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Different phosphorus doses in grain sorghum under Cerrado conditions, Goiás, Brazil

Felipe Hernandes Carvalho[1], José Milton Alves[1], Thais Gonçalves Veloso[1], Ritiane Souza Alcântara[1], Matheus Vinicius Abadia Ventura[1], Hellen Regina Fernandes Batista Ventura[1]

[1] Instituto Federal Goiano, Campus Rio Verde, Rio Verde, Goiás, Brasil. E-mail: 18fehcarvalho@gmail.com, jose.milton@ifgoiano.edu.br, thaisgoncalves_rv@hotmail.com, ritianealcantara15@gmail.com, matheusvinicius10@hotmail.com, hellenf13@gmail.com

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ABSTRACT

Sorghum bicolor is an important grain species used for food and feed production, where P is a key element/nutrient in grain production. The effect of increasing phosphorus doses to grain sorghum in Cerrado soil with sandy texture and low fertility in Cerrado conditions was evaluated. The study was conducted at the Pântano Farm, Jataí, Goiás, Brazil. The sorghum cultivar used was AG 1085. The doses of 0 (control), 40, 80, 120, and 160 kg ha^{-1} of P_2O_5 were used, whose source was triple superphosphate 46% of P_2O_5, with five replications each, designed in random blocks. The evaluated variables were stem length, stem diameter, leaf area, shoot dry mass, leaf phosphorus content, nutrient accumulation, fertilization efficiency, chlorophyll *a*, and chlorophyll *b*. For the variables shoot dry mass in (g plant^{-1}), leaf phosphorus content, dry mass expressed in (kg ha^{-1}), and chlorophyll *b* (CFI), the effect for the application of P doses in cultivar had a linear effect. The analysis of variance of the regression showed a quadratic effect for the variables stem length, stem diameter, leaf area, and phosphorus use efficiency, and for chlorophyll *a* (CFI), showing a maximum point at the best dose and best values of the variables. The application of Phosphorus influenced the development of the grain sorghum cultivar. The 129 kg ha^{-1} of P_2O_5 had the highest efficiency of phosphorus fertilization corresponding to 82.02%.

Keywords: Phosphate fertilization, *Sorghum bicolor,* Fertility.

Diferentes doses de fósforo em sorgo granífero em condições de Cerrado, Goiás, Brasil

RESUMO

O *Sorghum bicolor* é uma importante espécie granífera utilizada para produção de alimentos e ração, onde o P é um elemento/nutriente determinante na produção de grãos. Foi avaliado o efeito da adição de doses crescentes de fósforo em sorgo granífero em solo de Cerrado com textura arenosa e baixa fertilidade nas condições de Cerrado. O estudo foi realizado na Fazenda Pântano, Jataí, Estado de Goiás, Brasil. O cultivar de sorgo utilizado foi AG 1085. Foram utilizadas as doses de 0 (controle), 40, 80, 120 e 160 kg ha^{-1} de $P_2O_{5,}$ cuja fonte foi o superfosfato triplo 46% de P_2O_5, com cinco repetições cada, delineamento em blocos ao acaso. As variáveis avaliadas foram: comprimento do caule, diâmetro do caule, área foliar, massa seca da parte aérea, teor de fósforo na folha, acúmulo do nutriente, eficiência de adubação, clorofila *a* e clorofila *b*. Para as variáveis massa seca da parte aérea em (g planta^{-1}), teor quantitativo de fósforo foliar, massa seca expressa em (kg ha^{-1}) e pigmento clorofiliano *b* (ICF), o efeito para a aplicação das doses de P na cultivar tiveram efeito linear. A análise de variância da regressão exibiu efeito quadrático para as variáveis comprimento do caule, diâmetro do caule, área foliar, eficiência do uso de Fósforo e para a clorofila *a* (ICF), apresentando ponto máximo na melhor dose e melhores valores das variáveis. A aplicação de Fósforo influenciou no desenvolvimento do cultivar de sorgo granífero testado. A dosagem 129 kg ha^{-1} de $P_2O_{5,}$ exibiu maior eficiência da adubação fosfatada correspondente a 82,02%.

Palavras-chave: Adubação Fosfatada, *Sorghum bicolor,* Fertilidade.

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1. Introduction

Sorghum bicolor is an important grain species used for food and feed production and has several special points, among them, it adapts well to different soil types, climates, and altitudes, especially in semi-arid tropical and subtropical regions. In addition, sorghum has high nutritional value, good contents of carbohydrates, dry matter (Perazzo et al., 2017; Santos et al., 2018), starch, fatty acids, proteins, non-starch polysaccharides, various vitamins (B), and of fat-soluble vitamin complex (D, E, and K), micro and macronutrients, carotenoids, and polyphenols (Przybylska et al., 2019).

Cultivation of this crop is well established in the Americas, Africa, Asia, and Oceania, including the Australian continent. It is considered the fifth most produced grain in the world, behind wheat, rice, corn, and barley (Mabelebele et al., 2015). The use of sorghum in crop rotation is of great importance, as well as in the establishment of Integrated Crop-Livestock-Forestry (ICLF) systems, where it has relatively short growing seasons (Espitia-Hernández et al., 2020).

