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Effect of phosphorus (P) doses on tomato seedlings production in poor nutrients substrates and its importance on fruit yield

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Abstract

The effect of P on different plants and several growth stages are well known to scientists, but there is little information on the effect of P after transplanting the seedling until harvesting. The current study aimed to evaluate the effect of P on tomato seedling and fruit production of Paronset hybrid. Therefore, six treatments (0, 15, 30, 45, 60 and 75mg L^{-1}P) were evaluated in a randomized complete block design with four replications. Monoammonium phosphate (MAP) was used as P source, in addition to coconut fiber substrate. A linear increase was obtained for leaf area, seedling height, shoot and root fresh matter at 75mg P L^{-1}. However, yield and fruits characteristics were not affected by increasing P doses on seedlings.

K**eywords:** coconut husk fiber, fertigation, phosphate fertilizer, *Solanum lycopersicum*, substrate.
Abbreviations: AFW_ average fruit weight; CTC_ cation exchange capacity; CV_ coefficient of variation; DAT_ days after transplanting; FD_ diameter of fruit; FH_ height of fruit; MAP_ monoammonium phosphate; M.O_ organic matter; P_ phosphorus; PP_ production per plant; SB_ sum of bases; TNFP_ total number of fruits per plant; V_ base saturation.

Introduction

Tomato (*Solanum lycopersicum*) is wide cultivated in the world. In 2013, the Brazilian tomatoes production, including industry and fresh market, totalized 3,801,324 tons in 57,196 ha (i.e. an average yield of 66.4 t ha^{-1}). The Brazilian production is mainly concentrated in the Southeast (40%) and Midwest (35%) areas (AGRIANUAL, 2014). Tomatoes are propagated by seeds; trays are used to produce seedlings, which are obtained by using substrates with appropriate physicochemical properties, i.e. compatible with germination, seedling growth and development phase. Therefore, substrate should ensure water and nutrients supply in the liquid phase; oxygen and carbon dioxide in the gas phase; and root growth with no mechanical impedance, as well as plant stability in the solid phase (Silveira et al., 2002; Dias et al., 2009). Additionally, substrates should be free of pathogens, weeds, pests and minerals, as they can harm seedlings in higher levels. To find solutions that can reduce the environmental impact caused by urban and industrial waste, various sectors of society have been engaged in the development of research aimed at the economic exploitation of these materials. Coconut fiber is a good example of residue that became an important source of raw material to produce substrates, due to a combination of causes: easy production and high availability (Rosa et al., 2002). It is also important to mention that coconut fiber is poor in nutrients, thus fertilizer may be required (Cardoso and Ustulin Filho, 2013), such as phosphorus (P) (Dias et al., 2009). P fertilizer plays a central role in photosynthesis, as well as stimulating and developing the roots, thereby improving water use and nutrient uptake efficiency (Dias et al., 2009). Arruda Júnior et al. (2005) obtained the highest values of dry matter yield (4.35g $plant^{-1}$) and phosphorus content (4.6g kg^{-1}) by applying the highest P dose, while evaluating the effect of P on soil, productivity and phosphorus content in curly leaf lettuce. Moreover, Nicoulaud et al. (1990) obtained a linear response in dry matter yield of butterhead lettuce when evaluating doses between 0 and 120 kg ha^{-1} of P_2O_5; but such doses were insufficient to obtain the maximum yield. Silva et al. (2010) assessed different sources and doses of P (0-150 kg ha^{-1} of P_2O_5) in melon production, but no significant responses were found for average fruit matter in soil with 23 mg dm^{-3} P. In green bean, Oliveira et al. (2005) applied different P doses (from 0 to 176 kg ha^{-1}); being the maximum number of fruits obtained at 116 kg ha^{-1}. Amjad et al. (2002), observed a reduction of okra yield at 87 kg ha^{-1} by using different P doses (73; 87 and 104 kg ha^{-1}) in medium texture soil. It is worth mentioning that the responses varied in accordance with the soil type and soil P availability. The application of phosphorus showed a significantly positive effect in tomato yield (Melo et al., 2014), but the effects of P on seedling production are still unknown. Nishimoto et al. (1977) observed that P contents in tomato leaves ranged from 3.0 to 5.0 g/kg, when reaching their maximum yield of 95%. Faria et al. (1999), evaluated the production of industrial tomatoes with phosphate fertilization in soils with different phosphorus levels; reported that in soils where available P content was equal to or lower than 2 mg.dm^{-3}, productivity increased (about 191%); however, soils where available P content was equal to 8 mg dm^{-3}, it only increased 22%. Moreover, soils where available P content was equal to or greater than 14 mg dm^{-3}, no response was observed. By studying nutrient concentration on pruned tomatoes yield and densified due to phosphorus use, Silva et al. (2001), showed a linear increase the phosphorus content in leaves (from 1.7 to 3.0 g kg^{-1}).

