RESEARCH ARTICLE

Nutritional status of yellow passion fruit fertilized with phosphorus sources and doses

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Abstract

Phosphorus is important to plant growth due to its storage and energy transference processes and its involvement in the active absorption of other nutrients. The aim of this study was to evaluate the nutritional status of yellow passion fruit plants under fertilization from different P_2O_5 sources and rates. Treatments were distributed in randomized blocks in a 2×5 factorial design, with two phosphorus sources (simple and triple superphosphate) and five P_2O_5 doses of 0, 12, 18, 24 and 30 g hole^{-1}. A total of two applications were performed at 60 and 120 days after seedling transplanting; P_2O_5 doses of 0, 24, 36, 48 and 60 g hole^{-1} were equivalent to 0, 27, 40, 53 and 67 kg hole^{-1} of P_2O_5 from each superphosphate source, respectively. When the orchard was in fructification, 150 days after seedling transplanting, individual leaf samples were harvested from the median branches of the plants in each parcel in order to evaluate N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn and Na contents. The phosphate fertilization promoted adequate nutrition for passion fruit plants of N, P, K, Mg and S, independent of the source provided, but adequate Ca only for doses up to 36 g hole^{-1} of P_2O_5. Plants were impaired in B, Cu, Fe and Mn, except for Fe in those not fertilized with P_2O_5 and those treated with 24 and 36 g hole^{-1} of P_2O_5 in simple superphosphate form. Considering the adequate nutritional value of passion fruit, it is recommended to fertilize with 36 g hole^{-1} year^{-1} of P_2O_5, whether simple or triple superphosphate.

Keywords: *Passiflora edulis* Sims., superphosphates, mineral nutrition

1. Introduction

The yellow passion fruit (*Passiflora edulis* Sims.) is commercially grown throughout Brazil and in both tropical and subtropical regions due to soil and climatic conditions, which favour its development (Silva-Matos *et al*., 2016). This crop occupies a relevant place in tropical fruit farming and is considered a promising agricultural alternative for small estates due to its rapid economic return and year-round revenue (Meletti, 2011).

 The field explored by the passion fruit has been increasing over the last several years; however, because its productive potential may reach 50 t ha^{-1}, the mean productivity is considered low, approximately 14 t ha^{-1} (Meletti, 2011). Thus, despite advances in agricultural research and investments in new genotypes, the productive channel of this fruit tree still has issues that, in part, may be related to fertilization inadequacy and plant nutrition, resulting in low productivity.

Phosphorus is a crucial nutrient in plant metabolism, playing an important role in storage and energy transference, respiration and the photosynthetic process (Marschner, 2012). Yellow passion fruit requirements for phosphorus are relatively low compared to those for N and K, being the fourth-most accumulated nutrient in plant leaf dry mass (Malavolta *et al*., 1997; Carvalho *et al*., 2011; Cavalcante *et al*., 2012). However, it is an element supplied in large quantities in fertilization in Brazil, because of its high fixation capacity in tropical soils.

Phosphorus fertilization is essential for passion fruit plants, as research results indicate that adequate dose supplies stimulate plant growth, thus improving nutritional status during the seedling (Prado *et al*., 2005; Vitorazi Filho *et al.*, 2012; Silva *et al*., 2015) and mature stages (Borges *et al*. 2002a; Kondo and Higuchi, 2013). However, despite the importance of this macronutrient in plant nutrition and the microbiological

effects on its availability (Martínez *et al*., 2015), there is a lack of recent information about phosphorus's effects on passion fruit nutritional status during the productive stage and in field conditions.

In addition to adequate doses, one must consider, at the moment of fertilization, the source of phosphorus that will be used, as this influences the plants' nutritional supplies and the economic viability for the farmer (Barbosa *et al*., 2015). Market sources differ in their P contents and in other nutrients such as Ca and S as well as solubility, access and market prices. Source evaluation and phosphorus dose studies are crucial for economically viable harvest of yellow passion fruit.

The aim of this study was to evaluate the nutritional status of yellow passion fruit plants under fertilization with different sources and doses of phosphorus.

2. Materials and Methods

2.1. Site description

Growth activities were carried out from March 2010 to July 2011 (Santos *et al.*, 2014) and those related to plant nutritional status from March to July 2010. The experiments were conducted in Remígio (6º53'00''S / 36º02'00''W, 470 m), in the Curimataú Ocidental semiarid region, Paraíba state, Brazil. The climate is As'-type according to Köppen's classification (Alvares *et al.*, 2013), warm and dry. The rainfall recorded from January to July 2010 was 576 mm, the mean air temperature was 24.5 ºC and the average relative humidity was 81%.