According to Conab (2022), in the 2021/22 harvest, the Brazilian production was 2,825.9 million tons, and the State of Goiás presents a prominent position with 1.2 million tons, representing 8.8% growth compared to 2021, with average yields expected to increase by 10.3% (Oliveira et al., 2018; Ceccon et al., 2018; IBGE, 2022; Carvalho et al., 2022). The production growth is easily explained when the crop responds well to extreme weather factors compared to the corn crop (Andrade-Neto et al., 2010).

In Brazilian soils, the sorghum crop is established as the second crop as an alternative to the late cultivation of corn, soybean, or cotton because it demands less from the soil regarding macro and micronutrients (Tardin et al., 2013). However, low investment in fertilization and/or topdressing in sorghum can present certain problems observed at harvest time, such as low yield, which is influenced by the immobilization and/or mineralization of nutrients in the soil. According to Patidar et al. (2004) and Rossi et al. (2013), there is a growing link between high immobilization of important nutrients, mainly Phosphorus (P), in the first days after harvest.

P is a determinant element/nutrient in grain production, with 80 to 90% of its total absorbed by plants being exported as a source/drain to the grains, thus indicating the need for constant replacement of this element in the soil (Maia et al., 2003; Resende et al., 2006; Oliveira et al., 2018). Castro et al. (2016) evaluated corn grain yield in Barreiras, Western Bahia State, Brazil, in a soil classified as Dystrophic Red Yellow Latosol, with a 94.2 kg ha^{-1} of P_2O_5 applied as broadcast, where they obtained maximum grain yield results on corn cultivar.

Thus, the various studies presented show that the recommendation of phosphor (P) in this crop is not yet fully consolidated, lacking research on the understanding and adequacy of dose-response in the current scenario of the high cost of phosphate fertilizers due to various economic, political, and social factors. Given the above, this study aimed to evaluate the dose-response effect of P on grain sorghum cultivar AG 1085 in sandy and low fertility soil under Cerrado conditions in the State of Goiás, Brazil.

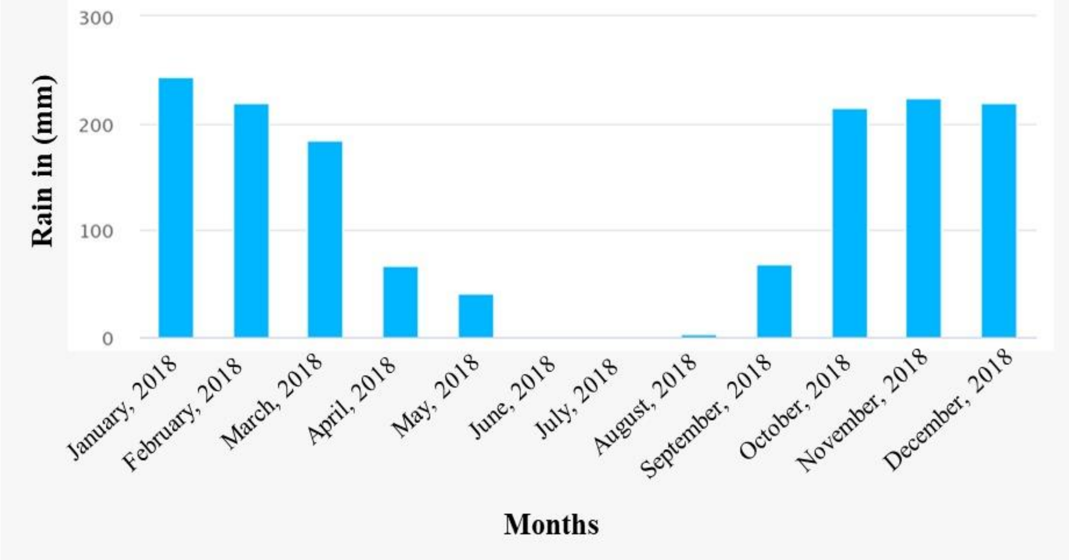
2. Material and Methods

The study was conducted in February 2018, in the Pântano Farm, located in Jataí, State of Goiás, Brazil (Latitude 17°59'15.87" S and Longitude 5°14'15.26" W), with an average precipitation of 219.2 mm, according to graph 1. Soil preparation was done by harrowing and correction according to the soil analysis results and recommendation criteria by Souza et al. (2004). The chemical and particle-size characteristics for the 0-20 cm soil layer are presented in Table 1. It is observed that according to the soil analysis results, the soil is of sandy texture type with acid pH. The organic matter, potassium (K), and (cation exchange capacity) CEC are low, and the P is very low.

Liming (2.5 t ha^{-1}) was performed 90 days before sowing to raise base saturation to 50%, according to Souza et al. (2004). Dolomitic limestone with an effective calcium carbonate equivalence (ECCE) of 85% was used. The experimental plots were formed by a 3x3 m square, with a distance between plots of 3 m and 3 m between blocks. The spacing used was 0.5 m between rows to obtain a population of 140 thousand plants per hectare, following the instructions from Embrapa Maize & Sorghum (2008), where the recommended population of grain sorghum can vary from 140 to 170 thousand plants per hectare at harvest.

The sorghum cultivar used was Agroceres AG 1085, which has an early cycle, excellent stem quality, and is tolerant to the main diseases (anthracnose, leaf blight, rust, charcoal rot, and ergot). In this study, five doses with five replications of P fertilization were evaluated using a randomized block design, totaling 25 experimental units.

