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Influence of phosphorus fertilizer on melon (*Cucumis melo* L.) production

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Abstract

The Mossoró-Assu agricultural region is one of the most important melon-producing and -exporting regions in Brazil. The soils of this region, though, are characteristically poor in phosphorus (P), a most important nutrient for high productivity. Two melon (*Cucumis melo* L.) cultivars, Olimpic express and Iracema, were used to evaluate doses of P in a randomized complete block design with six treatments (0, 50, 100, 200, 300, and 400 kg ha^{-1} P_2O_5) and five replicates. The following characteristics were evaluated: foliar P content, total (TNF) and commercial (NFC) number of fruits per hectare, total (TP) and commercial (CP) productivities, P level in the soil (determined by two methods: anionic exchange resin (AER) and Mehlich-1), and the optimum economic dose (OED) of P. Foliar P, TNF, NFC, TP, CP, and both determinations of P levels in the soil were significantly affected by P doses for both cultivars. The maximum NFC (18239 fruits ha^{-1}) and the CP (28.98 t ha^{-1}) for Olimpic express were achieved with 319.5 and 310.1 kg ha^{-1} P_2O_5, respectively. The maximum NFC (20361 fruits ha^{-1}) and CP (35.5 t ha^{-1}) for Iracema were observed with 400 kg ha^{-1} P_2O_5. The OED for Olimpic express was 306.1 kg ha^{-1} P_2O_5. The OED was not calculated for Iracema, because the CP was adjusted to a linear equation. P levels in the soil, corresponding to the maximum CP, were 49.6 mg dm^{-3} (AER) and 44.5 mg dm^{-3} (Mehlich-1) for Olimpic express and 46.2 mg dm^{-3} (AER) and 51.4 mg dm^{-3} (Mehlich-1) for Iracema. Foliar P was 3.2 g kg^{-1} for Olimpic express and 3.2 g kg^{-1} for Iracema. Iracema, with a larger number of fruits and high commercial productivity, was the most efficient cultivar in unfertilized soil. Olimpic express responded better to phosphorous fertilization by increasing the number of fruits and its commercial production.

Keywords: *Cucumis melo,* cultivars, economic dose, fertilization.
Abbreviations: AER_anionic exchange resin; TNF_total number of fruits; NFC_number of commercial fruits; CP_commercial productivity; OED_optimum economic dose; DAT_days after transplanting; RP_relative production; NI_net income.

Introduction

Melons are one of the most important horticultural crops in Brazil and are widely exported to countries such as The Netherlands, United Kingdom, Spain, and Italy (SECEX, 2011). Most of the melons in Brazil are produced in a semiarid region in the northeast. The soil type prevailing in this region is a Red-Yellow Argisol known for its low levels of available phosphorus (P) (Crisóstomo et al., 2002). P is a crucial element for plant production due to its effects on reproductive processes (Cantón et al., 2003). P is responsible for increasing pollen production (Lau and Stephenson, 1994) and is directly associated with cytokinins, plant hormones that stimulate flowering and that are active in fruit fixation (Jones, 1965; Menary and Staden, 1976; Neilsen et al., 1990), thus allowing larger harvests. The lack of research on the use of P fertilizers in melon plants has led to the application of P fertilizers by melon farmers based only on their own personal experiences. The current rate of application of P fertilizer is far higher than what the plants need, and this unnecessary use increases production costs (Fita et al., 2011) and the likelihood of groundwater contamination (Fageria, 2009). Melon producers are also unaware that the response to P fertilizers is genotype dependent. Recently developed genotypes have increased the efficiency of absorption and use of this element (Sánchez, 2006). Faria et al. (1994) have estimated that the maximum melon fruit yield (29.1 t ha^{-1}) in the Vertisol soil of the São Francisco valley would be reached with a P_2O_5 dose of 116 kg ha^{-1}. Abrêu et al. (2011) estimated that a dose of 273.5 kg ha^{-1} P_2O_5 would produce 42.7 t ha^{-1} in the Red-Yellow Argisol soil near the main melon-producing region. No research, however, has been conducted for optimizing P fertilization in the main melon-producing region itself. The objective of this research was to evaluate the nutritional status and the productive performance of two melon cultivars (Olimpic express, a cantaloupe, and Iracema, of the inodorous group) submitted to P fertilization and to determine the levels of P in the soil and in the plant leaves associated with maximum commercial production.

