Revista Brasileira de Ciência do Solo

Division - Soil Use and Management | Commission - Soil Fertility and Plant Nutrition

Phosphate fertilizer for more vigorous BRS SCS Belluna banana plants results in high yield and quality in different crop cycles

Hebert Teixeira Cândido[(1)*], Magali Leonel[(2)], Sarita Leonel[(3)], Paulo Ricardo Rodrigues de Jesus[(3)], Lucas Felipe dos Ouros[(2)], Edson Shigueaki Nomura[(4)] and Oriel Tiago Kölln[(1)]

[(1)] Universidade Estadual do Norte do Paraná, Departamento de Agricultura, Programa de Pós-Graduação em Agronomia, Bandeirantes, Paraná, Brasil.
[(2)] Universidade Estadual Paulista "Júlio de Mesquita Filho", Centro de Raízes e Amidos Tropicais, Botucatu, São Paulo, Brasil.
[(3)] Universidade Estadual Paulista "Júlio de Mesquita Filho", Departamento de Produção Vegetal, Botucatu, São Paulo, Brasil.
[(4)] Agência Paulista de Tecnologia dos Agronegócios, Pariquera-açu, São Paulo, Brasil.

*** Corresponding author:**
E-mail: hebert.candido@gmail.com

Received: July 31, 2024

Approved: February 12, 2025

How to cite: Cândido HT, Leonel M, Leonel S, Jesus PRR, Ouros LF, Nomura ES, Kölln OT. Phosphate fertilizer for more vigorous BRS SCS Belluna banana plants results in high yield and quality in different crop cycles. Rev Bras Cienc Solo. 2025;49nspe1:e0240160.
https://doi.org/10.36783/18069657rbcs20240160

Editors: Luciano Colpo Gatiboni and Jimmy Walter Rasche Alvarez.

ABSTRACT: Phosphorus is essential for plant metabolism. Although banana plants do not absorb large quantities, most of this mineral is exported together with the fruits, where the nutrients are related to sensory, nutritional, and technological qualities. Highly weathered soils, such as those found in most of Brazil, can immobilize phosphorus because of the cationic charges in iron and aluminum ions, making the element unavailable to plants and more challenging for phosphate fertilization. Brazil is the fourth-largest banana producer worldwide and plays an important role in national agribusiness. New banana cultivars are frequently introduced to address the adversities of banana farming and meet consumer expectations. This study aimed to evaluate the application levels of P_2O_5 in the BRS SCS Belluna banana plant in two crop cycles. A randomized block design with five blocks in a 6 × 2 factorial scheme was used. The first factor was the level of phosphorus application (P_2O_5), and the second factor was the crop cycle (first and second crop cycles). Variables related to plant vigor, production, and fruit quality were also evaluated. Shoot mass, plant height and diameter, number of photosynthetically active leaves, bunch yield, fruit mass, and nutritional aspects were analyzed. All plant biometric variables were positively affected by phosphate fertilization. Application of P_2O_5 promoted more vigorous banana plants with a larger number of leaves at the end of the crop cycle, and these variables were positively correlated with the production of bunches, fruit mass, and nutritional quality. The bunch yield per crop cycle increased by up to 84 % compared to the lowest level of P_2O_5 applied. In short, the BRS SCS Belluna banana plant responded well to phosphorus dosage, positively affecting plant vigor, which significantly influenced the production of bunches, fruit filling, and quality. The best results were achieved at P_2O_5 application levels close to the recommended reference level.

Keywords: *Musa* spp., thermophosphate, agronomic performance, genotypes update.

INTRODUCTION

Phosphorus is essential for plant growth and development and plays important roles in both primary and secondary metabolism, including the reduction of abiotic stress (Martinez et al., 2021; Kumari et al., 2022). Although banana plants do not absorb large amounts of phosphorus, they export most nutrients with their fruits. Despite the low demand, phosphate fertilizer is highly effective, leading to more vigorous plants, greater productivity, and improvements in nutritional quality and technological aspects of fruit processing (Cândido et al., 2024a; Maseko et al., 2024).

Brazilian soils are typically associated with low phosphorus concentrations owing to their parent material, as well as the factors and processes of formation. This has resulted in the predominance of highly weathered soils with high acidity and positive charges available in clays, primarily iron and aluminum oxides, where orthophosphate ions ($H_2PO_4^-$) are largely unavailable for plant absorption. This characteristic challenges fertilization programs and necessitates a special focus on phosphate fertilization (Martinez et al., 2021; Maseko et al., 2024).

Brazil is the fourth largest producer of bananas, and its production is of great importance to family farmers and businesses (Donato et al., 2021; Maseko et al., 2024). Globally, Cavendish bananas are cultivated most widely and dominate international markets. However, low genetic diversity in commercial cultivation can lead to the loss of valuable genes for breeding programs. New cultivars are frequently released to address the pressures on genotypes adapted to climate change, pests, new disease strains, and the demands of increasingly discerning consumers. These updates are crucial to prevent crises, such as the one in the 1950s, when the Gros Michel cultivar was devastated by Fusarium wilt, compromising the banana supply (Gross, 2022).

Launched in 2016, the BRS SCS Belluna banana, which belongs to the AAA genomic group, is a medium-to-tall cultivar resistant to yellow sigatoka, Fusarium wilt (races 1 and 2), and, under appropriate management, black sigatoka. This cultivar also has moderate resistance to rhizome borers and is suitable for subtropical conditions. Its fruits are small, nutritious, sweet, and low in acidity, making them suitable for both direct consumption and processing into green bananas, which helps reduce waste. The BRS SCS Belluna aims to diversify the national banana market and offer new opportunities to producers (Scherer et al., 2020; Donato et al., 2021).

