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Agronomic performance of forage sorghum in salt-affected soils and subjected to phosphate fertilization

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ABSTRACT

Pasture-based beef production in the Semi-Arid region is affected by irregular rainfall, requiring drought-tolerant forage crops, and forage sorghum stands out as a strategic alternative. This study evaluated the agronomic performance of forage sorghum cv. Sudan-4202 grown in saline Cambisols under different phosphate fertilizer doses. The experiment was conducted in the field in the Brazilian semi-arid region, using a randomized block design with five doses of P_2O_5 (0, 30, 60, 90, and 120 kg ha^{-1}), and irrigation with brackish water. Dry matter production showed a positive response to fertilization, but salinity restricted growth, which was reflected in reduced height, number of leaves, and productivity. Fresh weight ranged from 16 to 21.13 Mg ha^{-1}, while maximum dry matter reached 2.79 Mg ha^{-1}, values below the crop's productive potential in the region. The results indicate that in saline environments, the effect of phosphate fertilization is limited and not enough to overcome the restrictions imposed by salt stress. Therefore, it is recommended to adopt more tolerant cultivars, water management that minimizes salt accumulation, and the use of phosphorus sources with higher agronomic efficiency, aiming to optimize crop performance and productive sustainability in salt-affected areas.

RESUMO

A produção de carne bovina a pasto no Semiárido é impactada pela irregularidade das chuvas, exigindo forrageiras tolerantes à seca, o sorgo forrageiro destaca-se como alternativa estratégica. Este estudo avaliou o desempenho agronômico do sorgo forrageiro cv. Sudan-4202 cultivado em Cambissolos salinos sob diferentes doses de adubação fosfatada. O experimento foi realizado em campo, no semiárido brasileiro, utilizando delineamento em blocos casualizados com cinco doses de P_2O_5 (0, 30, 60, 90 e 120 kg ha^{-1}) e irrigação com água salobra. A produção de massa seca apresentou resposta positiva à adubação, porém a salinidade restringiu o crescimento, refletindo-se na redução da altura, número de folhas e produtividade. A massa fresca variou de 16 a 21,13 Mg ha^{-1}, enquanto a massa seca máxima atingiu 2,79 Mg ha^{-1}, valores inferiores ao potencial produtivo da cultura na região. Os resultados indicam que, em ambientes salinos, o efeito da adubação fosfatada é limitado, não sendo suficiente para superar as restrições impostas pelo estresse salino. Recomenda-se, portanto, a adoção de cultivares mais tolerantes, manejo hídrico que minimize o acúmulo de sais e utilização de fontes de fósforo com maior eficiência agronômica, visando otimizar o desempenho da cultura e a sustentabilidade produtiva em áreas afetadas pela salinidade.

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Introduction

Beef production on pasture in the Semi-arid region is affected by irregular rainfall, which requires the use of drought-tolerant forages. In this context, sorghum stands out as a strategic alternative because it is highly productive, energy-rich, easily digestible, and well adapted to hot and dry regions, ensuring greater stability in animal production throughout the year (Lima et al., 2017). Besides choosing the forage, assessing the dry matter (DM) content of forages is essential for formulating precise diets, since key nutrients like crude protein, fiber, and energy are calculated based on the DM (Ritz et al., 2020).

Arid and semi-arid regions are more vulnerable to soil salinization problems because the intense evapotranspiration and low rainfall throughout the year reduce water availability for crops and limit the leaching of salts from the root zone, leading to significant salinization (Valença et al., 2023).

Soil salinity affects the availability of P, which is causing a growing problem in agricultural soils, especially in arid, semi-arid, and irrigated lands, due to the accumulation of soluble salts. This reduction happens mainly because of changes in the soil's chemical properties, like increased ionic strength and competition for adsorption sites, affecting the solubility and mobility of phosphorus (Xie et al., 2022; Ye et al., 2025; Mishra et al., 2023).