Results and discussion

Foliar P content

The P_2O_5 doses significantly affected P content in the foliar tissues of both cultivars (Table 1). P levels were linearly correlated with P_2O_5 doses (Fig. 1). From the lowest to the highest P_2O_5 dose, P levels in foliar tissues increased from 2.5

Table 1. *F* values, significances, and coefficients of variation for foliar phosphorus content (PF), total number of fruits (TNF), commercial number of fruits (NFC), and total (TP) and commercial (CP) productivities of melon plants of the cultivars Olimpic express and Iracema.

Cause of variation	PF	TNF	NFC	TP	CP
Olimpic express					
P dose	12.73**	10.09**	6.10**	13.75**	9.46**
CV (%)	6.88	17.26	23.83	18.63	23.2
Iracema					
P dose	16.92**	2.41^{NS}	1.94^{NS}	7.91**	6.55**
CV (%)	7.66	11.68	14.23	12.25	14.34

**Significant at $p < 0.01$; * significant at $p < 0.05$; NS = not significant.

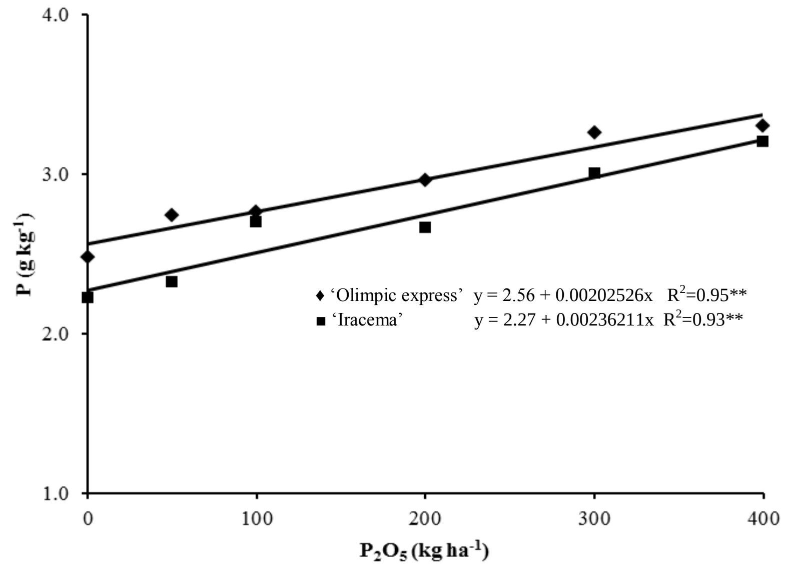

Fig 1. Effects of P_2O_5 doses on P levels in the foliar tissues of melon plants of the cultivars Olimpic express and Iracema. ** significant at $p < 0.01$.

to 3.3 g kg^{-1} in Olimpic express and from 2.3 to 3.2 g kg^{-1} in Iracema. Doses of P_2O_5 higher than 217 and 310 kg ha^{-1} applied to Olimpic express and Iracema, respectively, resulted in P levels in foliar tissues within the ranges established as adequate by Trani and Raij (1997), i.e. between 3 and 7 g kg^{-1}, and by Lambers et al. (2010), i.e. between 3 and 5 g kg^{-1}.

