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Phosphate fertilization and critical leaf phosphorus content for okra

Adubação fosfatada e teor crítico foliar de fósforo para o quiabeiro

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ABSTRACT - The objective of this study was to evaluate the growth and yield of okra as a function of phosphorus (P) doses and to obtain the critical leaf P content, under the edaphoclimatic conditions of Maranhão (MA), Brazil. The field experiment was carried out from February 15, 2017, to May 9, 2017, in São Luís, MA. The experimental design was randomized blocks, with four replications. The treatments were doses of 0, 80, 160, 240 and 320 kg ha^{-1} of P_2O_5, in the form of triple superphosphate, at planting, plus 10 t ha^{-1} of solid cattle manure. The increase of the P dose increased plant height, leaf dry mass and stem dry mass. With phosphorus supply, flowering occurred earlier than in plants without fertilization. Considering soils with low P content ($P_{(resin)}$ = 11 to 25 mg dm^{-3}) and the minimum recommended organic fertilization for the okra crop of 10 t ha^{-1} of solid cattle manure, the maximum number of fruits, length of fruit and yield (9960.36 kg ha^{-1}) were obtained with the fertilization of 80 kg ha^{-1} of P_2O_5, for the edaphoclimatic conditions of MA, Brazil. The critical leaf P content in okra is 3.4 g kg^{-1}.

Keywords: *Abelmoschus esculentus*. Foliar diagnosis. Mineral

RESUMO - O objetivo deste trabalho foi avaliar o crescimento e a produtividade do quiabo em função de doses de fósforo (P) e obter o teor crítico de P foliar, nas condições edafoclimáticas do Maranhão (MA), Brasil. O experimento de campo foi realizado no período de 15 de fevereiro de 2017 a 9 de maio de 2017, em São Luís, MA. O delineamento experimental foi de blocos casualizados, com quatro repetições. Os tratamentos foram doses de 0, 80, 160, 240 e 320 kg ha^{-1} de P_2O_5, na forma de superfosfato simples, no plantio, mais 10 t ha^{-1} de esterco bovino sólido. O aumento da dose de P aumentou a altura das plantas, massa seca de folhas e caule. Com o fornecimento de fósforo a precocidade do florescimento foi maior que em plantas não fertilizadas. . Considerando solos com baixo teor de P ($P_{(resina)}$ = 11 a 25 mg dm^{-3}) e a adubação orgânica mínima recomendada para a cultura do quiabo de 10 t ha^{-1} de esterco bovino sólido, o número de frutos, comprimento do fruto e a produtividade máxima de frutos (9960.36 kg ha^{-1}) foram obtidos com a adubação de 80 kg ha^{-1} de P_2O_5, para as condições edafoclimáticas de MA, Brasil. O teor crítico foliar de P em quiabeiro é de 3,4 g kg^{-1}.

Palavras-chave: *Abelmoschus esculentus*. Diagnose foliar. Nutrição mineral. Recomendação de adubação fosfatada.

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INTRODUCTION

Okra is an important crop for the state of Maranhão (MA), Brazil, playing a strategic socioeconomic role, especially on small farms. The last official statistics indicated MA as the seventh largest national producer and third largest producer in the Northeast and North regions, with 6,012 t of product produced and present in 3,470 agricultural establishments (IBGE, 2012).

Despite the great socioeconomic importance of okra for MA, the predominant cultivation system uses a low technological level and does not have regional technical information, mainly in relation to fertilization and plant nutrition. Fertilizing and liming recommendations are made in accordance with recommendations from other states. As an example, there are fertilization and liming recommendations for okra in the states of São Paulo (SP) (TRANI; PASSOS; NAGAI, 1997; TEODORO et al., 2018), Minas Gerais (MG) (CORREIA; AVELAR FILHO; NAGAI, 1999) and Goiás (GO) (COMISSÃO DE FERTILIDADE DE SOLOS DE GOIÁS, 1988). In the same way, there are few recent studies evaluating the fertilization and nutrition of okra for the edaphoclimatic conditions of MA. For example, Matos et al. (2020) evaluated okra yield as a function of cattle manure doses. For the conditions of the Northeast, there are studies evaluating phosphate fertilization (OLIVEIRA et al., 2013; SANTOS et al., 2019), nitrogen and potassium fertilization (SANTOS et al., 2019), and organomineral fertilization (OLIVEIRA et al., 2014; SANTOS et al., 2019; SALES et al., 2020; SALES et al., 2021).

