https://doi.org/10.18406/2316-1817v16nunico20241888 e-ISSN 2316-1817

Growth, dry matter and production components of cotton under phosphorus split application strategies

Aureliano de Albuquerque Ribeiro[1], Evandro Fabio da Silva[2], Célia Maria da Silva[3], Mayana Garcias da Silva[4], Cira Belém Gonçalves Correia[5]

[1] Faculdade de Tecnologia Centec (Fatec Cariri), Docente, aureliano@centec.org.br
[2] Faculdade de Tecnologia Centec (Fatec Cariri), Discente, 202010102685.evandro@centec.org.br
[3] Faculdade de Tecnologia Centec (Fatec Cariri), Discente, 202010102804.celia@centec.org.br
[4] Faculdade de Tecnologia Centec (Fatec Cariri), Discente, 202010102686.mayana@centec.org.br
[5] Faculdade de Tecnologia Centec (Fatec Cariri), Docente, cira.correia@centec.org.br

Received in: 07/01/2024
Accepted in: 26/03/2024

Abstract

Compared with single application, the split application of phosphorus during sowing can enhance the efficiency of phosphate fertilization. In view of this, this study aimed to evaluate the effect of phosphorus split application on the growth, dry matter, and production components of the cotton plant. The experiment was carried out in a greenhouse at the Faculdade de Tecnologia of the Instituto Centro de Ensino Tecnológico Cariri (Fatec Cariri), located in the municipality of Juazeiro do Norte, Ceará. The experiment was arranged in a completely randomized design (DIC), with four replications. The treatments were composed of a combination of different phosphorus split application strategies: T_1 = no phosphorus; T_2 = application of 100 % of the phosphorus at sowing (conventional way); T_3 = application of 50 % of the phosphorus at sowing and of 50 % at 35 days after sowing; T_4 = application of 70 % of the phosphorus at sowing and of 30 % at 35 days after sowing; and T_5 = application of 30 % of the phosphorus at sowing and of 70 % at 35 days after sowing. The following variables were evaluated: plant height; absolute growth rate; stem diameter; number of leaves; root dry matter; total dry matter; and number of flower buds and bolls. The treatments significantly influenced all the variables analyzed. Based on the outcomes, it was found that the split application of phosphorus did not improve the growth, dry matter and production components of the cotton plant compared to the single application.

Keywords: *Gossypium hirsutum* L. Soil fertility. Simple superphosphate.

Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important fiber crops in the world. On average, 35 million hectares of cotton are planted worldwide every year. The world cotton trade is worth around US$12 billion a year and involves more than 350 million people in its production. Asia leads the production of cotton in the world, with India in first place and China in second, followed by the United States in third and Brazil in fourth (ABRAPA, 2023). In Brazil, crops are concentrated in the Central-West, Northeast, and Southeast regions (IBGE, 2023). In the 2021/22 harvest, the area cultivated with cotton in Brazil totaled 1,600.5 thousand hectares, yielding 6,273.5 thousand tons of cotton (CONAB, 2023).

Since the 2015/16 harvest, Ceará has seen an increase in cotton production, which, in addition to the growth in volumes, represents a recovery in cotton cultivation. This evolution is the result of actions by farmers, companies, and government agencies, consolidated and made official in 2017 with the Cotton Crop Modernization Program, created to renew cotton farming in Ceará (EMBRAPA, 2017).

For the cotton crop to achieve adequate establishment in the field, the main management technique required is fertilization with macro and micronutrients (AGUILAR et al., 2021). Among the most important nutrients for the crop is phosphorus (P), an essential macronutrient for the formation and development of roots, flowers and fruit (LAMBERS, 2022; KONÉ et al., 2022).

However, although the natural content of total phosphorus in soils can reach values as high as 1,800 mg kg^{-1} in tropical soils (PAVINATO et al., 2021), only a very small amount of this P is readily available to plants, due to the strong adsorption of phosphorus by 1:1 clay minerals (e.g., kaolinite), iron (Fe) and aluminum (Al) oxides (FINK et al., 2016). In these soils, the only way to meet the demand of the crop is to add phosphate fertilizers (MUMBACH et al., 2021).

