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CROP PRODUCTION

Sunflower performance as a function of phosphate fertilization in semiarid conditions

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ABSTRACT. : The objective of this work was to evaluate the response of sunflower cultivars submitted to increasing levels of phosphate fertilization in two crops. The experimental design was a randomized complete block design with four replicates in subdivided plots, where five doses of simple superphosphate (0, 50, 100, 150, and 200 kg ha^{-1} P_2O_5) were allocated to the plots and three sunflower cultivars (Aguará 06, Altis 99, and Embrapa 122-V2000) were assigned to the subplots. The variables evaluated were the P content in the diagnostic leaf, number of achenes per capitulum, achene yield (kg ha^{-1}), oil content (%) and oil yield. The phosphorus doses increased the components of production. The dose that provided the best sunflower performance varied for the different cultivars. Among the doses studied, fertilization with 100 kg ha^{-1} P_2O_5 in the 2016 agricultural crop and 150 kg ha^{-1} P_2O_5 in the 2017 agricultural crop provided the best conditions for sunflower cultivation. The cultivar Aguará 06 produced more achenes and oil than the other cultivars analyzed in the agricultural crops.
Keywords: *Helianthus annuus* L., oleaginous, time of cultivation, nutrition.

Introduction

Sunflower (*Helianthus annuus* L.) is an oleaginous species of great importance in the world; has important agronomic characteristics, broad phenotypic plasticity, several purposes, and a high content and quality of oil in its achenes; and is considered one of the four main oleaginous crops with the highest index of expansion in the world (Araújo, Chaves, Guerra, Véras, & Oliveira, 2014).

In the state of Rio Grande do Norte, sunflower production has been widespread in recent years, mainly in the western region of the state, where sunflower is cultivated in rainfed and irrigated systems in crop rotation, to meet the demand of the National Production Program and Biodiesel Use - PNPB (Cavalcante Júnior et al., 2013). The selection of cultivars is one of the main concerns in a production system, mainly due to the genotype and environment interaction, which necessitates tests in different agricultural years to determine the agronomic behavior of the genotypes and their adaptation to the different local conditions (Tarsitano, Laforga, Proença, & Rapassi, 2016).

According to Soares et al. (2016), appropriately choosing the most productive cultivar that is adapted to the conditions of the region is an essential technique needed to increase productivity, especially since it is a practice that does not substantially affect the cost of production. To maintain high yields, in addition to the choice of cultivar, both environmentally and economically feasible fertilization is necessary.

Therefore, it has been observed that the sunflower crop accumulates large amounts of nutrients, mainly phosphorus, which is an essential nutrient for development and is found in low concentrations in the soil solution. In sunflower, until the achenes fill, P is required to be remobilized from the leaves and stem to the maturing achenes at a rate in the range of 30 to 60% (Aguiar Neto, Oliveira, Marques, Rodrigues, & Santos, 2010). P deficiency in the plants, mainly at the beginning of the vegetative cycle, results in slower growth, a delay in flowering, a smaller number of achene that reach the filling stage, and a lower oil content (Prado & Leal, 2006).

Experimental studies evaluating phosphate fertilization responses in Brazil were carried out under different soil and climatic conditions, and they demonstrated the importance of this nutrient for sunflower productivity. In the state of Bahia, Silva et al. (2011) indicated that the application of 120 to 186 kg ha^{-1} P_2O_5 was required, depending on the P content of the soil. In the state of Paraná, the best yields were achieved in clayey soils with medium to high levels of P (Eltz, Villalba, & Lovato, 2010). In addition, the P recommendations for sunflower crops in the state of Minas Gerais varied from 30 to 70 kg ha^{-1} P_2O_5 as a function of the soil nutrient content (Ribeiro, Guimarães, & Alvarez, 1999).

According to Carvalho et al. (2009), studies have been carried out to determine the correct management of phosphate fertilization since the plant availability of this element is strongly influenced by the amount present in the soil, soil type, climatic conditions, variations in the doses and solubility of the phosphate to be used.

The objective of this study was to evaluate the production of irrigated sunflower cultivars as a function of phosphate fertilization in two agricultural crops in the northeastern semiarid region of Brazil.

Material and methods

The experiments were conducted at the Rafael Fernandes Experimental Farm, belonging to the Rural Federal University of Semi-Arid, from September to December (1st crop) of 2016 and March to July (2nd crop) of

2017. The farm is located in the rural area of the municipality of Mossoró, Rio Grande do Norte State, Brazil, in the district of Alagoinha, which is located at the following coordinates: 5°03'37"S; 37°23'50"W; 72 m. According to Thornthwaite, the climate of the site is DdAa, i.e., semiarid, megatérmico with little or no excess water during the year, and according to Köppen, the climate is BSwh, i.e., dry and very hot with two climatic seasons: a dry season, which usually comprises the period from June to January and a rainy season, which is between February and May (Carmo Filho, Espínola Sobrinho, & Maia Neto, 1991).