Total and commercial numbers of fruits

P_2O_5 doses significantly affected the total (TNF) and commercial numbers of fruits (NFC) in Olimpic express (Table 1). TNF and NFC in Olimpic express fit a quadratic model (Fig. 2). P_2O_5 doses of 262.2 and 319.5 kg ha^{-1} promoted the highest TNF (25405 fruits ha^{-1}) and the highest NFC (18 230 fruits ha^{-1}), respectively. The highest dose of P_2O_5 that produced the highest NFC caused a reduction of 681 fruits ha^{-1}. A P_2O_5 dose of 262.2 kg ha^{-1}, which produced the highest TNF, produced an NFC of 17 838 per hectare, which was 70.2% of the total. A dose of 319.5 kg ha^{-1} P_2O_5 was necessary to produce the highest proportion of commercial fruits (71.8%). P fertilization of the soil brought about increments in TNF and NFC of 96 and 105%, respectively, relative to the control treatment. Fertilization of the soil significantly affected TNF and NFC of the Iracema cultivar. These parameters were linearly associated with P_2O_5 doses (Fig. 2), with the highest dose (400 kg ha^{-1}) producing the highest values. The control treatment had a TNF of 23012 fruits ha^{-1}, whereas the highest P_2O_5 dose had a TNF of 27 616 fruits ha^{-1}, an increment of 20%. The lowest NFC was 17 345 fruits ha^{-1}, and the highest NFC was 20361 fruits ha^{-1}, an increase of 17%. NFC represented 73.7% of TNF at the highest P_2O_5 dose, when the number of fruits was the maximum. Faria et al. (1994) reported similar results for the inodorous cultivar Eldorado in the São Francisco valley. Increasing the P_2O_5 dose from 0 to 160 kg ha^{-1} increased the number of fruits from 12 829 to 20 273 ha^{-1}. Abrêu et al. (2011) also reported increases (from 0 to 480 kg ha^{-1}) in NFC in the cultivar Goldex F_1 with increasing doses of P_2O_5, although the increase in NFC from the lowest to the highest dose was only 9% (from 30400 to 33400 fruits ha^{-1}), because the soil had a P level very close to the levels considered to be adequate. Having an adequate level of P in the soil permitted savings of 13 and 30% of the P necessary to maximize NFC relative to those necessary to maximize the NFC of Olimpic express and Iracema, respectively. Silva et al. (2007) reported no significant increase either in TNF or NFC for the Gold Mine cultivar up to a P_2O_5 dose of 150 kg ha^{-1} in soils with high levels of P ($P_{(Mehlich-1)}$ = 23.0 mg dm^{-3}).

Total and commercial productivities

Total (TP) and commercial (CP) productivities of both cultivars were significantly influenced by P_2O_5 doses (Table1). Mean TP and CP of Olimpic express were significantly fitted to quadratic models (Fig. 3). The doses maximizing TP (36.7 t ha^{-1}) and CP (28.9 t ha^{-1}) were 275 and 310 kg ha^{-1} P_2O_5, respectively. The dose maximizing TP resulted in a CP of 28.7 t ha^{-1}, similar to the CP produced with a dose of 310 kg ha^{-1} P_2O_5, representing 78.4% of the

Table 2. *F* values, significances, and coefficients of variation of P levels in the soil determined by the anionic exchange resin (AER) and Mehlich-1 analytic methods in melon plants of the cultivars Olimpic express and Iracema.

Causes of variation	AER	Mehlich-1
	Olimpic express	
P dose	27.65**	34.40**
CV (%)	35.37	34.56
	Iracema	
P dose	17.45**	21.84**
CV (%)	34.47	32.12

**Significant at $p < 0.01$; * significant at $p < 0.05$.

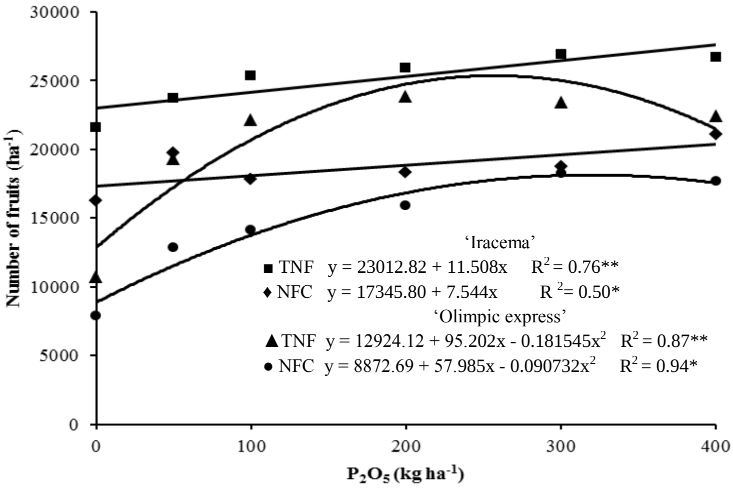

Fig 2. Effects of P_2O_5 doses on total (TNF) and commercial (NFC) numbers of fruit in melon plants of the cultivars Olimpic express and Iracema. ** significant at $p < 0.01$; * significant at $p < 0.05$.