Of all the phosphorus applied to the soil via fertilization, the plant only absorbs 15 to 25 %, the rest being fixed to the mineral particles of the soil, especially in acidic soils (AQUINO et al., 2014). In modern cotton cultivars, phosphorus absorption needs to increase by up to 83 kg ha^{-1} to reach maximum yield potential (5,000 kg fiber ha^{-1}) (CONSTABLE; BANGE, 2015). Thus, the use of strategies to improve the efficiency of phosphate fertilization is essential to increase the efficiency of P use, thus avoiding its deficiency (AQUINO et al., 2021).

One way to increase the efficiency of the phosphorus used, particularly in soils with a higher P-fixation capacity, is splitting nutrient application (AQUINO et al., 2014; MAROUELLI et al., 2015). Thus, the hypothesis tested in this research is splitting phosphorus application at sowing increases the efficiency of phosphate fertilization compared to the single application of phosphorus, improving growth, dry matter and production components of the crop. In this context, this study aimed to evaluate the effect of different phosphorus split application techniques on these factors, aiming at improving the efficiency of phosphate fertilization compared to the single application of phosphorus at sowing.

Material and methods

Location and characterization of the experimental area

The experiment was carried out from April to July 2023, in a greenhouse at the Faculdade de Tecnologia of the Instituto Centro de Ensino Tecnológico (Fatec Cariri), located in Juazeiro do Norte, Ceará, with geographical coordinates of 07 °12’47" S, 39 °18’55" W. The municipality is located 377 m above sea level, with a climate ranging from Tropical Semi-Arid to Tropical Mild Semi-Arid, with an average temperature of 24 to 26 °C and a rainy season from January to May. The average annual rainfall is 925 mm. The first quarter of the year is considered to have the most rain (LIMA; RIBEIRO, 2012).

Experimental design and treatments

The statistical design used was completely randomized (DIC). The treatments were composed of a combination of different phosphorus split application strategies: T_1 = no phosphorus; T_2 = application of 100 % of the phosphorus at sowing (conventional method); T_3 = application of 50 % of the phosphorus at sowing and of 50 % at 35 days after sowing; T_4 = application of 70 % of the phosphorus at sowing and of 30 % at 35 days after sowing; and T_5 = application of 30 % of the phosphorus at sowing and of 70 % at 35 days after sowing. The experimental unit was represented by an 8 L plastic pot containing one plant and four replicates, totaling 20 experimental units.

The phosphorus dose recommended for the crop was 70 kg ha^{-1} of P_2O_5, according to the Fertilization and Liming Guidelines of the state of Ceará (UFC, 1993). Granulated simple superphosphate was used for both sowing and top dressing , with 20 % P_2O_5, containing 16 % calcium (Ca) and 10 % to 12 % sulfur (S).

Characterization of the soil used

The soil used in this research was collected from the experimental area of Fatec Cariri at a depth of zero to 20 cm, sieved and then used to fill the pots. A 2 cm layer of gravel was placed at the bottom of each pot. Table 1 shows the chemical and physical characterization of the soil used.

Crop used

The cotton cultivar BRS 433FL B2RF was used. The seeds were purchased from the experimental field of the Brazilian Agricultural Research Corporation (EMBRAPA) Algodão, located in Barbalha, Ceará.

Development of the experiment

Four seeds were sown per pot at a 2 cm depth. Thinning was carried out 12 days after sowing, leaving one plant per pot.

Nitrogen (120 kg ha^{-1} of N) and potassium (50 kg ha^{-1} of K_2O) fertilizers were applied in portions, 25 % at thinning and the rest in two equal portions 15 and 30 days after thinning. Phosphate fertilization was carried out in accordance with the established treatments. The nitrogen and potassium sources used were urea (45 % N) and potassium chloride (60 % K_2O), respectively.

Irrigation was carried out daily by hand, slowly until the water drained from the pot, eventually reaching field capacity in all the pots.