The soil is classified according to Embrapa (2013) as Dystrophic Typic Quartzipsamment (Entisol), with a declivity of 4%. Before the application of the treatments, a chemical and physical characterization

was completed in soil samples at a depth of 0-40 cm (Table 1) according to the suggested methodologies of Embrapa (2011).

The yellow passion fruit (*Passiflora edulis* Sims) cv IAC 273/277 + 275 was cultivated in a 3 × 3 spacing, using a simple espalier system for plant support, with flat wire nº 12, built to a height of 2.2 m, at the apex of the cuttings. The planting pits were dug in a 40 × 40 × 40 cm dimension and prepared with 10 L of bovine manure with a C/N ratio of 18:1 (Table 1) and 12 g of dolomitic limestone (PRNT 80%, 26% of CaO and 14% of MgO) to enhance the soil base saturation percentage to 70%, according to Borges *et al*. (2002b).

Table 1. Soil chemical and physical characterization for fertility and fertilization at a depth of 0-40 cm and chemical attributes of bovine manure used in the experiment.

Chemical attributes	Soil	Manure	Physical attributes	Soil
pH in water (1:2.5)	5.70	8.64	Sand (g kg^{-1})	925
P (mg dm^{-3})	4.50	36.11	Silt (g kg^{-1})	54
K$^+$ (cmol$_c$ dm^{-3})	0.12	92.3	Clay (g kg^{-1})	21
Na$^+$ (cmol$_c$ dm^{-3})	0.10	3.86	Clay dispersed in water (g kg^{-1})	10.00
Ca^{2+} (cmol$_c$ dm^{-3})	0.50	5.40	Index of flocculation (%)	51.00
Mg^{2+} (cmol$_c$ dm^{-3})	0.75	4.50	Soil bulk density (g cm^3)	1.50
H$^+$ + Al^{3+} (cmol$_c$ dm^{-3})	1.46	-	Soil particle density (g cm^3)	2.70
C (g dm^{-3})	0.19	35.23	Total porosity (m^3 m^{-3})	0.50
OM (g dm^{-3})	3.30	-	Micro porosity (m^3 m^3)	0.04
SB (cmol$_c$ dm^{-3})	1.37	-	Macro porosity (m^3 m^3)	0.42
CEC (cmol$_c$ dm^{-3})	2.83	-	Water content FC (g kg^{-1})	46.00
V (%)	48.4	-	Water content PMP (g kg^{-1})	13.70
*LR (g hole^{-1})	140	-	Texture	Sandy

P, K and Na$^+$ = Mehlich 1 extractor; Al^{3+}, Ca^{2+}, Mg^{2+} = extractor KCl 1M; C = Organic carbon; OM = Organic matter in the soil by oxidation with potassium permanganate; SB = Sum of bases (Na$^+$ + K$^+$ + Ca^{2+} + Mg^{2+}); CEC = Cation exchange capacity = SB + (H$^+$ + Al^{3+}); V = Exchangeable base saturation (100*SB/CEC); LR = Liming requirement.

2.2. Experimental design and field management

Treatments were distributed in randomized blocks, with three replicates and 12 plants per parcel, in a 2 × 5 factorial design, with two phosphates sources (simple superphosphate - 18% P$_2$O$_5$, 18 in 20% Ca, 12% S and triple superphosphate - 42% P$_2$O$_5$, 12 in 14% Ca), in doses of 0, 12, 18, 24 and 30 g hole^{-1} of P$_2$O$_5$ in two equal applications at 60 and 120 days after seedling transplantation in the field, totalling 0, 24, 36, 48 and 60 g hole^{-1} of P$_2$O$_5$ broadcast supplied in a 0.5 m^2 area within a 40 cm radius from the plant stalk, where there is the highest proportion of active roots (Sousa *et al.*, 2002). The fertilizer doses studied were defined according to soil analysis following the recommendations of Ribeiro *et al*. (1999).

Fertilization with nitrogen and potassium, before orchard nutritional status determination, was carried out in the same area (0.5 m^2) as phosphate fertilization, in three applications under a proportion of 1N:1K$_2$O, assuming as sources, respectively, urea (44% N) and potassium chlorite (58% K$_2$O). After 60 and 90 days, respectively, 10 g of N and 10 g of K$_2$O were supplied, and 15 g of N and 15 g of K$_2$O were supplied at the beginning of flowering 120 days after planting according to Borges *et al*. (2002b). These values correspond to the application of 35 g plant^{-1} of N and K$_2$O, corresponding to 80 and 60 g plant^{-1} of urea and potassium chlorite, referring to 90 and 67 kg ha^{-1} of the mineral fertilizer, respectively, before plant fructification.

