Growth, yield and fruit quality of 'Maçã' banana under different rates of phosphorus fertilization

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Abstract

The aim of this study was to evaluate the agronomic performance and fruit quality of 'Maçã' banana cultivar. A field experiment was conducted to study the effect of phosphorus (P) on the cultivar. The study area presents a subtropical climate, where the mean temperature is 22°C; and the mean rainfall is 1377 mm. The experiment was conducted from November 2012 to May 2014. The experiment design was totally randomized, consisting of six treatments (0, 40, 60, 80, 100 and 120 kg P_2O_5 ha^{-1}) and seven repetitions. The results indicated that plant height, pseudo-stem diameter, number of live leaves, yield and fruit numbers per bunch increased at 51, 45, 44, 34 and 40 kg P_2O_5 ha^{-1}, respectively. The shortest harvest cycle was of 480 days at 60 kg P_2O_5 ha^{-1}. In unripe bananas, RSC improved 13% at 47 kg P_2O_5 ha^{-1}; while the highest level of P, Ca and Mg were obtained at 74, 41 and 58 kg P_2O_5 ha^{-1}, respectively. During banana ripening, maximum fruit firmness (3.07 N) was achieved at 63 kg P_2O_5 ha^{-1}. Application of triple superphosphate fertilizer (at 34 kg P_2O_5 ha^{-1}) increased yield, without changing physicochemical characteristics.

Keywords: Agronomic performance; physicochemical characteristics; mineral nutrition; *Musa*; triple superphosphate.
Abbreviations: Ca_Calcium; DM_Dry mass; MC_Moisture content; Mg_Magnesium; P_Phosphorus; RSC_Reducing sugar content; ST_Starch; SSC_Soluble solids content; TA_Titratable acidity; TSC_Total sugar content

Introduction

Bananas are among the world´s most popular fruits and it is consolidated in the international market (Jaiswal et al., 2014). India is the world´s largest producer. In 2013, India produced about 27.6 million tons of bananas. Brazil is the fourth largest producer (up from 6.89 million tons in 2013) (FAO, 2016). In Brazil, bananas had a great expansion due to the progress in strengthening all the supply chain, including fertilizer nutrients that are essential in meeting crop yield and fruit quality.

Phosphorus (P) is an essential plant macronutrient, as it is a structural constituent of essential biomolecules involved in energy metabolism, such as ATP (Navaneethakrishnan and Kumar, 2013; Stigter and Plaxton, 2015). P converts solar energy into amino acids and fibre, besides that P promotes root growth and plant development. Thus, P is fundamental to nearly all major metabolic processes in plants, including photosynthesis and respiration.

According to Silva and Rodrigues (2013), who evaluated the first cycle of 'Dwarf-prata' banana, observed an increase in height, pseudo-stem diameter, bunch mass and number of fruits per bunch at different rates of P_2O_5. Al-Harthi and al-Yahyai (2009) evaluated growth and yield of 'Wiliams' banana under NPK fertilizer. They found that P (100 g plant^{-1} year^{-1}) increased bunch mass, hand mass and number of fruits per hands. These studies have suggested a need to adjust the phosphorus-based fertilizer recommendations for bananas. In São Paulo state, they recommend an application of 20-260 kg P_2O_5 ha^{-1}, according to previous soil analysis and farmers' yield expectation (Teixeira et al., 1997).

In a study conducted in the North of Minas Gerais state (Brazil), Silva et al. (2007) found that the soils, where presented high productivity of banana, showed higher available P (39.2 mg dm^{-3}) compared to soils with low productivity of banana (23 mg dm^{-3}). Moreover, Silva et al. (2011) found that depending on the type of the soil, where banana grows, P can be used more efficiently by plants, resulting in higher dry matter production, i.e. inferring a need of providing P, when working with banana.

Regarding to the phosphate fertilizer on the root distribution system, by, it is important to consider that phosphate presents ions with low mobility; therefore, the more developed and extensive the roots are, the better P uptake. On the other hand, there are no studies on the effect of phosphorus on the banana starch synthesis. However, Zhao et al. (2015) studied the effect of N and P deficiency in transcription regulation of genes encoding key enzymes of the starch metabolism in duckweed (*Landoltia punctata*), they found that P deficiency caused a significant accumulation of starch. Thus, starch content increased from 8.86% (without treatment) to 23.0% (during P privation).