Considering the importance and challenges of phosphate fertilization, the importance of banana farming, the need to update genotypes, and the specific nutritional demands of each cultivar (Donato et al., 2021; Maseko et al., 2024), this study aimed to evaluate phosphate fertilization in the BRS SCS Belluna banana plants in two crop cycles. The following hypothesis was formulated and tested: the association between phosphorus doses and the crop cycle influences the vigor of banana plants or their production.

MATERIALS AND METHODS

The experiment was implemented in December 2019 and conducted until May 2023 under rainfed conditions on an experimental farm located in São Manuel, SP (22.771016° S, 48.574477° W). The local climate is classified as Cfa according to the Köppen classificaton system, with an average annual temperature above 22 °C and annual precipitation of 1,376 mm (Cunha and Martins, 2009). Climatic temperature and precipitation data for the experimental period are shown in figure 1.

The soil was plowed and harrowed two months before planting, followed by soil sampling for chemical and granulometric analyses. Soil analysis indicated the following values: pH($CaCl_2$) 5.4, organic matter 11 g dm^{-3}, phosphorus (P) (resin) 9.0 mg dm^{-3}, sulfur (S) 2.0 mg dm^{-3}, potassium (K^+) 1.08 mmol$_c$ dm^{-3}, calcium (Ca^{2+}) 16 mmol$_c$ dm^{-3}, magnesium

(Mg^{2+}) 6.0 $mmol_c$ dm^{-3}, iron (Fe) 32 mg dm^{-3}, copper (Cu) 2.4 mg dm^{-3}, manganese (Mn) 8.5 mg dm^{-3}, zinc (Zn) 2.2 mg dm^{-3}, boron (B) 0.2 mg dm^{-3}, cation exchange capacity (CEC) 38 $mmol_c$ dm^{-3}, and base saturation 60 %. The particle size analysis revealed 843 g kg^{-1} sand, 121 g kg^{-1} clay, and 36 g kg^{-1} silt, classifying it as "loose sand", according to the textural classification. Based on soil analysis, 0.42 Mg ha^{-1} of agricultural lime was applied in October 2019 to increase the base saturation to 70 % (Teixeira et al., 2014).

Micropropagated seedlings of the BRS SCS Belluna (AAA) cultivar were used in this study. Before field planting, they were grown for 60 days in a nursery, 40 days in a mini-tunnel, and 20 days in full sun. Transplanting to the field occurred in December 2019, with a spacing of 2.0 × 2.5 m, which is recommended for low and medium-sized plants. Seedlings were planted in furrows approximately 0.30 m deep (Teixeira et al., 2014).

A randomized block design with five blocks in a 6 × 2 factorial scheme was used. The first factor was the level of phosphorus application (P_2O_5) and the second factor was the crop cycle (first and second crop cycles). Phosphorus application levels were distributed as follows: 25, 50, 75, 100 % (reference level), 125, and 150 %. The distribution of phosphorus levels was based on reference fertilization (100 %), calculated according to the recommendations of Teixeira et al. (2014) and based on the P (resin) content present in the soil layer of 0.00-0.20 m (Table 1). The phosphorus source used was thermophosphate (17 % P_2O_5, 18 % Ca, 7 % Mg, 10 % Si, 0.1 % B, 0.3 % Mn, 0.55 % Zn, and 0.05 % Cu) (Yoorin Fertilizantes, 2024).

For all sidedressing fertilization, soil sampling took place in plots that received the reference treatment (100 % P_2O_5). Four points were sampled per plot, totaling 20 simple samples that were homogenized to obtain a representative sample of the area. Nitrogen and potassium fertilizer doses were applied in four installments, starting in November and ending in February, during the rainy season of the location (Figure 1). For nitrogen, a dose of 190 kg ha^{-1} yr^{-1} was applied during planting (2019), and subsequently as a side dressing in 2020/21, 2021/22, and 2022/23. The N sources were urea and ammonium sulfate, with the latter ensuring a supply of 30 kg ha^{-1} yr^{-1} of S. Potassium was supplied as potassium chloride with K_2O doses of 310 kg ha^{-1} at planting and 150 kg ha^{-1} for subsequent fertilization (sidedressing 2020/21, 2021/22, and 2022/23). Before sidedressing and when necessary, lime was applied to increase the base saturation to 70 %. Fertilization and liming followed the recommendations of Teixeira et al. (2014).