Irrigation was performed using a locally applied dripping method, with two emitters under a flow rate of 3.75 L h^{-1} at 20 cm from plant stalks, based on the crop evapotranspiration (ETc) estimated with reference to the evapotranspiration product (ET$_0$) of the crop coefficient of 1.2 (Souza *et al*., 2009), during the flowering stage at the end of harvesting. The ET$_0$ (ECA × 0.75) was obtained based on measured evaporation in a Class A pan installed at the experimental site.

At 150 days after seedling transplantation, when the orchard was fruiting, samples were individually collec-ted following the instructions of Malavolta *et al.* (1997), i.e. 48 leaves of healthy median branches (4th leaf from branch apex) for each parcel, for evaluation of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, Zn and Na in plant leaf dry mass, according to the methodology described by Bataglia *et al.* (1983).

2.3. Statistical analysis

The results were submitted to variance analysis using the F-test. The mean values of the P$_2$O$_5$ sources were compared using the F-test, which is conclusive for both factors, and the evaluation doses were evaluated by polynomial regression using the Sisvar software (Ferreira, 2014).

3. Results

According to variance analysis, among the macronutrients, the N leaf contents from yellow passion fruit plants were significantly influenced by the isolate action of P$_2$O$_5$ source and doses; P and K contents were influenced by the P$_2$O$_5$ doses and Ca, Mg and S responded to the interaction source x dose of P$_2$O$_5$ (Table 2).

Table 2. Overview of variance analysis by mean square regarding values of nitrogen, phosphorus, potassium, calcium, magnesium and sulphur contents in leaf dry mass of yellow passion fuits plants exposed to P$_2$O$_5$ sources and doses.

Source of variation	DF	Mean Square					
		N	P	K	Ca	Mg	S
Blocks	2	17.5[ns]	0.1[ns]	45.7*	6.5[ns]	0.4[ns]	0.2[ns]
Sources (S)	1	120.0*	0.1[ns]	13.3[ns]	108.3**	53.3**	13.3**
Doses (D)	4	101.5**	5.7**	57.8**	4.6[ns]	2.3**	9.5**
S × D	4	9.7[ns]	0.1[ns]	1.1[ns]	11.0*	6.4**	2.1**
Residue	18	279.0	0.3	11.2	3.0	0.5	0.2
CV (%)		9.0	15.5	9.4	10.5	9.2	11.5

DF = Degrees of freedom; ns = Not significant; * and **, respectively, represent $p<0.05$ and $p<0.01$; CV = Coefficient of variation.

The leaf content of N was significantly higher in plants where the P_2O_5 was supplied as triple super-phosphate, compared to that of those treated with simple superphosphate (Figure 1A).

The increase in P_2O_5 dose, independently of the source used, enhanced N leaf content up to a maximum value of 47.0 g kg^{-1} for the 34.1 g hole^{-1} P_2O_5 dose (Figure 1B).
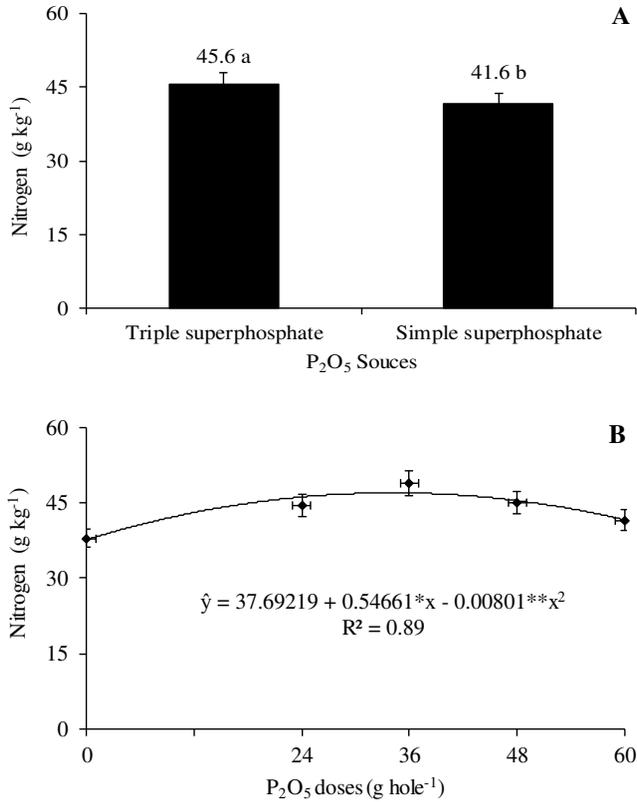

Figure 1. Leaf content of nitrogen in yellow passion fruit plants as a function of sources (A) and doses (B) of P_2O_5.

