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Initial growth of *Prosopis juliflora* (Sw.) DC. seedlings subjected to nitrogen fertilization

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ABSTRACT

Anthropogenic changes in land use have led to significant loss of vegetation globally, causing a biodiversity crisis through habitat destruction. This issue is acute in biomes like the Caatinga, characterized by low rainfall, high temperatures, and nitrogen-poor soils. Addressing this degradation requires multifaceted strategies, including changing human behaviors and adopting silvicultural techniques such as nitrogen fertilization. *Prosopis juliflora*, adapted to semi-arid conditions, is a promising species for rehabilitating this biome. This study investigated the impact of varying nitrate levels on the initial growth of *P. juliflora* seedlings, using a randomized design with nitrate concentrations ranging from 0.0 to 10.0 mmol dm^{-3}. Measurements of seedling height, stem diameter, and biomass were taken periodically up to 55 days after sowing. Findings reveal that high nitrate levels do not enhance *P. juliflora* seedling growth, with optimal concentrations between 3.5 and 6.5 mmol dm^{-3}. *P. juliflora*'s adaptability to infertile soils makes it a cost-effective and sustainable choice for restoring the Caatinga. Further research is recommended to refine these findings and improve reforestation practices, ensuring the species' full potential is utilized.

Keywords: Nitrate, algarobeira, semiarid, seedling production, plant nutrition

Crescimento inicial de mudas de *Prosopis juliflora* (Sw.) DC. submetidas à fertilização nitrogenada

RESUMO

As mudanças antropogênicas no uso da terra levaram a uma significativa perda de vegetação globalmente, causando uma crise de biodiversidade por meio da destruição de habitats. Este problema é crítico em biomas como a Caatinga, caracterizada por baixa pluviosidade, altas temperaturas e solos pobres em nitrogênio. Abordar essa degradação requer estratégias multifacetadas, incluindo a mudança de comportamentos humanos e a adoção de técnicas silviculturais, como a fertilização nitrogenada. *Prosopis juliflora*, adaptada a condições semiáridas, é uma espécie promissora para a reabilitação desse bioma. Este estudo investigou o impacto de diferentes níveis de nitrato no crescimento inicial de plântulas de *P. juliflora*, utilizando um delineamento inteiramente casualizado com concentrações de nitrato variando de 0,0 a 10,0 mmol dm^{-3}. As medições da altura, diâmetro do caule e biomassa das plântulas foram realizadas periodicamente até 55 dias após a semeadura. Os resultados revelam que altos níveis de nitrato não aumentam o crescimento das mudas de *P. juliflora*, com concentrações ótimas entre 3,5 e 6,5 mmol dm^{-3}. A adaptabilidade de *P. juliflora* a solos inférteis a torna uma escolha econômica e sustentável para a restauração da Caatinga. Recomenda-se pesquisas adicionais para aprimorar esses achados e melhorar as práticas de reflorestamento, garantindo o pleno aproveitamento do potencial da espécie.

Palavras-chave: Nitrato, algarobeira, semiárido, produção de mudas, nutrição de plantas

Introduction

The increasing changes in land use and cover have led to a significant reduction of native vegetation worldwide. This scenario implies a global biodiversity crisis, primarily caused by habitat destruction. This process is largely driven by changes in land use, such as the conversion of native vegetation areas into lands designated for agriculture or livestock (Brondizio et al., 2019).

According to the authors, global estimates indicate that approximately 23 % of the global land surface is characterized as degraded area. Between 2010 and 2015, more than 32 million hectares of primary or recovering forest in the tropics were lost, and, with these modifications, numerous species are added to the list of species threatened with extinction.

This impasse intensifies even further in certain biomes, such as the Caatinga, located in Northeast Brazil and characterized as an area with low precipitation, high temperatures, and soils with low nitrogen content. Over the years, the vegetation in this region has been exploited in a predatory manner, whether through excessive cattle grazing, the use of native firewood, and/or illegal logging, resulting in a reduction of the biome's biodiversity and consequently affecting soil quality, through the impoverishment of chemical resources, changes in physical and chemical composition, as well as a reduction in its microbiota, thus favoring a decrease in the quality of life for the population (Demartelaere et al., 2022).