There is a huge interest on cultivating 'Maçã' banana, as its fruit composition, productive characteristics and economic importance are extremely susceptible. This cultivar can be hampered by wilt, i.e. "Panama disease" (*Fusarium*

oxysporum f. sp./Foc), which limited the crop to only one productive cycle. Therefore, researching on fertilizer is viable and necessary; unlike other cultivars that generally require at least three productive crop cycles. Nutrients demand depends among cultivars and even within the same genomic group (Donato et al., 2010), while nutrient recommendations are mostly based on scientific data for 'Cavendish' varieties, as it is highly demanding variety. Banana absorbs less P than other macronutrients (Hoffmann et al., 2010). Consequently, there is little or no information in the literature on the effects of P fertilizers on banana crop, besides that Brazilian soil is generally very poor in available P. Therefore, it seems important to evaluate the agronomic performance and fruit quality of 'Maçã' banana under P fertilization.

Results and Discussion

Plants development

Regarding to the growth characteristics, there was a significant effect of triple superphosphate. It was also predicted a quadratic function on all adjustments. In biological terms, it means that soon after the inflection point, every increased unit of the applied fertilizer tends to decrease plant growth. Based on the equations, maximum plant height, pseudo-stem diameter and number of live leaves were of 51, 45 and 44 kg P_2O_5 ha^{-1}, respectively (Fig 1A, B and C). The results corroborate the findings of Reis and Chepote (2008), who evaluated the effect of P on 'Pacova' banana (AAB) in dystrophic red-yellow latosol (oxisoil), they also reported a quadratic function on plant height and pseudo-stem circumference. However, banana does not require large amounts of P (Silva and Rodrigues, 2013), phosphorus fertilization has proved to be necessary for growing 'Maçã' banana, which increases pseudo-stem diameter (4.6%), but available P content tends to be extremely low in most latosols, because assimilable forms is restricted to a few plant (Silva et al., 2011). P can notably increase vegetative growth; being indispensable for cell division, as it is a constituent element of nucleoproteins (Malavolta, 1997). However, large amounts of P_2O_5 produce phytotoxic effects, such as inhibition of plant growth and reduction of photosynthetic activity (Marschner, 2005). This negative effect was observed on all evaluated characteristics, such as growth and production, from the inflection point (Fig 1, 2 and 3), when increased P level. Based on crop cycle characteristics, equations were generated. It was found that the maximum function point was of 61 kg P_2O_5 ha^{-1}, when plants showed smaller interval in days from planting to flowering (367 days) (Fig 1D), whereas the lowest number of days (114 days) was of 53 kg P_2O_5 ha^{-1} from flowering to harvesting (Fig 1E). Regarding to the total cycle, the greatest plants precocity (480 days) has been observed at 60 kg P_2O_5 ha^{-1} (Fig 1F). Therefore, plants precocity subjected to P_2O_5 doses, as it was mentioned above, are in line with the results reported by Silva et al. (2012), who stated that an adequate P supply ensures proper formation of reproductive organs and fruit growth. However, it is worth mentioning that high levels of P (i.e. above estimated dose) affect the length of the cycle and the availability of nutrients in the soil, i.e. any nutritional deficiency will hinder plant development.

Plants agronomic performance

The effect of increasing P_2O_5 doses on yield was accompanied by a form of quadratic function. The maximum function for bunch mass (Fig 2A) and yield (Fig 2F) was of

34 kg P_2O_5 ha^{-1}. Regarding to the greatest fruit mass (Fig 2C) and the largest number of hands per bunch (Fig 2E) were of 33 and 35 kg P_2O_5 ha^{-1}, respectively. Therefore, it is clear that the maximum productive efficiency can be achieved at those levels of P_2O_5. On the other hand, rachis mass (Fig 2B) achieved its maximum function at 41 kg P_2O_5 ha^{-1}, while the largest number of fruit per bunch (Fig 2D) was of 41 kg P_2O_5 ha^{-1}.

These findings corroborates with the one found by Liu et al. (2015), evaluating banana crop under fertilizations in China. The effect of increasing P doses was reported by a significant quadratic function on yield, but much higher levels. This fact was confirmed by Reis and Chepote (2008), reported quadratic effect of increasing P doses on 'Pacova' banana traits, such as bunch mass, hands mass and number of hands per bunch. Whether there is a proper use of fertilizers at a lower rate, it reduces the production final cost. However, it needs to be emphasized that the results reported above (i.e., higher doses) can be related to residual P in the soil and each cultivar demands. 'Maçã' banana has a low demand for P. In the soil, its initial P content (16 mg dm^{-3}) was probably sufficient to the plant's needs; and root system development, because the mobility of phosphate ions is limited and apart from absorption, it is also related to the root length (Attia et al. 2009).