The soil type of the experimental area is classified as Abrupt Eutrophic Red-Yellow Latosol with loamy-sandy texture (Empresa Brasileira de Pesquisa Agropecuária [Embrapa], 2013). The mean meteorological data from the period of the experiments are shown in Figure 1.

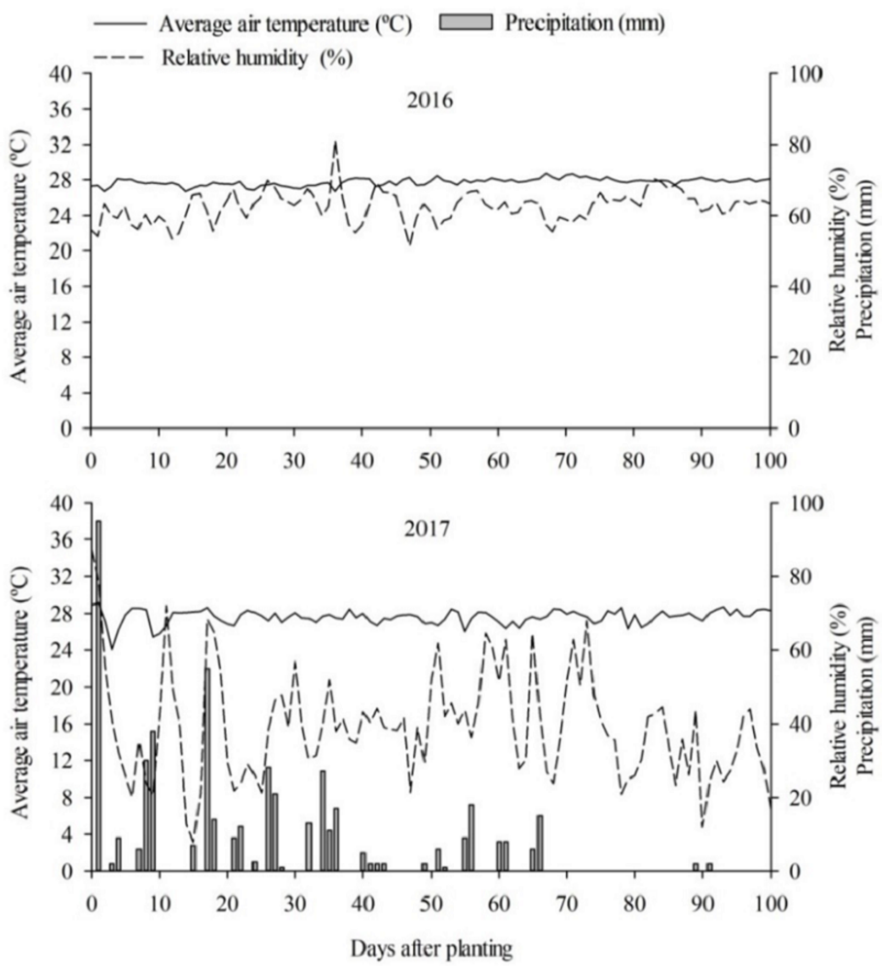


Figure 1
Mean values of the temperatures (°C), relative humidity (%) and precipitation (mm) in the two agricultural crops of sunflower. Mossoró, Rio Grande Norte State, Brazil, UFERSA, 2018. Source: INMET Automatic Weather Station and the rain gauge of the Rafael Fernandes Experimental Farm (UFERSA).

The experimental design used in each experiment was of a randomized complete block design with four replications in a subdivided plot scheme, where five doses of phosphorus (0, 50, 100, 150, and 200 kg ha^{-1} P_2O_5)

were allocated to the plots and three sunflower cultivars (Aguará 06, Altis 99, and Embrapa 122-V2000) were assigned to the subplots to verify the interaction of genotype x environment and thus to identify the cultivar that was the most productive and adapted to the conditions of the region under study. The total area of the experiment was 756 m^2, and each experimental plot consisted of four rows of plants with 0.30 m between plants and 0.7 m between rows, totaling an area of 12.6 m^2 (4.5 x 2.8 m), in which the two central lines were considered borders. The total population was 47,619 plants ha^{-1}.

Plowing and harrowing were carried out to prepare the soil. Soil samples were collected at a depth of 0-20 cm for the chemical analysis (Table 1). The fertilization was carried out according to recommendations of the state of Minas Gerais for the use of correctives and fertilizers (Ribeiro, Guimarães, & Alvarez, 1999).

Table 1

Soil chemical analyses of the experimental area. Mossoró, Rio Grande do Norte State, Brazil, UFERSA, 2018.

Agricultural Crops	OM	K	P	Na	Ca	Mg	pH	EC
	g kg^{-1}	-------- mg dm^{-3} --------			--- $cmol_c$ dm^{-3} ---			ds m^{-1}
2016	9.28	51.08	4.21	6.4	1.55	0.85	6.50	0.677
2017	12.78	58.8	3.0	4.8	1.00	1.80	5.63	0.747

*OM = organic matter. EC = electric conductivity. P, K+, and Na+: Mehlich (HCl + H2 SO4); Ca2+, Mg2+: KCl 1 M.