respective TP. The maximum TP and CP represented increases of 21.4 and 17.2 t ha^{-1}, i.e. increases of 140 and 146%, respectively, relative to the control treatment. These results support the premise by Srinivas and Prabhakar (1984) and Prabhakar et al. (1985) that P fertilization of the soil can produce significant increases in fruit production in soils with low levels of P. TP and CP for Iracema fitted a linear model, as was also observed for fruit number. These values were maximized by the highest P_2O_5 dose (Fig. 3). TP for the control treatment and the highest dose of P_2O_5 were 31.2 and 44.4 kg ha^{-1}, respectively, representing a 42.3% increase. CP increased by 42%, from 25 to 35.5 t ha^{-1} at a dose of 400 kg ha^{-1}. Faria et al. (1994) reported that Eldorado melon plants also showed a positive response to soil fertilization with P, with a dose of 115 kg ha^{-1} producing the highest fruit yield. Even in a soil with an adequate level of P, Abrêu et al. (2011) verified melon plants of the cultivar 'Goldex F_1', of the inodorous group, to show significant increments in CP with increasing doses of P_2O_5. Silva et al. (2007) verified no significant effect of P on melon production due to a high level of P in the soil. The highest PC for Iracema was 79.8% of the TP, similar to that for Olimpic express, although Iracema required a higher dose of P fertilizer.

P level in the soil

The levels of soil P in the plots of both cultivars increased with increasing doses of P_2O_5, as determined by both the anionic exchange resin (AER) and Mehlich-1 methods (Table 2). The mean P levels in the soil obtained by the AER method had a linear relationship with the P doses for both cultivars (Fig. 4). P levels in the soil increased from 2.3 to 63.3 mg dm^{-3} and from 6.6 to 46.2 mg dm^{-3} with increasing doses of P_2O_5 for Olimpic express and Iracema, respectively. P levels in the soil had a linear relationship only for Iracema when the Mehlich-1 method was used. Olimpic express, in contrast, fit a quadratic model with P_2O_5 dose (Fig. 5). P levels in the soil, with P fertilization, varied from 5.2 to 66.0 mg dm^{-3} for Olimpic express and from 6.8 to 51.4 mg dm^{-3} for Iracema.

Correlation analyses

The methods to evaluate P levels in the soil were highly correlated in both experiments. CP and P levels in the plant leaves were also highly correlated with P levels in the soil as determined by either method (Table 3). In the Red-Yellow Argisol soil, any of the methods to measure P levels may be used. The high correlation between the two methods can be attributed to the low level of clay. The absorption of P by soil is essentially an attribute of the fraction with the smallest particles, i.e. the clay fraction. If the soil has a low content of clay, it is necessarily a poor absorber of P (Amorim et al., 2008).

Optimum economic dose

The optimum economic dose (OED) of P_2O_5 for Iracema could not be calculated, because CP was linearly associated with P_2O_5 dose. The OED for Olimpic express was 306 kg ha^{-1}, which was only 4 kg ha^{-1} lower than the dose that maximized CP. The CP of the OED (28.97 t ha^{-1}) was similar to the CP (28.98 t ha^{-1}) from a dose of 310 kg ha^{-1} P_2O_5. Similarly, the levels of P in the soil and in the plant leaves at the OED were similar to those for the dose that maximized CP. The similarities of these P levels indicate that the market prices for the melons may compensate for the investment in P fertilization.

Table 3. Correlation coefficients (r) between methods to quantify available P, determined by the anionic exchange resin (AER) and Mehlich-1 methods, and between those values and foliar P content (PF) and commercial productivity (CP) of melon plants of the cultivars Olimpic express and Iracema.

Correlation	r
Olimpic express	
AER x Mehlich-1	0.96**
AER x PF	0.96**
Mehlich-1 x PF	0.92**
AER x CP	0.85*
Mehlich-1 x CP	0.78*
Iracema	
AER x Mehlich-1	0.98**
AER x PF	0.97**
Mehlich-1 x PF	0.94**
AER x CP	0.83*
Mehlich-1 x CP	0.76*