Analyses carried out

The number of flower buds was counted 50 days after sowing (DAS). At 70 DAS, the plants were collected for destructive sampling. Plant height, stem diameter, number of leaves, and number of bolls were assessed. Plant height was measured using a ruler with graduation in centimeters, and stem diameter was assessed using a digital caliper. When calculating the number of leaves, only those that were photosynthetically active were considered.

The absolute growth rate (AGR) was obtained from the plant height data, which were applied to Equation 1, proposed by Benincasa (2003):

$$TCA = \frac{AP_2 - AP_1}{T_2 - T_1} \quad (1)$$

In which:
- AGR - absolute growth rate in relation to height (cm day^{-1});
- PH2 and PH1 - variation in plant growth in height between two consecutive samples taken at times T1 and T2 (days); and
- T1 and T2 - time interval between evaluations, in days, without taking into account values prior to this variation.

The different parts of the plants (roots, stems, leaves, flowers, flower buds, and bolls) were separated, packed in paper bags and dried in an oven with forced air circulation, keeping the temperature from 65 to 70 °C. After drying, each sample was weighed on an analytical balance to determine root dry matter (RDM) and total dry matter (TDM).

Table 1. Chemical and physical characterization of the soil used in the experiment. Juazeiro do Norte (CE), 2024.

Chemical characteristics												
ECse	pH	C	OM	P	V	Ca	Mg	K	Na	SB	E	H+Al
dS m^{-1}	-------	g kg^{-1}		mg dm^{-3}	%	cmol$_c$ dm^{-3}						
0.16	7.2	2.3	3.9	4.0	80	2.48	0.49	0.2	0.02	3.17	3.97	0.80

Physical characteristics								
Sdt	Pdt	TP	Total sand	Coarse sand	Fine sand	Silt	Clay	Textural class
kg dm^{-3}		%	g kg^{-1}					
1.4	2.8	48	850.60	499.20	351.40	8.65	140.7	Loamy Sand

ECse – electrical conductivity of the saturated soil paste extract; pH – potential of hydrogen; C - carbon; OM - organic matter; P - phosphorus; V - base saturation; Ca - calcium; Mg - magnesium; K - potassium; Na - sodium; SB - sum of exchangeable bases; E - cation exchange capacity; H+Al - hydrogen + aluminum; Sdt - soil density; Pdt - particle density; TP - total porosity.

Source: Prepared by the authors.

Statistical analysis

The data obtained were subjected to analysis of variance (ANOVA). When significant according to the F test, the partial applications of phosphorus were compared to the respective doses applied only at sowing and to the no phosphorus application, using the Tukey's test at 5 % probability. Statistical analyses were carried out using SISVAR® statistical program, version 5.3 (FERREIRA, 2011), and graphs were generated using MS Excel.

Results and discussion

The treatments applied significantly influenced plant height ($p < 0.01$), absolute growth rate ($p < 0.01$), stem diameter ($p < 0.01$), number of leaves ($p < 0.01$), RDM ($p < 0.01$), TDM ($p < 0.01$) and the number of flower buds ($p < 0.01$) and bolls ($p < 0.01$) of the cotton plants (Table 2).

Growth

The plants grown in soil without phosphate fertilization (T_1) obtained mean values of height, absolute growth rate, stem diameter, and number of leaves equal to 46.25 cm, 0.59 cm day^{-1}, 6.50 mm, and 16.25, respectively. These values were 47 %, 54 %, 40 %, and 67 % lower, respectively, than those obtained when phosphorus was applied conventionally, i.e., single dose at sowing (T_2) (Table 3), which shows that the soil used in this study had a low phosphorus content (Table 1). Cotton is considered sensitive to soil phosphorus deficiency (TEWOLDE et al., 2018; AWALE; HORNBUCKLE; QUAYLE, 2022), meaning that a lack of this nutrient in the soil negatively affects crop growth (SUN et al., 2023; SADIQ et al., 2023; KHALEEQ; FARYAD; QARLUQ, 2023) due to a decrease in cell division (JIANG et al., 2019).