To reverse and decelerate this scenario of ecosystem degradation, predominantly caused by human activities, profound and lasting transformations are necessary, involving various agents at different levels (Nielsen et al., 2021). Furthermore, the need to apply and develop silvicultural techniques aimed at seedling production is highlighted, with the goal of recovering these areas (Santos et al., 2023). In this context, nitrogen fertilization has proven to be a promising technique by assisting in the initial growth and survival of seedlings (Lima Goulart et al., 2021).

Among the species potentially used for the recovery of the Caatinga, mesquite (*Prosopis juliflora* (Sw.) DC.) stands out. This xerophytic species, native to Peru and belonging to the Fabaceae family, is commonly employed in the biome due to its adaptability to semi-arid conditions. It is characterized by the abundant production of pods during the driest times of the year, serving as an alternative food source due to its excellent palatability, good digestibility, and high nutritional value in both animal and human diets during drought periods (Albuquerque et al., 2018). According to these authors, the density of its wood suggests potential for use in sawmills for manufacturing rustic furniture, as well as for various applications such as posts, stakes, sleepers, firewood, and charcoal.

Moreover, *P. juliflora* is already used in the restoration of degraded areas and reforestation due to its tolerance to environmental stresses, and its association with nitrogen-fixing bacteria in the soil, thereby enhancing the physical and chemical properties of the soil (Edrisi et al., 2020; Puppo & Felker, 2021; Sharma et al., 2022)

Considering that most soils in the Caatinga biome are nutrient-poor, particularly deficient in nitrogen, and that the recovery of degraded areas in this region is a pressing need, combined with the frequent use of *P. juliflora* in the Brazilian semi-arid zone, it becomes evident that research focused on producing high-quality seedlings with robust development is of paramount importance. In this context, nitrogen fertilization emerges as a promising strategy to enhance the development of propagative material (Silva et al., 2024; Wiegand et al., 2021).

Nitrogen is one of the essential macronutrients required by plants, playing a crucial role in growth and development in forest systems (Li et al., 2020; Qin et al., 2021). However, its availability in the environment must be carefully balanced, as its deficiency negatively affects leaf development, photosynthesis, and metabolic processes, directly impairing plant growth and vitality. Conversely, an excess of nitrogen can be toxic to plants, inducing deficiencies or reducing the uptake of other nutrients, thereby disrupting plant metabolism (Cândido et al., 2020; Li et al., 2020).

Despite its importance, there are still gaps in understanding the optimal dosage for different crops. Recent studies indicate that plant responses to nitrogen fertilization vary significantly among species, underscoring the need for species-specific approaches to optimize the use of this nutrient (Freires et al., 2020; Kumar et al., 2022; Li et al., 2020; Singh et al., 2023; Soares et al., 2021).

In this context, the present study aimed to evaluate the effect of nitrogen fertilization on the initial growth of *P. juliflora* seedlings subjected to increasing concentrations of $N^{-}NO^{-3}$ (nitrate). The hypothesis is that nitrogen fertilization significantly enhances the initial growth and quality of *P. juliflora* seedlings compared to those that do not receive nitrogen supplementation.

Material and methods

Location and characterization of the experimental environment

The study was conducted in the greenhouse of the Forest Nursery at the Center for Health and Rural Technology at the Federal University of Campina Grande, located on the Patos campus (PB), at 7°06'00.0" South latitude, 37°27'50.0" West longitude, and an elevation of 242 meters (Figure 1).