The nitrogen source used was urea, of which 60 kg ha^{-1} was between two applications as follows: 20 kg ha^{-1} at plantation and 40 kg ha^{-1} 50 days after emergence. For the potassium source, potassium chloride was used, and 50 kg ha^{-1} was applied at planting according to the recommendation of Ribeiro, Guimarães, and Alvarez (1999). For the phosphate fertilization, simple superphosphate was used, and the amounts were applied according to the treatments studied.

The evaluated sunflower cultivars have the following characteristics: Aguará 06 has an average height of up to 1.30 m, an average cycle of approximately 110 days, an average capitulum diameter of 19 cm and an oil content between 44 - 49%; the cultivar Altis 99 is medium-sized and up to 1.20 m in height and has a 115-day cycle, a mean capitulum diameter of 21 cm, and an oil content between 43-50%; and the cultivar Embrapa BRS 122-V2000 is medium-sized and up to 1.50 m high and has a 100-day cycle, a capitulum diameter of 18 cm and an oil content ranging from 40 to 44% (Silva et al., 2011). These characteristics can be altered, varying according to genotype and the edaphoclimatic conditions, in addition to the sowing season (Cadorin, Souza, Manfron, Caron, & Medeiros, 2012).

The sunflower was planted on September 20, 2016, for the 1st crop, and the second crop was planted on March 23, 2017. Direct sowing was performed at a 2 cm depth, and 3 to 4 seeds were sown per pit. Fifteen days after emergence, thinning was performed, leaving one plant per hole.

The irrigation system used was drip irrigation with spaces between the tapes of 0.70 m and emitters of 0.30 m. Irrigation was performed daily based on the ETc of the estimated crop (ETc = ETo x Kc), where the Kc values corresponded to the development of the sunflower crop (Amaral & Silva, 2008). The fertilizers were injected into the irrigation water with the aid of a bypass tank. N and K fertilizer was applied via fertirrigation. The doses of P were applied directly to the hole manually according to each treatment established at the time of planting. The handling of the plants and phytosanitary control were carried out according to the technical recommendations and needs of the crop.

The sunflowers were harvested in 2016 and 2017 when the plants were in phase R9, which indicates the maturity of the achenes (physiological maturation), when the moisture content is between 30 and 32%, the bracts have changed color from yellow to brown, and a large part of the back of the capitulum has turned brown (Blanchet, 1994), which occurred 88 days after sowing (DAS) for Embrapa 122-V2000 and 90 DAS for the cultivars Aguará 06 and Altis 90 in the 2016 crop. In the 2017 crop, the cultivar Embrapa 122-V2000 was harvested at 91 DAS; Aguará 06 and Altis 99, 97 DAS. The capitula of all the plants in the experimental area were harvested and then dried. After drying, the achenes were threshed and cleaned.

For the evaluation of the P content in the leaf, the diagnostic leaf (fifth to sixth leaf below the capitulum) of all plants of the harvest area was collected at the beginning of full flowering (Silva et al., 2011). The samples were washed in running water with detergent, and finally, twice with distilled water (Cortez, Cecílio Filho, Grangeiro, & Oliveira, 2014). The samples were conditioned in paper bags, which were labeled, and placed in an oven with forced air circulation at a temperature of 65°C. After drying, the leaves were ground, and sulfuric digestion was performed to determine the phosphorus content using a spectrophotometer.

The number of achenes per capitulum was obtained by the average of 5 capitulum in the harvest area. The productivity of the achenes was calculated by the mass of achenes in an experimental plot, which was corrected to 13% humidity and transformed to kg ha^{-1}. The oil content was obtained by the Soxhlet method, which consists of extracting the oil with hexane followed by a gravimetric determination. First, the moisture content of the seeds was determined according to the method described in Farmacopéia Brasileira (Agência Nacional de Vigilância Sanitária [ANVISA], 1988), which is based on the loss of water by oven desiccation. After being dried and ground, the seeds were placed in a Soxhlet extractor for triplicate assays with n-hexane (Vetec, 99% purity). The extractions were performed according to the AOAC (1999) adapted method with a total extraction time of 6 hours. The oil yield was obtained by multiplying the oil content and the yield of achenes.

The analysis of variance of the agricultural crops was carried out separately for all the evaluated characteristics with SISVAR 3.01 (Ferreira, 2011). After observing the homogeneity of the variances between the agricultural crops, a joint analysis of the same characteristics was performed. The procedure of adjusting the response curves was performed using the Table Curve 2D program (Systat Software, 2002), and the graphs were constructed in SigmaPlot 12.0 (Systat Software, 2011). Tukey's test ($p < 0.05$) was used to compare the means between the cultivars and each crop.