The accumulation of P by okra is estimated at approximately 24 kg ha^{-1}, being the fifth most absorbed nutrient by the crop (GALATI et al., 2013). However, due to the high rate of P adsorption by tropical soils, the fertilization efficiency is relatively low, requiring large P inputs to the soil. In SP, Trani, Passos and Nagai (1997) recommend using 120 to 360 kg ha^{-1} of P_2O_5 at planting, depending on the $P_{(resin)}$ contents in the soil. In a more recent recommendation for SP, Teodoro et al. (2018) recommend the application of 60 to 280 kg ha^{-1} of P_2O_5 at planting, depending on the $P_{(resin)}$ contents in the soil. There are still recommendations for phosphate fertilization for okra in the state of MG (CORREIA; AVELAR FILHO; NAGAI, 1999), recommending doses of 40 to 240 kg ha^{-1} of P_2O_5, depending on the P content and soil textural class, and in GO (COMISSÃO DE FERTILIDADE DE SOLOS DE GOIÁS, 1988), which recommends from 50 to 350 kg ha^{-1} of P_2O_5, depending on the P content in the soil. It is noteworthy that, in all state recommendations for okra, there is an indication to apply organic fertilizers at planting, regardless of the soil fertility level, the amount of nutrients provided by the organic fertilizer and the subsequent use of mineral fertilizers in planting and in side dressing.

Due to the lack of official fertilization and liming recommendations for okra in the state of MA, farmers and technicians adopt the recommendations from other states, especially São Paulo. Therefore, there is a need to evaluate the response of okra to phosphorus doses for MA. The objective of this study was to evaluate the growth and yield of okra as a function of P doses, as well as obtaining the critical leaf P content, under the edaphoclimatic conditions of MA, Brazil.

MATERIAL AND METHODS

The field experiment was carried out from February 15, 2017, to May 8, 2017, in São Luís, MA, in an area located at 2º36'35.94" South, 44º15'52.02" West, and at 34 meters altitude. The climate of the region is B1Aw, according to Köppen’s classification, characterized as humid, with little rain in winter, between the months of July and December (LABGEO/UEMA, 2002). The minimum and maximum temperatures, rainfall and relative humidity during the experiment were recorded using a conventional meteorological station (Table 1).

Table 1. Maximum, minimum and average temperatures, rainfall, days with rain (DR), and average relative humidity (RH) during the okra cultivation cycle.

Month	Monthly average temperatures			Rainfall	DR	RH
	Maximum	Minimum	Average			
	--------------------------	ºC	--------------------------	mm	days	%
February	30.3	23.6	26.9	162.2	10	89.9
March	30.5	23.8	27.1	442.8	28	91.8
April	31.5	24.3	27.9	362.1	25	84.0
May	32.0	24.0	27.5	98.2	08	85.3

The soil of the experimental area was classified as Typic Hapludult (SOIL SURVEY STAFF, 2014), and the granulometric analyses showed contents of sand, silt and clay of 660, 110 and 230 g kg^{-1}, respectively. Before offsetting up the experiment, soil samples from the 0-20 cm layer were chemically analyzed and showed the following results: pH ($CaCl_2$) = 3.5; organic matter = 11 g kg^{-1}; P_{resin} = 14 mg dm^{-3}; K = 0.7 mmol$_c$ dm^{-3}; Ca = 9 mmol$_c$ dm^{-3}; Mg = 6 mmol$_c$ dm^{-3}; H+Al = 46 mmol$_c$ dm^{-3}; CEC = 61.7 mmol$_c$ dm^{-3} and V = 25%. The P content in the soil of the experimental area was low (TRANI; RAIJ, 1997).

The treatments corresponded to doses of 0, 80, 160, 240 and 320 kg ha^{-1} of P_2O_5, in the form of triple superphosphate applied at planting. The experimental design was randomized blocks, with four replications. The plot was three meters wide and five meters long (15 m^2). The spacing between planting rows was 1.0 m and the spacing between plants was 0.5 m (20,000 plants hectare^{-1}), totaling three planting rows and 30 plants per plot. The usable area (4.0 m^2) was formed by the eight internal plants of the central row of the plot.