There is a lack of researches to assess the effects of fertilizers on seedlings produced in poor nutrients substrates and their effect after transplanting until harvesting, because most researches stop at the evaluation of seedlings, but not after transplanting. Therefore, the current study aimed to evaluate the effects of phosphorus fertigation on tomato seedlings production and its role on tomatoes fruit production.

Results and Discussion

Characteristics of the seedlings

A linear increase was observed in seedling height (Fig 1A), which varied from 106.0 (dose 0) to 117.9 mm (at 75 mg L^{-1}P). Lima et al. (2007) studied the effects of black tea (an agro-industrial waste) on tomato seedling production, and obtained maximum height of 47.1mm; therefore, lower than the current study. Regarding to the leaf area, a linear increase was also obtained (Fig 1B). Therefore, leaf area increased from 96.07 (dose 0) to 130.87 cm² per plant (at 75 mgL^{-1}P). In other words, the leaf area increased 4.64 cm^2 for every 10 mgL^{-1}P. For seedling shoot fresh matter, a linear effect was observed (Fig 1C). Every 10 mgL^{-1}P increased 0.04 g plant^{-1}; i.e. from 1.17 (dose 0) to 1.47 g plant^{-1} (at 75 mg L^{-1}P). Silveira et al. (2002) evaluated the coir dust (single or associated with other substrates) to produce tomato seedlings, but obtained lower values (a maximum of 0.96g) than the current study. With regards to root fresh matter, a linear effect was obtained (Fig 1D), ranging from 0.77(dose 0) to 1.00 g plant^{-1} (at 75 mg L^{-1}P); therefore, an increase of 0.03g plant^{-1} for every 10 mg L^{-1}P. For stem diameter, shoot and root dry matter, there were statistically significant difference among treatments and the average values were of 2.82 mm, 0.15 g plant^{-1} and 0.0059 g plant^{-1}, respectively. Although P increased in fresh matter, it was indifferent in seedlings dry matter.

By comparing the values obtained in the current study with those reported by other authors, there were significant differences in seedling height and fresh matter; due to the treatment, genotypes (cultivars and hybrids), trays size, climate, evaluation day, among other factors. Furthermore, the current study presented some positive effects of P on tomato seedlings development. P stimulates plant development, acting as a nutrient in the biomass production for both shoot and root (Lópes-Bucio et al., 2002). Additionally, P acts mainly on maximizing root development; providing mechanical support and facilitating water and nutrients uptake (Malavolta, 2006).

P content increased linearly in shoot and root of seedlings. In the shoot, P ranged from 1.60 to 5.90 g kg $^{-1}$(Fig 2A). In the root, P varied from 2.23 to 6.46 g kg $^{-1}$ (Fig 2B). Dias et al. (2009) stated that coconut fiber does not increase P level in the foliar biomass of "mangabeiras" seedlings; consequently, P must be supplied.