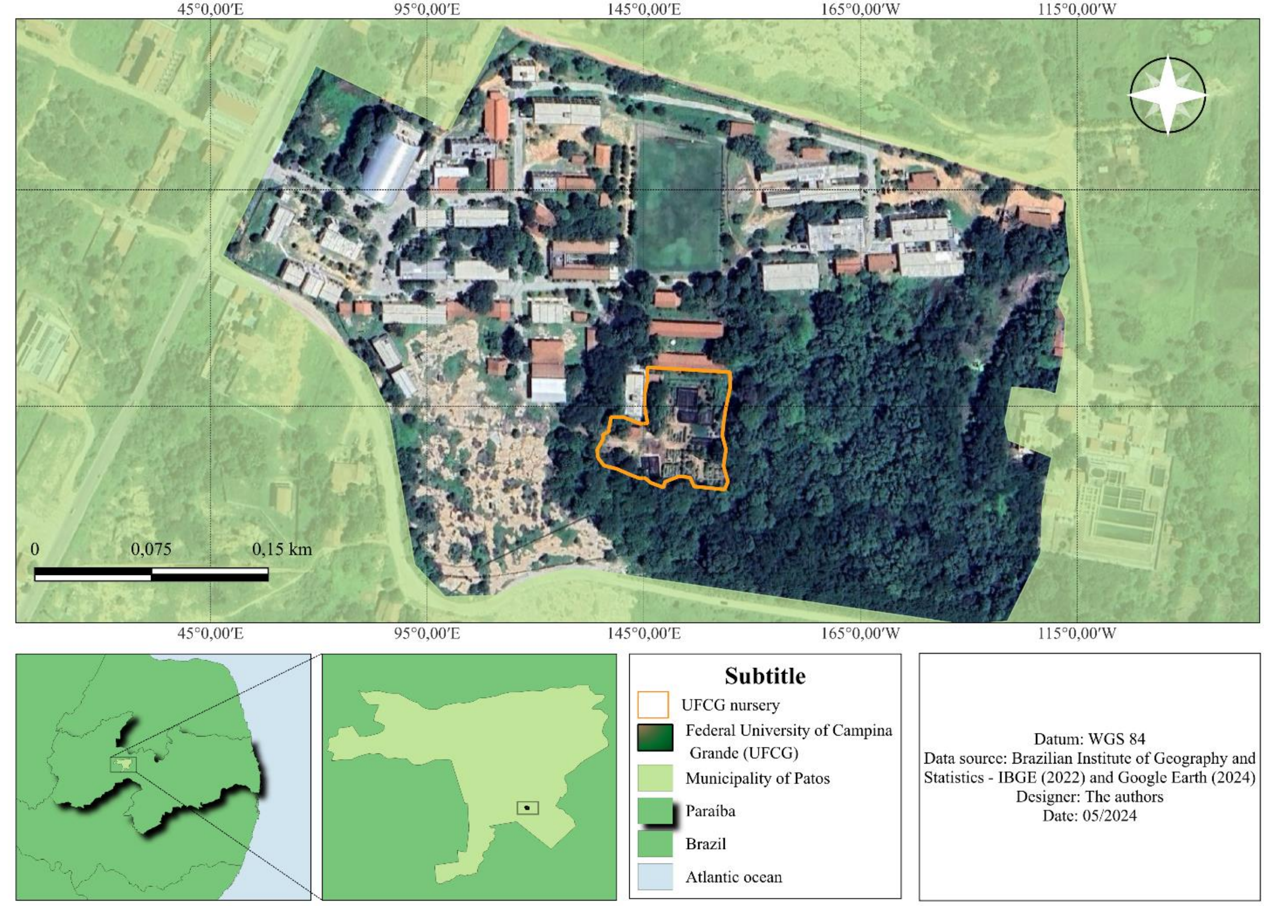

Figure 1. Location map of the Forest Nursery at the Center for Health and Rural Technology at the Federal University of Campina Grande, Patos Campus (PB), where the experiment was conducted.