In relation to P leaf contents, it is possible to infer that independently of the P source, the P leaf content was enhanced up to 4.2 g kg^{-1} for the dose of 36.9 g hole^{-1} of P_2O_5 (Figure 2A). The K leaf content in the passion fruit plants was linearly enhanced with an increase in P_2O_5 dose supplied to the soil (Figure 2B).
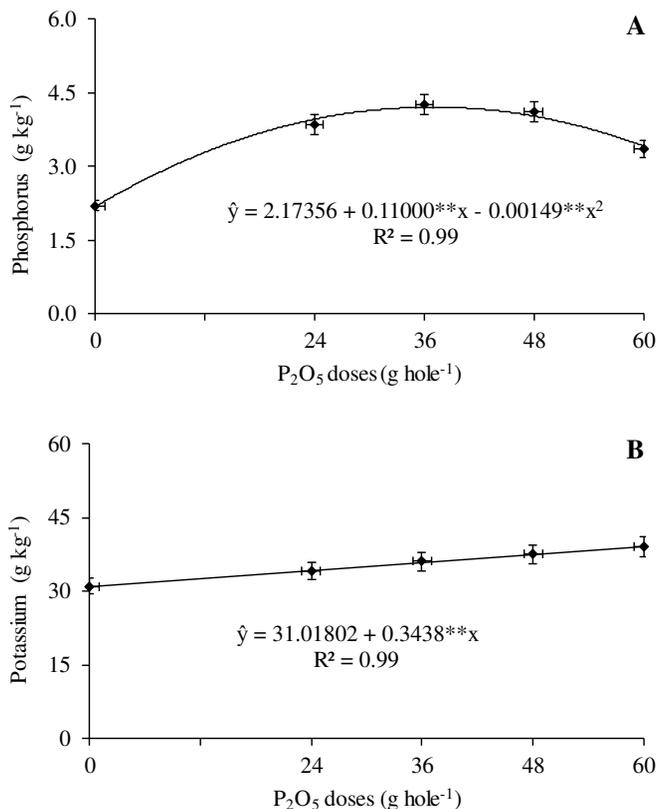
Figure 2. Phosphorus (A) and potassium (B) leaf contents in yellow passion fruit plants as a function of P_2O_5 doses.

Regarding Ca, it was observed that plants treated with simple superphosphate had Ca contents linearly enhanced as a function of P_2O_5 dose, achieving a maximum Ca value of 20.19 g kg^{-1} with a P_2O_5 dose of 60 g $hole^{-1}$ (Figure 3A). Indeed, the leaf contents of Ca in plants treated with simple superphosphate were higher than those treated with triple superphosphate (Figure 3A).

The sources of P displayed the opposite effects for Mg leaf contents, as compared to Ca (Figure 3B).

In plants treated with triple superphosphate, the increase in P_2O_5 dose enhanced Mg contents up to a maximum value of 9.74 g kg^{-1}, for the 38.0 g $hole^{-1}$ of P_2O_5 dose. In contrast, the plants treated with simple superphosphate had Mg contents that linearly decreased from 7.8 to 4.66 g kg^{-1}.