There are few studies addressing the effect of nutrient supply on vegetables seedlings production with coconut fiber substrate. However, Silveira et al. (2002) evaluated tomato seedlings production with coconut fiber substrate without nutrient supplementation, such study reported low seedling development due to reduced nutrient content of the substrate, thus fertigation was necessary on seedlings trays, as it allows enough water and nutrients supply onto the seedlings. Oliveira et al. (2009) reported that the coconut fiber substrate without fertilizer resulted in the worst eggplant seedlings, requiring fertigation with macronutrients. Squash, beet and endive seedlings produced in coconut fiber without fertigation also resulted in lower vegetative characteristics values (Higuti et al., 2010b; Oliveira et al., 2012; Cardoso and Ustulin Filho, 2013).

Therefore, fertilizers are of great importance for seedlings production, since some substrates do not present appropriate nutrients levels, such as the coconut fiber, whose efficiency is only relied on retaining moisture, root aeration and respiration.

Effect on fruit production

With regards to fruit production traits, there were no statically significant effects on both total and early production. Despite all the significant differences in seedlings height, leaf area, shoot and root fresh matter (Fig 1), after transplanting all plants from the six treatments developed well and the differences that were significant, no longer existed.

The average of total fruits production per plant was 3.45 kg per plant^{-1}; being the average yield of 69.09 t ha^{-1} (Table 1). This value is within the Brazilian production range (AGRIANUAL, 2014). In 2013, the average yield of Brazilian tomato crops was 66.4 t ha^{-1}. It was obtained an average of 30.06 fruits per plant, which is much higher than those found by Andriolo et al. (2004). During the experiment, the average temperatures were higherthan25^{o}C; consequently, harmful to fruit development (Alvarenga, 2013).

Some of the parameters used to assess the commercial quality of tomato fruits are diameter, height and average matter; however, there were no differences among treatments, whose averages were 59.94mm, 51.23 mm and 114.68 g, respectively (Table 1). These values are below the ones found by Higuti et al. (2010a), when evaluated Platinum hybrid, which belongs to the same group, and obtained 78.5 mm, 65.8 mm and 124.1g, respectively.

It should be noted that the soil presented good chemical conditions with high levels of MO (15 g dm^{-3}), P (95 mg dm^{-3}), K (3.9 mmol$_c$dm^{-3}), Ca (57 mmol$_c$dm^{-3}) and Mg (22 mmol$_c$dm^{-3}), as proposed by Trani et al. (1997). Regardless the treatments, all plants were equally cultivated after transplant, i.e. the same chemical fertilizer was applied at sowing and topdressing. Not even for early production were obtained any differences, showing a fast recovery of the least developed seedlings. After transplanting, the favourable conditions (i.e. mainly fertilizer and sanity) contributed to the plants full development. Therefore, the initial differences between seedlings did not remain until the end of the cycle. Kano et al. (2008) and Magro et al. (2011) reported that after transplanting under favourable conditions, plants may present similar yields when transplanting seedlings with different leaf numbers, fresh and dry matter.

In the current study, the results of P demonstrated its importance on seedlings development until the final production stage. Whether the experiment was discontinued on the transplanting day and evaluated only the seedlings characteristics, it could have been concluded that the higher the P dose, the best would be the seedlings (Cardoso and Ustulin Filho, 2013). However, higher yields do not necessarily result in seedlings with greater matter and height

Table 1. Averages obtained for fruit production per plant (PP), yield, total number of fruits per plant (TNFP), diameter (FD), height (FH) and average fruit weight (AFW) of tomato for each P doses, F test for P doses and coefficient of variation (CV). São Manuel-SP, 2013.

Total fruit production characteristics						
P doses	PP	Yield	TNFP	FD	FH	AFW
(mg L^{-1})	(kg $plant^{-1}$)	(t ha^{-1})		(mm)	(mm)	(g $fruit^{-1}$)
0	3.30	66.14	28.41	60.22	51.99	117.50
15	3.24	64.90	28.00	60.56	52.14	116.09
30	3.91	78.20	33.75	60.34	51.23	116.78
45	3.36	67.32	29.08	60.26	51.18	114.81
60	2.81	56.30	27.66	58.21	49.33	101.67
75	4.07	81.53	33.50	60.04	51.50	121.25
General average	3.44	69.06	30.06	59.93	51.22	114.68
F_{doses}	1.02^{ns}	1.03^{ns}	1.03^{ns}	0.81^{ns}	1.51^{ns}	0.65^{ns}
CV (%)	13.62	13.61	15.17	3.92	3.37	8.41

ns = not significant at 5% probability.