Results and discussion

According to the results of the joint analysis of the variables evaluated as a function of the agricultural crops, of the doses of P and of the cultivars of sunflower, triple interactions were observed for all characteristics evaluated.

For the phosphorus content in the diagnostic leaf, it was observed that as the dose of phosphorus increased, there was an increase in the P content. The highest accumulation of P was obtained at 200 kg ha^{-1} P_2O_5, with maximum values of 5 g kg^{-1} (Embrapa BRS 122-V2000) and 4 g kg^{-1} (Altis 99), except for Aguará 06, which obtained a maximum concentration of 4 g kg^{-1} at the dose of 182 kg ha^{-1} P_2O_5 in the 2016 agricultural crop (Figure 2A). In the 2017 harvest, the highest concentrations of P were also found when 200 kg ha^{-1} P_2O_5 was applied for the cultivars Aguará 06 (8 g kg^{-1}) and Embrapa 122-V2000 (7 g kg^{-1}), and for the cultivar Altis 99, a maximum concentration of 6 g kg^{-1} was obtained at the dose of 90 kg ha^{-1} P_2O_5 (Figure 2B). There was a large response with increasing doses of phosphorus since the soil had very low levels of P (Table 1). The increased dose of applied P increased the concentration in the soil solution and, consequently, the availability of this nutrient to the plants, as P was absorbed in larger quantities.

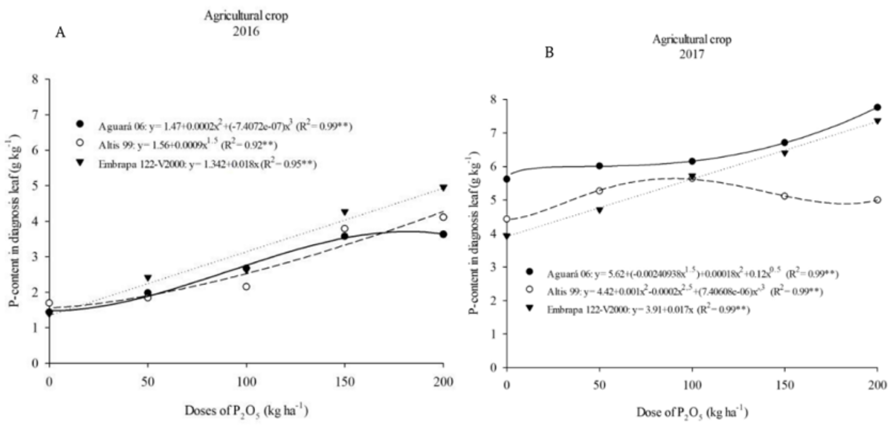


Figure 2
Phosphorus contents in the diagnostic leaf of the sunflower cultivars in the 2016 (A) and 2017 (B) agricultural crops.

In the 2016 harvest, the dose of 150 to 200 kg ha^{-1} P_2O_5 provided the ideal P content in the diagnostic leaf; that is, the sunflower plants were well nourished according to Ribeirinho, Melo, Silva, Figueiredo, and Melo (2012), whom determined that the appropriate range or sufficient level of P in the diagnostic leaf is between 3 and 5 g kg^{-1}. In the 2017 harvest, the P content in the leaf was above the adequate limit, and there was a higher concentration in 2017 than 2016, probably due to the rainfall that occurred (Figure 1). A greater volume of water present in the soil increased the availability of P in the soil solution, which allowed greater absorption and accumulation of P by the plants.

The different responses among the cultivars in the concentration of P_2O_5 in the diagnostic leaf reflect the genotypic and environmental factors. It is believed that, probably in all cultures, there are interactions between genotypes and environments, in which the cultivars present different behaviors in different environments (Ribeirinho, Melo, Silva, Figueiredo, & Melo, 2012).

The number of achenes per sunflower capitulum in the 2016 crop, in general, increased with the addition of phosphate fertilizer. The cultivar Aguará 06 showed the highest number of achenes per capitulum, reaching a maximum value of 1,540.41 at the dose of 117 kg ha^{-1} P_2O_5, followed by 1,329.90 (Altis 99) associated with 90 kg ha^{-1} P_2O_5 and 812 (Embrapa 122-V2000) with 83 kg ha^{-1} P_2O_5 (Figure 3A). There were no adjustments were made for the regression curves for the 2017 harvest, with the mean values observed of 632 (Aguará 06), 681 (Altis 99), and 443 (Embrapa 122-V2000) achenes per capitulum (Figure 3B).