The S leaf contents were enhanced up to 6.13 and 3.72 g kg^{-1} for P_2O_5 doses of 33.68 and 32.29 g $hole^{-1}$, using simple and triple superphosphate, respectively (Figure 3C).
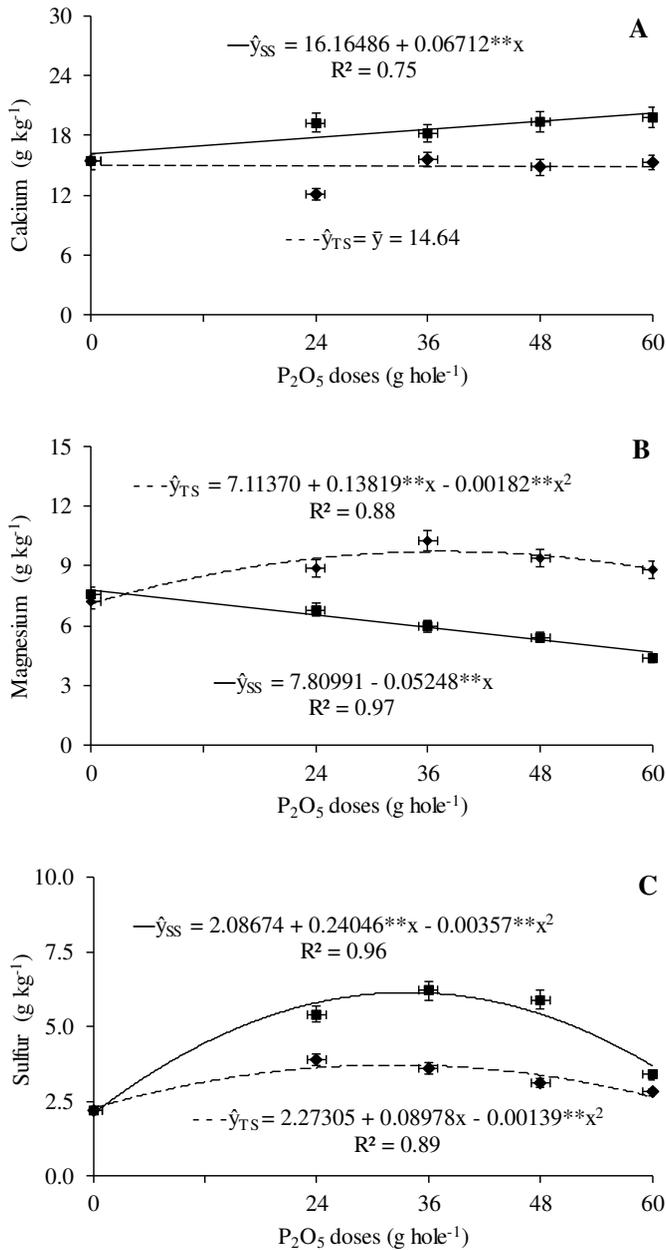
Figure 3. Calcium (A), magnesium (B) and sulfur (C) leaf contents in yellow passion fruit plants as a function of P_2O_5 doses of simple superphosphate (—) and triple superphosphate (---).

Regarding micronutrients, it was verified that only B leaf content significantly responded to the isolated effects of the provided phosphorus sources (Table 3).

The Cu, Fe, Mn and Zn contents were not significantly affected from either of the sources adopted.

Table 3. Overview of variance analysis by mean square regarding leaf contents of boron, copper, iron, manganese, zinc and sodium contents in leaf dry mass of yellow passion fruit plants exposed to P_2O_5 sources and doses.

Source of variation	DF	Mean Square					
		B	Cu	Fe	Mn	Zn	Na
Blocks	2	23.63^{ns}	3.10^{ns}	16.93^{ns}	16.90^{ns}	4.90^{ns}	1.30^{ns}
Sources (S)	1	61.63^{**}	2.70^{ns}	1400.83^{ns}	24.30^{ns}	19.20^{ns}	235.20^{*}
Dose (D)	4	31.38^{ns}	7.95^{ns}	254.63^{ns}	106.50^{ns}	35.50^{ns}	2942.55^{**}
S x D	4	9.88^{ns}	1.93^{ns}	227.33^{ns}	13.80^{ns}	21.45^{ns}	2298.4^{**}
Residue	18	13.18	3.43	377.15	87.78	30.01	48.74
CV (%)		12.28	27.66	17.10	13.48	15.39	10.33

DF = Degrees of freedom; ns = Not significant; * and **, respectively, represent $p<0.05$ and $p<0.01$; CV = Coefficient of variation.

The B leaf contents were higher in yellow passion fruit plants fertilized with simple superphosphate (Figure 4A).

As seen in Table 4, the Cu leaf contents (6-9 mg kg^{-1} for simple superphosphate and 5-8 mg kg^{-1} for triple superphosphate) and Mn leaf contents (62-76 mg kg^{-1} for simple superphosphate and 66-75 mg kg^{-1} for triple superphosphate) presented a large range. Additionally, Fe leaf contents ranged from 133 to 127 mg kg^{-1} for simple superphosphate and from 100 to 121 mg kg^{-1} for triple superphosphate, while Zn leaf contents ranged from 32-39 mg kg^{-1} (simple superphos-

phate) and 32-40 mg kg^{-1} (triple superphosphate).