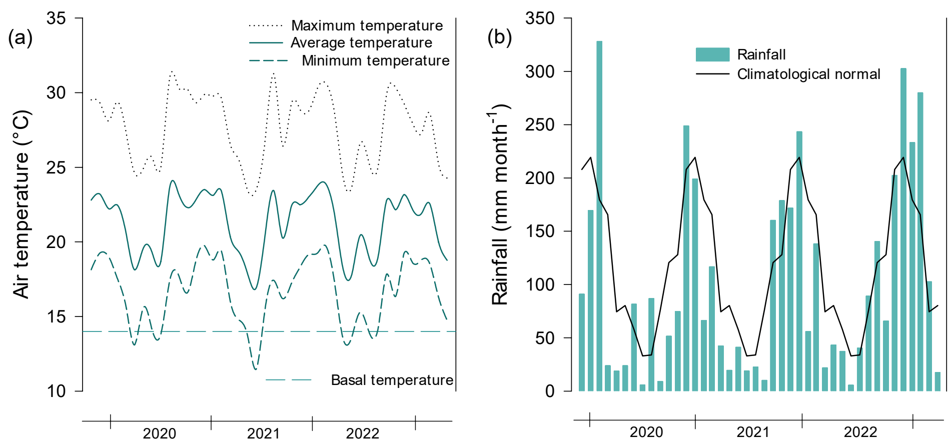

Figure 1. Monthly data for air temperature (a) and precipitation (b) at the experiment farm for the field experimentation period (Dec 2019–May 2023). São Manuel, São Paulo, Brazil. Basal temperature: minimum temperature for assimilation of dry matter (growth), 14 °C (Donato et al., 2016, 2021) (a). Climatological normal: data observed for 36 years (Cunha and Martins, 2009) (b). Source: author of this study based on data made available by the Department of Rural Engineering and Socioeconomics at the Faculty of Agricultural Sciences (Unesp) of Botucatu.

Table 1. Doses of P_2O_5 based on recommended application level for the experiment. São Manuel, SP

Fertilizantion	25 %	50 %	75 %	$100\ \%_{(R)}$	125 %	150 %
	g plant^{-1}					
Planting	10	20	30	40	50	60
Sidedressing 2020/21	10	20	30	40	50	60
Sidedressing 2021/22	6.3	12.5	18.8	25	31.3	37.5
Sidedressing 2022/23	10	20	30	40	50	60

R: reference level (Teixeira et al., 2014).

Plants were cultivated according to the crop practices outlined by Donato et al. (2021). For harvesting, the criteria used for banana plants from the Cavendish group were adopted: fruits with a diameter of 34 mm and a slightly rounded surface, which can also be applied to the BRS SCS Belluna cultivar (Scherer et al., 2020). The first crop cycle harvest began in October 2021 and extended throughout 2022. The second crop cycle harvest began in the second half of 2022 and ended in May 2023.

Four plants per plot were evaluated for fresh and dry shoot mass, height, diameter, number of photosynthetically active leaves, bunch mass, fruit mass, total starch, ash, and protein. The height, diameter, and number of photosynthetically active leaves were evaluated during flowering and harvesting (Bolfarini et al., 2016; Leonel et al., 2020). Height was assessed using a tape measure that measured the length of the pseudo stem from the base of the plant to the insertion of the first leaf. The diameter was calculated (diameter = circumference π^{-1}) from the circumference measured using a tape measure placed 0.30 m above the ground.

Shoot fresh mass was measured at harvest by summing the masses of the aerial parts of the plant (pseudostem, bunch, leaves, and inflorescence). The inflorescence was the only tissue from which the mass was obtained before harvesting and evaluated at the time of crop practice, that is, removal of the inflorescence. To determine the dry mass, the material was dried in an oven with forced air circulation at 65 °C until a constant weight was achieved (Hoffmann et al., 2010). Dry mass of the bunch was determined by adding the dry weights of the peel, fruit, and stalk. Mass measurements were performed using a digital scale with an accuracy of 1.0 g.

The yield per crop cycle was calculated by multiplying the bunch mass by the number of plants per hectare (Scherer et al., 2020). Fruit mass, total starch, protein, and ash content were used only for the correlation analysis. Thus, fruit mass was obtained by averaging five green fruits per bunch sampled second-hand (Bolfarini et al., 2016). Total starch content was determined using the enzymatic hydrolysis method (method 76-13.01), ash content was measured by high-temperature combustion in a muffle furnace (method 08-01.01), and protein content was calculated by multiplying the nitrogen content by a conversion factor of 6.25 (method 46-13.01) (American Association of Cereal Chemists, 2018).

The means were subjected to analysis of variance, and when the null hypothesis was rejected, Fisher's LSD mean test was applied ($p \leq 0.05$). AgroEstat software was used for statistical analyses (Barbosa and Maldonado Junior, 2015).

RESULTS

Shoot fresh mass was affected only by the level of phosphorus application ($p<0.0001$), whereas dry mass had isolated effects by application level ($p<0.0001$) and crop cycle (p=0.0043). Phosphorus application increased fresh mass by 54.5 % and dry mass by 40.9 % (Figures 2a and 2b). In the second crop cycle, a higher dry mass value was obtained (2.02 kg plant^{-1}; or 4.04 Mg ha^{-1}) compared with that of the first cycle (1.79 kg plant^{-1}; or 3.58 Mg ha^{-1}) (Figure 2c). The bunches (fruits and stalk+rachis) represented an average of 36.6 % of the dry mass accumulated by the shoot part of the plant at the time of harvest, and this value was not influenced by any of the variation factors tested (p>0.05).

The level of P_2O_5 application and crop cycle individually influenced the pseudostem height at the time of flowering and harvest (p=0.0037 and p<0.0001, respectively). The responses to height were quadratic and promoted gains of up to 13.3 % (at flowering) (Figure 3a) and 14.5 % (at harvest) (Figure 3b).

In the second crop cycle, the average plant heights at flowering (154 cm in the 1st cycle; 169 cm in the 2nd cycle) and harvest (156 cm in the 1st cycle; 165 cm in the 2nd cycle) were higher than those in the first cycle. This represented an average variation of 7.7 % during this period (Figures 3b and 3d).