Regarding to the traits of the second hands of the bunch, which was verified by equations, the highest values were obtained for bunch mass, fruit number, length and diameter of the central five fruits at 41, 42, 42 and 40 kg P_2O_5 ha^{-1}, respectively (Fig 3A, B, C and D). Results noted that supplying P to the maximum function point (i.e. at 34 kg P_2O_5 ha^{-1}) increased the yield (11.92 t ha^{-1}) (Fig 2F). It is noteworthy that the estimated dose in this study is higher than the recommended for the crop, corresponding to 20 kg P_2O_5 ha^{-1} (Teixeira et al., 1997). This result emphasizes the importance of this kind of study, since the use of appropriate doses for each cultivar result in higher production and financial return. However, the lower performance in the maximum function can be explained by the high concentration of salt in the soil due to the high concentrations of phosphate fertilizer, which may be toxic to the plants and according to Oliveira et al. (2006) it reduces root growth, i.e. affecting nutrients absorption.

Physicochemical aspects of banana fruits

There was no significant difference of P on moisture content (MC); dry mass (DM); total sugar content (TSC); starch (ST); and micronutrients in unripe fruits. There was also no significant difference in fruit peel colour parameters; pH; SSC (soluble solids content); TA (titratable acidity); ratio; and RSC (reducing sugar content) in ripened fruits (Table 1). Absorbing small amounts of elements appears to have little influence compared to nutrients demand for all major parts of banana. Thus, micronutrients content have not responded to the P fertilization. RSC increases during ripening as a result of starch hydrolysis. However, low starch deposition resulted in similar levels of RSC among the treatments, in terms of P_2O_5 doses. Fruit peel colour; pH; SSC; TA; malic acid; and ratio found to be similar to those described in the literature for the same cultivar (Pinheiro et al., 2007).

There was a significant effect of P on RSC in unripe fruits. The highest value was of 47 kg P_2O_5 ha^{-1} (Fig 4). Higher doses of P reduce sugars deposition in fruit, causing toxicity, impairing roots function and reducing essential nutrients uptake; according to Marschner (2005), high P concentrations tend to reduce photosynthetic process.

Table 1. Mean values of moisture content, dry mass, total sugar content, starch and micronutrients in unripe fruits; and mean brightness values (L), *a e *b coordinates, pH, soluble solids content, titratable acidity, ratio (SS/TA) and reducing sugar in ripened fruits of 'Maçã' banana, fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015.

Dose of P_2O_5 (kg ha^{-1})	Unripe fruits								
	MC	DS	TSC	ST	B	Cu	Fe	Mn	Zn
	---------------- g 100g^{-1} ----------------				---------------- mg kg^{-1} ----------------				
0	61.93	38.07	0.65	21.89	6.98	4.00	17.30	13.33	5.60
40	61.78	38.22	0.72	22.02	7.07	4.50	18.10	15.33	5.80
60	61.82	38.18	0.78	21.91	7.29	4.50	18.00	14.67	6.00
80	62.11	37.89	0.69	21.53	7.16	4.25	16.20	13.92	5.40
100	62.24	37.76	0.63	21.44	7.07	4.00	16.35	14.50	5.40
120	62.59	37.41	0.66	20.77	6.44	3.75	16.00	14.00	5.25
Effect	NS[1]	NS	NS	NS	NS	NS	NS	NS	NS
CV[2] (%)	5.04	8.25	13.68	10.03	9.94	17.44	12.98	14.71	9.79

Dose of P_2O_5 (kg ha^{-1})	Ripened fruits							
	Fruit peel colour			pH	SSC (°Brix)	TA (g 100g^{-1})	Ratio (SS/TA)	RSC (%)
	L	a*	b*					
0	69.97	4.10	46.18	4.37	23.60	0.51	46.68	16.88
40	70.67	4.74	47.85	4.38	23.88	0.50	47.70	17.09
60	70.92	4.14	47.73	4.40	24.00	0.48	50.02	17.13
80	70.41	3.91	47.58	4.35	23.56	0.52	45.66	16.79
100	68.79	3.94	47.28	4.38	23.48	0.53	44.24	16.70
120	68.68	4.12	47.35	4.33	23.42	0.53	43.93	16.65
Effect	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	3.05	14.38	8.92	0.98	3.54	7.03	9.46	7.34