The yellow passion fruit plants subjected to a P supply, in a triple superphosphate form, had Na leaf contents enhanced linearly, with a maximum value 107.3 mg kg^{-1} for a P_2O_5 dose of 60 g hole^{-1} (Figure 4B). Moreover, the Na contents were enhanced up to 85.4 mg kg^{-1}, with the increase in simple superphosphate form up to an estimated maximum P_2O_5 dose of 32.7 g hole^{-1}. Indeed, plants treated with simple superphosphate presented lower Na leaf content compared to those fertilized using triple superphosphate.
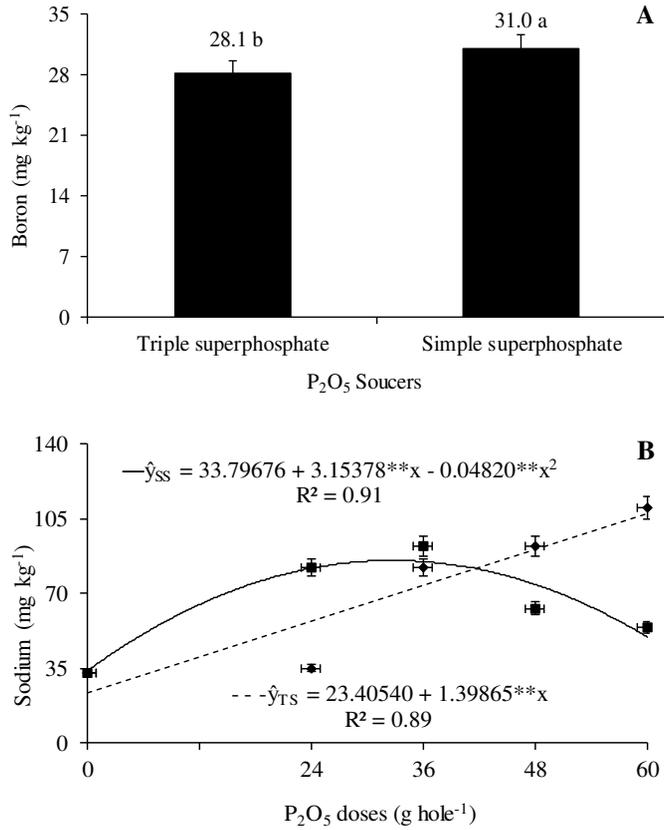
Figure 4. Boron leaf contents (A) as a function of P_2O_5 sources and sodium leaf contents (B) of yellow passion fruit as a function of P_2O_5 doses of simple superphosphate (—) and triple superphosphate (---).

Table 4. Mean contents of copper, iron, manganese and zinc in yellow passion fruit plant leaf dry mass exposed to P_2O_5 sources and doses.

P_2O_5 doses	Cu		Fe		Mn		Zn	
	SS	TS	SS	TS	SS	TS	SS	TS
g hole^{-1}	- mg kg^{-1} -							
0	7[ns]	7[ns]	121[ns]	121[ns]	69[ns]	69[ns]	32[ns]	32[ns]
24	6	5	124	116	76	75	34	35
36	6	5	127	113	71	71	39	37
48	7	8	117	103	65	71	37	38
60	9	7	113	100	62	66	32	40

ns = non-significant; SS = Simple superphosphate; TS = Triple superphosphate.

4. Discussion

Higher N leaf content in plants fertilized with triple superphosphate occurred because the higher P concentration in the triple superphosphate has a positive action on N absorption in photosynthetic reactions and C metabolism, processes that are fundamental for assimilation and utilization of N and P (Malavolta *et al.*, 1997; Brown *et al.*, 2011).

The increase in N contents in fertilized plants with P was also observed by Silva *et al.* (2015) in wild passion fruit (*Passiflora edulis*) and by Lemos *et al.* (2015) in coffee (*Coffea arabica*) plants. Moreira *et al.* (2016) attested that fertilization with phosphorus enhanced the nitrogen accumulation in pitaya plants (*Hylocereus undatus*). According to Brown *et al.* (2011), there is a strong correlation between N and P contents, indicating that these nutrients interact in a synergistic way, where adequate doses of both nutrients promote enhancement of each other's absorption, while inhibition occurs when the nutrients are applied in excessive amounts (Cerutti and Delatorre, 2013).

Despite the N content decrease with application of P doses higher than the maximum physical efficiency, it was noted that, except in the testing dose, the levels obtained are in range of 40-50 g kg^{-1}, considered adequate by Malavolta *et al.* (1997) for the yellow passion fruit (Figure 1B).

Leaf P content as shown in Figure 2A above 4.2 g kg^{-1} is adequate for a yellow passion fruit crop, since it is within the range of 4-5 g kg^{-1} (Malavolta *et al.*, 1997). These results are in accordance with those verified by Brunetto *et al.* (2015) when attesting that phosphate fertilization enhanced P content in soil and pear tree leaves (*Pyrus communis* L.). Moreira *et al.* (2016) attested that the phosphate fertilization in pitaya plants enhanced P content and its accumulation in plants.