Although there are several studies on P dynamics in salt-affected soils, experimental results vary depending on the type of phosphate fertilizer (P), the applied dosage, and other factors. Additionally, conditions like salinity, soil pH, and cultivated species directly influence the efficiency of P in soil and plants. In soils with high salinity or high pH, there is greater P fixation (precipitation), further reducing its availability to crops (Xie et al., 2022). Research indicates that the ideal levels of available P for winter wheat and summer corn are 16.1 and 14.6 $mg.kg^{-1}$, respectively. However, in saline soils, the average concentration of available P is only 5 $mg.kg^{-1}$, which is insufficient to meet plant demands. The availability of this nutrient is also affected by soil salinity and pH, as well as by the form and amount of fertilizer applied. Analyses show that the response of available P to phosphate fertilization varies significantly in soils with different levels of salinity and alkalinity (Liu et al., 2024).

In this context, the aim of this work was to evaluate the agronomic performance of forage sorghum grown in salt-affected soils, subjected to different doses of phosphate fertilization.

Materials and methods

The experiment was carried out in 2014 under field conditions at the Academic Unit of Serra Talhada (*Unidade Acadêmica de Serra Talhada* - UAST), part of the Federal Rural University of Pernambuco (*Universidade Federal Rural de Pernambuco* - UFRPE), located in the municipality of Serra Talhada, Pernambuco (7.96°S, 38.30°W, and 507 m above sea level).

The local climate follows the Köppen-Geiger classification, and it is BShw, characterized as hot semi-arid with rainfall concentrated at the end of summer and beginning of autumn. The average annual temperature is around 25.9°C, and the average annual rainfall ranges between 630 and 680 mm, with approximately 70% to 85% of the rain occurring from January to April (da Rosa et al., 2019; Silva et al., 2023).

The trial was conducted in randomized blocks (RCB) with four replications, with treatments consisting of five phosphorus doses applied at the area's foundation (0, 30, 60, 90, and 120 kg ha^{-1} of P_2O_5). The irrigation depth was determined based on reference evapotranspiration (ETo), calculated using the Penman-Monteith method, as recommended by FAO Bulletin 56 (Allen et al., 1998), and was applied 2 to 3 times per week. The irrigation water was classified as C3S1 - water with high salinity (EC between 0.75 and 2.25 dS/m at 25 ºC) and low sodium concentration. The area used was at the UAST Campus (7.9521° south latitude and 38.2949° west longitude), on flat terrain, with soil classified as Solodic Cambisols. Soil samples were collected for chemical characterization (Da Silva, 2009) and physical characterization (Brazilian Agricultural Research Corporation, 1997) (see Table 1).

Table 1.

Characterization of the studied soil: levels of exchangeable Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), and Potassium (K^+), available Phosphorus (P) (mehlich^{-1}), remaining Phosphorus (Prem), Base Saturation (V%), exchangeable Sodium Percentage (ESP), and clay content.

pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	(H^+Al)	P	P-rem	V	PST	Clay
(H2O)	------ cmol$_c$ dm^{-3} ------					mg L^{-1}		dag kg^{-1}		g kg^{-1}
7.3	4.35	1.25	1.30	1.92	2.85	65.9	42.4	75.59	11.16	80

Source: Marques (2014).

The planting was done manually, with spacing of 0.20 × 0.80 m. Weed control was carried out by hand weeding. Each plot consisted of four rows, 4 m long, with the two central rows considered for the usable area, discarding 1.0 m at each end, totaling 20 useful plants per plot.

The seeds of forage Sudan Sorghum (*Sorghum sudanense* (Piper) Stapf), variety SUDAN-4202, were provided by the Agronomic Institute of Pernambuco (*Instituto Agronômico de Pernambuco* - IPA).