**Significant at $p < 0.01$; * significant at $p < 0.05$.

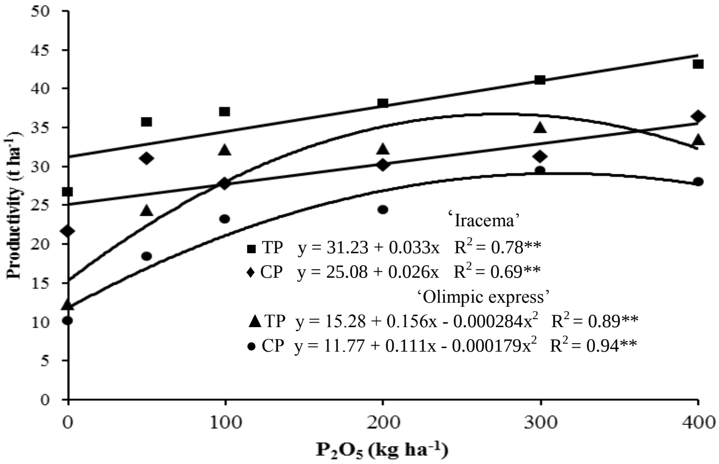

Fig 3. Effects of P_2O_5 doses on total (TP) and commercial (CP) productivities in melon plants of the cultivars Olimpic express and Iracema. ** significant at $p < 0.01$.

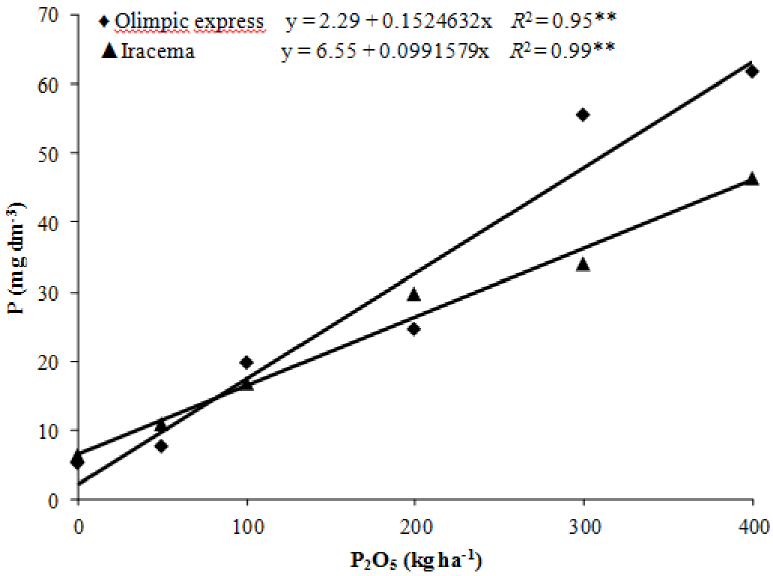

Fig 4. Effects of P_2O_5 doses on P levels in the soil determined by the anionic exchange resin method in plots of melon plants of the cultivars Olimpic express and Iracema. ** significant at $p < 0.01$.

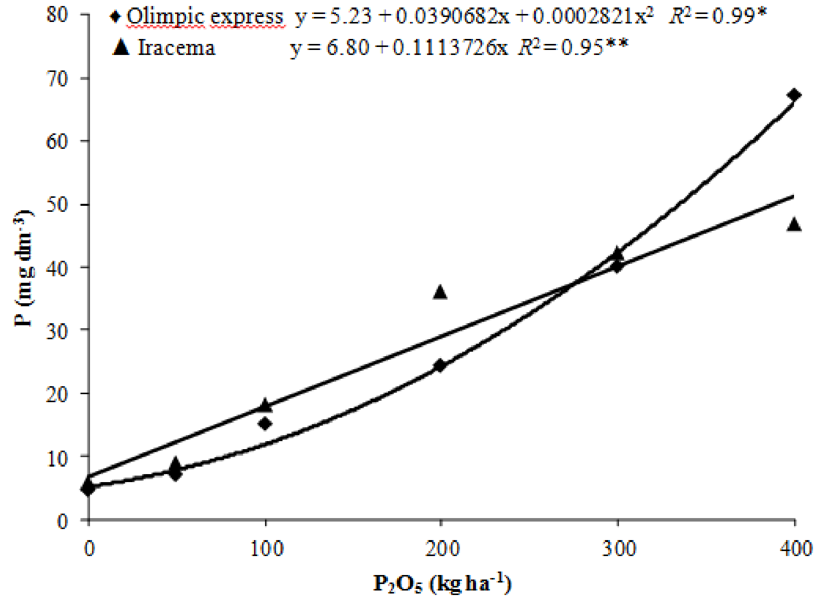

Fig 5. Effects of P_2O_5 doses on P levels in the soil determined by the Mehlich-1 method in plots of melon plants of the cultivars Olimpic express and Iracema. ** significant at $p < 0.01$; * significant at $p < 0.05$.