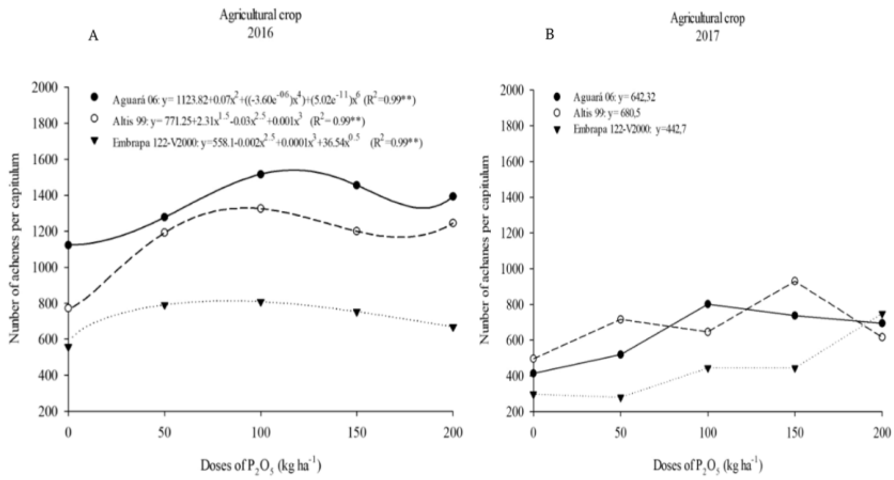


Figure 3

Number of achenes per capitulum of the sunflower plants in the 2016 (A) and 2017 (B) agricultural crops.

The result was superior to what was found by Birck et al. (2017), with dose of phosphorus of 84 kg ha^{-1} in the sunflower crop obtained 978 achenes per capitulum (Agurá 06) for a soil P content of 6.1 mg dm^{-3}. Phosphorus plays a fundamental role in the process of achene formation since its absorption occurs until the filling stage of achenes, supplying the development of the capitulum through a source-drain relationship.

Achene production had a responsive effect as a function of the applied P_2O_5 doses. In the 2016 harvest, the cultivar Aguará 06 reached a maximum value of 3,273.31 kg ha^{-1} associated with the dose of 115 kg ha^{-1} P_2O_5, Altis 99 reached a yield of 2,790.85 kg ha^{-1} at the dose of 147 kg ha^{-1} P_2O_5, and Embrapa 122-V2000 obtained a maximum production of 1,697.29 kg ha^{-1} at the amount of 122 kg ha^{-1} P_2O_5 (Figure 4A). In the 2017 harvest, the maximum values obtained for the cultivars were 1,766.37 kg ha^{-1} (Aguará 06) at the dose of 133 kg ha^{-1} P_2O_5 and 1,430.50 kg ha^{-1} (Embrapa 122-V2000) at the dose of 187 kg ha^{-1} P_2O_5. To cultivate Altis 99, there was no curve adjustment because the highest production of achenes was observed at 1,434.06 kg ha^{-1} with fertilization at 150 kg ha^{-1} P_2O_5, averaging 1,183.27 kg ha^{-1} of achenes (Figure 4B).

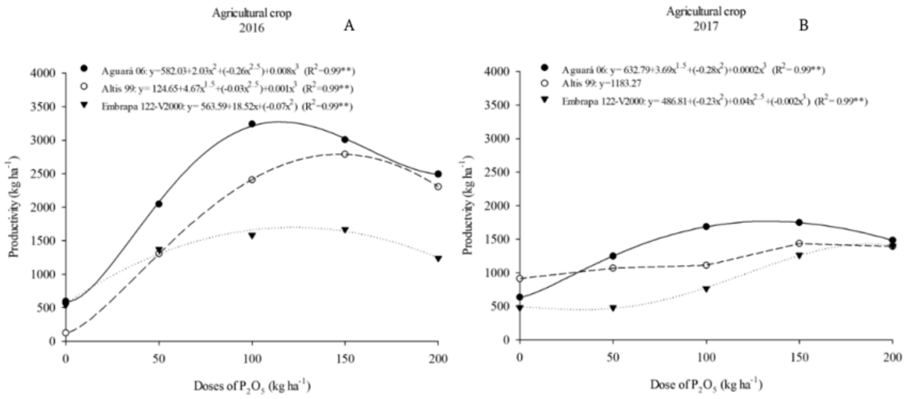
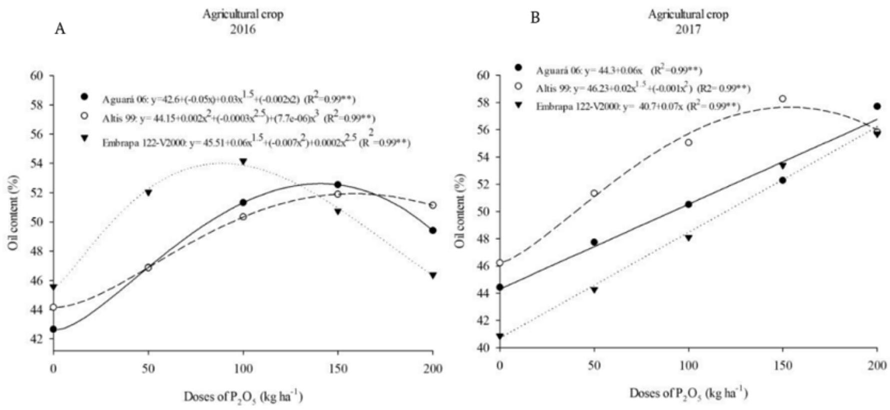


Figure 4

Production of sunflower achenes in the 2016 (A) and 2017 (B) agricultural crops.