[1]No significant by Tukey test at 5% probability. [2]Coefficient of variation.
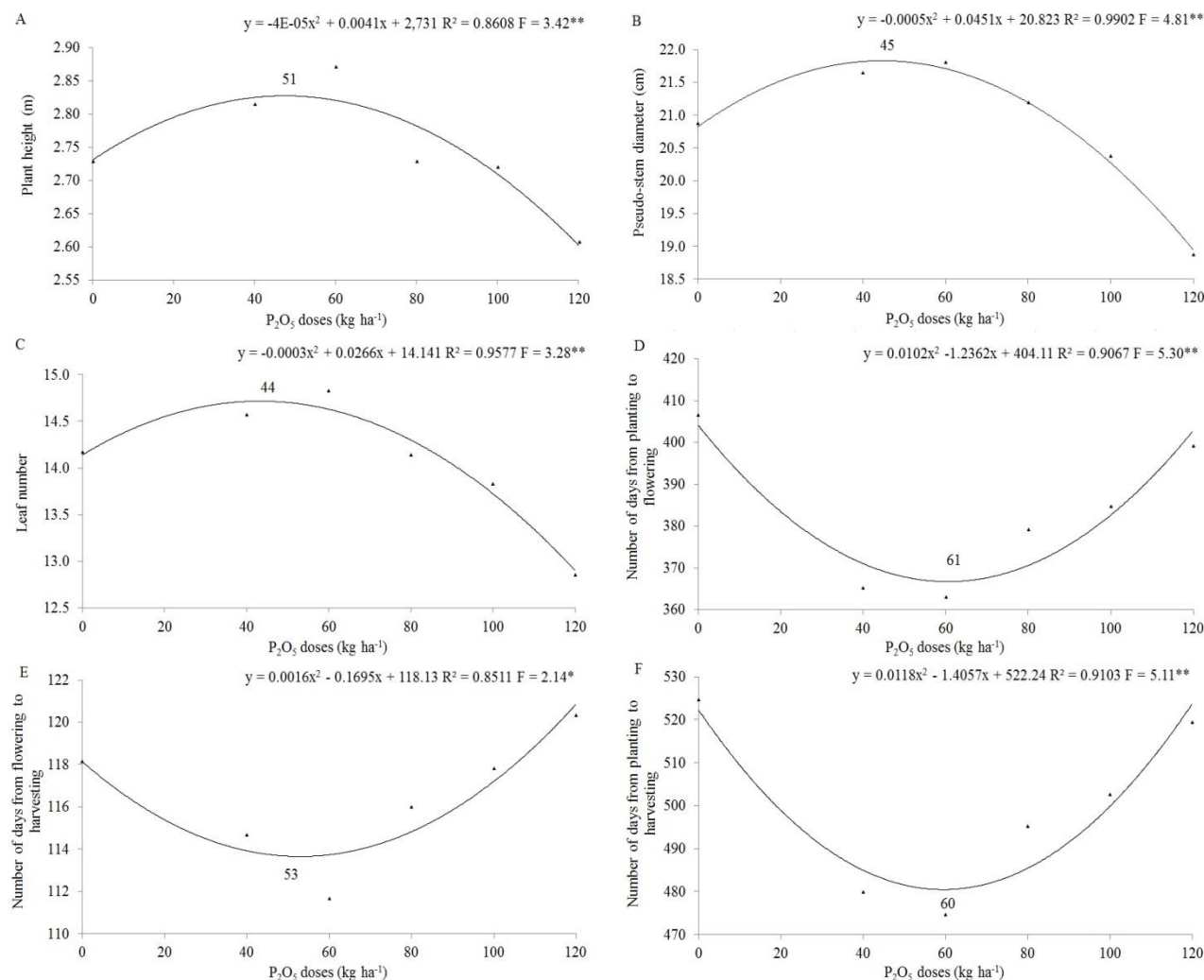
Fig 1. Plant height (m) (A), pseudo-stem diameter (cm) (B), leaf number (C), number of days from: planting to flowering (D), flowering to harvesting (E) planting to harvesting (crop cycle) (F) of 'Maçã' banana, fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015. **Significant