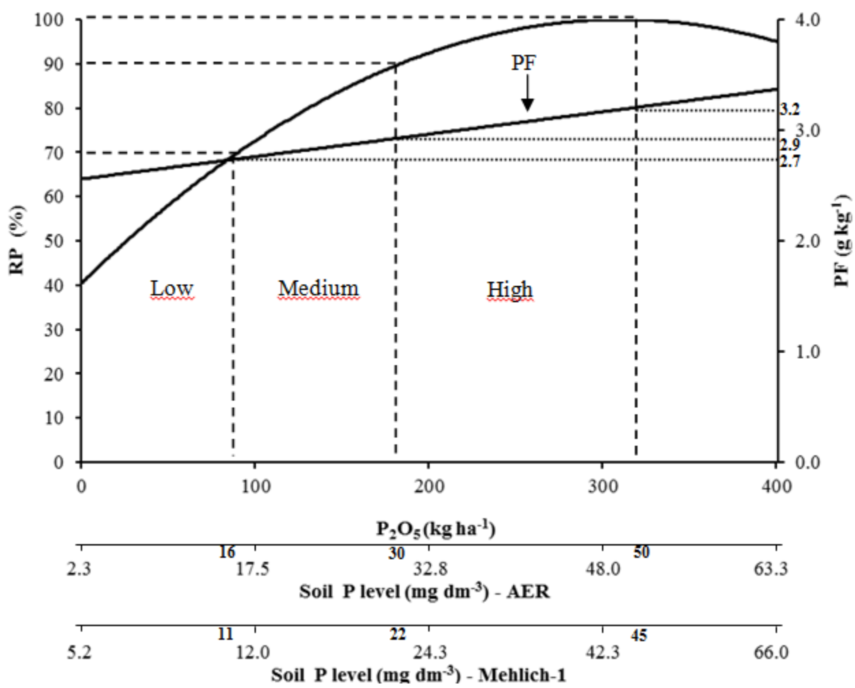

Fig 6. Effects of P_2O_5 doses on relative production (RP), foliar P level (PF), and soil P levels determined by the anionic exchange resin (AER) and Mehlich-1 methods in the cultivar Olimpic express.

Relationships between relative production and P levels in the soil and leaves

Olimpic express and relative production (RP) fitted a quadratic equation ($Y = 40.61 + 0.383x - 0.000617x^2$; $R^2 = 0.94$**). Three levels of RP were established: low (RP < 70%), medium (70 ≤ RP < 90%), and high (90 ≤ RP ≤ 100%), with levels of P in the leaves and the soil corresponding to each (Fig. 6). An RP of 90-100% was achieved when soil P was between 30 and 50 mg dm^{-3} when determined by the AER method but was between 22 and 45 mg dm^{-3} when determined by the Mehlich-1 method. Levels of P in the soil between 26 and 60 mg dm^{-3}, as determined by the AER method, are considered average for vegetables (Raij et al., 1997). Levels of P in the soil between 30.1 and 45.0 mg dm^{-3}, as determined by the Mehlich-1method, are considered high (Alvarez V. et al., 1999). In our study, levels of P in melon leaves between 2.9 and 3.2 g kg^{-1} produced RPs between 90 and 100%, so a level of 3 g kg^{-1} may be considered adequate. The P levels verified for RPs between 90 and 100% are close to the lower limit considered as adequate, i.e. between 3 and 7 g kg^{-1} for melons (Trani and Raij, 1997) and between 3 and 5 g kg^{-1} for herbaceous plants (Lambers et al., 2010). For RPs between 70 and 90%, the levels of P in the soil were between 16 and 30 mg dm^{-3} and between 11 and 22 mg dm^{-3} as determined by the Mehlich-1 method. Levels of P in the soil between 11 and 25 mg dm^{-3}, as determined by the AER method, are considered low for vegetable production (Raij et al., 1997), which may account for the high losses in productivity of melon plants (Fig. 6). Most of the values determined by the Mehlich-1 method for RPs between 70 and 90% are considered as medium values (12.1-30.0 mg dm^{-3}), and some are considered low, i.e. lower than 12.0 mg dm^{-3} (Alvarez V. et al., 1999). Within this range of RP, each kg of P_2O_5 added increased RP by 0.22 percentage points. For RPs between 90 and 100%, the increase was only 0.08 percentage points. The best chance of producing a response from P fertilization is thus when P levels in the soil are lower than 30 and 22 mg dm^{-3}, as determined by the AER and Mehlich-1 methods, respectively. The foliar P contents for RPs between 70 and 90% are below the levels considered adequate by Trani and Raij (1997) and Lamberts et al. (2010), because the foliar levels required to achieve an RP higher than 90% were already close to the lower limit. For RPs lower than 70%, the levels of P in the soil were below 16.01 mg dm^{-3} (AER) and 11.04 mg dm^{-3} (Mehlich-1), and the levels of P in the foliar tissues were below 2.74 g kg^{-1}. P levels in our soils were classifiable as low by both Raij et al. (1997) (below 11 to 25 mg dm^{-3}) and Alvarez et al. (1999) (below 10.1 and 12.0 mg dm^{-3}). Soil P was thus insufficient to supply the Olimpic express plants with all the P they needed, leading to a loss of productivity of more than 30%. P levels in the leaves were lower than the values considered as sufficient by Trani and Raij (1997) and Lambers et al. (2010).