The P doses to be applied were defined based on the studies of Valderrama et al. (2011) and Gonçalves Junior (2010), where Valderrama et al. (2011) in a study with corn, used for phosphorus the doses of 0 kg ha^{-1}, 50 kg ha^{-1}, 100 kg ha^{-1}, and 150 kg ha^{-1} and in the study of Gonçalves Junior (2010) the tested P doses were 0, 80 and 160 kg ha^{-1} of P_2O_5 in soybean crop.



Graph 1. Average precipitation in 2018. Source: National Institute of Meteorology - INMET.

Table 1. Chemical and particle-size characteristics in the 0-20 and 20-40 cm soil layers.

Depth	pH	Ca	Mg	K	Al	CEC	BS	OM	
(cm)	$CaCl_2$			$cmol_c\ dm^{-3}$			%	$g\ dm^{-3}$	
0-20	4.20	0.3	0.1	0.05	0.45	5.2	9.0	16.4	
20-40	4.01	0.2	0.1	0.04	0.65	4.4	8.0	14.2	
Depth	P (Mel.)	S	Zn	B	Cu	Mn	Clay	Silt	Sand
			$mg\ dm^{-3}$					%	
0-20	0.8	5.4	0.3	0.4	0.7	10.9	15	5	80
20-40	0.8	6.9	0.3	0.5	0.8	12.0	15	7	78

CEC – Cation-exchange capacity; BS – Base saturation; OM – Organic matter.

For the evaluation of P doses, the following doses were used: 0 (control), 40, 80, 120, and 160 kg ha^{-1} of P_2O_5, using as source triple superphosphate (46% of P_2O_5). The application occurred in the sowing furrow in all treatments containing P (doses). Twenty days after sowing, there was an incidence of fall armyworm (*Spodoptera frugiperda*). The control was based on the insecticide Karate Zeon 250 CS®, with Lambda-cyhalothrin as the active ingredient and a concentration of 250 g L^{-1}. The product was applied at 30 mL ha^{-1} using a boom sprayer attached to the tractor.

The variables evaluated were: stem length (SL), stem diameter (SD), leaf area (LA), shoot dry mass (DM), leaf phosphorus content (PC), phosphorus accumulation (PA), fertilizer efficiency (FE), chlorophyll *a* (CHA) and chlorophyll *b* (CHB). The analyses were performed on plants at the V5 physiological stage. Three plants from each plot were harvested randomly using scissors to determine the shoot dry mass. The samples were separated in the experimental area, placed in identified paper bags, and then taken to the laboratory for drying in an oven with forced air circulation for 72 h at 65 °C, and later, the dry mass was obtained.

The length of the stem was measured with a tape measure, and the height from the base of the plant to the insertion of the last leaf was measured in three plants in the plot. The diameter of the stem was obtained with a digital caliper in the base of the plant (0.05 m from the ground) in three plants in the plot. To determine leaf area, an adapted method described by (Rodrigues et al., 1999; Santi et al., 2006) was used, in which the total length and average width of the leaves were measured according to the equation: $LA = 0.7811x - 14.964$," where LA is the leaf area, and x is the length multiplied by the width in cm^2. Data were collected from three leaves in each plot.

The chlorophyll *a* and *b* content was obtained in chlorofiLOG®, with measurements in three leaves per plot during the daytime. The P content was evaluated by collecting three leaves per plant, randomly collected in the central third of the plant according to Sousa et al. (2004), and then sent to a reference laboratory for leaf analysis. The quantification of nutrient accumulation was obtained with the equation $PA = \frac{DM\ X\ PC}{1000}$, where PA is the phosphorus accumulation in kg ha^{-1}; DM is the shoot dry mass in kg ha^{-1}; PC is the phosphorus content in g kg^{-1} (Perin et al., 2004).

The nutrient application efficiency data have used the formula $EF = \frac{NA\ treatment - NA\ control}{NA\ treatment} * 100$, where EF is the nutrient application efficiency in (%); NA treatment is the nutrient accumulation in the treatment with P_2O_5, kg ha^{-1}; and NA control is the nutrient accumulation in the control treatment (without P_2O_5 application), in kg ha^{-1} (Leal et al., 2015). The data obtained were submitted to the regression analysis of variance on the effect of P doses on all variables analyzed. The statistical software used was SISVAR by Ferreira (2011).

3. Results and Discussion

The effects of increasing P doses on the shoot dry mass (g plant^{-1}) in the grain sorghum are described in Table 2. According to the regression analysis, a linear effect was observed by the increasing P doses on the shoot dry mass (g planta^{-1}) in the sorghum plants (Figure 1). This indicates that the P dose responses used in this study were still low regarding the potential response of the crop under these growing conditions in low-fertility soils from Cerrado.

Cruz et al. (2009) observed similar results on the linear effect for sorghum dry matter production according to the P doses on two grain sorghum cultivars BRS304 and BRS310 at doses between 0-75 kg ha^{-1}, where they obtained an increase in total plant dry matter in both cultivars. In the study described by Sá et al. (2018), increasing the doses of simple superphosphate stimulated the total dry mass independently using a saline water irrigation system.

Our results were similar to those described previously in the studies by Cruz et al. (2009), Khalili et al. (2008), and Sá et al. (2018), demonstrating that increases in P doses have positive responses, increasing the accumulation of dry mass produced, which is important in maintaining and preserving soil quality for crop rotation. This was also observed in Persian clover (*Trifolium resupinatum* L.) by Krolow et al. (2004), where they found an increase in dry mass production as the phosphorus dose increased.