at 1% probability and * Significant at 5% probability.
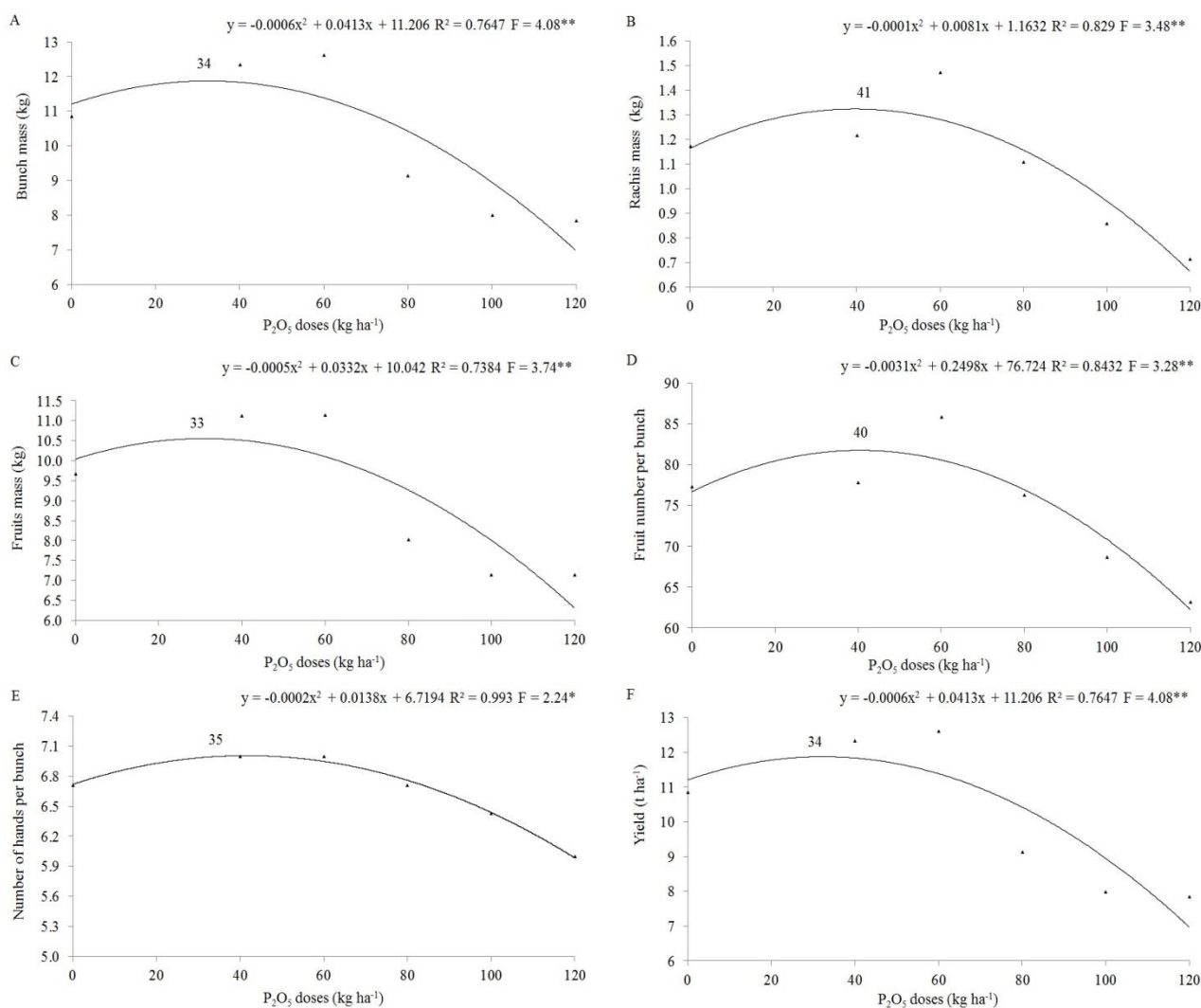
Fig 2. Bunch mass (A), Rachis mass (B), Fruits mass (C), Fruit number per bunch (D), Number of hands per bunch (E) and yield (F) of 'Maçã' banana, fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015. **Significant at 1% probability and *Significant at 5% probability.