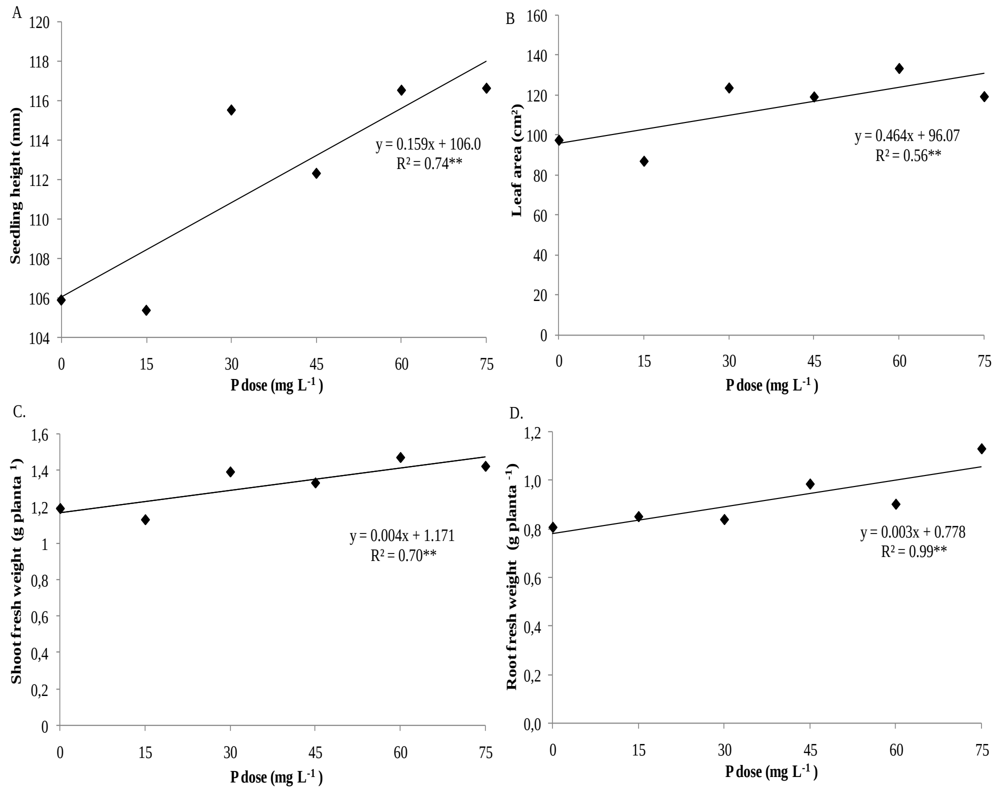

Fig 1. Seedling height (A), leaf area (B), shoot (C) and roots fresh weight (D) of tomato seedlings, according to the P doses. São Manuel SP-2013.

Table 2. Averages obtained for early production (sum of the first three crops) characteristics: production per plant (PP), yield, total number of fruits per plant (TNFP), diameter (FD), height (FH) and average fruit weight (AFW) of tomato. São Manuel-SP, 2013.

Early fruit production characteristics						
P doses	PP	Yield	TNFP	FD	FH	AFW
(mg L^{-1})	(kg $plant^{-1}$)	(t ha^{-1})		(mm)	(mm)	(g $fruit^{-1}$)
0	0.96	19.21	6.74	63.80	53.57	142.15
15	0.96	19.20	6.66	67.42	55.83	148.37
30	1.35	27.15	8.83	64.57	53.59	151.82
45	1.19	23.85	8.58	66.15	55.03	139.12
60	1.30	26.05	1.83	62.93	52.20	120.35
75	1.19	23.80	8.75	63.86	52.36	136.98
General average	1.15	23.21	8.39	64.78	53.76	139.79
F_{doses}	0.85^{ns}	0.85^{ns}	1.64^{ns}	2.36^{ns}	5.60^{ns}	2.27^{ns}
CV (%)	31.31	28.74	28.74	3.38	2.24	10.47

ns = not significant at 5% probability.

