Original Research Article

Initial growth of sesame under nutrient omission

ABSTRACT

Sesame is an oilseed, nutritionally important in the world, for its seeds are rich sources of protein and calcium. Fertilizer management is fundamental for the development of this crop and consequently to increase its productivity. In this context, this research aimed to evaluate the initial development of sesame under nutrient omission in the Cerrado of Mato Grosso, Brazil. The experiment was conducted under controlled conditions in a greenhouse, at the Federal University of Rondonópolis. The soil used was Oxisol and the crop used was black sesame. The design was in randomized blocks, with five treatments (absence of nitrogen, absence of phosphorus, absence of potassium, complete fertilization and control (absence of nutrients)) and four repetitions. The variables analyzed were pH, chlorophyll index, plant height, number of leaves, stem diameter, leaf area, aboveground dry mass, root volume, and root dry mass. The pH variable showed a statistical difference 45 days after emergence. The chlorophyll index showed a difference between 30 and 45 days after emergence. The stem diameter, leaf area, plant height, number of leaves, aboveground dry mass, root volume, and dry mass showed a difference among treatments. The absence of nitrogen, phosphorus, and potassium significantly affects the initial development of sesame.

Keywords: Sesamum indicum, nitrogen fertilization, phosphate fertilization, potassium fertilization.

1. INTRODUCTION

Sesame (*Sesamum indicum* L.) is an annual, oleaginous plant belonging to the Pedaliaceae family that has high oil content and quality, and the seeds are rich sources of protein and calcium [1] [2].It is an economically and nutritionally important crop, so it is increasing its demand in the global market [3].

This oilseed grows well in different seasons under different cropping systems [4]. One of the limitations in sesame production is the lack of information about the nutritional aspects of the crop, and nutrient deficiency can affect its development. There are some studies showing plant response to fertilization with specific nutrients.[5] observed the effects of nitrogen fertilization on sesame growth and found that yield is greatly influenced by nitrogen application.Research on the influence of nitrogen fertilizer management on sesame has found that nitrogen influences the phytometric and yield characteristics of sesame [6].

[7] explain that phosphate fertilization in sesame significantly increases sesame growth and seed yield, even recording a yield of 770kg/ha^{-1}. [8]studying the influence of potassium and phosphate fertilization on sesame cultivation, observed that fertilization significantly influences the phytometric characteristics of the crop.[9]explain in their research on the

influence of potassium fertilization on sesame development that the application of this nutrient influences the growth and production of the crop.

In this context, soil fertility management in sesame cultivation can influence its growth. Considering the nutritional importance of the crop, this research aimed to evaluate the initial development of sesame under nutrient omission in the Cerrado of Mato Grosso, Brazil.

2. MATERIAL AND METHODS

The experiment was conducted in a greenhouse at the Federal University of Rondonópolisin Mato Grosso, Brazil, located at the geographical coordinates 16º 27' 50" S, 54º 34' 49" W. The region's climate is of type Aw [10]. In addition, it is characterized by a tropical climate, rainy in summer and dry in winter [11].

The soil used in the experiment was Oxisol, according to Embrapa's classification [12]. The soil was collected at a depth of 0 to 0.20m under Cerrado vegetation, whose geographic coordinates are 16º 27’ 35” S, 54º 35’ 00” W (Figure 1). After the collection, it was sieved in a 4mm mesh for the composition of the experimental unitsand 2mm mesh for chemical and granulometric characteristics of the soil[13](Table 1).

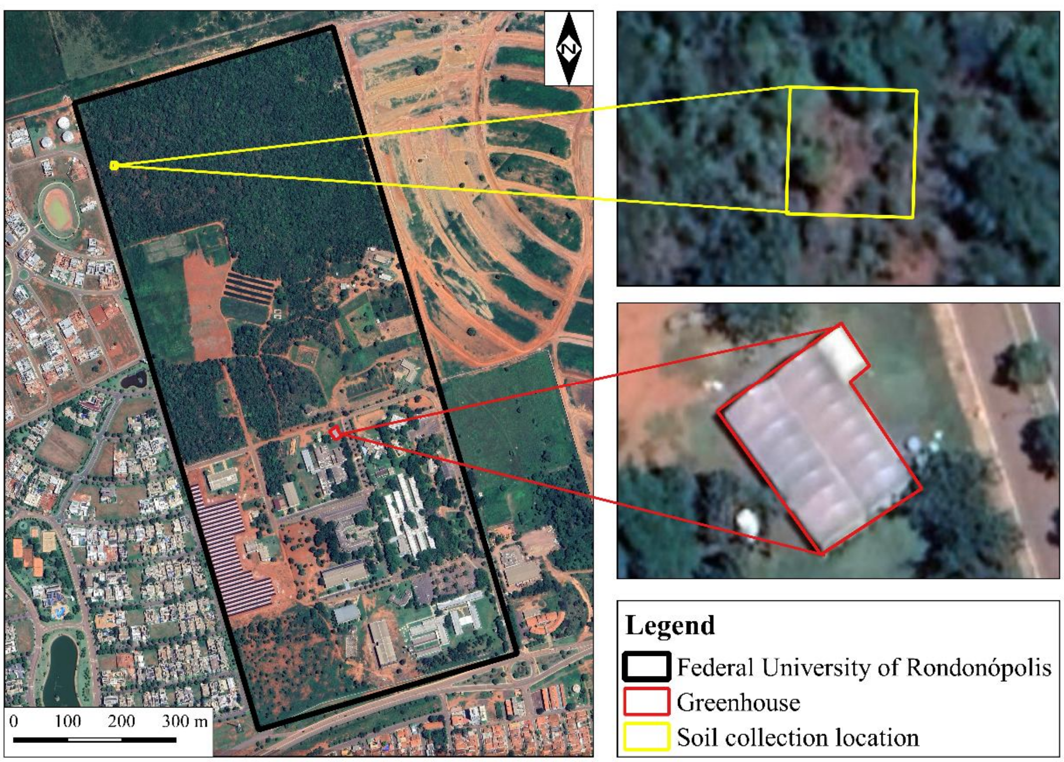

Fig. 1. Geographic location of the greenhouse and the soil collection location, at the Federal University of Rondonópolis, Rondonópolis – MT.