The phosphorus source used was monoammonium phosphate (MAP), which was applied in the furrow 5 days before planting. The need for nitrogen and potassium fertilization was determined through analysis, following the recommendations of the Fertilization Manual of the State of Pernambuco (2008). The nitrogen added by the MAP doses was balanced with the addition of urea.

The sorghum harvest was carried out at the dough stage, which occurred 55 days after planting. At that time, the plant height and the number of leaves were measured, and the fresh weight (FW) of the aboveground parts was determined. Then, the material was dried in an oven with forced air circulation at 65–70 °C until it reached a constant weight, at which point the dry weight was obtained. The fresh and dry weight yields were estimated, expressed in megagrams per hectare (Mg ha^{-1}).

The variables analyzed were subjected to analysis of variance (ANOVA) and, when relevant, regression models were adjusted to describe the relationship between sorghum productivity and the doses of phosphorus (P) applied.

Results and discussion

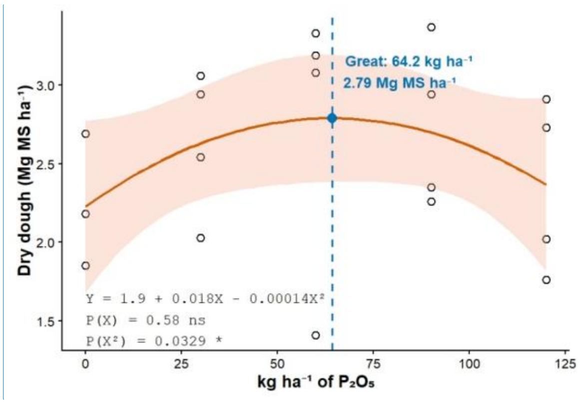
The productivity of sorghum ranged from 16 to 21.13 Mg ha^{-1} of fresh mass. There was no significant difference between the P doses, nor was it possible to fit a regression model. These values fall within the average range observed in soils in good condition. Among the sorghum genotypes evaluated by Oliveira et al. (2024), two stood out, with an average productivity of 31.12 Mg ha^{-1} and a range from 14.29 to 68.88 Mg ha^{-1}.

Considering that the increasing doses of P did not influence low-performance productivity, this may be related to the combination of soil alkalinity and the use of salty irrigation water with a high pH (7.2) and more than 11% ESP. Pessoa et al. (2022) observed an increase in soil salinity in cultivated and desertified areas, which happened due to the rise in the cationic and anionic composition of the soil solution. The high ion concentration intensifies the ionic strength and, consequently, the electrical conductivity (Black and Campbell, 1982). In this specific case, this process results from irrigated agriculture without a drainage system, favoring the accumulation of salts along the soil profile (Liu et al., 2020). Additionally, irrigation with brackish water and continuous use of mineral fertilizers further worsen this condition.

In the DM analysis of the cultivated sorghum, it was possible to fit a significant regression model based on the increasing doses of applied P (See Figure 1). Da Silva et al. (2018) found that the increase in simple superphosphate doses stimulated the total dry matter independently when using a saline water irrigation system. In Lima et al. (2017), 24 sorghum genotypes were evaluated in four municipalities under different growing conditions, and the results showed significant differences among the genotypes at all locations, with yields ranging from 12.23 to 23.15 Mg ha^{-1}, corresponding to genotypes 12F39006 and 12F37005.

Figure 1.

Sorghum field productivity in Mg ha⁻¹ of dry matter as a function of increasing P doses, maximum (optimal) productivity, and the maximum point of the significant model.



Source: Research data, Marques (2014).

The maximum DM productivity of sorghum obtained was approximately 2.79 Mg ha⁻¹ (see figure 1), a value lower than the expected average of 5 Mg ha⁻¹, according to the fertilizer recommendation manual for the State of Pernambuco (2008), which shows low productivity when compared to a regional productivity standard on soils without chemical limitations. On the other hand, similar results were found by Alves et al. (2016), who reported average productivities ranging from 2.02 to 6.05 Mg ha⁻¹ when evaluating four sorghum cultivars (BRS 655, BRS 700, BRS 810, and IPA 2502) under no-till conditions in the Brazilian semi-arid region.