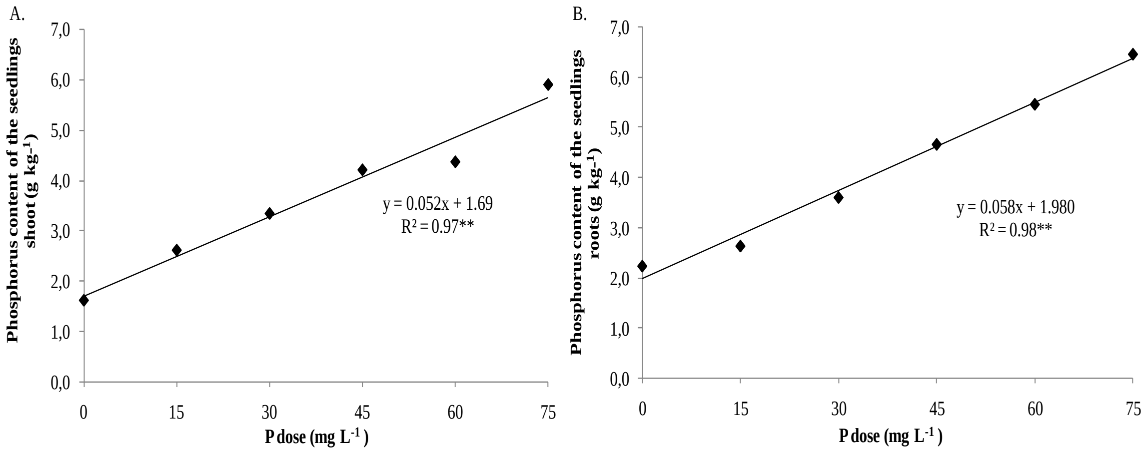

Fig 2. Phosphorus content of the tomato seedlings shoot (A) and roots (B) according to the P doses. São Manuel-SP, 2013.

(Minami, 2010), a good quality seedling does not need to be too long or the heaviest.

There are also reports stating that the differences in the plants initial phase usually affect the final production, but mainly in short cycle species (Tekrony and Egli, 1991). However, in longer cycle species, the initial differences do not always remain until the end of the cycle, as noted by Rodo and Marcos Filho (2003). On the other hand, if the environmental conditions and handling are not good, it will result in plants loss and production will also be reduced, because of poor seedlings or seeds, as reported by Rodo and Marcos Filho (2003) in onion and Godoy and Cardoso (2005) in cauliflower.

Materials and Methods

Location and soil classification

The experiment was conducted in São Manuel, São Paulo State (22°46'28"S 48°34'37"W and altitude of 740m). The climate type is *cwa* (Temperate Mesothermal), according to Köppen classification. The mean annual rainfall is 1377mm and the rainy season is between November and April. The mean annual temperature of the warmest month was at least 22°C (Cunha and Martins, 2009).

The soil is classified as Dystrophic Red Latosol (Oxisoil). Samples were collected at a depth of 0-20 cm for chemical analysis prior to experiment installation and the following results were obtained: $pH_{(CaCl2)}$= 6.5; P_{resin} = 95mg dm^{-3}; organic matter = 15g dm^{-3}, V% = 88; and H + Al; K; Ca; Mg; SB and CTC values, expressed in $mmol_c dm^{-3}$, respectively: 11; 3.9; 57; 22; 82 and 93.

Plant materials

The hybrid Paronset (Syngenta Brasil) was used. On August 21, 2013, sowing was held in polypropylene trays with 162 cells with Golden Mix® substrate, which contains coconut husks fibers, being placed one seed per cell.