Table 1. Chemical and granulometric characteristics of Oxisol collected in the 0 to 0.20m depth layer.

pH	P	K	S	Ca	Mg	Al	H+Al	CEC	SB	OM	V	m
$CaCl_2$	……mg dm^{-3}…….			…….. $cmol_c$ dm^{-3}………				$cmol_c$ dm^{-3}		g kg	….. % …..	
4.3	1.5	18	2	0.5	0.2	0.6	4.8	5.6	0.8	21.3	13.5	44.4
Zn	Mn	Cu	Fe	B				Clay	Silt	Sand		
……………………… mg dm^{-3}……………..…………								……………..…g kg^{-1}……………..				
0.7	21.8	0.2	64	0.15				475	100	425		

CEC:Cations Exchange Capacity, SB: Sum of bases,OM: Organic matter, V:Base saturation,m:Aluminum saturation.

The design was a randomized block, with 5 treatments: absence of nitrogen, absence of phosphorus, absence of potassium, complete (complete fertilization of nutrients) and control (absence of nutrients), and four repetitions totaling 20 experimental units (Figure 2). The black sesame crop was used and pots with a capacity of 1.5 dm-3. Sowing took place on April 5, 2022, when 10 seeds were sown per pot, and later thinning was performed, leaving only 3 plants per pot.

Fig. 2. 3D sketch of the isometric view of the nutrient omission experiment on sesame cultivation at the Federal University of Rondonópolis.

The base saturation (V%) was raised to 70% in the experimental unitsaccording to the recommendation [14]. The soil was incubated with liming 30 days before sowing and the moisture was adjusted to 60% of the maximum water-holding capacityaccording to field capacity determination methodology[15]. Irrigation during the experimental period was done by the gravimetric method[16].

The nitrogen recommendation was 40 mg dm^{-3}[14], using urea as a source. The nitrogen fertilization was done in two applications, the first 10 days after sowing and the second 7 days after the first application. The potassium recommendation was 60 mg dm^{-3} [14], using simple superphosphate as the source. The phosphorus recommendation was 80 mg dm^{-3}[14], and the source used was potassium chloride. The recommendation for FTE (Fritted Trace Elements. Composition: Boron 1.8%, Copper 0.8%, Iron: 3.0%, Manganese 2.0%, Molybdenum 0.1% and Zinc 9.0%) was 50 mg dm^{-3}.

Soil pH was determined at sowing and 45 days after emergence, using $CaCl_2$ solution (concentration 0,01 mol L^{-1}) and pH meter equipment (Figure 3). The chlorophyll index was measured at 30 and 45 days after emergence using a Minolta portable Chlorophyll meter SPAD-502 (Soil Plant Analysis Development). The height of plants was determined with a graduated ruler, which was measured from the ground to the apex of the highest leaf. The number of leaves was counted manually, and the diameter of the stem was determined with a digital pachymeter. Plant height, number of leaves, and stem diameter were measured at 15, 30, and 45 days.

Fig.3. Determination of Oxisol pH in the soil laboratory of the Federal University of Rondonópolis, Rondonópolis-MT

For leaf area, the leaf area integrator model LI 3100was used to measure the total leaf area of each plot (pot). The determination of the dry mass of the aerial part of the sesame was performed at the moment of cutting, placing the aerial part in a closed circulation oven at 65ºC, for 72 hours to dry them and later weighing them on a semi-analytical scale[17]. The root volume was determined with a 500mL graduated cylinder, in which the root of each plant was placed inside the cylinder with a known volume of water, and the excess volume difference observed after placing the root equals its volume[17].

The data were submitted to variance analysis by the F test, and when significant, to the Tukey test, at a 5% error probability. For the statistical analyses, the SISVAR software was used [18].

3. RESULTS AND DISCUSSION

3.1 pH do solo

For the pH variable, it was observed that at the time of sowing there was no significant difference (Table 2). The soil acidity was corrected, increasing the base saturation (V%) to 70% in all treatments, so that all had the same condition at the time of application of the treatments and sesame sowing. This justifies the fact that initially no difference in pH was observed among the treatments.

Table 2. Oxisol pH at the time of sesame sowing (initial) and 45 days after emergence as a function of nutrient omission.

Treatments	pH	
	Initial$^{n.s.}$	45 DAE
Absence of N	5.4	5.21bc
Absence of P	5.28	4.83d
Absence of K	5.27	5.45ab
Complete	5.26	5.57a
Control	5.43	5.07cd
CV (%)$^{(a)}$	3.91	2.99

N: nitrogen; P: phosphorus; K: potassium; DAE: days after emergency; $^{(a)}$ coefficient of variation; n.s.: not statistically significant. Means followed by equal letters do not differ statistically by the Tukey test (*P*= .05)

At 45 days after crop emergence, a difference was noted among the treatments (Table 2). There was a reduction in pH at 45 days after emergence concerning the initial pH in most treatments. Some factors may have influenced the acidification of the soil during the experiment, such as nitrogen fertilization in some treatments.

[19] observed in their studies on the influence of liming and doses of nitrogen on soil pH that as the dose of N increased, the greater the acidification of the soil, i.e. nitrogen fertilization acidifies the soil lowering the pH.

During crop growth, the plant needs to absorb nutrients through the roots to develop properly, and the process of releasing H^+ ions by the roots also occurs, so the soil acidifies and consequently lowers the pH.

3.2 Chlorophyll index

For the chlorophyll index, a significant difference was observed at 30 and 45 days after sesame emergence (Figure 4). At 30 days, the treatments with nitrogen omission, potassium omission, and complete were those with the highest chlorophyll index, 35.72, 39.17, and 41.40, respectively. At 45 days, in the treatments with complete and omission of nitrogen the highest chlorophyll indices were observed, 47.45 and 45.62, respectively.