Firmness was significantly affected by P fertilization in ripe fruits. The maximum value was of 63 kg P_2O_5 ha^{-1} (Fig 5). This has suggested that increasing calcium (Ca) by using P, contributed to increase fruit firmness.

Regarding to the macronutrients content, there was a significant effect of P_2O_5 for P; Ca; and Mg (Fig 6) in unripe fruits. The mean values for N; K and S content were of 6.04, 10.67 and 0.97 mg kg^{-1}, respectively. Triple superphosphate increased P uptake, causing a quadratic effect. The maximum value of P was of 74 kg P_2O_5 ha^{-1} (Fig 6A). The highest value of Ca was of 41 kg P_2O_5 ha^{-1} (Fig 6B), while the maximum value of Mg was of 58 kg ha^{-1} (Fig 6C). However, it was observed a side effect, as the fruits presented more macronutrients than needed, which damaged the root system by impairing its absorption, as reported by Oliveira et al. (2006).

By applying triple superphosphate, the soil available P increased linearly (Fig 7), but leaf P content did not alter, with a mean of 1.58 g kg^{-1}. The result corroborates the findings of Silva and Rodrigues (2013), evaluated 'Dwarf-prata' banana in four production cycles and reported that the third leaf from the apex, which is commonly used for nutrient content analysis, may not be sensitive to detect P deficiency or excess.
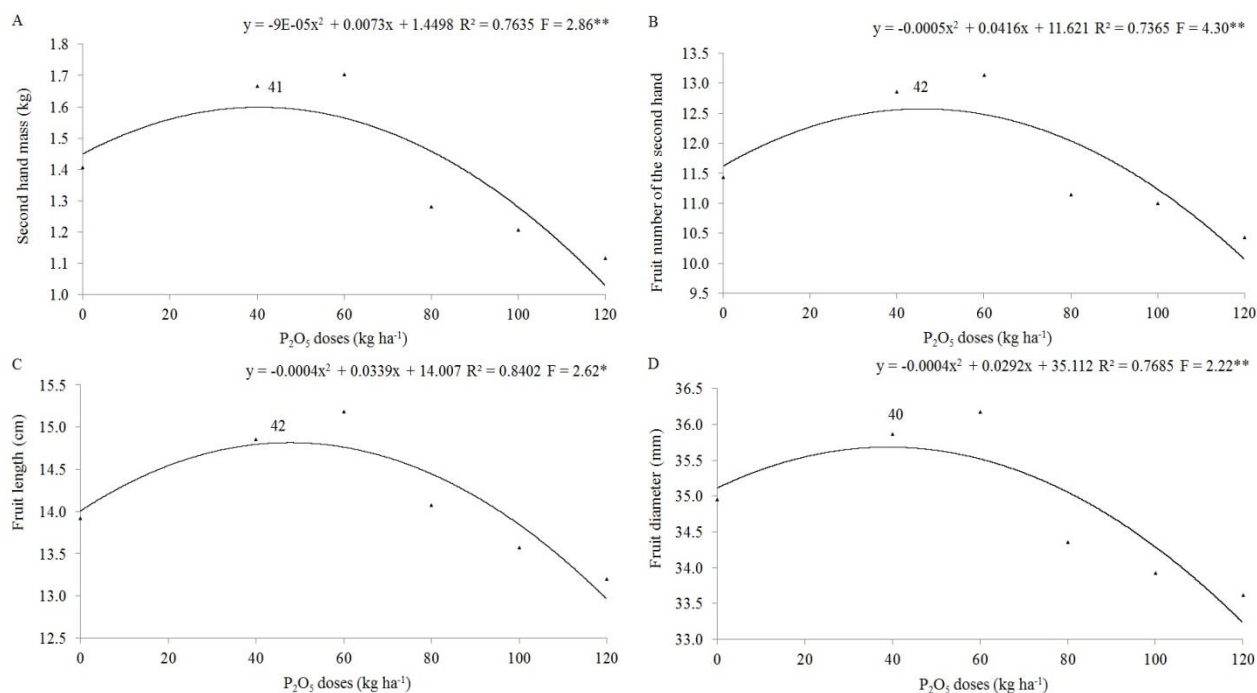
Materials and Methods

Location and soil classification

The fruit were harvested in the São Manuel Experimental Farm, Botucatu School of Agronomy, UNESP (22°44'28"S, 48°34'37"W; 740m m altitude; climate type Cfa, according to Köppen's classification). The mean annual rainfall of São Manuel is 1377 mm; and the mean annual temperature is 22°C. The soil is classified as Dystrophic Red Latosol (Oxisoil). The experiment was conducted from November 2012 to May 2014, when it was evaluated the first productive cycle of 'Maçã' banana in dryland cropping system.

Soil samples were collected at a depth of 0-20cm to determine their chemical properties: pH in CaCl$_2$, 5.5; M.O., 12 g dm^{-3}; Presin, 16 mg dm^{-3}; H+Al, 15 mmol$_c$ dm^{-3}; K, 1 mmol$_c$ dm^{-3}; Ca, 13 mmol$_c$ dm^{-3}; Mg, 5 mmol$_c$ dm^{-3}; SB, 19 mmol$_c$ dm^{-3}; CTC, 34 mmolc dm^{-3}; V%, 57; S, 1 mg dm^{-3}.

$$y = -9E\text{-}05x^2 + 0.0073x + 1.4498 \quad R^2 = 0.7635 \quad F = 2.86**$$

$$y = -0.0005x^2 + 0.0416x + 11.621 \quad R^2 = 0.7365 \quad F = 4.30**$$

$$y = -0.0004x^2 + 0.0339x + 14.007 \quad R^2 = 0.8402 \quad F = 2.62*$$

$$y = -0.0004x^2 + 0.0292x + 35.112 \quad R^2 = 0.7685 \quad F = 2.22**$$

Fig 3. Second hand mass (A), Fruit number of the second hand (B), Fruit length (C) e Fruit diameter (D) of 'Maçã' banana, fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015. **Significant at 1% probability and *Significant at 5% probability.