Pseudostem diameter was affected by the crop cycle (at flowering, p=0.0331) and the level of P_2O_5 application (at harvest, p=0.0033). During flowering, the mean plant diameter in the second cycle, 13.6 cm, was greater than that in the first crop cycle, 13.0 cm (Figure 4a). At the time of harvest, the P_2O_5 application doses promoted a 15.3 % increase in pseudostem diameter, with the highest value estimated at 12.4 cm, and with a quadratic adjustment of the regression (Figure 4b).

Photosynthetically active leaves at the time of flowering were not influenced by any of the factors (p>0.05). The overall average of the experiment was 8.5 ± 1.24 leaves per plant. At the time of harvest, the dose effect was quadratic (p=0.0137) and managed to maintain up to 66.6 % more photosynthetically active leaves compared to the lowest application of P_2O_5, with the highest value in 4.5 leaves, according to the regression analysis (Figure 5a). Leaf loss during the period between flowering and harvest was 51.36 % in the first cycle and 55.8 % in the second cycle (Figure 5b).

The period, in days, between flowering and bunch harvesting was 117.0 ± 22.1 days. Bunch yield was influenced by the interaction between the level of P_2O_5 application and the crop cycle (p=0.0008; CV% = 6.59), resulting in quadratic responses and gains of 44.3 % (1st crop cycle) and 84.0 % (2nd crop cycle), compared to the lowest level of P_2O_5 application.

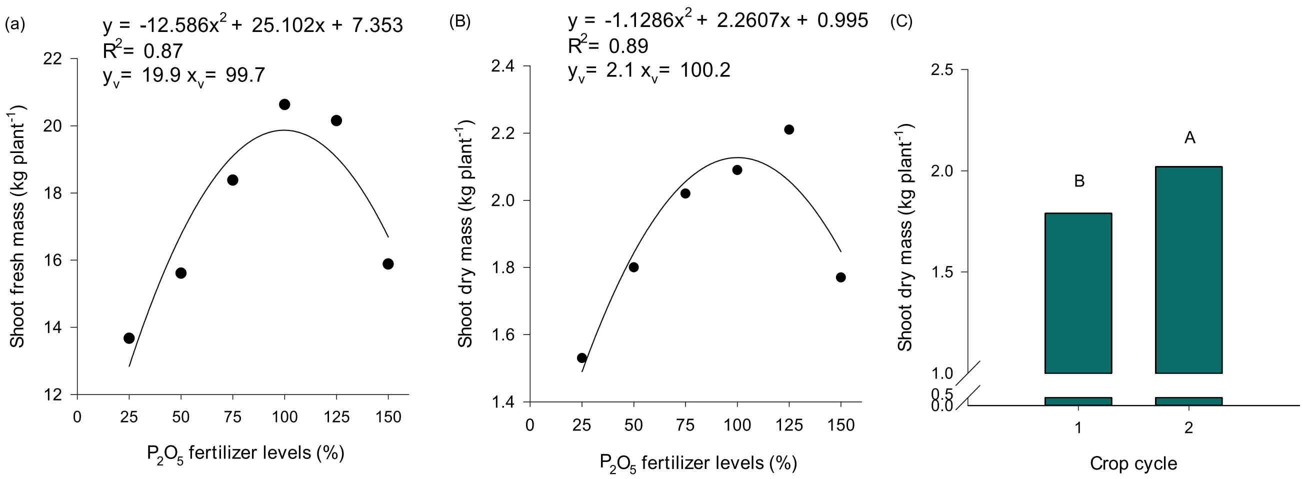

Figure 2. Fresh mass of the aerial part as a function of the level of application of P_2O_5 (a), dry mass of the aerial part depending on the level of application of P_2O_5 (b), and dry mass of the aerial part depending on the banana crop cycle (c). Different letters in the cycle bars differ statistically from each other by the LSD test Fisher (p≤0.05) (c). Yv: coordinate of vertex of the parabola in relation to the vertical axis; Xv: coordinate of the vertex of the parabola in relation to the horizontal axis.