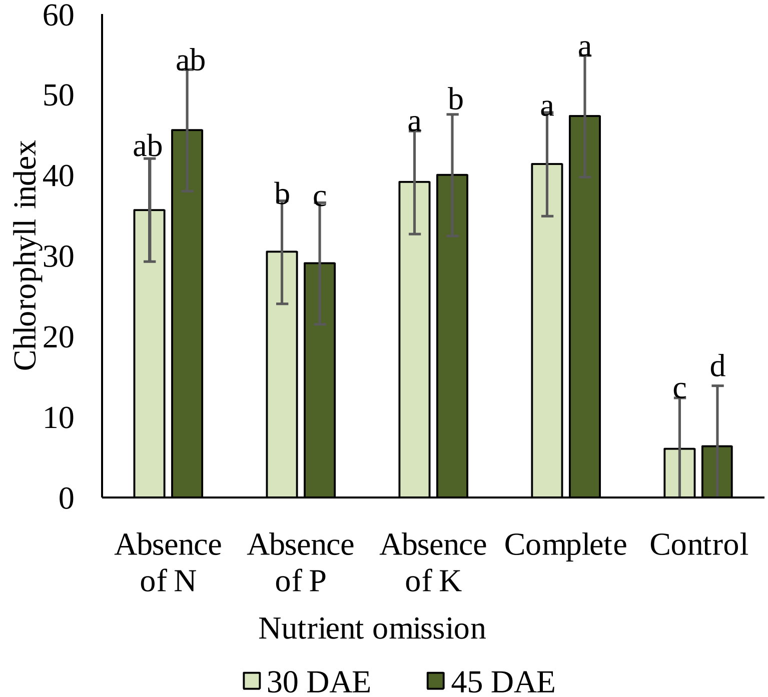

Fig. 4.Chlorophyll index as a function of nutrient omission at 30 and 45 days after emergence of black sesame. DAE: Days after emergence; N: nitrogen; P: phosphorus; K: potassium. The vertical bars are the confidence interval for the mean (*P*= .05).

[20] studying the effects of nitrogen, phosphorus, and potassium on cotton leaves found that the combined application of nitrogen, phosphorus, and potassium significantly increased the chlorophyll index compared to treatments that had no application of phosphorus and potassium. This explains why the complete treatment obtained the highest chlorophyll values at 30 and 45 days after emergence. Furthermore, the control treatment obtained the lowest chlorophyll indexes in both evaluations.

The treatment with phosphorus omission was the one that showed the lowest chlorophyll index after the control. The supply of phosphorus provides greater nitrogen uptake by the crop, for having as one of its functions the formation of ATP, which releases energy for nitrogen uptake by the crop, in addition, nitrogen has a high correlation with the chlorophyll index, for acting directly in the photosynthesis process [21] [22]. This explains why the treatment with phosphorus omission provided low chlorophyll index values even with the application of nitrogen in this treatment.

At 30 days after sesame emergence, the treatment with nitrogen and potassium omission had no significant difference in chlorophyll index compared to the treatment with complete fertilization. At 45 days after emergence, the treatment with the absence of potassium had a lower chlorophyll index than the treatments with nitrogen omission and complete fertilization.Studies on the influence of potassium fertilization on the chlorophyll index of arugula plants observed that increased potassium availability favors nitrogen assimilation and consequently elevates photosynthetic activity [23]. Therefore, potassium omission influenced the decrease in chlorophyll index as sesame developed.

3.3 Plant height

For the variable plant height there was a significant difference at 15, 30, and 45 days after emergence (Figure 5). Initially, at 15 days, the complete treatment showed the greatest plant height (20.40 cm). In addition, the control and the absence of phosphorus showed the lowest values of height, 4.17, and 4.90 cm, respectively.

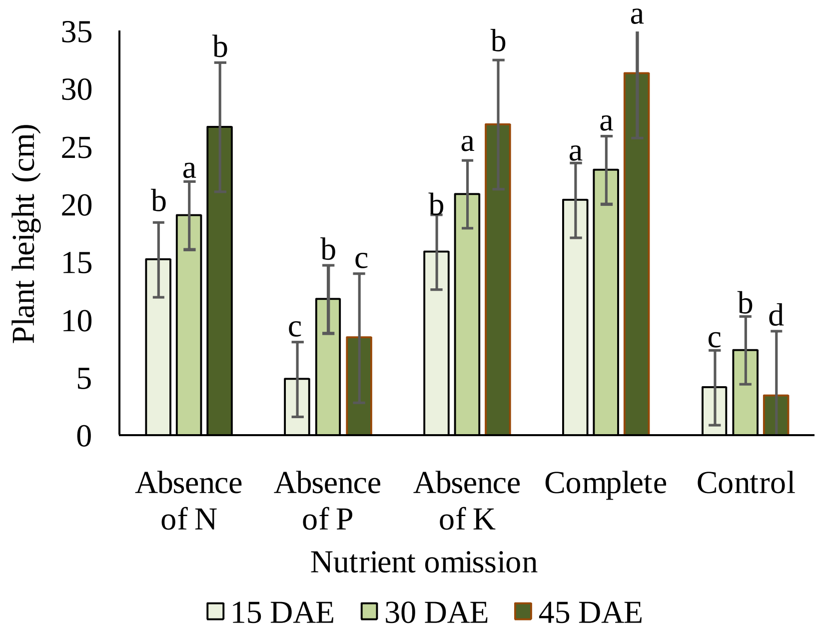

Fig. 5. Plant height (cm) as a function of nutrient omission at 15, 30, and 45 days after emergence of black sesame. DAE: Days after emergence; N: nitrogen; P: phosphorus; K: potassium. Vertical bars are the confidence interval for the mean (*P* =.05).

Thus, the importance of phosphorus in the initial development of sesame can be seen. The height of the plant in this treatment without application of phosphorus was statistically equal to the treatment without application of any nutrient (control) at 15 and 30 days after emergence (Figure 5).

At 30 and 45 days after crop emergence, it was observed that the treatments with phosphorus omission and control presented the lowest values of plant height, while the complete treatment presented the highest values (Figure 5). At 30 days, the treatment with absence of nitrogen and potassium were statistically equal to the complete treatment, but at 45 days, the complete treatment presented the highest plant height (Figure 5).