Treatments and experimental design

Six treatments (0; 15; 30; 45; 60 and 75 mg L^{-1}P) were evaluated in a randomized complete block design with four replications. Monoammonium phosphate (MAP: 10.5% P and 9% N) was used as P and N source. It was considered the solution described by Hoagland and Arnon (1950), where P dose contains 31mg $L^{-1}$of water.

In addition to P, other nutrients were applied according to aforementioned solution: N (210 mg L^{-1}), Ca (160 mg L^{-1}), K (230 mg L^{-1}) Mg (48 mg L^{-1}) and S (75 mg L^{-1}) by using ammonium nitrate (32% N), calcium chloride (24% Ca), potassium chloride (58% K_2O) and magnesium sulphate (9 % Mg and 14% S). Moreover, it was used two sources for N: MAP and ammonium nitrate in order to complete the required dose (210 mg L^{-1}N).

In each tray, three experimental plots were installed, each one with 45 plants (five lines with nine cells each), but only 27 were considered useful, because within the five lines, the first and the last one were used as borders. Among the experimental plots, a line with nine cells was left empty to avoid interference during treatments.

Application of treatments

All treatments received fertigation at 7, 14, 21 and 28 days after seedling emergence (September 30, 2013) by using 250 mL of solution per plot in each application.

Conduction of experiment

On September 28, 2013, seedlings were transplanted at a spacing of 1.0 x 0.5m. Each experimental plot was composed of five transplanted plants, but only the three central plants were considered useful for data collection.

Plants were cultivated in protected environment, i.e. an arch-type greenhouse (2.5m height x 7 m width x 20 m length), covered with low density polyethylene (150 µm thick) and the sides were covered with anti aphid screen.

At planting, the fertilizers doses were based on the recommendation for São Paulo state by Trani et al. (1997): urea (3g $plant^{-1}$of N), triple superphosphate (1.5g $plant^{-1}$of P_2O_5) and potassium chloride (5g $plant^{-1}$of K_2O).

Top pruning was performed by the time that plants reached 2-meters height and two stems (main stem and one stem side below the first inflorescence). Pest control and drip irrigation were performed.

Topdressing fertilizations were carried out weekly, being the first application at 20 days after transplanting (DAT). Each application provided 1.04 g $plant^{-1}$ N as calcium nitrate; and 0.75 g $plant^{-1}$ K_2O as potassium chloride.

Measurements: Vegetative characteristics of seedlings and fruit production

A sample of ten seedlings per plot was evaluated at the transplanting day. Furthermore, the following traits were assessed: seedling height, stem diameter, leaf area, fresh and dry shoot weight, and root dry matter and P levels in shoots and roots. Seedling height was measured with a ruler from the substrate surface to the seedling upper portion; stem diameter was determined by using a digital calliper; leaf area meter (Li-3100C) was used to obtain leaf area; a digital scale was used at 0.01g accuracy to obtain fresh and dry matter; phosphorus levels were determined by the method presented by Malavolta et al. (1997), contents were expressed in g kg^{-1} of dry matter.

Fruits were harvested when fully red (from December 11, 2013 to January 22, 2014). Only the three central plants were evaluated in each plot. During harvest, fruits of each plot were counted and weighed to obtain the fruit average matter (ratio between total fruit matter and total number of fruits of each plot); plant production (number or kg of fruits $plant^{-1}$);and estimated yield (t ha^{-1}), calculated by the ratio between total fruit fresh matter and acreage. It was also determined fruit diameter and height by using a digital calliper.

Finally, early production was determined by the sum of the three initials harvestings (from December 11, 2013 to December 24, 2013).

Statistical analysis

Data were submitted to variance and regression analysis to determine the effect of phosphorus doses on the evaluated characteristics. All analysis was performed by System for Analysis of Variance Computer Program – SISVAR 5.3 (Ferreira, 2010).

Conclusion

A linear increase was obtained for leaf area, seedling height, shoot and root fresh matter by growing tomato seedlings on coconut fiber substrate at the highest P dose. Therefore, P fertilizer could be recommended for seedlings at 75mg P L^{-1}. However, yield and fruits characteristics were not affected by increasing P doses on seedlings.

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