Plant height, absolute growth rate, stem diameter, and number of leaves obtained with the different phosphorus split application techniques tested (T_3, T_4 and T_5) did not differ statistically from the mean values found when phosphorus was applied only at sowing (T_2) (Table 3). Similarly, Aquino et al. (2011) and Pereira et al. (2020), in field experiments in the north of Minas Gerais and in the Cerrado of Piauí, respectively, also observed no effect of split phosphorus application on the growth parameters of the cotton plant.

Dry matter

The RDM and TDM obtained with the different phosphorus split techniques tested (T_3, T_4 and T_5) did not differ statistically from the mean values found when phosphorus was applied only at sowing (T_2) (Table 4). Similarly, Aquino et al. (2014) found that the dry matter of the leaves, stems and reproductive structures

Table 2. Summary of the analysis of variance for the cotton plant variables in response to different phosphorus splitting techniques. Juazeiro do Norte (CE), 2024.

SV	Mean square								
	DF	PH	AGR	SDM	NL	RDM	TDM	NFB	NB
Treatments	4	2176.5**	0.57**	21.5**	830.8**	102.2**	6309.3**	97.4**	126.6**
Residue	15	176.2	0.051	0.58	24.16	11.51	222.6	5.16	6.90
Total	19	-	-	-	-	-	-	-	-
CV (%)		15.3	18.08	7.24	11.73	33.48	18.47	23.19	24.55

PH – plant height; AGR – absolute growth rate; SDM – stem diameter; NL – number of leaves; RDM – root dry matter; TDM – total dry matter; NFB – number of flower buds; NB – number of bolls; SV – source of variation; DF – degree of freedom; CV – coefficient of variation; **,* - significant at 1 % and 5 %, respectively.

Source: Prepared by the authors.

Table 3. Variations in the growth of cotton cultivated under different phosphorus split application techniques. Juazeiro do Norte (CE), 2024.

Treatment	PH	AGR	SDM	NL
T_1	46.25 b	0.59 b	6.50 b	16.25 b
T_2	87.75 a	1.27 a	10.75 a	48.75 a
T_3	99.75 a	1.45 a	12.00 a	48.50 a
T_4	97.25 a	1.42 a	12.00 a	50.00 a
T_5	102.75 a	1.51 a	11.50 a	46.00 a
Mean	86.75	1.25	10.55	41.40
$MSD_{5\,\%}$	28.99	0.49	1.66	10.73

PH - plant height; AGR - absolute growth rate; SDM - stem diameter; NL - number of leaves; T_1 - no phosphorus application; T_2 - 100 % phosphorus application at sowing (conventional method); T_3 - 50 % phosphorus application at sowing and 50 % at 35 days after sowing; T_4 - 70 % phosphorus application at sowing and 30 % at 35 days after sowing; and T_5 - 30 % phosphorus application at sowing and 70 % at 35 days after sowing.

Data followed by equal letters in the columns do not differ according to Tukey's test at a 5 % significance level.

Source: Prepared by the authors.

of the cotton plant were not influenced by the technique of phosphorus application. On the other hand, in an experiment carried out over two years with the same crop, but under different field conditions, on a loamy soil and in an arid region in Pakistan, Din et al. (2014) observed that the split application of phosphorus led to a significant increase in dry matter production.

Table 4. Root dry matter and total dry matter of cotton grown under different phosphorus split application techniques. Juazeiro do Norte (CE), 2024.

Treatment	RDM	TDM
T_1	1.19 b	10.25 b
T_2	11.24 a	91.75 a
T_3	12.12 a	103.75 a
T_4	13.10 a	101.75 a
T_5	13.01 a	96.50 a
Mean	10.13	80.80
$MSD_{5\,\%}$	7.41	32.59

T_1 - no phosphorus application; T_2 - 100 % phosphorus application at sowing (conventional method); T_3 - 50 % phosphorus application at sowing and 50 % at 35 days after sowing; T_4 - 70 % phosphorus application at sowing and 30 % at 35 days after sowing; and T_5 - 30 % phosphorus application at sowing and 70 % at 35 days after sowing.