Liming was performed 80 days before transplanting to increase base saturation to 80%, as recommended by Trani, Passos and Nagai (1997). 5.6 t ha^{-1} of dolomitic limestone (32% CaO and 15% MgO) were incorporated in the layer from 0 to 30 cm of the soil. In the planting fertilization, 10 t ha^{-1} of solid cattle manure, 20 kg ha^{-1} of N and 90 kg ha^{-1} of K_2O were incorporated in the planting furrow. The side dressing fertilization with 106 kg ha^{-1} of N and 90 kg ha^{-1} of K_2O was divided into equal amounts and applied at 10, 17, 30 and 60 days after transplanting (DAT). The respective doses of mineral P of each treatment were applied together with the planting fertilization. The mineral sources of N, P and K were urea, triple superphosphate and potassium chloride, respectively. Fertilizer doses are in accordance with the most recent recommendation proposed by Teodoro et al. (2018) for state of São Paulo. Organic fertilization provided 19.5, 65.8 and 150.0 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, values estimated considering the contents and the mineralization rates of N, P and K in the cattle manure suggested by Nicoloso et al. (2016).

'Speedy' okra seedlings (Horticeres Sementes, Indaiatuba, SP, Brazil) were planted on February 15th, 2017. Irrigation was not necessary, due to the rainfall that occurred during the experiment (Table 1). Weed control was performed with manual weeding before planting, at 30 and 60 DAT. Preventive control of insect pests was carried out by spraying neem oil at 20 and 40 DAT. The preventive control of foliar diseases was carried out by spraying Bordeaux mixture at 45 and 60 DAT.

The harvests were carried out during the period from March 21, 2017 to May 8, 2017. The fruits that reached more than 15 cm in length were harvested. The number, production and length of fruits were evaluated. The date of beginning of flowering was recorded when 70% of the plants produced the first flower. At 40 DAT, at the beginning of fruiting, the N, P and K contents of the first newly developed leaf (physiologically mature) of all the okra plants in the usable area of the plot were evaluated, as recommended by Trani et al. (2018). At 45 DAT, the height, leaf dry mass and stem dry mass of plants in the usable area of the plot was evaluated.

Data were subjected to analysis of variance using the F test at 5% error probability and, when statistical significance was detected, polynomial regression analysis was performed. Statistical analyses were performed using the procedures of the AgroEstat program (BARBOSA; MALDONADO JÚNIOR, 2016).

RESULTS AND DISCUSSION

Tables 2 and 3 show the summaries of the analyses of variance and polynomial regression for the characteristics evaluated.

Table 2. Summaries of variance analysis for beginning of flowering (BF), plant height (PH) and dry mass of leaf (LDM) and stem dry mass (SDM) of 'Speedy' okra as a function of phosphorus doses.

Phosphorus ($kg\ ha^{-1}\ P_2O_5$)	BF (DAT)	PH (cm)	LDM (g)	SDM (g)
0	35.0	60.1	17.5	27.0
80	33.3	67.4	23.8	46.1
160	33.8	66.8	23.4	48.5
240	33.0	70.3	27.4	51.3
320	34.0	67.5	30.9	56.9
Teste F	2.72^{ns}	3.32*	8.20**	9.25**
CV (%)	2.79	6.25	14.22	16.20

^{ns}, * and ** correspond to not significant, significant at 5% and 1% probability, respectively.

Table 3. Summaries of variance analysis for nitrogen (N), phosphorus (P), potassium (K), length of fruit (LF), number of fruits (NF) and yield of 'Speedy' okra as a function of phosphorus doses.

Phosphorus	N	P	K	LF	NF	Yield
($kg\ ha^{-1}\ P_2O_5$)	---------------------	g kg^{-1}	-----------------------	cm	fruits $plant^{-1}$	kg ha^{-1}
0	34.6	3.4	34.4	16.6	19	7037.04
80	29.1	3.4	32.0	17.4	28	10657.50
160	30.3	3.5	49.2	17.4	23	9719.40
240	29.8	3.5	37.2	17.4	25	9735.69
320	26.9	4.2	37.3	17.0	23	9728.95
F test	16.40**	3.62*	3.02^{ns}	10.35**	8.76**	9.52**
CV (%)	4.58	9.96	20.04	1.24	10.23	9.46

^{ns}, * and ** correspond to not significant, significant at 5% and 1% probability, respectively.