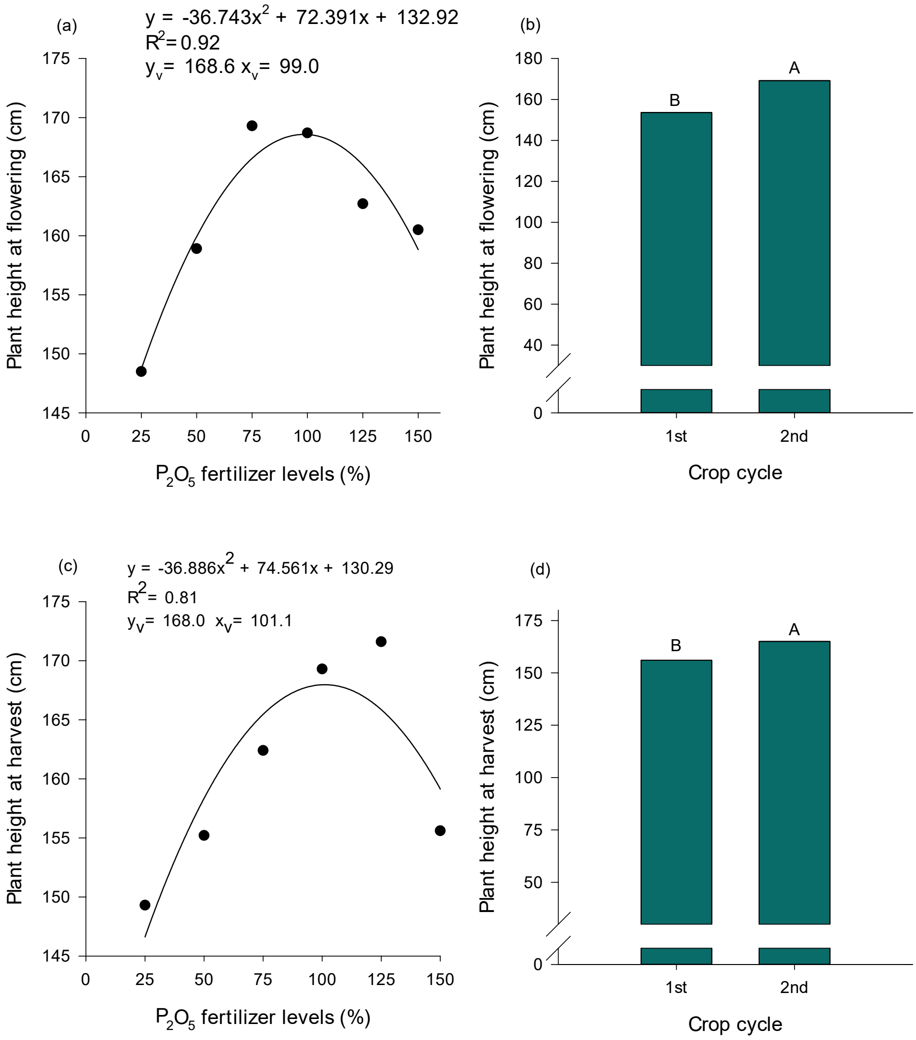

Figure 3. Plant height at flowering as a function of P_2O_5 (a) application level, plant height at flowering as a function of the banana crop cycle (b), plant height at harvest as a function of the level of application of P_2O_5 (c), and plant height at harvest as a function of cycle (d). Different letters in the bars crop cycle differ statistically from each other using Fisher's LSD test ($p \leq 0.05$) (b and d). Yv: coordinate of the vertex of the parabola in relation to the vertical axis; Xv: coordinate of the vertex of the parabola in relation to the horizontal axis.

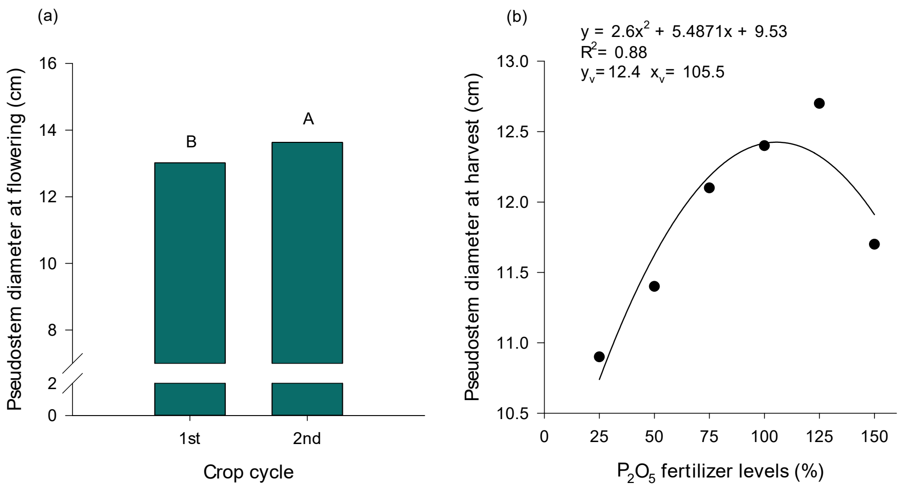

Figure 4. Pseudo-stem diameter at flowering as a function of banana crop cycle (a) and pseudo-stem diameter at harvest depending on the level of P_2O_5 (b) application. Different letters on the cycle bars differ statistically compared to each other using Fisher's LSD test ($p \leq 0.05$) (a). Yv: coordinate of the vertex of the parabola in relation to the vertical axis; Xv: coordinate of the vertex of the parabola in relation to the horizontal axis.

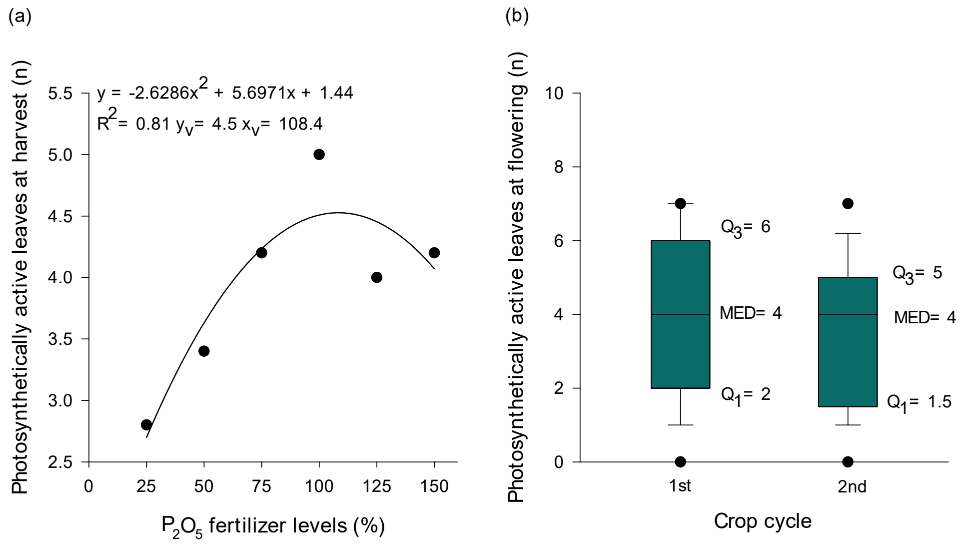

Figure 5. Photosynthetically active leaves at harvest depending on the level of application of P_2O_5 (a) and distribution in quartiles of photosynthetically active leaves at flowering in banana plants (b). Yv: coordinate of the vertex of the parabola in relation to the vertical axis; Xv: coordinate of the vertex of the parabola in relation to the horizontal axis (a). Q1: First quartile; MED: median; Q3: third quartile; ●: represents the interval that concentrates 95 % of the observations (b).