The leaf P content reduction in plants submitted to doses greater than 36.9 g hole^{-1} of P$_2$O$_5$ is possibly linked to a greater stimulus of biomass production, which may result in dilution of P content in leaf dry mass. According to Barretti *et al.* (2008), when a chemical analysis is performed in a shoot, the same dry material quantity is used in all samples, and nutrients are extracted from it; in larger plants, the nutrients are less concentrated due to the greater area, and thus, lower nutrient levels may occur in plants with higher vegetal mass. It is important to note that plant species could present different P strategies to acquire P from soil, and this is important in defining crop management strategies at improving P use (Sandaña and Pinochet, 2016), especially for poorly studied species such as passion fruit.

Leaf K concentration enhancement with higher P$_2$O$_5$ doses (Figure 2B) was also observed by Prado *et al.* (2005) in passion fruit seedlings submitted to phosphorus doses, with a verified linear increase in leaf and root content of K. Silva *et al.* (2015) also attested that phosphate fertilization enhances K leaf content in larger passion fruit plants.

The presence of P and Ca in two sources and S in simple superphosphate favours root growth, which expand to a greater soil volume, contributing to higher water and nutrient absorption by the plants (Marschner, 2012; Moreira *et al.*, 2016). In contrast, when the Ca ranges from low to adequate concentrations in leaf tissues (condition verified in Figure 3A), it favours K absorption as a synergistic effect (Malavolta *et al.*, 1997).

Malavolta *et al.* (1997) attested that K leaf contents between 35-45 g kg^{-1} are adequate for yellow passion fruit growth and production. According to the results herein presented in Figure 2B, for yellow passion fruit plants whose K content must be greater than 35 g kg^{-1}, P$_2$O$_5$ doses greater than 30 g hole^{-1} would be necessary, independent of the supply source.

The leaf Ca contents with P$_2$O$_5$ dose enhancement was a result of the higher input of calcium in the

soil as a function of higher simple superphosphate doses, which contains more Ca in its formulation than the triple superphosphate (18-20%, while triple superphosphate has 12-14%). In contrast, the Ca leaf contents in plants treated with triple superphosphate did not adjust to any mathematic model, being represented by the Ca mean value 14.64 g kg^{-1}. Similar results were observed by Borges *et al.* (2002a), Prado *et al.* (2005) and Neves *et al.* (2008) in leaf contents of Ca in passion fruit and umbu (*Spondias tuberosa*) plants, respectively, under phosphate fertilization, using triple superphosphate doses. The lack of significance reported for Ca leaf contents should be caused by the high Ca bovine manure value (Table 1) used in the experiment, according to Borges *et al.* (2002b).

Considering adequate Ca contents for the passion fruit are between 15-20 g kg^{-1} (Malavolta *et al.*, 1997), the plants fertilized with triple superphosphate were properly supplied with this nutrient only for doses up to 36 g hole^{-1} of P_2O_5, while all the P_2O_5 doses provided by simple superphosphate resulted in adequate supply for plants with Ca. Presumably the Ca amount provided by the triple superphosphate was not sufficient to supply the plants' requirements for this macronutrient.

The incongruent effects of the different P_2O_5 sources on Mg leaf content differs from Prado *et al.* (2005) who verified Mg leaf content enhancement in passion fruit seedlings when doses of simple superphosphate applied to the soil were increased. These effects are also in disagreement with Kondo and Higuchi (2013), who studied different P doses on plant nutritional status and observed higher Mg leaf content when higher P doses were applied.

The linear reduction and lower Mg leaf content in plants submitted to simple superphosphate is due to the inhibition of absorption of this element caused by increase in K (Figure 2B) and Ca content (Figure 3A), as these nutrients compete for the same adsorption site in the leaf membranes (Malavolta *et al.*, 1997;

Marschner, 2012), associated to the high Mg of the bovine manure (Borges *et al.*, 2002b) used in the experiment, as can be seen in (Table 1). However, even though it was reduced, the Mg leaf content in plants fertilized with simple superphosphate was higher, in the range of 3-4 g kg^{-1}, which means that the crop was nutritionally balanced in Mg (Malavolta *et al.*, 1997). The maximum Mg level obtained with the maximum physical efficiency doses of triple superphosphate is two-fold that of 4.0 g kg^{-1}, considered as a limit value of adequacy. Because the initial content of this element in soil is considered a mean (Table 1), the applied limestone provided Mg in quantities greater than that deemed adequate for the crop.

As a function of P_2O_5 dose, the S leaf contents increased until reaching a peak (Figure 3C) and then decreased, a tendency that agrees with the results recorded by Miyake *et al.* (2016) but differs from the results of Prado *et al.* (2005), who recorded a linear decrease in S content in passion fruit seedlings under triple superphosphate doses. On the other hand, for red alder plants (*Alnus rubra*), Brown *et al.* (2011) attested as well that fertilization with triple superphosphate enhanced S leaf content during the first year growing the crop.