Phosphate fertilization influenced plant height at 45 DAT (Figure 1). The highest plant height (70 cm) was estimated at the dose of 320 kg ha^{-1} of P_2O_5 (Figure 1), seven centimeters more than the treatment without phosphate fertilization. The number of days to the beginning of flowering was lower when P was applied. Between 80 and 320 kg ha^{-1} P_2O_5, the flowering began 1.5 day earlier than when P was not applied (Figure 1). The result agrees with that reported by Uddin et al. (2014), who also observed that the increase of phosphorus dose reduced the number of days to the beginning of flowering. These authors observed earlier flowering (39 days) with 80 kg ha^{-1} of P_2O_5, which was not different from the result obtained with 90 kg ha^{-1} of P_2O_5, but it was five days earlier than without phosphorus application. The increase in plant height as a function of phosphate fertilization was also observed by Firoz (2009) and Uddin et al. (2014), but the authors observed the highest plant height with 100 and 80 kg ha^{-1} of P_2O_5, respectively.

Leaf dry mass and stem dry mass were influenced by phosphorus dose. For both characteristics, the higher the phosphorus dose, the greater the accumulation of leaf and stem mass (Figure 2). The result agrees with those reported by

Firoz (2009) and Uddin et al. (2014), who observed that better phosphorus-nourished okra plants show higher growth, as reported for higher height, number of leaves, leaf size and number of branches. Phosphorus deficiency is characterized by low ATP content and ATPase activity, which are partly responsible for drastic reduction in growth and yield (SUPATRA; MUKHERJI, 2004).

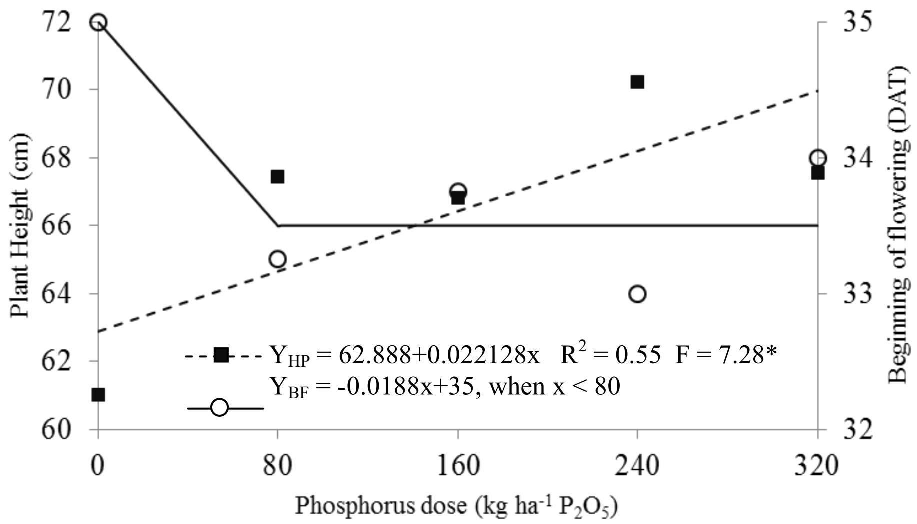

Figure 1. Beginning of flowering and plant height of okra as a function of phosphorus dose at planting. * $p < 0.05$.