Materials and methods

Plant materials

The melon cultivars were Olimpic express of the cantaloupe group (*Cucumis melo* var. *reticulatus*) and Iracema of the inodorous (yellow) group (*C. melo* var. *inodorus*).

Experimental site

The experiments were performed at Universidade Federal Rural do Semi-Árido (UFERSA) in Mossoró city, Brazil, located at 5°3´37″S and 37°23´50″W at an altitude of 72 m.

Soil and climatic characteristics

The soil was classified as a Red-Yellow Argisol (EMBRAPA, 2006) with 820, 40, and 140 g kg^{-1} of sand, silt, and clay, respectively. A chemical analysis of the soil between 0 and 20 cm performed before the experiment obtained the following results: pH, 6.2; organic matter, 1.9 g dm^{-3}; $P_{(Mehlich-1)}$, 6.7 mg dm^{-3}; K, 80.7 mg dm^{-3}; Na, 16.7 mg dm^{-3}; Ca, Mg, Al, H + Al, sum of bases, and cation exchange capacity, 21, 8.0, 0.0, 5.0, 31.8, and 38.6 $mmol_c$ dm^{-3}, respectively; soil base saturation, 87%; and exchangeable Na, 2%. No rain fell during the experimental period, and the mean maximum, minimum, and median temperatures were 32.8, 20.8, and 26.3 °C, respectively. The mean maximum, minimum, and median relative air humidities were 81.5, 35.5, and 62.8%, respectively.

Experimental design

Each of the two cultivars constituted an experiment. Both experiments were arranged in the field in a randomized complete block design with six treatments (0, 50, 100, 200, 300, and 400 kg ha^{-1} P_2O_5) and five replicates. The P fertilizer (triple superphosphate) was applied before planting and incorporated. The experimental plots were 8 × 6 m. Each plot contained four rows 2 m apart, each with 20 plants 30 cm apart. The central fourteen plants of each of the two central rows were used to evaluate the effects of the treatments.

Planting, management practices, and harvesting

Seeds of each cultivar were sown in 200-cell polypropylene trays on September 9 2010, and the resulting seedlings were transplanted to the field 10 days later. The rows were covered with a polypropylene film to control weeds and to maintain soil moisture. Five days after transplanting (DAT), white 15 g m^{-2} polypropylene microtunnels were inserted over the rows to control the attack of insect pests, mainly *Liriomiza* spp. These microtunnels were removed 27 DAT when the plants started to flower. By means of fertigation (a drip irrigation system), 118, 146, 19, 13, and 38 kg ha^{-1} of N, K, Ca, Mg, and S, respectively, were applied to the soil in each of the experiments. Between 2 and 30 DAT and between 31 and 63 DAT, 30% and 70%, respectively, of the N and K were applied to the soil. Ca was applied in two equal doses, 12 and 40 DAT, and the Mg and S doses were applied from 18 to 41 DAT. The fertilizers used were urea (45% N), potassium chloride (60% K_2O), potassium nitrate (13% N and 46% K_2O), calcium nitrate (15.5 % N and 27% CaO), and magnesium sulfate (32.5% SO_4^{2-} and 16% MgO). Doses of 730, 4, 28, 26, 0.3, and 37 g ha^{-1} of B, Cu, Fe, Mn, Mo, and Zn were also applied as boric acid (17% B) and a commercial chelate fertilizer whose composition was 2.1% B, 0.36% Cu, 2.66% Fe, 2.48% Mn, 0.036% Mo, 3.38% Zn, 11.6% K_2O, 0.86% Mg, and 1.28% S . B was applied twice, 28 and 33 DAT; the other micronutrients were applied 19 DAT.