Research on the effects of nitrogen and phosphorus on sesame plant height on vertisol observes that nitrogen and phosphorus influence the growth parameters of the crop; moreover, the interaction of the nutrients significantly increases plant height concerning the control treatment, without the application of nitrogen and phosphate fertilizer [24].

[25] studying the influence of nitrogen and potassium fertilization on sesame development, noted that nitrogen fertilization significantly influenced plant height at 30 days after sowing, furthermore, in the initial development of sesame, they also observed increased plant height with the application of potassium doses.

Nitrogen plays a role in several physiological processes, and potassium also performs functions such as enzyme activation therefore the availability of these nutrients directly influences the vegetative growth of crops. [25]. This shows the importance of nitrogen and potassium fertilization for the vegetative development of plants. This justifies that the treatments with the absence of nitrogen, phosphorus, and potassium did not develop adequately as the treatment with a complete fertilization.

Therefore, the importance of complete fertilization of the nutrient nitrogen, phosphorus and potassium for the initial development of the sesame can be seen. The difference in plant height between treatments at 15 (Figure 6A), 30 (Figure 6B) and 45 (Figure 6C) days after emergence is visible.

Fig. 6.Plant height as a function of nutrient omission at (A) 15; (B) 30; and (C) 45 days after emergence of black sesame. -N: absence of nitrogen; -P: absence of phosphorus; -K: absence of potassium; C: complete; T: control.

The soil pH at 45 days after emergence in the treatment with absence of phosphorus was below the adequate range for crop development, 4.8 (Table 2). This may have also influenced the development of plant height in the treatment with phosphate fertilizer omission.

3.4 Stem diameter

For stem diameter, there was a statistical difference at 30 and 45 days after sesame emergence. At 30 and 45 days, the treatments with absence of nitrogen, absence of potassium and complete showed the largest stem diameters, while in the treatments with absence of phosphorus and control were observed the lowest values (Figure 7).

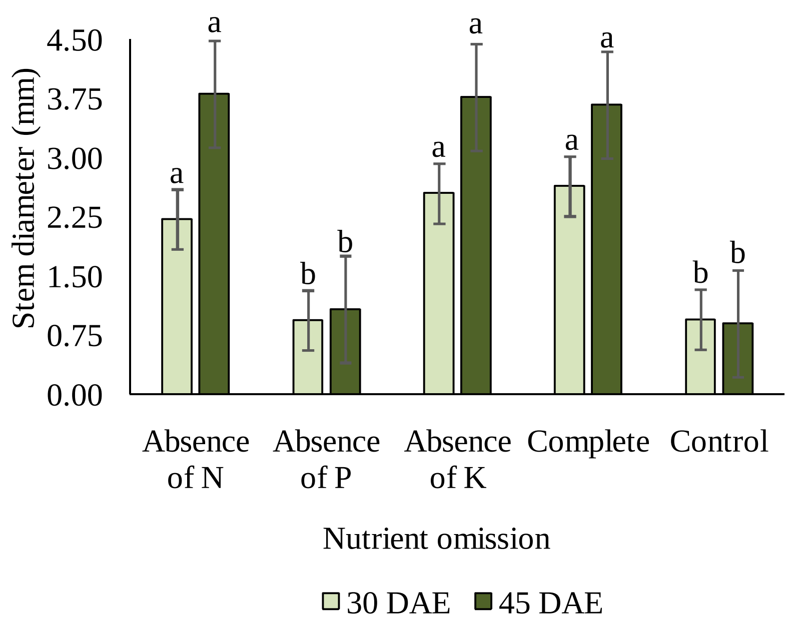

Fig. 7.Stem diameter (mm) as a function of nutrient omission at 30 and 45 days after emergence of black sesame. DAE: Days after emergence; N: nitrogen; P: phosphorus; K: potassium. Vertical bars are the confidence interval for the mean (*P* = .*05*).

[26] in their studies on the influence of phosphate fertilization on the initial growth of seven different crops, observed that the application of phosphorus influenced the initial growth of the crops, distinctly. Research with nutrient omission in early sesame development observed a 70% reduction in stem diameter of plants submitted to phosphorus omission in comparison with plants submitted to complete fertilization [27].

Phosphorus omission significantly affected sesame stem diameter at 30 and 45 days after emergence, with up to a 71% reduction compared with the complete fertilization treatment (Figure 7).Thus, the importance of phosphate fertilization in the initial development of sesame can be observed because the treatment with the absence of this macronutrient showed low values for plant height and stem diameter. (Figure 5 and Figure 7).

3.5 Number of leaves

For the variable number of leaves there was a statistical difference for 30 and 45 days after emergence (Figure 8). At 30 days, the absence of phosphorus and the control showed the lowest values for number of leaves, while the absence of potassium and the complete treatment showed the highest number. At 45 days, the highest number of leaves was observed in the treatments absence of nitrogen, absence of potassium and complete. Thus, for plant height and stem diameter, phosphorus was the nutrient that most significantly affected sesame development.

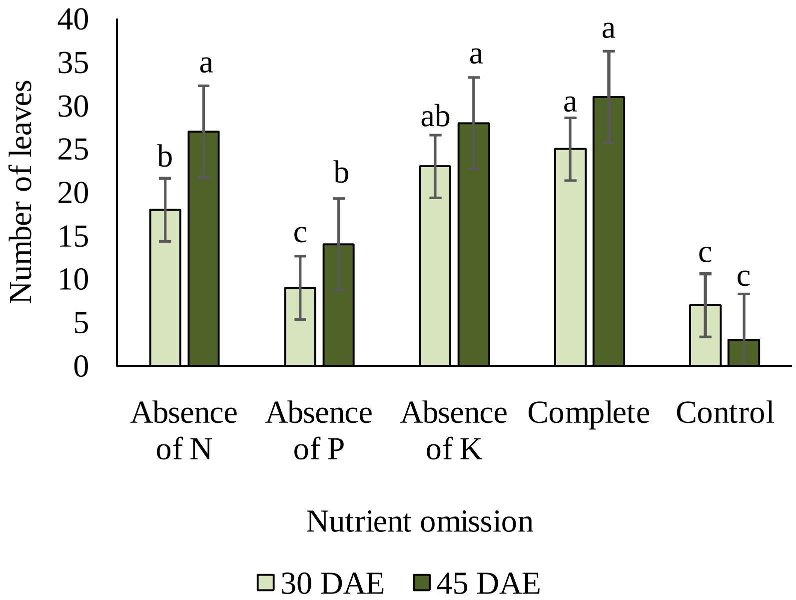

Fig. 8.Number of leaves as a function of nutrient omission at 30 and 45 days after emergence of black sesame. DAE: Days after emergence; N: nitrogen; P: phosphorus; K: potassium. Vertical bars are the confidence interval for the mean (*P = .05*).