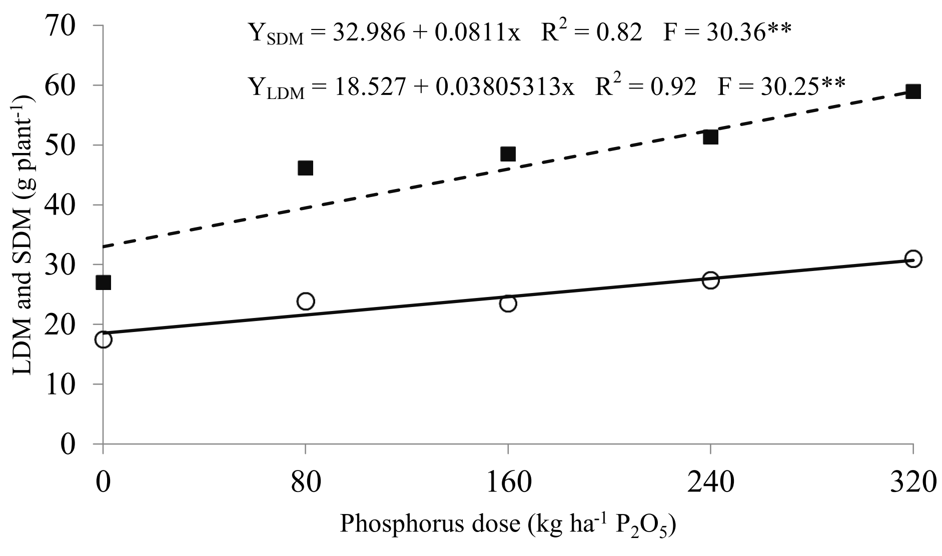

Figure 2. Leaf dry mass (LDM) and stem dry mass (SDM) of 'Speedy' okra fruit as a function of phosphorus dose at planting. ** $p < 0.01$.

The P doses did not affect the leaf K contents, with the average of the treatments being 38.0 g kg^{-1}. Leaf K contents remained within the range from 25 to 40 g kg^{-1}, which is considered adequate in okra leaves (TRANI et al., 2018). On the other hand, the phosphate fertilization affected the leaf N content in the okra diagnostic leaf with increasing P doses ($Y = 33.12 - 0.0183438x$, $R^2 = 0.68$, $F = 44.91$**), possibly due to the dilution of N in the tissue caused by the increase in plant vegetative growth. It is also noteworthy that the N levels were below the range considered adequate for okra, that is, 35 to 50 g kg^{-1} (TRANI et al., 2018).

Phosphate fertilization influenced fruit length and number of fruits per plant (Figure 3), which responded similarly to the increase in P dose at planting. The maximum length (17.3 cm) and number of fruits (26.6 fruits plant^{-1}) were estimated at the dose of 80 kg ha^{-1} P_2O_5. The increase in the number of fruits per plant as a function of the increase in the P dose has also been observed by Oliveira et al. (2007), Firoz (2009), Oliveira et al. (2013) and Uddin et al. (2014). Regarding the absence of phosphate mineral fertilizer at planting, there were increases of 4.8 and 37.1% in length and number of fruits, respectively, at the optimal dose of P.

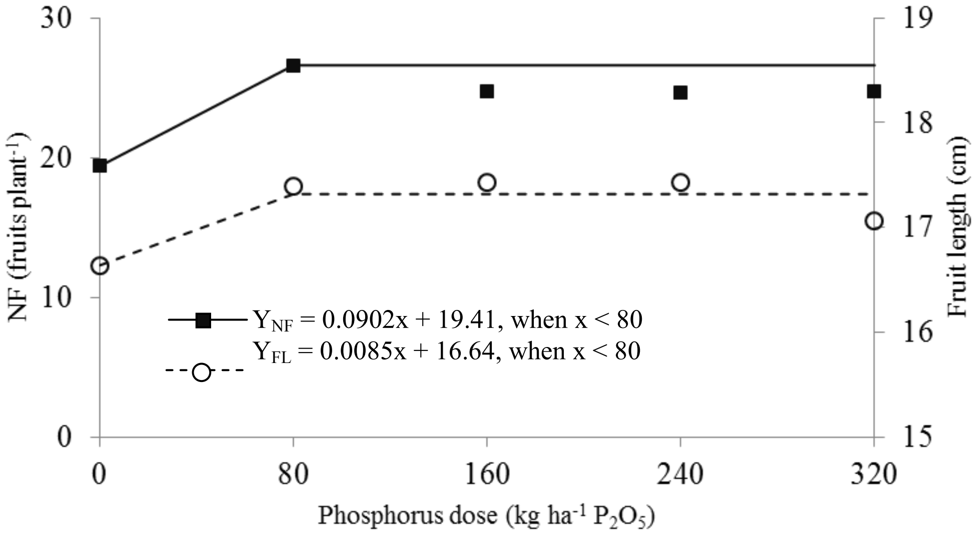

Figure 3. Number of fruits (NF) and fruit length of 'Speedy' okra as a function of phosphorus dose at planting.