The superiority of S contents in plants fertilized with simple superphosphate is because this input contains 12% of S in its composition, which does not occur in triple superphosphate. According to the results, it was verified that independent of source supplied, the maximum contents obtained are greater than 2-3 g kg^{-1} meaning that the plants were properly supplied with S (Malavolta *et al.*, 1997). Although triple superphosphate does not contain S in its composition, plants submitted to this treatment were also properly nurtured with S. This nurturing occurs because the manure used in planting pit preparation provides S for the plants; furthermore, this element may be absorbed in low quantities from the atmosphere by leaf absorption.

Although there were positive effects of simple super-phosphate on B leaf content (Figure 4A), the values observed for both P sources are well below the B range of 40-50 mg kg^{-1}, considered adequate for the crop (Malavolta *et al*., 1997). Prado *et al*. (2005) attested that enhancement of P supply, in simple superphos-phate form, resulted in a decrease in B leaf content for yellow passion fruit seedlings. The Ca and Mg of the limestone with the Ca supplied with the P sources possibly increased the soil pH, impairing B absorp-tion. In addition, Borges *et al*. (2002a) evaluated the effect of phosphorus doses (simple superphosphate) on the nutritional status of passion fruit and recorded no effect on B leaf contents.

Although there was a wide range recorded for Cu and Mn leaf contents (Table 4), all average values are be-low the limits of 10-20 mg kg^{-1} and 400-600 mg kg^{-1} considered adequate for yellow passion fruit, respec-tively (Malavolta *et al*., 1997). Regarding Fe, when it is considered that passion fruit plants properly supplied must contain leaf contents between 120-200 mg kg^{-1}, it was observed that plants were also impaired in terms of this micronutrient, except in plants not fertilized with P_2O_5 and those treated with 24 and 36 g $hole^{-1}$ of P_2O_5 in simple superphosphate form.

Low availabilities of micronutrients, associated with high soil pH due to the lime and calcium provided by the P sources, may have decreased the absorption of Cu, Fe and Mn, resulting in values below the critical limit, impairing the plants (Malavolta *et al*., 1997). This follows Santin *et al*. (2013), who concluded that high doses of lime decrease micronutrient ab-sorption by the plants.

Despite not being significantly influenced by the vari-ation in sources, Zn leaf contents contained in Table 4 are within the range of 25-40 mg kg^{-1}, considered ad-equate for the crop by Malavolta *et al*. (1997). Prado *et al*. (2005) and Lemos *et al.* (2015) verified that en-hancement in P supply resulted in low Zn contents in

passion fruit and coffee plants, respectively. Accord-ing to Malavolta *et al.* (1997), the higher P absorp-tion by plants may result in lower absorption of other nutrients such as Zn. In contrast, Borges *et al*. (2002a) in a study performed in a sandy loam soil, recorded no effect of phosphorus doses on Zn leaf content.

Higher simple superphosphate doses also promoted high Na leaf contents (Figure 4B), a result that is in agreement with Silva *et al*. (2015), who attested en-hancement of Na leaf contents in wild passion fruit plants fertilized with simple superphosphate. In addi-tion, the higher Na leaf content promoted by triple su-perphosphate in relation to the simple superphosphate occurred because it contains higher Ca level in its composition, which favours larger Na displacement in soil charge sites, resulting in leaching and a decrease in its availability to plants (Leite *et al*., 2010).

In general, the sodium contents observed are below toxic levels for plants, that is, 0.25-0.50%, respec-tively, 2500-5000 mg kg^{-1} of sodium in leaf dry mass (Dias and Blanco, 2010), which means that crop nu-trition was not compromised by accumulation of the element detected in the leaf dry mass.

5. Conclusions

Phosphate fertilization promoted adequate nutrition for passion fruit plants in terms of N, P, K, Mg and S, inde-pendent of the source provided, but promoted adequate Ca only for doses up to 36 g $hole^{-1}$ of P_2O_5. Addition-ally, triple superphosphate enhanced the leaf content of N and Mg and simple superphosphate Ca and S.

Except for B, the micronutrient leaf contents were not influenced by P_2O_5 doses or sources.

Plants were impaired in B, Cu, Fe and Mn, except for Fe in those not fertilized with P_2O_5 and those treated with 24 and 36 g $hole^{-1}$ of P_2O_5 in simple superphos-phate form.

Considering the adequate nutritional status for passion fruit, it is recommended that a fertilization of 36 g hole^{-1} year^{-1} of P$_2$O$_5$ be applied, whether simple or triple superphosphate.

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