A study with cotton under the omission of macronutrients such as nitrogen, phosphorus, and potassium, observed a significant reduction in the number of leaves in the treatments with nitrogen, phosphorus, and potassium omission, in which the plants with nitrogen and phosphorus deficiency showed a reduction of up to 65% at 50 days after sowing, compared to the treatment with a complete fertilization [27].

Sesame plants were significantly affected by the treatments with nitrogen and phosphorus omission 30 days after emergence, reaching a reduction in the number of leaves of up to 64% compared with the plants submitted to complete fertilization. At 45 days, the treatment with phosphorus omission showed a 55% reduction in the number of leaves compared to the complete treatment.

3.6 Leaf area

For the variable leaf area, there was a significant difference between the treatments. Note that the absence of nitrogen and potassium did not differ statistically from the complete treatment, so these treatments obtained the largest leaf areas. The absence of phosphorus did not differ from the control, obtaining the smallest leaf areas (Figure 9). The leaf area of sesame was significantly affected by the absence of phosphorus compared to the complete fertilizer treatment.

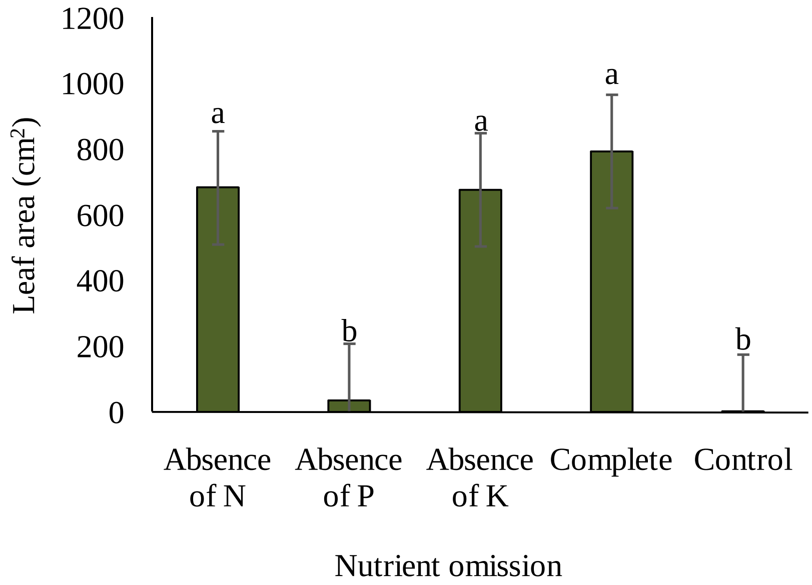

Fig. 9. **Leaf area (cm^2) as a function of nutrient omission in black sesame cultivation. N: nitrogen; P: phosphorus; K: potassium. Vertical bars are the confidence interval for the mean (*P = .05*).**

[5] in their studies with sesame under the influence of nitrogen fertilization, found that nitrogen greatly influences the growth and production of sesame, moreover, they observed that fertilization with nitrogen, phosphorus, and potassium significantly increased the production of the crop. [28] in their research on the initial development of quinoa under the influence of phosphate fertilization, explained that phosphorus fertilization influences the initial growth of the crop.

In this context, it is observed that for sesame, the nutrient that most influenced the initial development of the crop as a function of the response variable leaf area was phosphorus, in which the plant statistically obtained the same behavior as the treatment with the absence of nutrients (Figure 9).

3.7 Aboveground dry mass

For the aboveground dry mass, there was a statistical difference between the treatments (Figure 10). The highest masses were found in the treatments without nitrogen, without potassium, and complete, 4.50, 4.01, and 5.66, respectively. The lowest masses were observed in the treatments with the absence of phosphorus and control. The aboveground dry mass of sesame was significantly affected by the absence of phosphorus compared to the complete fertilizer treatment.

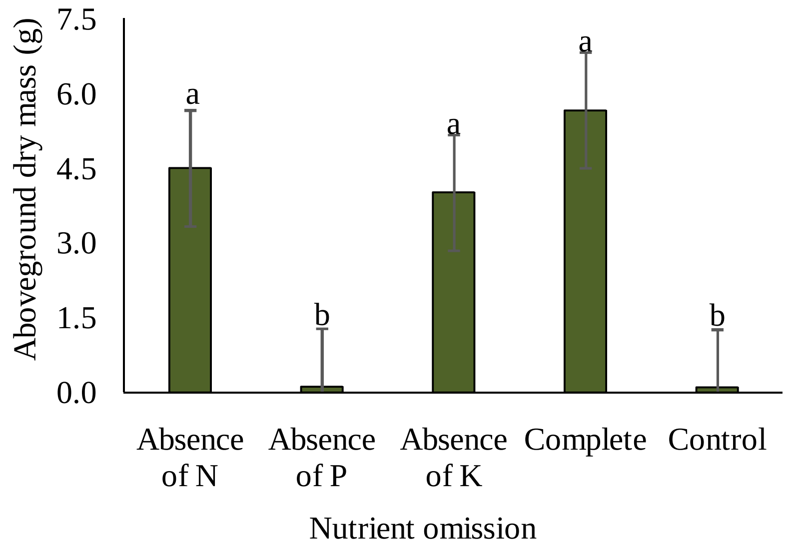

Fig. 10.**Aboveground dry mass (g) as a function of nutrient omission in black sesame cultivation. N: nitrogen; P: phosphorus; K: potassium. Vertical bars are the confidence interval for the mean (*P* = *.05*).**

[7] in their studies with phosphate fertilization in sesame cultivation, explain that the application of superphosphate in the adequate dose significantly increases plant height, leaf area index, and consequently the dry matter of the crop. This justifies that the treatment of phosphorus omission presented low values of plant height (Figure 6), leaf area index (Figure 9), and dry mass of the aerial part (Figure 10).