The response to phosphate fertilization varies according to the soil type of each region and its soil-climatic conditions, i.e., sunflower cultivations in different regions may have similar productivities, but the amount of phosphate fertilization to reach the same productivity may be different. Works carried out in different regions corroborate this statement. Santos, Melo, Souza, and Primo (2010), studying phosphorus and boron in sunflower grain production in the state of Bahia, obtained a maximum yield of 2,302.7 kg ha^{-1} with an application of 80 kg ha^{-1} P_2O_5, and Eltz, Villalba, and Lovato (2010) also achieved a similar yield of achenes (2,448 kg ha^{-1}) associated with a dose of 171 kg ha^{-1} P_2O_5 in the region of Paraguay.

Compared to the 2017 harvest, the 2016 agricultural harvest in general had a higher production of achenes per capitulum, greater growth and an adequate supply of nutrients, which was reflected in the larger diameter of the capitula and, consequently, the greater number of achenes produced in this year. The climatic variables are factors that interfere with the agronomic performance of the sunflower. The temperature influences the crop cycle, since low temperatures increase the crop cycle, delay flowering and maturation, and affect productivity when they occur at the beginning of flowering. High rainfall mainly in the physiological maturation phase slows the loss of water from the capitulum, favoring end-of-cycle diseases and decreasing product quality, which is corroborated by Taiz, Zeiger, Møller, and Murphy (2017), whom also described that these same climatic variables directly influence the efficiency of fertilization.



In the 2017 harvest, due to the high amount of rainfall that occurred during planting and in the initial phase of development (Figure 1), where it coincided with nitrogen fertilization, there was probably a great loss of the nitrogen applied through leaching, which resulted in a reduction in the availability of this nutrient for cultivation. The loss of nitrogen would have also caused smaller plants to develop since a low availability of N causes nutritional and physiological disturbances and reduces the production of achenes and the percentage of oil (Nobre et al., 2014).

According to (Sanchez, 2007), the response of sunflower to phosphate fertilization is mainly related to P availability in the soil. Regions with low P levels in the soil, as in the conditions of this work (Table 1), require a higher supply of phosphate fertilizer to increase soil availability and improve the crop response.

For the oil content, maximum values of 52 (Aguará 06), 52 (Altis 99), and 55% (Embrapa 122-V2000) were obtained at the dose of 141, 158, and 84 kg ha^{-1} P_2O_5, respectively, in the 2016 crop (Figure 5A). In the agricultural crop 2017, the oil content in the achenes increased linearly with increasing amounts of phosphate fertilizer. Maximum values of 58 (Aguará 06) and 58% (Altis 99) were reached at the dose of 200 kg ha^{-1} P_2O_5. The cultivar Altis 99 obtained a 58% oil content with 154 kg ha^{-1} P_2O_5 (Figure 5B).

The percentage of oil accumulated by the cultivars is within the average obtained in many regions of northeastern Brazilian (35 to 55%) and obtained in other studies of sunflower cultivars (Birck et al., 2017). Similar results were reported by Santos, Melo, Souza, and Primo (2010), whom studied the effect of phosphorus and boron on the yield of grain and oil from sunflower in the state of Bahia and obtained the highest oil content (45%) with application of 200 kg ha^{-1} P_2O_5. Temperature exerts a strong influence on the oil content and composition of seeds. According to Gazzola et al. (2012), with the maximum and minimum temperatures in the period between flowering and maturation, there is a decrease in the total oil content and the linoleic acid content of the achenes. However, the effect of air temperature on the content and composition of oils may be different between cultivars. Oil production increased as a function of the applied P rates. In the 2016 crop, the cultivar Aguará 06 at 117 kg ha^{-1} P_2O_5 reached the maximum production of 1,683.32 kg ha^{-1} and the Embrapa 122-V2000 cultivar obtained the highest yield (875 kg ha^{-1}) at a dose of 107 kg ha^{-1} P_2O_5. There were no adjustments to the regression curves for Altis 99, which obtained the highest oil yield of 1,154.68 kg ha^{-1} (Figure 6A). In the 2017 harvest, the 200 kg ha^{-1} dose of P_2O_5 caused a higher oil yield for Altis 99 (810 kg ha^{-1}) and Embrapa 122-V2000 (767 kg ha^{-1}). The cultivar Aguará 06 obtained the highest yield (873 kg ha^{-1}) associated with a dose of 118 kg ha^{-1} P_2O_5 (Figure 6B).