Data followed by equal letters in the columns do not differ according to Tukey's test at a 5 % significance level.

Source: Prepared by the authors.

Phosphorus split application can result in different responses from cotton plants depending on soil conditions (PEREIRA et al., 2020) and climate. Mean RDM and TDM values of 1.19 and 10.25 g, respectively, were observed in plants grown in soil without phosphate fertilization (T_1). These values were 89.4 % and 88.8 % lower than those obtained when phosphorus was applied all at once at sowing (T_2) (Table 4). This is a consequence of the low phosphorus content of the soil in the experiment (Table 1). Phosphorus deficiency in the soil can affect the accumulation of dry matter by the plant (AQUINO et al., 2012; SANTOS et al., 2018). Singh et al. (2013), Li et al. (2019), and Sadiq et al. (2023) observed that phosphorus deficiency in the soil decreased the growth and dry matter of the cotton plant.

Production components

The split application of phosphorus (T3, T4 and T5) did not significantly influence the number of flower buds and bolls, which reached mean values that were statistically equal to those obtained with the single application at sowing (T2) (Table 5). In a soil with phosphorus availability classified as medium in northern Minas Gerais, Aquino et al. (2011) and Aquino et al. (2012) also observed that phosphate fertilization in split doses did not increase the number of reproductive structures (flower buds, flowers, and bolls) compared to total application at sowing.

Plants grown in soil without phosphate fertilization (T1) accumulated mean values of 1.50 and 1, respectively, for the number of flower buds and bolls. These values were 84 and 91 % lower than those obtained when phosphorus was applied conventionally, i.e., all at once at sowing (Table 5). This result is associated with the low content of this nutrient in the soil in this study (Table 1). Phosphorus deficiency in the soil can cause flower bud drop and poor boll retention in the cotton plant (CARVALHO et al., 2008).

Table 5. Number of flower buds (NFB) and bolls (NB) of cotton grown under different phosphorus split application techniques. Juazeiro do Norte (CE), 2024.

Treatment	NFB	NB
T_1	1.50 b	1.00 b
T_2	9.50 a	11.00 a
T_3	14.25 a	15.25 a
T_4	11.75 a	13.00 a
T_5	12.00 a	13.25 a
Mean	9.80	10.70
$MSD_{5\,\%}$	4.96	5.73

T_1 - no phosphorus application; T_2 - 100 % phosphorus application at sowing (conventional method); T_3 - 50 % phosphorus application at sowing and 50 % at 35 days after sowing; T_4 - 70 % phosphorus application at sowing and 30 % at 35 days after sowing; and T_5 - 30 % phosphorus application at sowing and 70 % at 35 days after sowing; NFB - Number of flower buds; NB - Number of bolls .

Data followed by equal letters in the columns do not differ according to Tukey's test at a 5 % significance level.

Source: Prepared by the authors.

Conclusions

Splitting phosphorus application did not improve the growth, dry matter, and production components of cotton compared to the single application of phosphorus at sowing.

Acknowledgements

The authors would like to thank the Cearense Foundation of Support for Scientific and Technological Development (Funcap) for granting scientific initiation scholarships to the second, third and fourth authors of this manuscript.

References

ABRAPA. Associação Brasileira de Produtores de Algodão. **Algodão no mundo.** 2023. Disponível em: https://abrapa.com.br/Paginas/dados/algodao-no-mundo.aspx. Acesso em: 01 dez. 2023.

AGUILAR, J. V.; MARCOS, A. M.; SANCHES, C. V.; YOSHIDA, C. H. P.; CAMARGOS, L. S.; FURLANI-JÚNIOR, E. Application of 2,4-D hormetic dose associated with the supply of nitrogen and nickel on cotton plants. **Journal of Environmental Science and Health. Part b: pesticides, food contaminants, and Agricultural Wastes**, v. 56, n. 9, p. 1-8, 2021. Disponível em: https://www.tandfonline.com/doi/abs/10.1080/03601234.2021.1966280. Acesso em: 10 nov. 2023.