Table 2 - Effect of phosphorus doses on grain sorghum under field conditions in southwestern Goias. Table of mean squares.

Parameters	Mean squares	Regression (V%)	CV (%)
DM (kg ha^{-1})	426.359030	Linear** NS	2.93
SL (cm)	47.472246	Linear** Quadrat**	2.83
SD (cm)	0.172156	Linear** Quadrat**	13.14
LA (cm^2)	9568.651026	Linear** Quadrat**	4.12
PC (g kg^{-1})	0.841000	Linear** NS	13.30
SA (kg ha^{-1})	86.521606	Linear** NS	13.92
EF (%)	5364.251914	Linear** Quadrat**	8.23
CHA (CFI)	84.316600	Linear** Quadrat*	9.95
CHB (CFI)	12.620000	Linear** NS	22.09

Note: NS: not significant; *: Significant ($p < 0.05$); **: Significant ($p < 0.01$). Quadrat = Quadratic; DM = shoot dry mass; SL = stem length; SD = stem diameter; LA = leaf area; PC = leaf phosphorus content; PA = phosphorus accumulation; EF = efficiency; CHA = chlorophyll *a* and CHB = chlorophyll *b*. Source, Authors, 2018.

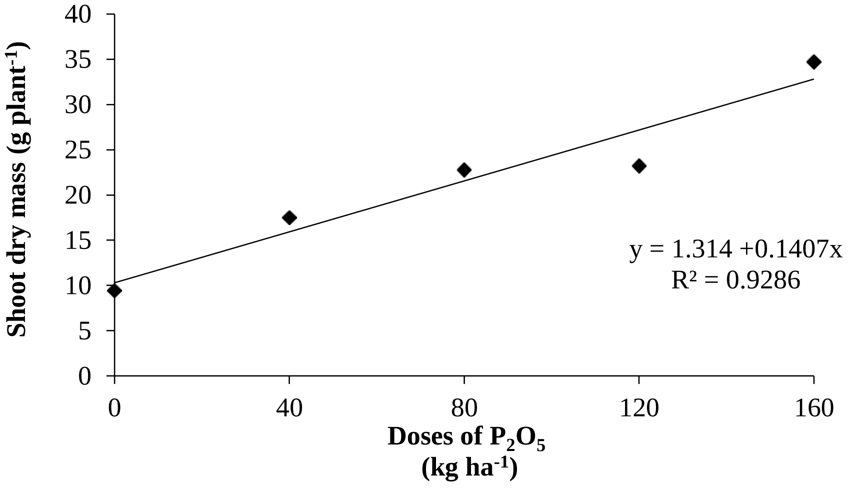


Figure 1. Shoot dry mass of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 2.93. Source: Authors, 2018.

In the study of Stahl (2013), the addition of P to the soil increased the production of dry mass and interfered with parameters related to the nutritional efficiency of *Eucalyptus dunnii* and *Eucalyptus benthamiicultured* seedlings in pots. According to Raij (1991), phosphorus greatly influences root development and increases crop production. Phosphorus is important in plant growth because it improves water use efficiency and promotes root formation and growth (Lopes, 1989). Phosphorus is the only anion capable of making diester bonds; this characteristic gives it singular importance since it is involved in essential plant processes such as photosynthesis, protein regulation, and respiration (Marschner, 1995).

This element also plays an important role in the growth of new tissue and cell division, and phosphate fertilization in adequate amounts stimulates root development, ensures a vigorous start, hastens physiological maturation, stimulates flowering, aids seed formation, increases cold resistance of cereals, and also increases yield (Malavolta, 1989). For stem length, the regression analysis showed a linear and quadratic effect on the different P doses on the cultivar, as observed earlier in Table 1. It can be seen that the point of maximum P for stem length was at a concentration of 128 kg ha^{-1} of P_2O_5 and that, at this dose, an average stem length of 24.56 cm was obtained, as shown in Figure 2.

Fonseca et al. (2008) evaluated a grain sorghum cultivar, with developmental effects in plants 113.1 cm for height, showing an increase between 50-122% concerning the treatments with P omission respectively, where with the increase of the dose, there is an increase in the stem length up to its maximum point. Santos et al. (2002) state that phosphorus plays an important role in the growth of grasses because it is an integral component of important compounds in plant cells, including intermediates of respiration and photosynthesis, as well as nucleotides used in the energy metabolism of plants (Taiz and Zeiger, 2006). In their studies, Rosolem et al. (1995) demonstrated that soil-related factors are more limiting to plant growth than plant characteristics in P-poor soils.

The regression analysis for stem diameter showed linear and quadratic effects for applying P doses for stem diameter (cm) in this cultivar, as seen in Table 1, previously presented. The model defined to present the results was the quadratic model, as it was possible to see differences between its abilities to explain the effect of the combination of independent variables on a dependent variable compared to the linear model (Campos, 2017). Quadratic regression makes it possible to find explanations of variance of greater magnitude when compared to linear models (Campos, 2017).