Weeds were controlled by hoeing whenever necessary. Insect pests and diseases were controlled by registered products. The Iracema melons were harvested on December 9 2010, and the Olimpic express melons were harvested on 5 and 10 December 2010.

Characteristics evaluated

a) P foliar content: at the onset of fruit development (diameter of 5 cm) the 5th leaf from the tip of the plant branch (Trani and Raij, 1997) was collected. A total of 20 leaves per plot were collected. These leaves were washed in running water, deionized water with a neutral detergent (1 ml L^{-1}), and then deionized water. The leaves were placed inside paper bags and dried in an oven with forced air circulation at 65 °C to a constant weight. After drying, the leaves were ground for determining their P contents, using analytical procedures described in Bataglia et al. (1983).

b) Number of fruits per hectare: the number of fruits per plot were counted. Commercial fruits were all those that were not misshapen, overripe, fissured, or rotten.

c) TP and CP (t ha^{-1}) of the fruits were determined separately.

d) P levels in the soil (mg dm^{-3}): after harvest, all plants were pulled from the soil, and four soil samples were collected from points equidistant from the two central rows in each plot, for a total of eight samples. The samples from each plot were pooled to produce a composite sample representing each experimental unit. P levels were measured in these samples by the extractors Mehlich-1 (EMBRAPA, 1997) and anionic exchange resin (Raij et al., 2001).

e) The OED was calculated with the help of the equation:

$$NI = (P_R*Q_P) – (P_P*X)$$

where NI = net income (R$ ha^{-1}), P_R = price of the product (R$ t^{-1}), Q_P = quantity produced (t ha^{-1}), P_P = P price (R$ kg^{-1}), and X = amount of P applied (kg ha^{-1}). Q_P was replaced by the second degree polynomial equation to estimate yield as a function of doses of P:

$NI = [P_R * (a + b*X + c*X^2)] – (P_P*X)$

where a, b, and c are constants of the polynomial equation that estimated production:

$NI = (P_R*a) + (P_R*bX) + (P_R*cX^2) – (P_P*X)$

Factoring:

$NI = P_R*a + (P_R*b – P_P)X + P_R*cX^2$ when $dNI/dX = 0$:

$OED = (P_R*b – P_P) / 2 P_R*c$

With the known values of P_R (R$1,370.00 t^{-1}) and P_P (R$ 1.93 kg^{-1}) (AGRIANUAL, 2011; CEAGESP, 2012), the OED for P was estimated for calculating the economic commercial production of fruits of both cultivars.

Data analysis

With the exception of OED, all data of the evaluated characteristics were submitted to analysis of variance using the *F*-test and to polynomial regression analysis. OED data were evaluated when the mean commercial production adjusted itself significantly to the second degree polynomial equation. Levels of P in the soil and the leaves were correlated with the commercial production of fruits by simple correlation analyses. P levels in the soil and the leaves were also correlated with RP and P doses. RP was calculated by the equation RP = (estimated commercial productivity in the P dose / maximum commercial productivity) * 100.

Conclusions

Iracema was the most efficient cultivar, with a larger number of fruits and higher CP, when the soil was not fertilized with P. Olimpic express responded best to P fertilization of the soil, with higher numbers of fruits and CP at higher P doses. Both analytical procedures for the quantification of P in the soil were highly correlated with P levels in the leaves and with CP for both cultivars. The two methods were also highly correlated with each other. Melon plants of the Olimpic express cultivar were more likely to be influenced by P fertilization when the P level in the soil was lower than 30 and 22 mg dm^{-3} as determined by the AER and the Mehlich-1 methods, respectively. Foliar P levels in Olimpic express between 2.9 and 3.2 g kg^{-1} were considered to be adequate.

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