AQUINO, L. A. de; BERGER, P. O.; NEVES, J. C. L.; LIMA, T. C.; AQUINO, R. F. B. A. de. Parcelamento de fósforo em algodoeiro irrigado. **Pesquisa Agropecuária Tropical**, v. 42, n. 1, p. 1-8, 2012. Disponível em: https://revistas.ufg.br/pat/article/view/13152/10378. Acesso em: 17 dez. 2023.

AQUINO, L. A.; BERGER, P.G.; OLIVEIRA, R. A.; NEVES, J. C.L.; LIMA, T. C.; BATISTA, C.

H. Parcelamento do fertilizante fosfatado no algodoeiro em sistema de cultivo irrigado e de sequeiro. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 15, n. 5, p. 463–470, 2011. Disponível em: https://www.scielo.br/j/rbeaa/a/Phf9rtYvsvkB3Sn6VttXXZQ/?lang=pt&format=html. Acesso em: 16 dez. 2023.

AQUINO, L.A.; BERGER, P.G.; NEVES, J.C.L.; AQUINO, R.F.B.A. Acúmulo e exportação de nutrientes pelo algodoeiro com a aplicação parcelada de fósforo. **Bioscience Journal**, v. 30, Suplemento 1, p. 12–21, 2014. Disponível em: https://seer.ufu.br/index.php/biosciencejournal/article/view/13949/14473. Acesso em: 11 nov. 2023.

AQUINO, R. F. B. A.; CAVALCANTE, A. G.; CLEMENTE, J. F.; MACEDO, W. R.; NOVAIS, R. F.; AQUINO, L. A. Split fertilization of phosphate in onion as strategy to improve the phopsphorus use efficiency. **Scientia Horticulturae**, v. 290, n. 15, p. 110494, 2021. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0304423821006014. Acesso em: 17 dez. 2023.

AWALE, R.; HORNBUCKLE, J. W.; QUAYLE, W. C. Using poultry litter for cotton phosphorus nutrition in Australia. **Agronomy Journal**, v. 115, n. 2, p. 909-931, 2022. Disponível em: https://acsess.onlinelibrary.wiley.com/doi/full/10.1002/agj2.21199. Acesso em: 21 nov. 2023.

BENINCASA, M. M. P. **Análise de crescimento de plantas:** noções básicas. Jaboticabal: Unesp, 2003. 41p.

CARVALHO, M. da C. S.; FERREIRA, G. B.; CARVALHO, R. S.; SILVA, O. R. R. F.; MEDEIROS, J. da C. Nutrição, calagem e adubação. In: BELTRÃO, N. E. de M.; AZEVEDO, D. M. P. de (Eds.). **O Agronegócio do algodão no Brasil.** 2 ed. v. 2. Brasília: Embrapa Informação Tecnológica, 2008. p. 677-790.

CONAB. Companhia Nacional de Abastecimento. **Acompanhamento da safra brasileira**. 2023. Disponível em: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras. Acesso em: 28 dez. 2023.

CONSTABLE, G. A.; BANGE, M. P. The yield potential of cotton (Gossypium hirsutum L.), **Field Crops Research**, v. 182, p. 98-106, 2015. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0378429015300204. Acesso em: 26 dez. 2023.

DIN, S.; AHMAD, F.; AKHTAR, M. N.; MANAN, M. Phosphorus application strategies to improve cotton productivity under arid climatic conditions. **The Pakistan Cotton**, v. 56, n. 1-4, p. 14-23, 2014. Disponível em: https://ccri.gov.pk/publications/phorphorus%20application.pdf. Acesso em: 25 nov. 2023.

EMBRAPA. **Programa busca retomada da produção de algodão no Ceará**, Brasília, DF, 2017. Disponível em: https://www.embrapa.br/busca-de-noticias/-/noticia/30248953/programa-busca-retomada-da-producao-de-algodao-no-ceara. Acesso em: 25 dez. 2023.