Shoot biometrics influenced the yield and fruit mass of the bunches (Table 2). The nutritional quality of the fruit was influenced by the following biometric characteristics: total starch × plant height at the inflorescence (0.335, p = 0.009), starch × pseudostem diameter at the inflorescence (0.340, p = 0.008), protein × plant height at harvest (0.338, p = 0.008), and ash × pseudostem diameter at harvest (0.282, p = 0.029).

DISCUSSION

Quadratic responses to banana plant biometrics have also been demonstrated by other researchers who evaluated the influence of phosphate fertilization on the dry matter of the aerial parts (Silva et al., 2011), plant height, pseudo-stem diameter, and number of leaves (Bolfarini et al., 2016; Dhutraj et al., 2018). The highest measurements obtained for the second crop cycle, with more vigorous plants, are also in accordance with the literature, and occur because of a more developed clump (Scherer et al., 2020; Donato et al., 2021), such that biometric characteristics tend to stabilize in subsequent crop cycles (Silva et al., 2002).

Table 2. Values obtained for *Pearson* correlations between biometrics of the aerial part of the plant and production aspects in banana crop. São Manuel, SP, 2021/23

SFM	PHF	PDF	PLF	PHH	DPC	PLH	BBM	GFM
SFM	0.438*	0.434*	0.311**	0.795*	0.840*	0.213ns	0.706*	0.370*
	PHF	0.741*	0.316**	0.527*	0.444*	0.119ns	0.486*	0.060ns
		PDF	0.240ns	0.430*	0.523*	-0.023ns	0.371*	0.013ns
			PLF	0.291**	0.335*	-0.018ns	0.036ns	0.070ns
				PHH	0.780*	0.183ns	0.708*	0.282**
					DPC	0.177ns	0.585*	0.306**
						PLH	0.464*	0.608*
							BBM	0.617*

* Statistically significant at 1 % by T test; ** Statistically significant at 5 % by T test; ns not significant; SFM: shoot fresh mass; PHF: plant height at flowering; PDF: plant diamenter at flowering; PLF: photosynthetically active leaves at flowering; PHH: plant height harvest; PDH: plant diameter at harvest; PLH: photosynthetically active leaves at harvest; GFM: green fruit mass. GFM: green fruit mass.

To obtain vigorous banana plants, maintaining a balance between the growth of the shoot and root systems, which act as source and sink organs for the photoassimilates produced by the leaves and the minerals absorbed by the roots, is essential (Donato et al., 2021). This relationship is mainly regulated by phosphorus and nitrogen, which are considered the primary nutrients that can limit agricultural production (Martinez et al., 2021). Low application level of P_2O_5 may have compromised the growth of banana plants, as phosphorus plays an extremely important role in their primary metabolic processes, such as photosynthesis, respiration, nitrogen assimilation, energy storage and transfer, cell elongation, and division (Kumari et al., 2022). However, a high level of P_2O_5 application may cause a nutritional imbalance in the plant or an antagonistic effect on other minerals in the soil, such as zinc and sulfur (Fagan et al., 2016; Martinez et al., 2021). In other paper, the results for zinc and sulfur in banana pulp corroborate the previous arguments, as their levels decreased with higher applications of P_2O_5 (Cândido et al., 2024b).

Hoffmann et al. (2010) found 9.6 Mg ha^{-1} of shoot dry mass for the Grande Naine (AAA) banana and 9.8 Mg ha^{-1} for the Gros Michel (AAA) cultivar. For the Nam (AAA) cultivar, the genotype that produced cv. BRS SCS Belluna, Silva et al. (2003) presented averages of 228 cm (1st crop cycle) and 275 cm (2nd crop cycle) in height from assessments in four locations; and Silva et al. (2002) presented 16.4 cm (1st cycle) and 20.2 cm (2nd cycle) for diameter. Scherer et al. (2020) presented average values of 227 cm (1st crop cycle) and 298 cm (2nd crop cycle) in height for the BRS SCS Belluna banana plant and evaluated in two locations, yields of 11.39 and 9.0 Mg ha^{-1} (1st crop cycle) and 20.26 and 16.72 Mg ha^{-1} (average of other crop cycles).

In general, the plants presented lower biometric measurements than those reported for other AAA genotypes (Oliveira et al., 2007; Hoffmann et al., 2010) or those expected for cv. BRS SCS Belluna (Scherer et al., 2020). Donato et al. (2016) highlight that banana plants require a high (approximately 2,000 to 2,500 mm of annual precipitation) and well-distributed water supply throughout the year, with an average consumption of approximately 25 mm $week^{-1}$ (dessert cultivars) and 125 mm $month^{-1}$ for plantains. This estimate varies according to atmospheric conditions, soil characteristics, and phenological stage, with the authors presenting an example of consumption of up to 96 L $plant^{-1}$ day^{-1}. Thus, the local climatic conditions (Figure 1), which during this period experienced extreme drought caused by three consecutive years of *La Niña* (Cabrini et al., 2022), may have contributed to the development of less vigorous plants. Wesemael et al. (2019) demonstrated that banana genotypes consisting solely of A alleles were more adversely affected under water-deficit conditions. This stress compromises dry matter accumulation in roots and reduces CO_2 absorption, leading to less vigorous plant growth.