An almost 98% reduction in aboveground dry mass is observed in the treatments with phosphorus omission in comparison with the treatment with a complete fertilization.Thus, it is observed that phosphorus is the macronutrient that most interferes with the dry mass of the aboveground part in the initial development of sesame.

3.8 Root volume

For the root volume variable, there was a statistical difference among treatments, in which the treatments without potassium and complete showed the highest volumes, 47.50 and 58.75, respectively (Figure 11). The lowest root volume values were observed in the control and the absence of phosphorus.

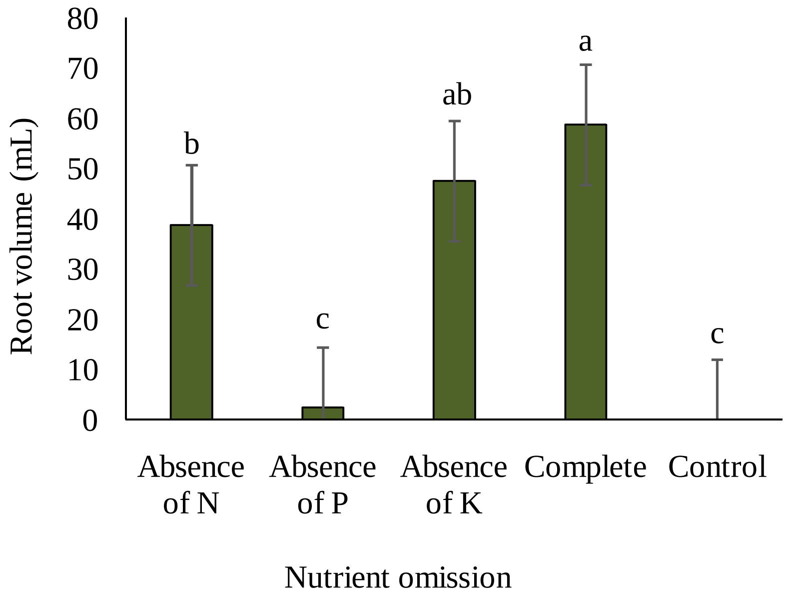

Fig. 11. **Root volume (mL) as a function of nutrient omission in black sesame cultivation. N: nitrogen; P: phosphorus; K: potassium. Vertical bars are the confidence interval for the mean (*P = .05*).**

In the treatments absence of potassium and the complete treatment, nitrogen was Applied. [29] in their research on nitrogen fertilization, explain that the application of this fertilizer to the soil increases the mineralization of organic matter in the soil. This may have influenced these treatments to have greater root development and consequently greater volume.

The absence of phosphorus inhibited the initial development of sesame roots. This nutrient is very much required by sesame culture because it stimulates root growth, thus obtaining better root development. Moreover, the application of phosphate fertilization results in significant improvements in sesame growth and yield [30].

The difference in root volume in the treatments is visibly observed, especially when comparing the absence of phosphorus and the control with the other treatments (Figure 12). Note that complete fertilization is fundamental for adequate root development; moreover, when there is an absence of any nutrient, deficiency occurs in the sesame, affecting its growth.

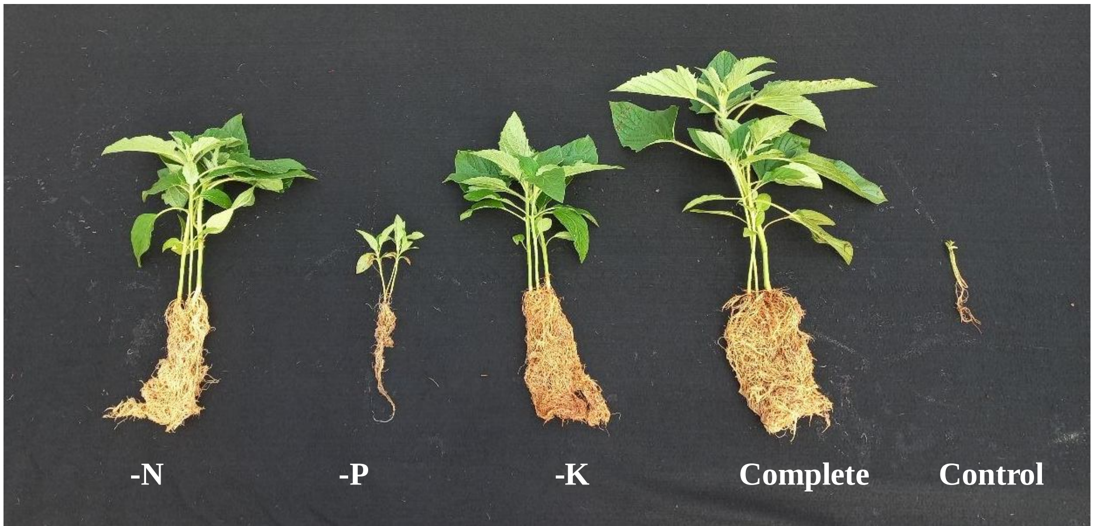

Fig. 12. Root volume (mL) as a function of nutrient omission in black sesame cultivation. -N: absence of nitrogen; -P: absence of phosphorus; -K: absence of potassium.

The absence of phosphorus and nitrogen significantly affected root volume in early sesame development when compared to the complete fertilization treatment. The absence of nitrogen provided up to a 35% reduction in root volume, while the absence of phosphorus provided up to a 96% reduction in root volume. Thus, the importance of complete fertilization for the initial root growth of sesame is noted.

3.9 Root dry mass

For the root dry mass, statistically, there was a significant difference between treatments (Figure 13). In the complete treatments, the absence of nitrogen and potassium, the largest dry masses were observed, thus, it is noted that nitrogen and potassium fertilizers do not interfere initially in sesame root development, in relation to dry mass. On the other hand, the absence of phosphorus and the control showed the lowest dry masses.