It can be seen that the point of maximum P dose on the stem diameter was 92 kg ha^{-1} of P_2O_5 with a stem diameter of 1.12 cm, as shown in Figure 3. Pereira et al. (2014), evaluating the doses of 30, 60, 90, and 120 kg of P_2O_5 for sorghum plants, observed a quadratic effect on the stem diameter, ranging from 13.83 mm (control) to 19.03 mm for a dose of 120 kg ha^{-1} of P_2O_5, and the estimated dose for obtaining the maximum stem diameter was 96.03 kg ha^{-1}. In plants, phosphorus plays a key role in forming ATP (Adenosine triphosphate), the main energy source for photosynthesis, cell division, transport of assimilates, and genetic load (Nutri Facts, 1996).

As a result of its role and importance in the participation of internal processes of plant morphology, phosphorus is related to crop yield (Alcântara Neto et. al, 2010). When phosphorus has a low presence in the soil, plants can suffer consequences such as reduced leaf surface expansion, as well as reduced leaf number, height, and stem diameter (Terra Magna, 2022). The shoot development and growth are also greatly impacted. As root growth is reduced by nutrient deficiency, the uptake of water and nutrients becomes even smaller (Terra Magna, 2022). A linear and quadratic effect for the leaf area was observed for the P doses, as shown in Table 1. It can be seen that the P dose that provided the maximum leaf area was 116 kg ha^{-1} of P_2O_5 and resulted in a leaf area of 220.49 cm^2, as shown in Figure 4.

In other dose-response studies, Rodríguez et al. (1998) found that low P supply reduces leaf area and, consecutively, leaf number. This is because phosphorus is important for the formation of the primordia of the reproductive parts, growth, and development of the shoot, being essential for the good formation of fruits and increase the production in crops due to the realization of processes such as photosynthesis and cell division (Taiz and Zeiger, 2006). Phosphorus also contributes to the increase in the concentration of alkaloids and other active principles, and its deficit causes a reduction in biomass and, consequently, in metabolic substances, where the low supply of this nutrient results in a decrease in the leaf area and can directly interfere with photosynthetic rates (Taiz and Zeiger, 2006).

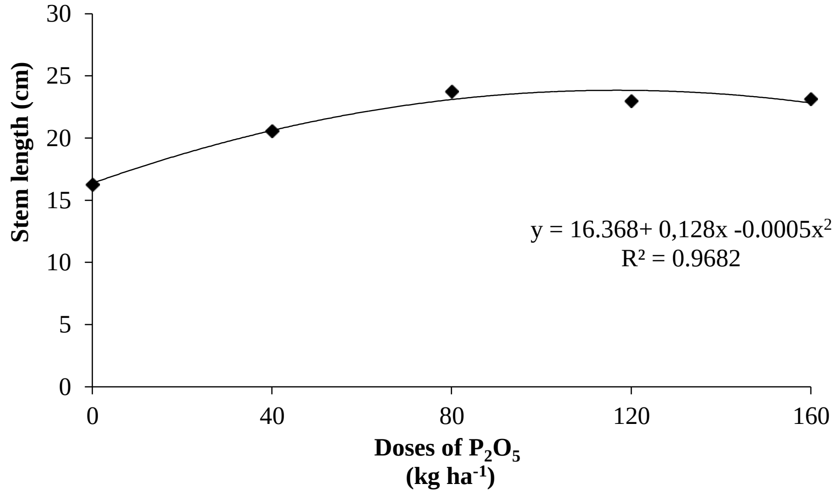


Figure 2. Stem length of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 2.83. Source: Authors, 2018.

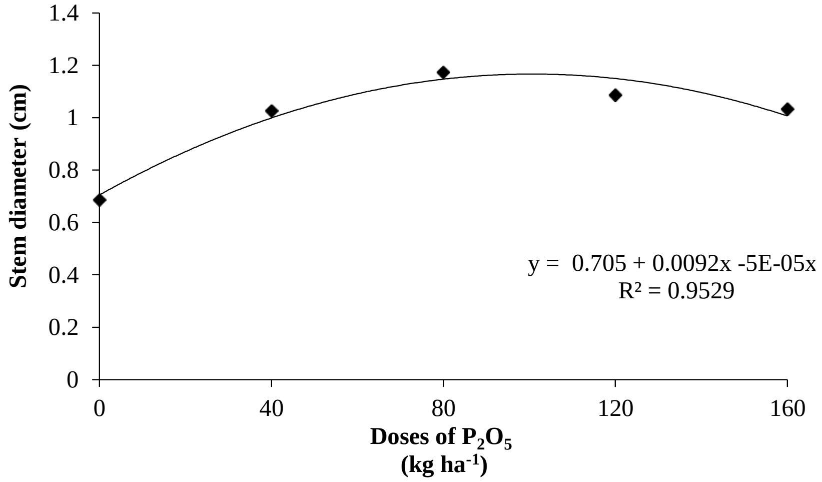


Figure 3. Stem diameter of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 13.14. Source: Authors, 2018.