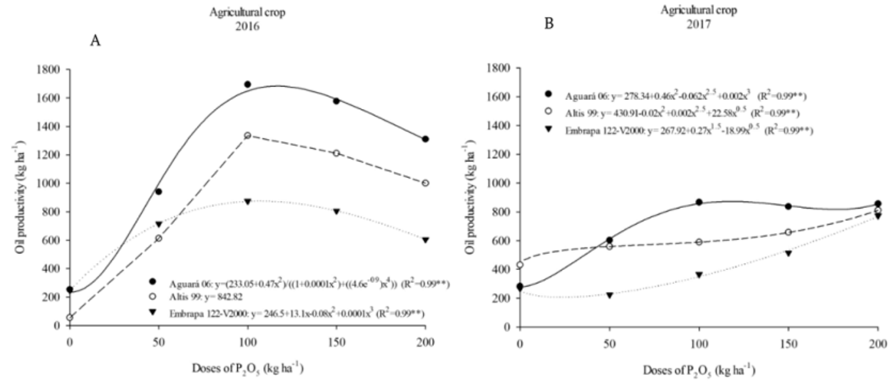


Figure 6

Production of sunflower oil in the 2016 (A) and 2017 (B) agricultural crops.

These results show that P is essential for oil production, corroborating the results from Taiz and Zeiger (2012), whom affirmed that this nutrient is directly linked to the development of the plant, filling of the achenes and yield of oil. Studies have shown that the sunflower oil yield responds to phosphate fertilization. Santos, Melo, Souza, and Primo (2010), studying the effect of phosphorus and boron on the production of grain and oil in sunflower, obtained the highest oil yield of 980 kg ha^{-1} at a dose of 200 kg ha^{-1} P_2O_5.

The different yields of oil obtained by the cultivars are due to genotype-environment interactions. The effect of the environment (mainly temperature) on the oil content and composition may be different between cultivars; in some cases, the oil content decreases with a drop in the average daily temperature after anthesis, and in others, the ratio of linoleic/oleic acid decreases with high temperatures (Gazzola et al., 2012). There was a higher yield of oil in the 2016 crop, which was associated with the higher yield of achenes in the same harvest since the oil content followed the crop productivity curve and since the oil content in the achenes along with achene production determine the oil yield.

In industry, the oil content in the achenes is very important, but when combined with high grain production, the oil yield per unit area also becomes commercially important. For this to happen, it is necessary to provide adequate P and use cultivars that can achieve their maximum genetic potential under the conditions of the growing region.

Conclusion

Phosphorus fertilization increased the agronomic production components (the P content in the leaf, yield of achenes and yield of oil).

Among the doses studied, fertilization with 100 kg ha^{-1} P_2O_5 in the 2016 agricultural crop and 150 kg ha^{-1} P_2O_5 in the 2017 agricultural crop provided the best conditions for sunflower cultivation.

The cultivar Aguará 06 had a higher production of achenes and oil than the other cultivars analyzed in the crops.

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References

Agência Nacional de Vigilância Sanitária [ANVISA]. (1988). *Farmacopéia Brasileira* (4a ed.). São Paulo, SP: Atheneu.

Aguiar Neto, P., Oliveira, F. A., Marques, L. F., Rodrigues, A. F., & Santos, F. G. B. (2010). Efeitos da aplicação do fósforo no crescimento da cultura do girassol. *Revista Verde*, 5(4), 148-155.

Amaral, J. A. B., & Silva, M. T. (2008). Evapotranspiração e coeficiente de cultivo do gergelim por manejo de irrigação. *Revista Brasileira de Oleaginosa e Fibrosa*, *12*(1), 25-33.

Araújo, D. L., Chaves, L. H. G., Guerra, H. O. C., Véras, M. L. M., & Oliveira, T. L. (2014). Efeito da adubação fosfatada e estresse hídrico nas características fenológicas do girassol (*Helianthus annuus* L.). *Agropecuária Científica no Semiárido*, *10*(4), 26-31. DOI: 10.30969/acsa.v10i4.482

Association of Official Analytical Chemists [AOAC]. (1999). *Official Methods of Analysis.* Arlington, TX: Association of Official Analytical Chemists International.

Birck, M., Dalchiavon, F. C., Stasiak, D., Iocca, A. F. S., Hiolanda, S., & Carvalho, C. G. P. (2017). Performance of sunflower cultivars at different seeding periods in central Brazil. *Ciência e Agrotecnologia*, *41*(1), 42-51. DOI: 10.1590/1413-70542017411021216

Blanchet, R. (1994). Ecophysiologie et élaboration du rendement du tournesol: principaux caractères. In L. Lombe, & D. Picard (Ed.), *Élaboration du rendement des principales cultures annuelles* (p. 97-99). Paris, FR: INRA.

Cadorin, A. M. R., Souza, V. Q., Manfron, P. A., Caron, B. O., & Medeiros, S. L. P. (2012). Características de plantas de girassol, em função da época de semeadura, na Região Noroeste do Rio Grande do Sul. C*iência Rural*, *42*(10), 1738-1743. DOI: 10.1590/S0103-84782012001000004

Carmo Filho, F., Espínola Sobrinho, J., & Maia Neto, J. M. (1991). *Dados climatológicos de Mossoró: um município semi-árido nordestino*. Mossoró, RN: ESAM.