For the same banana genotype, more vigorous plants produce better yields (Turner et al., 2007). One reason for this is that, after the emission of the bunches, they become the main sink for assimilated substances. Thus, reservoirs, such as the pseudo-stem and leaves, become the primary sources for filling fruits, with less contribution from roots (Donato et al., 2021). This was confirmed in the present study by the significant correlations of bunch production with plant biometric variables, fresh mass of the aerial part, height, pseudo-stem diameter, and photosynthetically active leaves at harvest. Furthermore, as reported by other researchers (Rodrigues et al., 2009), the importance of maintaining leaves for good fruit filling has been confirmed, resulting in heavier bunches. Biometric measurements of the plant also contributed to the nutritional quality of the fruits, with positive correlations between the pseudostem measurements and starch, ash, and protein contents.

All variables affected by the level of P_2O_5 application showed quadratic responses with gains relative to the lowest level of phosphorus application. However, nutrients have synergistic and antagonistic relationships with each other, and in addition to environmental conditions, plant metabolism is regulated by the nutritional balance (Fagan et al., 2016; Maseko et al., 2024). Therefore, if other sources of variation, such as meteorological and mineral sources, had been controlled, higher responses could have been obtained with P_2O_5 application levels at doses higher than those presented in this study.

CONCLUSION

The BRS SCS Belluna banana plants responded to phosphorus dose, positively affecting plant vigor and significantly influencing bunch production, fruit filling, and quality. The best results were achieved with P_2O_5 application levels close to the recommended reference level. Application of P_2O_5 levels ranging from 91.0 to 108.4 % of the reference level yielded the best results for matter accumulation, number of leaves, leaf height, pseudo-stem diameter, and banana bunch mass, with yielded gains of up to 84 %. The BRS SCS Belluna cultivar presents a more robust plant in its second crop cycle, with greater pseudo-stem growth and the accumulation of shoot mass.

DATA AVAILABILITY

The data will be provided upon request.

FUNDING

Conselho Nacional de Desenvolvimento Científico e Tecnológico Grant No: GD no. 140924/2020-5.

AUTHOR CONTRIBUTIONS

Conceptualization: Hebert Teixeira Cândido (equal), Magali Leonel (equal) and Sarita Leonel (equal).

Data curation: Hebert Teixeira Cândido (lead).

Formal analysis: Hebert Teixeira Cândido (equal), Lucas Felipe dos Ouros (equal) and Paulo Ricardo Rodrigues de Jesus (equal).

Funding acquisition: Hebert Teixeira Cândido (equal), Magali Leonel (equal) and Sarita Leonel (equal).

Investigation: Hebert Teixeira Cândido (equal), Lucas Felipe dos Ouros (equal), Magali Leonel (equal), Paulo Ricardo Rodrigues de Jesus (equal) and Sarita Leonel (equal).

Methodology: Hebert Teixeira Cândido (equal), Magali Leonel (equal) and Sarita Leonel (equal).

Project administration: Hebert Teixeira Cândido (equal), Magali Leonel (equal), Paulo Ricardo Rodrigues de Jesus (equal) and Sarita Leonel (equal).

Supervision: Magali Leonel (equal) and Sarita Leonel (equal).

Validation: Edson Shigueaki Nomura (equal) and Oriel Tiago Kölln (equal).

Writing – original draft: Hebert Teixeira Cândido (equal) and Magali Leonel (equal).

Writing – review & editing: Edson Shigueaki Nomura (equal) and Oriel Tiago Kölln (equal).

REFERENCES

American Association of Cereal Chemists. Approved methods of analysis, methods. 11th. St Paul, USA: AACC; 2018.

Barbosa JC, Maldonado Junior W. Experimentação agronômica & AgroEstat: Sistemas para analises estatísticas e ensaios agronômicos. Jaboticabal, SP: Gráfica Multipress Ltda.; 2015.

Bolfarini ACB, Leonel S, Leonel M, Tecchio MA, Silva MS, Souza JM. Growth, yield and fruit quality of ‘Maçã’ banana under different rates of phosphorus fertilization. Aust J Crop Sci. 2016;10:1368-74. https://doi.org/10.21475/ajcs.2016.10.09.p7892

Cabrini S, Colussi J, Schnitkey G. Third Consecutive La Niña? What to expect from soybean yields in the United States, Brazil and Argentina. Farmdoc daily. 2022;12:75.

Cândido HT, Leonel M, Leonel S, Jesus PRR, Ouros LF, Molha NZ, Domiciano VM. Phosphate fertilization to improve yield and chemical composition of banana ‘BRS SCS Belluna’ fruit. J Plant Nutr. 2024b;47:3868-88. https://doi.org/10.1080/01904167.2024.2387806

Cândido HT, Leonel M, Nomura ES, Leonel S. O fósforo no cultivo de bananeiras. In: Santos ED, Barbosa MS, Mello RG, editors. Ciências agrárias e da natureza: novas abordagens para a coexistência e o desenvolvimento sustentável. Rio de Janeiro: e-Publicar; 2024a. p. 212-28. https://doi.org/10.47402/ed.ep.c240217820935

Cunha AR, Martins D. Classificação climática para os municípios de Botucatu e São Manuel, SP. Irriga. 2009;14:1-11. https://doi.org/10.15809/irriga.2009v14n1p1-11

Dhutraj SV, Deshmukh RV, Damodhar VP, Waghmare GM. Effect of different levels of phosphorus on growth and yield of banana cv. Grand Naine. Int J Curr Microbiol App Sci. 2018;6:105-8.