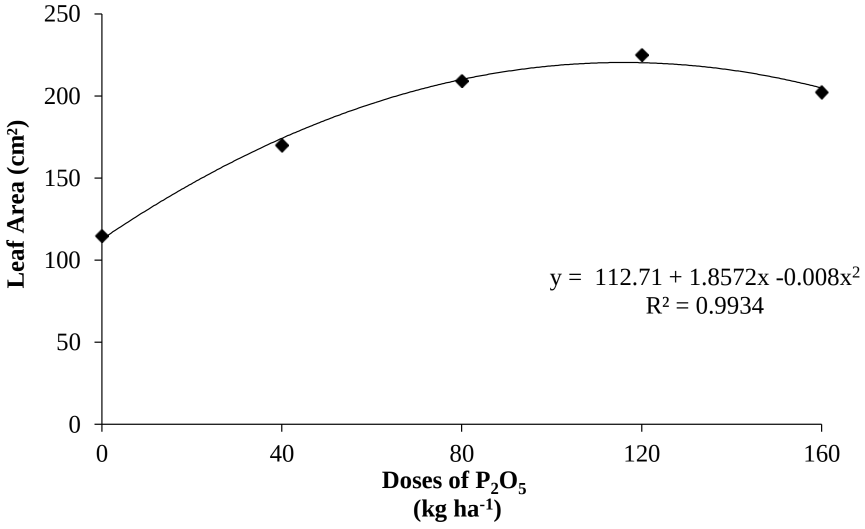


Figure 4. Leaf area (cm^2) of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 4.12. Source: Authors, 2018.

A similar result was found in our study, where it can be observed that the increase in leaf area was proportional to the dose of maximum point applied. Verifying this statement for other grains, Zabot et al. (2004) evaluated the growth of the bean cultivar BR Ipagro 44 Guapo Brilhante in the second harvest with four sowing densities, where they found that the leaf area showed quadratic behavior in the adopted model, on the application of P_2O_5, thus demonstrating that the density can also influence on the leaf area in different grain crops, not only for sorghum.

A linear effect was obtained in the regression analysis with P doses on the quantitative leaf phosphorus content (g kg^{-1}), as described previously in Table 1. For the leaf P content, the data obtained presented significance when evaluated by the linear model, as seen in Figure 5, indicating that the doses used in this study were still low to the potential response on the crop under these soil conditions, yield, and regionality.

Pereira et al. (2014) presented for grain sorghum cultivar BR304 and four doses of P (30-120 kg ha^{-1}) results with significant effect for regression adjusted according to the linear model adopted on leaf P content with $p < 0.01$. However, our study observed a similar result for Agroceres cultivar AG 1085. Other studies, such as those of Fonseca et al. (2008) evaluating different sorghum cultivars, obtained leaf P contents of 4.0 g kg^{-1}. For Ribeiro et al. (1999), researchers suggest that the ideal P content is 4.4 g kg^{-1} resulting in a higher value than the one obtained in our study, as shown in Figure 5.

The regression analysis showed a linear effect of P doses on the accumulation of this element on the dry mass expressed in (kg ha^{-1}) in the cultivar evaluated, as observed in Table 1. For the accumulation of P in the dry mass, the values obtained were significant for the linear model (Figure 6), thus indicating that the doses used in our study were still below the potential response of the crop under Cerrado conditions.

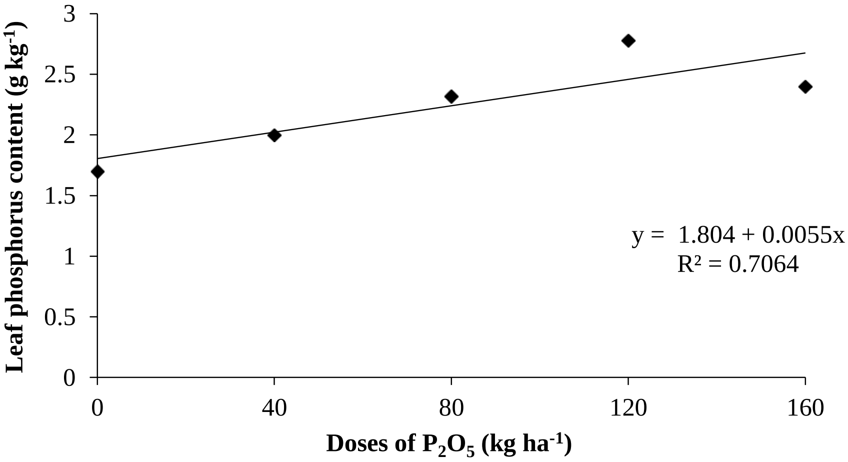


Figure 5. Leaf phosphorus content (g kg^{-1}) of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 13.30. Source: Authors, 2018.

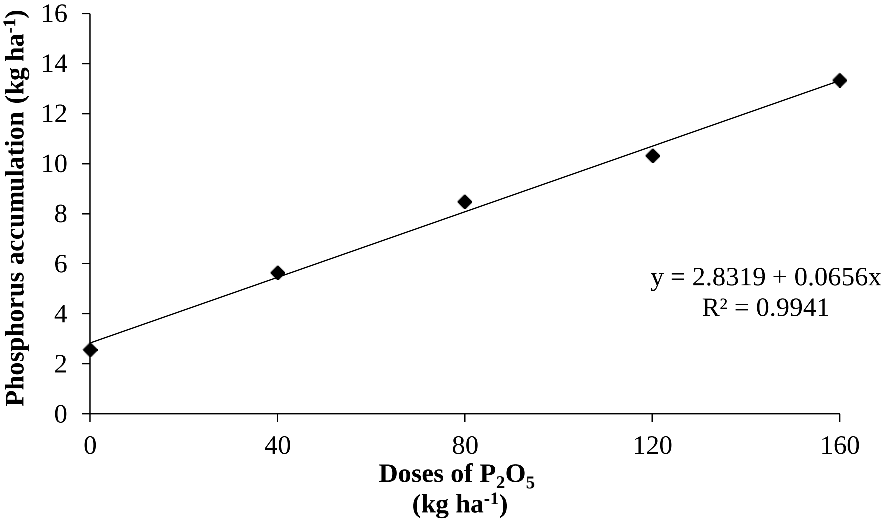


Figure 6. Phosphorus accumulation on the dry mass of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 13.92. Source: Authors, 2018.