$$y = -3E\text{-}05x^2 + 0.0028x + 0.4575 \quad R^2 = 0.7705 \quad F = 4.02**$$
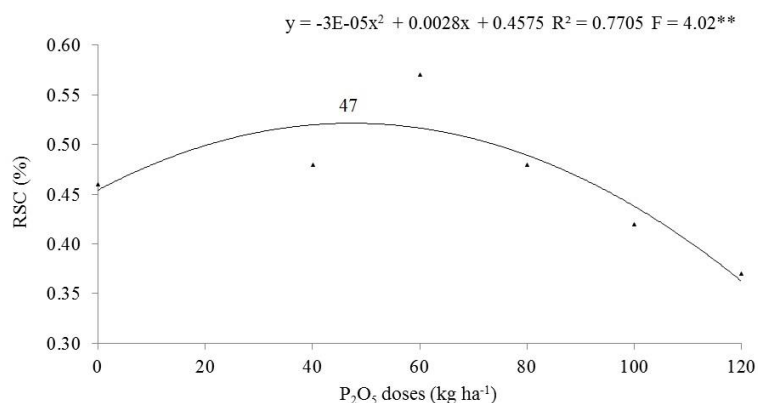
Fig 4. Reducing sugar content in unripe fruits of 'Maçã' banana, fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015. ** Significant at 1% probability.

$$y = -9E\text{-}05x^2 + 0.0113x + 2.7180 \quad R^2 = 0.8200 \quad F = 3.53**$$
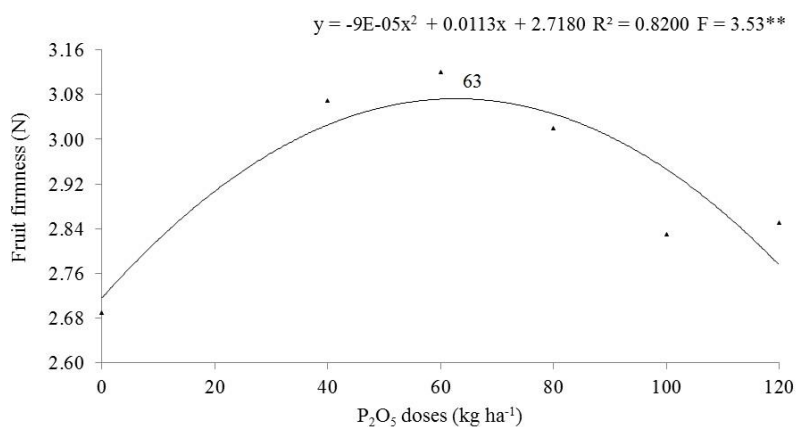
Fig 5. Fruit firmness in ripened fruits of 'Maçã' banana, fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015. ** Significant at 1% probability.
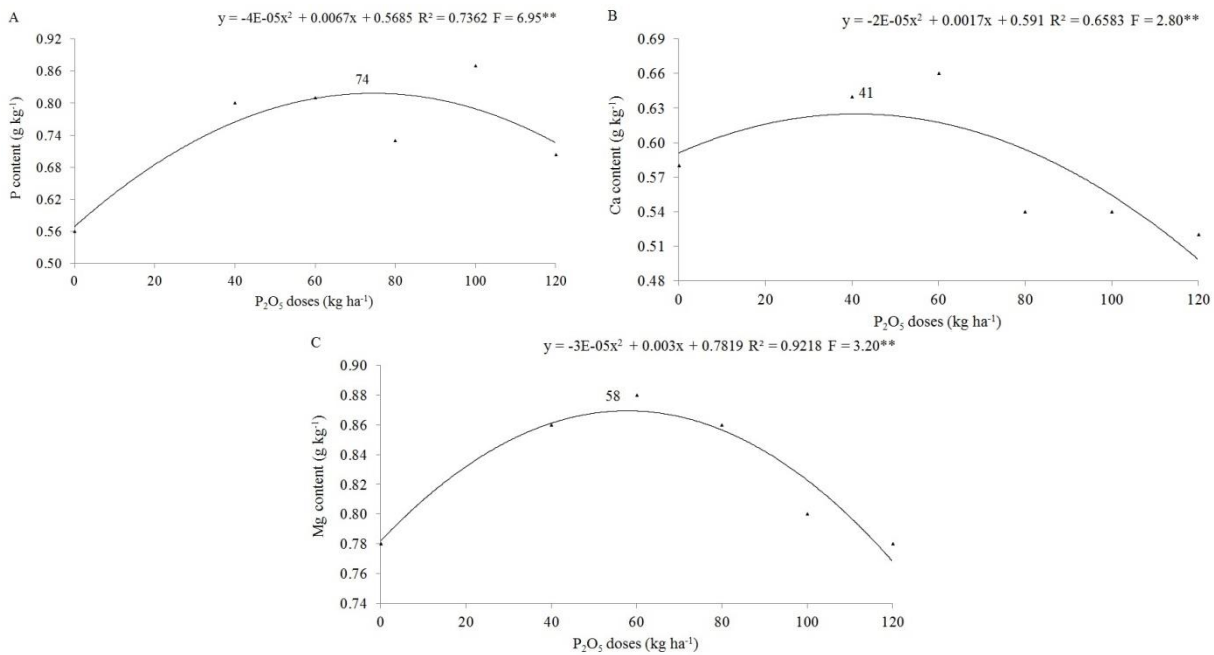
Fig 6. Phosphorus (E), calcium (B) and magnesium (C) content on dry mass in unripe fruits of 'Maçã' banana, fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015. ** Significant at 1% probability.