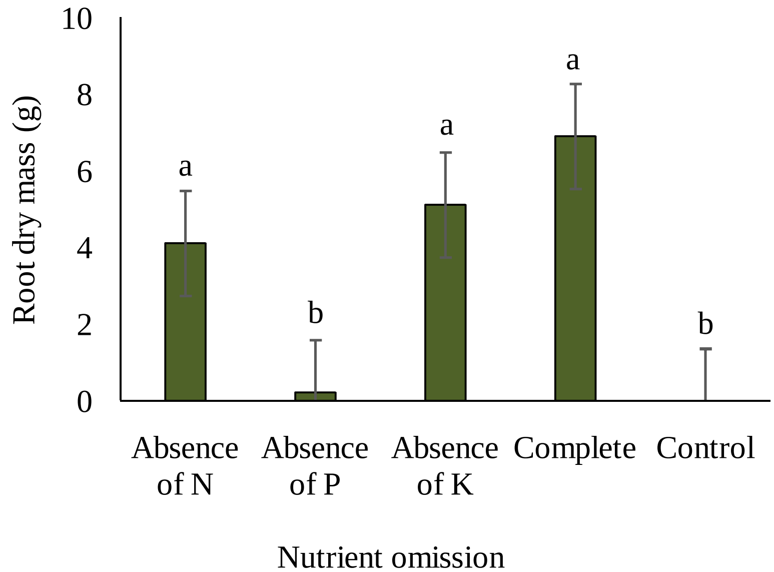

Fig. 13. Root dry mass (g) as a function of nutrient omission in black sesame cultivation. N: nitrogen; P: phosphorus; K: potassium. Vertical bars are the confidence interval for the mean (*P = .05*).

[31] in their studies on the morphological response of radish as a function of phosphate fertilization, observed the influence of phosphorus on the variables root length and root dry mass. This explains why the treatment with no phosphorus showed low values for root volume and root dry mass of the sesame in relation to the other treatments.

The absence of phosphorus significantly affected root dry mass in early sesame development when compared to the complete fertilization treatment. The absence of phosphorus provided up to a 97% reduction in root dry mass when compared to the complete fertilization treatment.

4. CONCLUSION

The omission of nitrogen, phosphorus and potassium in sesame fertilization affects the initial development of the crop, phosphorus being the most limiting nutrient in the Brazilian Cerrado Oxisol.

REFERENCES

1. ÖLMEZ YA, SEVILMIŞ D. Importance of Oilseed Crop Sesame (*Sesamum indicum* L.): A review. Journal of MuşAlparslan University Agricultural Production and Technologies. 2021; 1(2): 86-97. Available: https://dergipark.org.tr/en/pub/maujan/issue/69491/1106547

2. SHARMA L, SAINI CS, PUNIA S, NAIN V, SANDHU KS. Sesame (*Sesamum indicum*) Seed. In: Tanwar B, Goyal A, editors. Oilseeds: Health Attributes and Food Applications. Springer, Singapore: 2021. Available: https://doi.org/10.1007/978-981-15-4194-0_12

3. MYINT D, GILANI SA, KAWASE M, WATANABE KN. Sustainable Sesame (*Sesamum indicum* L.) Production through Improved Technology: An Overview of Production, Challenges, and Opportunities in Myanmar. Sustainability. 2020; 12(9): 3515. Available: https://doi.org/10.3390/su12093515

4. KUMAR KC, MAITRA S, SHANKAR T, PANDA M, SAGAR L. Growth and productivity of sesame (*Sesamum indicum* L.) as influenced by spacing and nitrogen levels. Crop Research. 2022; 57(3): 190-194. Available: 10.31830/2454-1761.2022.029

5. ZENAWI G, MIZAN, A. Effect of Nitrogen Fertilization on the Growth and Seed Yield of Sesame (Sesamum indicum L.). International Journal of Agronomy. 2019; 2019:1-7. Available: https://doi.org/10.1155/2019/5027254

6. SILVA ES, DIAS JA, MEDEIROS DA, DE MEDEIROS RD, GUEDES YA, DE ALBUQUERQUE JDAA et al. Management of nitrogenous fertilization in sesame (*Sesamum indicum L.*) growth and production. Journal of Experimental Agriculture International. 2019; 40: 1-11. Available: http://www.sdiarticle3.com/wp-content/uploads/2019/08/Revised-ms_JEAI_50580_v1.pdf

7. BHAVANA T, SHANKAR T, MAITRA S, SAIRAM M, KUMAR PP. Impact of phosphorus and sulphur levels on growth and productivity of summer sesame. Crop Research. 2022; 57(3): 178-184. Available: 10.31830/2454-1761.2022.027

8. AHMAD F, AHMAD J, NAWAZ H, ABBAS MW, SHAH MA, IQBAL S, et al. Influence of sulphur and potassium levels on yield and yield attribute of sesame (Sesamum indicum L.). Research in Agriculture Livestock and Fisheries. 2018;5(2):147-150. Available: https://doi.org/10.3329/ralf.v5i2.38050

9. BIJARNIA A, SHARMA OP, KUMAR R, KUMAWAT R, CHOUDHARY R. Effect of nitrogen and potassium on growth, yield and nutrient uptake of sesame (*Sesamum indicum L.*) under loamy sand soil of Rajasthan. Journal of Pharmacognosy and Phytochemistry. 2019; *8*(3): 566-570. Available: https://www.phytojournal.com/archives/2019/vol8issue3/PartK/8-3-12-834.pdf

10. KÖPPEN W, GEIGER R. Klimate der Erde. Justus Perthes, Gotha. Wall-map 150 x 200cm. 1928. Germany.

11. APARECIDO LEO, MORAES JRSC, MENESES KC, TORSONI GB, LIMA RF, COSTA CTS. Köppen-Geiger and Camargo climate classifications for the Midwest of Brasil. Theoretical and Applied Climatology, 2020; 142(3-4): 1133–1145. Available: https://doi.org/10.1007/s00704-020-03358-2

12. EMBRAPA. Sistema Brasileiro de Classificação de Solos. 5th ed. Brasília; 2018. Brazil. Available: https://www.embrapa.br/solos/busca-de-publicacoes/-/publicacao/1107206/sistema-brasileiro-de-classificacao-de-solos

13. EMBRAPA. Manual de métodos de análises de solo. 2th ed. Rio de Janeiro; 1997. Brazil.

14. VAN RAIJ B, CANTARELLA H, QUAGGIO JÁ, FURLANÍ AMC. Recomendações de adubação e calagem para o estado de São Paulo. 2th ed. Campinas: INSTITUTO AGRONÔMICO; 1997. Brazil.