The predominant climate in the municipality is classified as BSh (hot semi-arid) according to Köppen and Geiger, with an average annual temperature and precipitation of 27.5 °C and 390 mm, respectively. The region experiences a hot and dry season from June to December and receives scant rainfall during the winter months from January to May, which is distributed irregularly (https://pt.climate-data.org/america-do-sul/brasil/paraiba/patos-42575/#climate-graph).

Experiment Description

The seeds used in the experiment were collected from parent trees located across the campus, selected based on characteristics such as good health, size, and the shape of the canopy and trunk. Dormancy breaking of *P. juliflora* seeds was achieved by immersing them in concentrated sulfuric acid for five minutes, followed by rinsing under running water for 10 minutes and surface sterilization with 5 % (v/v) sodium hypochlorite (El-Keblawy et al., 2021). This protocol was designed to expedite and standardize the germination process.

Experimental Design

The treatments were arranged in a completely randomized design, with five concentrations of nitrate ($N^{-}NO^{-3}$) in the irrigation solution (0.0, 2.5, 5.0, 7.5, and 10.0 mmol dm^{-3}), with five replicates each, totaling 25 experimental units. The substrate used was coarse sand collected from a riverbed, sieved through a 2 mm mesh, washed in running water to remove colloids and ions, and then dried in full sun for seven days. After this phase, 2 dm^3 of substrate was added to black plastic pots with a capacity of 2.6 dm^3.

Germination and Seedling Development

In each pot, a total of five seeds were sown and irrigated daily for a period of 21 days after sowing (DAS). Irrigation was performed until the substrate reached field capacity.

After the acclimation period, the seedlings were irrigated with a nutrient solution, as described by Hoagland and Arnon (1950), which was adjusted to 25 % of its ionic strength. The salts used in the preparation of the solutions for this study, as well as their respective concentrations, are detailed in Table 1. The stock solutions were stored under controlled conditions, with temperatures ranging between 25 and 30 °C, in a ventilated environment and protected from light.

Table 1. Chemical compounds and their respective concentrations for the preparation of stock solutions.

Chemical compound	Concentration (M)	Concentration (g dm^{-3})
KNO_3	1.0	101.10
$MgSO.7H_2O$	1.0	246.50
$NH_4H_2PO_4$	0.5	123.50
$CaCl_2$	1.0	147.00
KCl	1.0	75.55
Fe – EDTA	0.5	14.80
Micronutrients	0.5	2.36

Source: Adapted from Hoagland and Arnon (1950).

Subsequently, at 28 days after sowing (DAS), the ionic strength of the solution was increased to 100 % (full strength solution). This condition was maintained until the 35th DAS, when thinning was performed, leaving only three plants per pot, all uniform in height, and the evaluations began.

Treatments and Seedling Irrigation

The nutrient solutions corresponding to the treatments were prepared using tap water, by diluting the stock solutions according to the concentrations (mmol dm^{-3}) established in Table 2. To adjust the five levels of nitrate ($N^{-}NO^{-3}$) evaluated, the concentrations of potassium nitrate (KNO_3) and potassium chloride (KCl) were the only ones that varied in concentration.

Table 2. Concentration (mmol dm^{-3}) of stock solutions used in the construction of treatments.

	Concentração (mmol dm^{-3})						
	KNO_3	$MgSO.7H_2O$	$NH_4H_2PO_4$	$CaCl_2$	KCl	Fe – EDTA	Micro
T1	0.0	2	1	4	10.0	0.5	0.5
T2	2.5	2	1	4	7.5	0.5	0.5
T3	5.0	2	1	4	5.0	0.5	0.5
T4	7.5	2	1	4	2.5	0.5	0.5
T5	10.0	2	1	4	0.0	0.5	0.5

To minimize variations in the nutrient solution concentration in the root zone of the substrate, the seedlings were irrigated four times a day with the solutions from each treatment using a 100 mL plastic graduated cylinder (a sufficient volume to allow partial drainage of the solution) between 7:00 AM and 5:00 PM.