Carvalho, C. G. P., Grunvald, A. K., Goncalves, S. L., Terra, I. M., Oliveira, A. C. B., Ramos, N. P., ... Brighenti, A. M. (2009). *Informes da avaliação de genótipos de girassol 2008/2009*. Londrina, PR: Embrapa Soja.

Cavalcante Júnior, E. G., Medeiros, J. F., Melo, T. K., Espínola Sobrinho, J., Bristot, G., & Almeida, B. M. (2013). Necessidade hídrica da cultura do girassol irrigado na chapada do apodi. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *17*(3), 261-267. DOI: 10.1590/S1415-43662013000300003

Cortez, J. W. M., Cecílio Filho, A. B., Grangeiro, L. C., & Oliveira, F. H. T. (2014). Crecimiento, acumulación de macronutrientes y producción de melón cantaloupo y amarillo. *Revista Caatinga*, *27*(3), 72-82.

Eltz, F. L. F., Villalba, E. H., & Lovato, T. (2010). Adubação fosfatada para girassol sob sistema plantio direto no Paraguai. *Bragantia*, *69*(4), 899-904. DOI: 10.1590/S0006-87052010000400016

Empresa Brasileira de Pesquisa Agropecuária [Embrapa]. (2013). *Sistema Brasileiro de classificação de solos*. Brasília, DF: Serviço de Produção de Informação.

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, *35*(6), 1039-1042. DOI: 10.1590/S1413-70542011000600001

Gazzola, A., Ferreira Júnior, C. T.G., Cunha, D. A., Bortolini, E., Paiao, G. D., Primiano, I. V., ... Oliveira, M. S. (2012). *A cultura do girassol*. Piacicaba, SP: Fealq.

Nobre, R. G., Sousa, W. B. D., Lima, G. S. D., Gheyi, H. R., Dias, A. S., & Pinheiro, F. W. (2014). Sources and doses of nitrogen in the production of sunflower plants irrigated with saline water. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *18*(1), 59-65. DOI: 10.1590/1807-1929/agriambi.v18nsupps59-s65

Prado, R. M., & Leal, R. M. (2006). Desordens nutricionais por deficiência em girassol var. Catissol-01. *Pesquisa Agropecuária Tropical*, *36*(3), 187-193.

Ribeirinho, V. S., Melo, J. W., Silva, D. H., Figueiredo, L. A., & Melo, G. M. P. (2012). Fertilidade do solo, estado nutricional e produtividade de girassol, em função da aplicação de lodo de esgoto. *Pesquisa Agropecuária Tropical*, *42*(2), 166-173. DOI: 10.1590/S1983-40632012000200002

Ribeiro, A. C., Guimarães, P. T. G., & Alvarez, V. V. H.(1999). *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais - 5a. aproximação*. Viçosa, MG: Comissão de Fertilidade do Solo do Estado de Minas Gerais.

Sanchez, C. A. (2007). Phosphorus. In A. V. Barker, & D. J. Pilbeam (Eds.), *Handbook of plant nutrition* (p. 51-90). Boca Raton, CA: Taylor & Francis Group.

Santos, L. G., Melo, F. V. S., Souza, U. O., & Primo, A. R. S. (2010). Fósforo e boro na produção de grãos e óleo no girassol. *Enciclopédia Biosfera*, 6(11), 1-8.

Silva, J. A. G., Schwertner, D. V., Carbonera, R., Crestani, M., Gaviraghi, F., Schiavo, J., & Arenhardt, E. G. (2011). Distância genética em genótipos de girassol. *Current Agricultural Science and Technology*, *17*(3), 326-337. DOI: 10.18539/cast.v17i3.2066

Soares, L. E., Emerenciano Neto, J. V., Silva, G. G. C., Oliveira, E. M. M., Bezerra, M. G. S., Santos, T. J. A., & Difante, G. S. (2016). Crescimento e produtividade do girassol sob doses de nitrogênio e fósforo. *Revista Brasileira de Agropecuária Sustentável*, 6(2), 19-25.

Systat Software. (2002). *Table curve 2D and 3D*. San Jose, US: MMIV Systat Software Inc.

Systat Software. (2011). *SigmaPlot for Windows Version 12.0*. San Jose, US: Systat Software Inc.

Taiz, L., & Zeiger, E. (2012). *Fisiologia vegetal* (5a ed.) Porto Alegre, RS: Artmed.

Taiz, L., Zeiger, E., Møller, I. M., & Murphy, A. (2017). *Fisiologia e desenvolvimento vegetal* (6 ed.). Porto Alegre, RS: Artmed.

Tarsitano, R. A., Laforga, G., Proença, É. R., & Rapassi, R. M. A. (2016). Custos e rentabilidade da produção de girassol no estado do Mato Grosso, Brasil. *Revista Espacios*, *37*(12), 1-9.

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