When checking other studies with different grain sorghum cultivars, we can cite Han et al. (2011) with sorghum using at planting doses between 30-75 kg ha^{-1} of P_2O_5, observing that plants increasingly accumulated this nutrient until physiological maturity. The results of Han et al. (2011) corroborate our findings, where increasing P accumulation was observed with increasing doses. For Giacomini et al. (2003), the increase of P concentration in the soil for turnip rape stood out as to the amount of accumulated P, reaching an average in three years of 4.1 mg kg^{-1} of P on the dry matter produced.

Corroborating with our statements, Sá et al. (2018) found for sweet sorghum significant response on phytomass accumulation with doses of simple superphosphate with a maximum yield peak at 96 mg dm^{-3}. Thus, the results found in this work, compared to those of Giacomini et al. (2003) and Sá et al. (2018), were similar to our findings for the specific sorghum crop and cultivar, where the increase in P was significant in the accumulated content of this macronutrient in the dry mass evaluated. The regression analysis also showed a linear and quadratic effect of P doses on phosphorus use efficiency (%) in the sorghum cultivar evaluated, as shown in Table 1. It can be seen that the maximum point for efficiency is presented for the 129 kg ha^{-1} dose of P_2O_5, with an efficiency of 82.02 %, as shown in Figure 7.

In comparison, in the work of Khan et al. (2005), using two corn cultivars submitted to different doses of P in saline conditions, they obtained the highest physical efficiency of production for the dose of 75 kg ha^{-1} of P_2O_5, different from this study, where the doses tested were still low, not fitting the quadratic model, without showing the maximum point of production efficiency. Ray et al. (2019) and Irfan et al. (2020) also worked with corn; they concluded that different genotypes show low efficiency when grown in nutrient solution with P omission; the same was observed in our study until reaching the maximum point dose.

The linear and quadratic effect of P doses was found for chlorophyll *a* (CFI) in the sorghum crop evaluated as data presented earlier in Table 1. It can be seen that the highest index of chlorophyll *a* was on the dose 128.5 kg ha^{-1} of P_2O_5, with chlorophyll *a* index = 29.2, as shown in Figure 8. For cowpea, Silva et al. (2010) obtained in two soluble P sources a quadratic effect on chlorophyll content according to the phosphate fertilization, with values of 41 and 56 units for doses 66 and 86 kg ha^{-1} employing simple and triple superphosphate, respectively.

Lower doses were determined for sorghum in this research, with a result of 29.2. For Souza et al. (2011), the chlorophyll content increases with different doses of P, and the increase in N in the leaf tissue was also provided by fertilization with a source of P, thus favoring the synthesis in the physiological processes of production of the chlorophyll pigment. The regression analysis also showed an effect, however, only linear for applying P doses on chlorophyll pigment *b* (CFI) in the sorghum cultivar in our study and presented in Table 1.

For chlorophyll *b*, the data obtained were significant for the linear model employed, as seen in (Figure 9), indicating that the doses used in this study were still low to the potential response of the sorghum cultivar under these uncontrolled environmental conditions. Gazola et al. (2013) developed a study with different doses of P_2O_5 in soil classified as Latossolo Vermelho distrófico and simple hybrid cultivar Biogene 7049 corn, and concentrations between 0-150 kg ha^{-1} observed variation between 51.65 to 53.89 CFI.

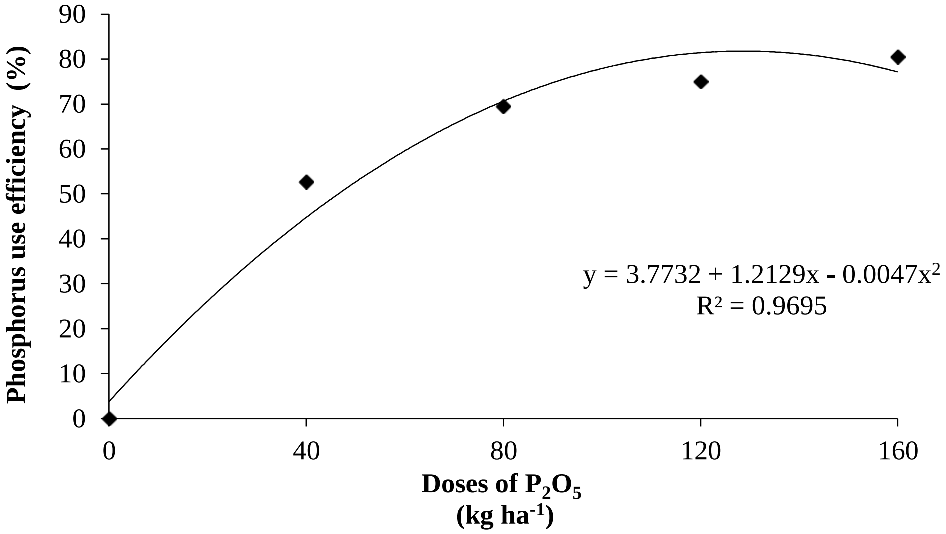


Figure 7. Phosphorus use efficiency (%) of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 8.23. Source: Authors, 2018.

