The application of 150 kg ha^{-1} P_2O_5 promotes maximum agronomic efficiency of chickpea. Application of molybdenum increases aboveground dry matter of chickpea and does not change soil chemical attributes. Application of P in the form of single superphosphate reduces soil pH and increases the concentrations of P and T only in the crop row of chickpea.

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