In the analysis of plant height, a variation from 131 to 151 cm was observed, with an average of 143 cm (see figure 2), with no significant difference between the P doses. Similarly, Ngidi et al. (2024), who evaluated 50 sorghum genotypes, recorded heights ranging from 107.06 to 223.28 cm, with an overall average of 156.01 cm, highlighting genotypes AS205, AS391, AS109, AS113, and AS11, with an average height above 180 cm. In Lima et al. (2017), they evaluated 24 sorghum genotypes in four municipalities under different cultivation conditions and observed a wider variation from 172 to 283 cm, with genotypes 12F38006, 12F40006, and 12F37016 showing the highest averages (204 to 268 cm) in all locations, demonstrating a significant influence of the environment on the growth of these genotypes.

Comentado [RD1]: TRADUÇÃO DOS TEXTOS DESTA FIGURA:

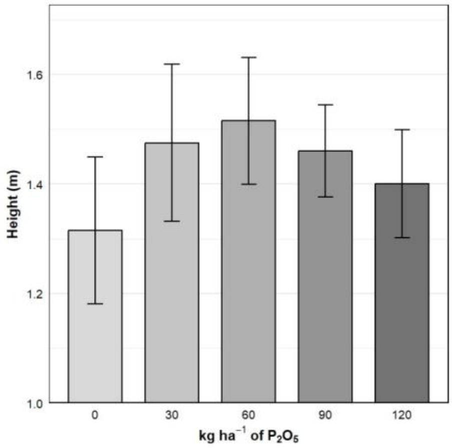
Dry dough

Great:

Kg ha⁻¹ of P_2O_5

Figure 2.

Average height (m) of sorghum plants subjected to increasing doses of P_2O_5.



Source: Research data, Marques (2014).

Comentado [RD2]: TRADUÇÃO DOS TEXTOS DESTA FIGURA:

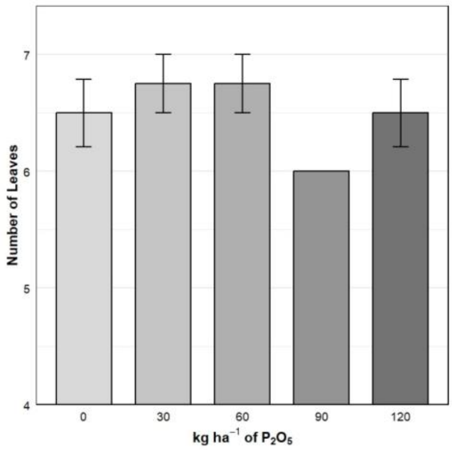
Height (m)

Kg ha^{-1} of P_2O_5

The average number of leaves in the present study was 6.50, with no significant difference between the P doses (See Figure 3). For comparison, Perazzo et al. (2017) evaluated 21 experimental sorghum hybrids and three commercial hybrids and, at the first cut, observed variation from 5.33 to 9.83 leaves, with an average of 7.28, forming four distinct groups. Two hybrids stood out, showing the highest values for this variable (9.83 and 9.33 leaves, respectively). At the second cut, two groups were formed, with the number of leaves ranging from 6.00 to 8.67 and an average of 7.40 leaves.

Figure 3.

Average number of leaves of sorghum plants subjected to increasing doses of P_2O_5.



Source: Research data, Marques (2014).

Comentado [RD3]: TRADUÇÃO DOS TEXTOS DESTA FIGURA:

Number of Leaves

Kg ha^{-1} of P_2O_5

Conclusion

Phosphate fertilization increased the dry matter yield of forage sorghum, even in saline soil and under irrigation with brackish water. However, fertilization does not eliminate the need for additional management practices aimed at reducing the effects of salinity and ensuring more sustainable production.

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