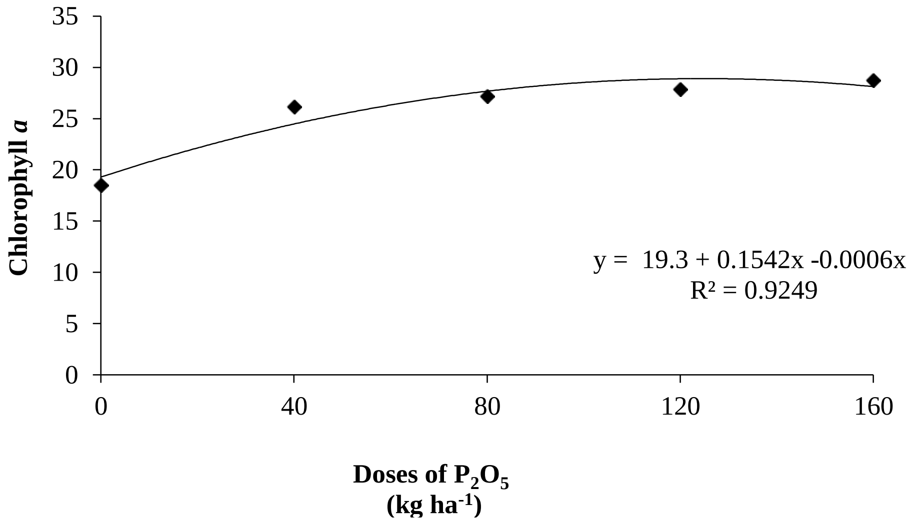


Figure 8. Chlorophyll *a* of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 9.95. Source: Authors, 2018.

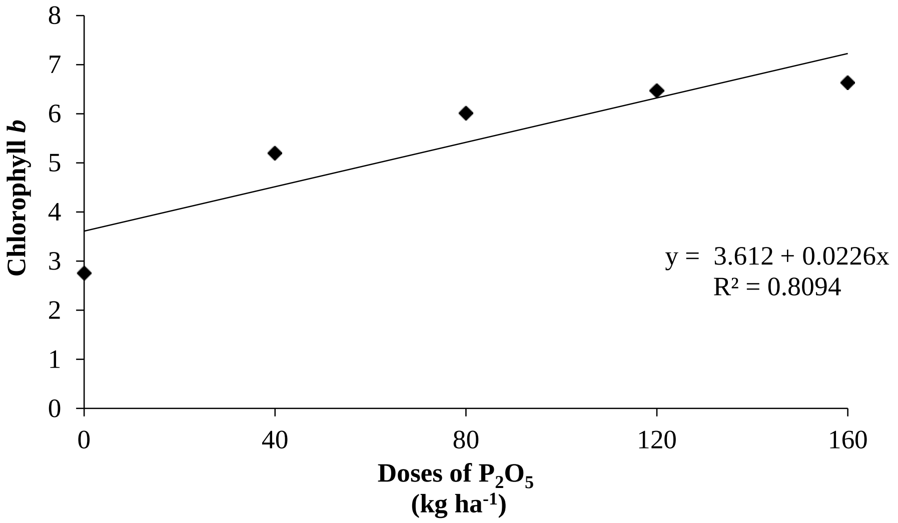


Figure 9. Chlorophyll *b* of grain sorghum plants according to the phosphorus doses under field conditions in the Cerrado of Southwest Goiás, Brazil. Average from five observations. CV% = 22.09. Source: Authors, 2018.

From the results obtained by Rodrigues (2015), it was observed that there was no significant interference between chlorophyll indexes and phosphorus fertilization, where the doses of phosphorus also did not significantly influence the chlorophyll *a*, *b*, and total chlorophyll contents in corn plants, but the concentration of chlorophyll in the leaves tended to increase with the doses of phosphorus applied, as also observed in this work.

These observations are associated with the elevation of nitrogen concentration in the leaf tissue provided by phosphate fertilization, favoring chlorophyll synthesis (Lima Júnior et al. 2006). The effect of the interaction P and the indirect measurement of chlorophyll is possibly due to the role of P in plant nutrition, as it is a component of ATP, which provides energy to the active N uptake process (Malavolta et al. 1989).

4. Conclusions

The application of phosphorus positively influenced the development of the grain sorghum cultivar Agroceres AG 1085. The dose of 129 kg ha^{-1} of P_2O_5 gave the highest efficiency of phosphate fertilization, corresponding to 82.02%. Future studies should be carried out, evaluating more than one year of cultivation of the cultivar tested for new observations on the action of this macronutrient (P) on the soil type in the Cerrado area of Brazil.

Authors’ Contribution

Felipe Hernandes Carvalho, José Milton Alves and Matheus Vinicius Abadia Ventura contributed to the organization of the research, execution of the experiment, data collection, statistical analysis of the data, interpretation of the results, writing of the manuscript, and final correction of the manuscript. Thais Gonçalves Veloso, Ritiane Souza Alcântara and Hellen Regina Fernandes Batista Ventura also contributed to organizing the experiment, interpreting the results and final correction of the manuscript.

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