FERREIRA, D. F. Sisvar: a computer statistical analysis system. **Ciência e Agrotecnologia**, v. 35, n. 6, p. 1039-1042, 2011. Disponível em: https://www.scielo.br/j/cagro/a/yjKLJXN9KysfmX6rvL93TSh. Acesso em: 01 dez. 2023.

FINK, J. R.; INDA, A.V.; TIECHER, T.; BARRÓN, V. Iron oxides and organic matter on soil phosphorus availability, **Ciência e Agrotecnologia**, v. 40, n. 4, p. 369-379, 2016. Disponível em: https://www.scielo.br/j/cagro/a/LSkxx83fPT5pLnf6MmK9vnn/?lang=en. Acesso em: 17 nov. 2023.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Levantamento sistemático da produção agrícola**. 2023. Disponível em: https://www.ibge.gov.br/estatisticas/economicas/

agricultura-e-pecuaria/9201-levantamento-sistematico-da-producao-agricola.html?=&t=resultados. Acesso em: 28 dez. 2023.

JIANG, M.; CALDARARU, S.; ZAEHLE, S.; ELLSWORTH, D.S.; MEDLYN BE. Towards a more physiological representation of vegetation phosphorus processes in land surface models. **New Phytologist**, v. 222, n. 3, p. 1223-1229, 2019. Disponível em: https://nph.onlinelibrary.wiley.com/doi/full/10.1111/nph.15688. Acesso em: 21 dez. 2023.

KHALEEQ, K.; FARYAD, A. H.; QARLUQ, A. G. Response of cotton varieties to phosphorus fertilizer on growth, yield and economic efficiency in northeast of Afghanistan, **Journal for Research in Applied Sciences and Biotechnology,** v. 2, n. 6, p. 32-36, 2023. Disponível em: https://jrasb.com/index.php/jrasb/article/view/361/298. Acesso em: 20 dez. 2023.

KONÉ, I.; KOUADIO, K.; KOUADIO, E. N.; AGYARE, W. A.; AMPONSAH, W.; GAISER, T. Assessment of soil fertility status in cotton-based cropping systems in cote d'Ivoire. **Frontiers in Soil Sciense**, v. 2, 959325, 2022. Disponível em: https://www.frontiersin.org/articles/10.3389/fsoil.2022.959325/full. Acesso em: 27 nov. 2023.

LAMBERS, H. Phosphorus acquisition and utilization in plants. **Annual Review of Plant Biology**, v. 20, n. 1, p. 17-42, 2022. Disponível em: https://pubmed.ncbi.nlm.nih.gov/34910587/. Acesso em: 27 nov. 2023.

LI, J. H.; WANG, Y. Y.; LI, N.N.; ZHAO, R. H.; KHAN, A.; WANG, J.; LUO, H. H. Cotton leaf photosynthetic characteristics, biomass production, and their correlation analysis under different irrigation and phosphorus application, **Photosythetica**, v. 57, n. 4, p. 1066 - 1075, 2019. Disponível em: https://ps.ueb.cas.cz/pdfs/phs/2019/04/17.pdf. Acesso em: 11 dez. 2023.

LIMA, G. G.; RIBEIRO, S. C. Geomorfologia e paisagem do município de Juazeiro do Norte/CE: relações entre a natureza semiárida e os impactos antrópicos. **Revista Geonorte**, v. 2, n. 4, p. 520-530, 2012. Disponível em: https://www.periodicos.ufam.edu.br/index.php/revista-geonorte/article/view/2104/1981. Acesso em: 01 dez. 2023.

MAROUELLI, W. A.; GUIMARAES, T. G.; BRAGA, M. B.; SILVA, W. L.C. Frações ótimas da adubação com fósforo no préplantio e na fertirrigação por gotejamento de tomateiro. **Pesquisa Agropecuária Brasileira**, v. 50, n. 10, p. 949-957, 2015. Disponível em: https://www.scielo.br/j/pab/a/LPmGWyWxtLnmnj7t3MYFHpH/?lang=pt. Acesso em: 10 dez. 2023.