Donato SLR, Borém A, Rodrigues MGV. Banana: Do plantio a colheita. Belo Horizonte: Epamig; 2021.

Donato SLR, Coelho EF, Marques PRR, Arantes AM. Considerações ecológicas, fisiológicas e de manejo. In: Ferreira CF, Silva SO, Amorim EP, Santos-Serejo JA, editors. O agronegócio da banana. Brasília, DF: Embrapa; 2016.

Fagan EB, Ono EO, Rodrigues JD, Soares LH, Dourado Neto D. Fisiologia vegetal: Metabolismo e nutrição. São Paulo: Editora Andrei; 2016.

Gross M. The trouble with bananas. Curr Biol. 2022;32:R1201-3. https://doi.org/10.1016/j.cub.2022.10.033

Hoffmann RB, Oliveira FHT, Souza AP, Gheyi HR, Souza Junior RF. Acúmulo de matéria seca e de macronutrients em cultivares de bananeira irrigada. Rev Bras Frutic. 2010;32:268-75. https://doi.org/10.1590/S0100-29452010005000026

Kumari VV, Banerjee P, Verma VC, Sukumaran S, Chandran MAS, Gopinath KA, Venkatesh G, Yadav SK, Singh VK, Awasthi NK. Plant nutrition: An effective way to alleviate abiotic stress in agricultural crops. Int J Mol Sci. 2022;23:8519. https://doi.org/10.3390/ijms23158519

Leonel S, Bolfarini ACB, Souza JMA, Leonel M, Ferreira RB, Putti FF, Tecchio MA. Agronomic performance of banana ‘FHIA 18’ in response to phosphate fertilization. Agron J. 2020;112:2033-46. https://doi.org/10.1002/agj2.20166

Martinez HEP, Lucena JJ, Bonilla I. Relações solo-planta: Bases para a nutrição e produção vegetal. Viçosa, MG: Editora UFV; 2021.

Maseko KH, Regnier T, Meiring B, Wokadala OC, Anyasi TA. *Musa* species variation, production, and the application of its processed flour: A review. Sci Hortic. 2024;325:112688. https://doi.org/10.1016/j.scienta.2023.112688

Oliveira CAP, Peixoto CP, Silva SO, Ledo CAS, Salomão LCC. Genótipos de bananeira em três ciclos na Zona da Mata Mineira. Pesq Agropec Bras. 2007;42:173-81. https://doi.org/10.1590/S0100-204X2007000200005

Rodrigues MGV, Dias MSC, Pacheco DD. Influência de diferentes níveis de desfolha na produção e qualidade dos frutos da bananeira ‘Prata-anã’. Rev Bras Frutic. 2009;31:755-62. https://doi.org/10.1590/S0100-29452009000300019

Scherer RF, Lichtemberg LA, Maro LAC, Beltrame AB, Klabunde GHF, Sônego M, Peruch LAM, Amorim EP, Serejo JAS, Ferreira CF, Haddad F. BRS SCS Belluna – a new banana cultivar for processing and fresh consumption. Agropec Catarinense. 2020;33:32-7. https://doi.org/10.52945/rac.v33i1.532

Silva JTA, Silva IP, Pereira RD. Adubação fosfatada em mudas de bananeira 'Prata Anã' (AAB), cultivadas em dois Latossolos. Rev Ceres. 2011;58:238-42. https://doi.org/10.1590/S0034-737X2011000200016

Silva SO, Passos AR, Donato SLR, Salomão LCC, Pereira LV, Rodrigues MGV, Lima Neto FP, Lima MB. Avaliação de genótipos de bananeira em diferentes ambientes. Cienc Agrotec. 2003;27:737-48. https://doi.org/10.1590/S1413-70542003000400001

Silva SO, Flores JCO, Lima Neto FP. Avaliação de cultivares e híbridos de bananeira em quatro ciclos de produção. Pesq Agropec Bras. 2002;37:1567-74. https://doi.org/10.1590/S0100-204X2002001100007

Teixeira LAJ, Nomura ES, Damatto ER Jr, Fuzitani EJ. Banana *Musa* spp. In: Aguiar ATE, Gonçalves C, Paterniani MEAGZ, Tucci MLS, Castro CEF, editors. Instruções agrícolas para as principais culturas econômicas. 7. ed. Campinas: Instituto Agronômico de Campinas; 2014.

Turner DW, Fortescue JA, Thomas DS. Environmental physiology of the bananas (*Musa* spp.). Braz J Plant Physiol. 2007;19:463-84. https://doi.org/10.1590/S1677-04202007000400013

Wesemael J van, Kissel E, Eyland D, Lawson T, Swennen R, Carpentier S. Using growth and transpiration phenotyping under controlled conditions to select water efficient banana genotypes. Front Plant Sci. 2019;10:352. https://doi.org/10.3389/fpls.2019.00352

Yoorin Fertilizantes. Produtos: Yoorin [internet]. Poços de Caldas; 2024. Available from: https://www.yoorin.com.br/produtos/yoorin/.