The leaf P content increased as a function of the increase in the dose of phosphate fertilizer (Figure 4). The highest leaf P content (3.9 g kg^{-1}) was estimated at the dose of 320 kg ha^{-1} P_2O_5. Leaf P contents, at all P doses, were considered adequate for the okra crop, between 3 and 5 g kg^{-1} (TRANI et al., 2018). The adequate P content in the diagnostic leaf, even in the absence of mineral P application in soil with low nutrient content, can be attributed to P from the cattle manure applied at planting. The application of organic fertilizer in the okra crop is a practice recommended by Trani, Passos and Nagai (1997) and Teodoro et al. (2018), and adopted in this work. The most recent recommendation indicates the use of 10 up to 20 t ha^{-1} of cattle manure, regardless of the soil fertility level, the amount of nutrients provided by the organic fertilizer and the need for subsequent mineral fertilization. Considering the average P_2O_5 content in solid cattle manure of 14.0 kg t^{-1} and the decay rate of mineralized P proposed by Nicoloso et al. (2016), the 10 t ha^{-1} of aged cattle manure applied at planting has the potential to provide 65.8 kg ha^{-1} of P_2O_5 during the present okra cycle. This amount of P_2O_5 released by cattle manure is equal to 22% of the P requirement indicated by Teodoro et al. (2018) for soils with low P content, to be supplied with mineral fertilizer.

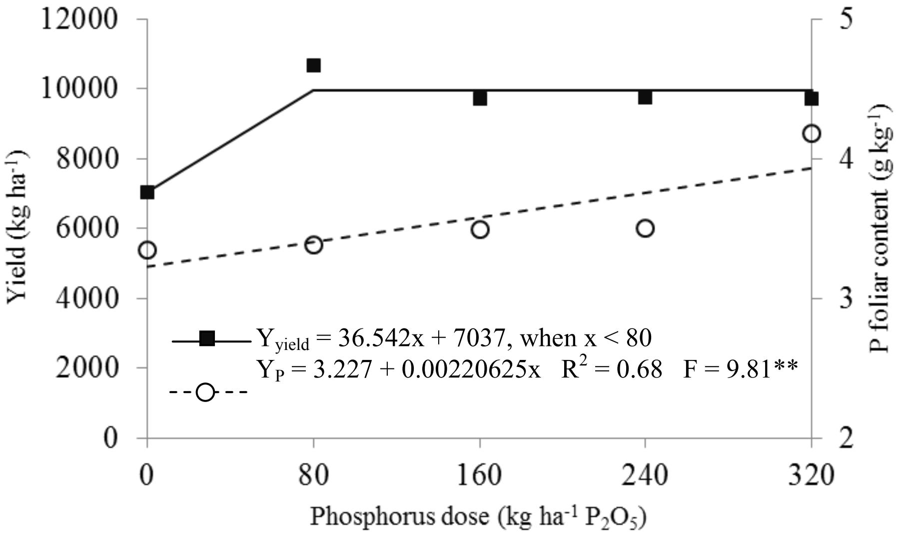

Figure 4. P foliar content and yield of 'Speedy' okra as a function of phosphorus dose at planting. ** $p < 0.01$.

The maximum fruit yield (9960.36 kg ha^{-1}) was obtained with 80 kg ha^{-1} P_2O_5 (Figure 4). This yield represents an increase of 41.5% compared to fruit yield in the absence of mineral phosphate fertilizer at planting. At the dose of 80 kg, which allowed the maximum yield to be reached, the leaf P content was 3.4 g kg^{-1}. Increasing the dose of P increased the leaf P content, but without increasing the yield. This value is within the range considered adequate by Trani et al. (2018) for the okra crop, which is 3.0 to 5.0 g kg^{-1}.

Considering the recent recommendation by Teodoro et al. (2018), who indicate the phosphate mineral fertilization at planting with 280 kg ha^{-1} of P_2O_5 for soils with less than 25 mg dm^{-3} of P, the value found in the present study represents a 71.4% reduction in the need for P for the okra crop. It is noteworthy, however, that the phosphate fertilization recommendations proposed by Teodoro et al. (2018) are for expected yields of 15 to 22 t ha^{-1}, values higher than the maximum yield obtained in the present study. Also, high rainfall (1065 mm) during the experimental period may have contributed to the low yield.

CONCLUSION

Considering soils with low P content and the minimum recommended organic fertilization for the okra crop of 10 t ha^{-1} of solid cattle manure, the maximum fruit yield is obtained with mineral fertilization at planting of 80 kg ha^{-1} of P_2O_5, for the edaphoclimatic conditions of the experimental site.

The critical leaf P content in okra to obtain the maximum fruit yield was 3.4 g kg^{-1}.

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