MUMBACH, G. L.; GATIBONI, L. C.; DALL' ORSOLETTA, D. J.; SCHMITT, D. E.; GRANDO, D. L.; JÚNIOR, A. A. S.; BRIGNOLI, F. M.; LOCHIMS, D. A. Refining phosphorus fertilizer recommendations based on buffering capacity of soils from southern Brazil. **Revista Brasileira de Ciência do solo**, v. 45, e0200113, 2021. Disponível em: https://www.scielo.br/j/rbcs/a/Q7HPp3hpFy8ncs6bmZbGJLs/. Acesso em: 11 dez. 2023.

PAVINATO, P. S.; ROCHA, G. C.; CHERUBIN, M. R.; HARRIS, I.; JONES, D. L.; WITHERS, P. J. A. Map of total phosphorus content in native soils of Brazil. **Scientia Agricola**, v. 78, n. 6, e20200077, 2021. Disponível em: https://www.scielo.br/j/sa/a/F3HnmskZ9WjkZQPcHwDZm6d/. Acesso em: 17 nov. 2023.

PEREIRA, F. F.; RATKE, R. F.; ZUFFO, A. M.; SOUSA, P. W.; ALMEIDA, F. A.; PETTER, F. A. Características agronômicas do algodão submetido a épocas e doses de aplicação de fósforo no Cerrado Piauiense, **Cultura Agronômica,** v. 29, n. 1, p. 11-21, 2020. Disponível em: https://ojs.unesp.br/index.php/rculturaagronomica/article/view/2446-8355.2020v29n1p11-21/pdf. Acesso em: 24 dez. 2023.

SADIQ, G. A.; AZIZI, F.; KHALEEQ, K.; FARKHARI, Z.; AMINI, A. M. Effect of different seeding rates on growth and yield of Common Bean. **Journal of Environmental and Agricultural Studies,** v. 4, n. 3, p. 41-45, 2023. Disponível em: https://www.al-kindipublisher.com/index.php/jeas/article/view/6252. Acesso em: 22 dez. 2023.

SANTOS, M. G.; RIBEIRO, R. M. P.; ALBUQUERQUE, J. R. T; LINS, H. A.; BARROS JÚNIOR, A. P.; BEZERRA NETO, F.; SILVEIRA, L. M; SOARES, E. B.; SOUZA, A. R. E. Production performance of sesame cultivars under different nitrogen rates in two crops in the Brazilian semiarid region. **Industrial Crops and Products**, v. 124, n. 15, p. 1-8, 2018. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0926669018306150. Acesso em: 01 dez. 2023.

SINGH, S. K.; BADGUJAR, G. B.; REDDY, V. R.; FLEISHER, D. H.; TIMLIN, D. J. Effect of phosphorus nutrition on growth and physiology of cotton under ambient and elevated carbon dioxide. **Journal of Agronomy and Crop Science**, v. 199, n 6, p. 436-448, 2013. Disponível em: https://onlinelibrary.wiley.com/doi/abs/10.1111/jac.12033. Acesso em: 23 dez. 2023.

SUN, M.; ZHENG, C.; FENG, W.; SHAO, J.; PANG, C.; LI, P.; DONG, H. Low soil available phosphorus level reduces cotton fiber length via osmoregulation. **Frontiers in Plant Sciense**, v. 14, 1254103, 2023. Disponível em: https://www.frontiersin.org/articles/10.3389/fpls.2023.1254103/full. Acesso em: 21 dez. 2023.

TEWOLDE, H.; SHANKLE, M. W.; WAY, T. R.; POTE, D. H.; SISTANI, K. R.; HE, Z. Poultry litter band placement affects accessibility and conservation of nutrients and cotton yield. **Agronomy Journal**, v. 110, n. 2, p. 675–684, 2018. Disponível em: https://acsess.onlinelibrary.wiley.com/doi/full/10.2134/agronj2017.07.0387. Acesso em: 20 dez. 2023.

UFC, Universidade Federal do Ceará. **Recomendações de adubação e calagem para o Estado do Ceará**. Fortaleza: Imprensa Universitária, 1993. 247p.