15. BONFIM-SILVA EM, SILVA TJA, CABRAL CEA, KROTH BE, REZENDE D. Desenvolvimento inicial de gramíneas submetidas ao estresse hídrico. Revista Caatinga. 2011; 24(2): 180-186. Brazil. Available: https://periodicos.ufersa.edu.br/caatinga/article/download/1871/4729/6196

16. BÄR C, KOETZ M, BONFIM-SILVA EM, SILVA, TJA. Influence of water availability and wood ash doses on the productive characteristics and water usage of potted gerbera. Journal of Experimental Agriculture International. 2018; 23(6): 1-9. Available: 10.9734/JEAI/2018/42049

17. BONFIM-SILVA EM, VIEIRA APA, DAMASCENO APAB, JOSÉ JV, DOURADO LGA, SILVA TJA. Growth and development of cowpea under wood ash doses and liming. Brazilian Journal of Development. 2019; 5(12): 28701-28718. Available: DOI:10.34117/bjdv5n12-046

18. FERREIRA DF. SISVAR: A computer analysis system to fixed effects Split Plot type designs. Revista Brasileira de Biometria. 2019; 37(4): 529-535. Brazil. Available: https://doi.org/10.28951/rbb.v37i4.450

19. BHELLA HS, WILCOX GE. Lime and Nitrogen Influence Soil Acidity, Nutritional Status, Vegetative Growth, and Yield of Muskmelon. Journal of the American Society for Horticultural Science. 1989; 114(4): 606-610. Available: https://doi.org/10.21273/JASHS.114.4.606

20. AHMAD I, ZHOU G, ZHU G, AHMAD Z, SONG X, HAO G, et al. Response of leaf characteristics of BT cotton plants to ratio of nitrogen, phosphorus, and potassium. Pakistain Journal of Botany. 2021; 53(3):1-9. Available: DOI 10.30848/PJB2021-3(33)

21. HURTADO SMC, RESENDE AV, SILVA CA, CORAZZA EJ, SHIRATSUCHI LS. Clorofilômetro no ajuste da adubação nitrogenada em cobertura para o milho de alta produtividade. Ciência Rural. 2011; 41 (6): 1011-1017. Brazil. Available: https://doi.org/10.1590/s0103-84782011005000074

22. TAIZ L, ZEIGER E, MØLLER IM, MURPHY A. Plant physiology and Development. 6th ed. Sinauer Associates Incorporated; 2015.

23. PORTO RA, BONFIM-SILVA EM, SOUZA DSM, CORDOVA NRM, POLYZEL AC, SILVA TJA. Adubação potássica em plantas de rúcula: produção e eficiência no uso da água. Revista Agroambiente. 2013; 7(1): 25-35. Brazil. Available: https://doi.org/10.18227/1982-8470ragro.v7i1.760

24. AMARE M, FISSEHA D, ANDREASEN C. The effect of N e P fertilizers on yield and yield components of Sesame (*Sesamum indicum L.)* in low-fertile soil of North-western Ethiopia. Agriculture. 2019; 9(10): 1-12. Available: http://dx.doi.org/10.3390/agriculture9100227

25. KALE PD, THAOKAR A, GAWALI KA, SARDA A, NAGMOTE A, JATAV SK. Response of sesame (Sesamum indicum L.) to nitrogen and potassium fertilization. Journal of Pharmacognosy and Phytochemistry. 2019; 8(6): 411-414. Available: https://www.phytojournal.com/archives/2019/vol8issue6/partg/8-5-425-686.pdf

26. SILVA OMC, NIERI EM, SANTANA LS, ALMEIDA RS, ARAÚJO GCR, BOTELHO SA, et al. Adubação fosfatada no crescimento inicial de sete espécies florestais nativas destinadas à recuperação de uma área degradada. Ciência Florestal. 2022; 32(1): 371-394. Brazil. Available: https://doi.org/10.5902/1980509861339

27. SOUZA FG, CHAVES LHG, ALVES AN, SOUZA JA. Macronutrients omission in the growth of Cotton, BRS Topázio cultivar grown in nutritious solution. American Journal of Plant Sciences. 2017; 8, 2345-2357. Available: https://doi.org/10.4236/ajps.2017.810157

28. RODRIGUES DB, ALMEIDA AS, KONZEN LH, REIS NA, TUNES LVM. Adubação fosfatada no desenvolvimento inicial de Quinoa. Revista Brasileira de Engenharia e Sustentabilidade. 2019; 6(2): 26-32. Brazil. Available: https://doi.org/10.15210/rbes.v6i2.16826

29. MULVANEY RL, KHAN SA, ELLSWORTH TR. Synthetic nitrogen fertilizers deplete soil nitrogen: a global dilemma for sustainable cereal production**.** Journal of Environmental Quality. 2009; 38(6): 2295–2314. Available: https://doi.org/10.2134/jeq2008.0527

30. YOUNIS M, SHAH S, INAMULLAH, GUL R, JALAL A, KHALIL F, et al. Effect of Phosphorus and Sulphur on Yield and Yield Components of Sesame. SarhadJournal of Agriculture. 2020; 20(10): 1-7. Available: http://dx.doi.org/10.17582/journal.sja/2020/36.2.722.728

31. JESUS FQ, GOMES MB, SILVA VL. Resposta morfológica e produtiva do rabanete submetido à adubação fosfatada. ScientificElectronicArchives. 2022; 15(11): 31-37. Brazil. Available: http://dx.doi.org/10.36560/151120221624