Fig 7. Available phosphorus content in soil cultivated with 'Maçã' banana fertilized with P_2O_5 in kg ha^{-1}. Botucatu School of Agronomy UNESP, São Manuel, SP, 2015. ** Significant at 1% probability.
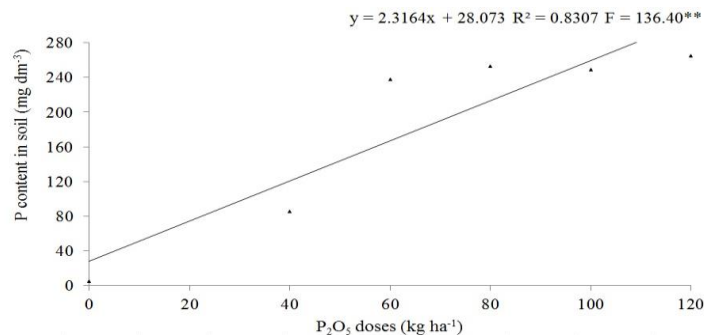
Plant materials and experimental design

In November 2012, micropropagated 'Maçã' banana plantlets (AAB) were transplanted with a spacing of 4 m between rows and 2.5 m between the plants, totalling 1000 ha^{-1} plant. The experiment design was totally randomized, consisting of 6 doses of triple superphosphate (0, 40, 60, 80, 100 and 120 kg P_2O_5 ha^{-1}) and 7 repetitions. P fertilizer was applied twice: half of the six doses were applied into the planting hole; and at 80 days after planting, the other half was applied within a radius of 100 cm around the plants. The doses were defined according to the method described by Teixeira et al. (1997), with respect to initial available P content in the soil (16 mg dm^{-3}); and expected yield for the first cycle (< 20 t ha^{-1}).
During inflorescence phase, it was collected leaf samples (Teixeira et al., 1997); and P levels were evaluated (Malavolta et al., 1997). At the end of harvest, the resin method was used to measure the quantity of potentially available P by collecting four simple soil samples per plot (at a depth of 0-20 cm) in the fertilization area, which formed a composite sample (Silva and Rodrigues, 2013).

Plants development and agronomic performance

The plants development characteristics were: plant height, pseudo-stem diameter and number of live leaves, which were all measured at the inflorescence appearance. The plant cycle was determined in days from planting to flowering; from flowering to harvesting; and from planting to harvesting. The agronomic performance analyses were: bunch mass; fruit mass; rachis mass; number of fruits per bunch; yield; and number of hands per bunch. The physical analyses were: mass; fruit number; length and diameter of the five central fruits of second hand of the bunch.

Physicochemical aspects of banana fruits

The physicochemical analysis determined fruit quality. The process was carried out in unripe and ripened fruit by using five bunches per treatment. In unripe fruits, it was randomly selected twelve fruits during ripening stage 1 (totally green peel), according to Von Loesecke (Leonel et al, 2011.). After dehydration, the analyses were: MC, DM, TSC and RSC, starch, macro and micronutrients (Somogy-Nelson, 1944;

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Malavolta et al., 1997; AOAC, 2005). When the fruits of the second hand reached maturity at stage 6 (fruit peel colour: 100% yellow), firmness was determined in a texture meter (TA.XTplus Texture Analyzer), with a penetration depth of 2.0 mm s^{-1}; fruit peel colour (with a Minolta CR-300 colorimeter); pH; TA (expressed in grams of malic acid 100 g^{-1} pulp); SSC (AOAC, 2005); ratio (SS/TA); and RSC.

Statistical analysis

Data were subjected to analysis of regression using the statistical Sisvar software (Ufla, Lavras, MG, Brazil) and graphical representations were made with Excel. Differences between means were subjected to analysis of variance by F test, and compared by Tukey test at 5% probability.

Conclusion

The evaluated cultivar presented better growing conditions; cycle length; and productive performance at 33-61 kg P$_2$O$_5$ ha^{-1}. Fruit quality is not affected by P fertilization, except of RSC (at 47 kg P$_2$O$_5$ ha^{-1}) in unripe fruits; and firmness (at 63 kg P$_2$O$_5$ ha^{-1}) in ripe fruits. The use of P on soil did not change any micronutrients levels in unripe fruit; but it provided higher quantitative values for P; Ca and Mg at 74, 41 and 58 kg P$_2$O$_5$ ha^{-1}.

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