Evaluated Parameters

At 35, 40, 45, 50, and 55 days after sowing (DAS), plant height (H) and stem diameter (SD) were measured using a graduated ruler (cm) and a digital caliper (mm), respectively. Plant height was defined as the distance from the insertion point of the cotyledon leaves to the apical bud. The robustness index (RI) was calculated using the following equation:

$$RI = \frac{fH}{fSD}$$

Where: RI - robustness index (dimensionless); fH - final height (cm); fSD - final stem diameter (mm).

The absolute growth rate (AGR) was evaluated according to the equation described by Benincasa (2003):

$$AGR = (\frac{fH - iH}{\Delta t})$$

Where: AGR - absolute growth rate (cm day^{-1}); iH – initial height (cm); fH – final height; Δt - time interval between measurements (days).

After the last measurement, the seedlings were cut at the cotyledon insertion point and separated into shoot (leaves, stem, and branches) and root components. These parts were weighed using an analytical balance to determine the shoot fresh mass (SFM) and root fresh mass (RFM). Subsequently, the samples were placed in properly labeled paper bags and dried in a forced ventilation oven at 55 °C until a constant weight was achieved. After drying, the samples were weighed again to determine the shoot dry mass (SDM), root dry mass (RDM) and total dry mass (TDM). Using these data, the root-to-shoot ratio (RSR) was calculated using the following equation:

$$\mathrm{RSR} = \frac{\mathrm{SDM}}{\mathrm{RDM}}$$

Where: RSR - root-to-shoot ratio (g g^{-1}); SDM - shoot dry mass (g plant^{-1}); RDM – root dry mass (g plant^{-1}).

Using the data, the Dickson Quality Index (DQI), proposed by Dickson et al. (1960), was determined using the following equation:

$$DQI = \frac{TDM}{(RI + RSR)}$$

Where: DQI - Dickson Quality Index (dimensionless); TDM – total dry mass (g plant^{-1}); RI - robustness index (dimensionless); RSR - root-to-shoot ratio (g g^{-1}).

Data Analysis

The data were analyzed using analysis of variance with the F-test. For significant variables ($p < 0.05$), polynomial regression equations were fitted. The relationship between nitrate concentrations and response variables was evaluated using Pearson's linear correlation, with significance set at $p < 0.05$ according to the t-test, with n = 25. Additionally, multivariate analysis was performed using principal component analysis (PCA) to determine the importance of eight characteristics in the study of growth, biomass, and seedling quality across the different nitrate concentrations. All analyses were conducted using R software (https://www.r-project.org/).

Results

The dosages of nitrogen fertilizer did not influence the variables height (H), stem diameter (SD), absolute growth rate (AGR), shoot fresh mass (SFM), Dickson Quality Index (DQI), and robustness index (RI). On the other hand, the evaluated variables such as fresh, dry, and total biomass exhibited a quadratic polynomial response to nitrate ($N^{-}NO^{3-}$) concentrations (Figure 2).

The derivative analysis of the equation representing root fresh mass and shoot dry mass revealed that nitrate concentrations of 3.64 and 5.69 mmol dm^{-3} promoted the maximization of root (approximately 13.16 g) and shoot (approximately 5.34 g) production, respectively, which were superior to the highest means obtained in the experiment (approximately 12.62 g and 4.58 g, respectively). Beyond these values, a gradual decrease in these variables was observed (Figure 2b-c).

For root dry mass, a decline in values was observed as nitrate concentrations increased. Higher fertilizer concentrations resulted in reduced root production, showing an improvement in the control treatment (0.0 mmol dm^{-3}) with an average of 3.15 g. The derivative analysis applied to this variable revealed that a concentration of 7.89 mmol dm^{-3} of the fertilizer was responsible for the lowest root production (Figure 2d).

Similarly, total dry mass exhibited a pattern analogous to that of root fresh mass and shoot dry mass, with decreasing values as fertilizer concentrations increased. The highest average values (approximately 6.30 g) were observed in the control treatment (0.0 mmol dm^{-3}) (Figure 2e).

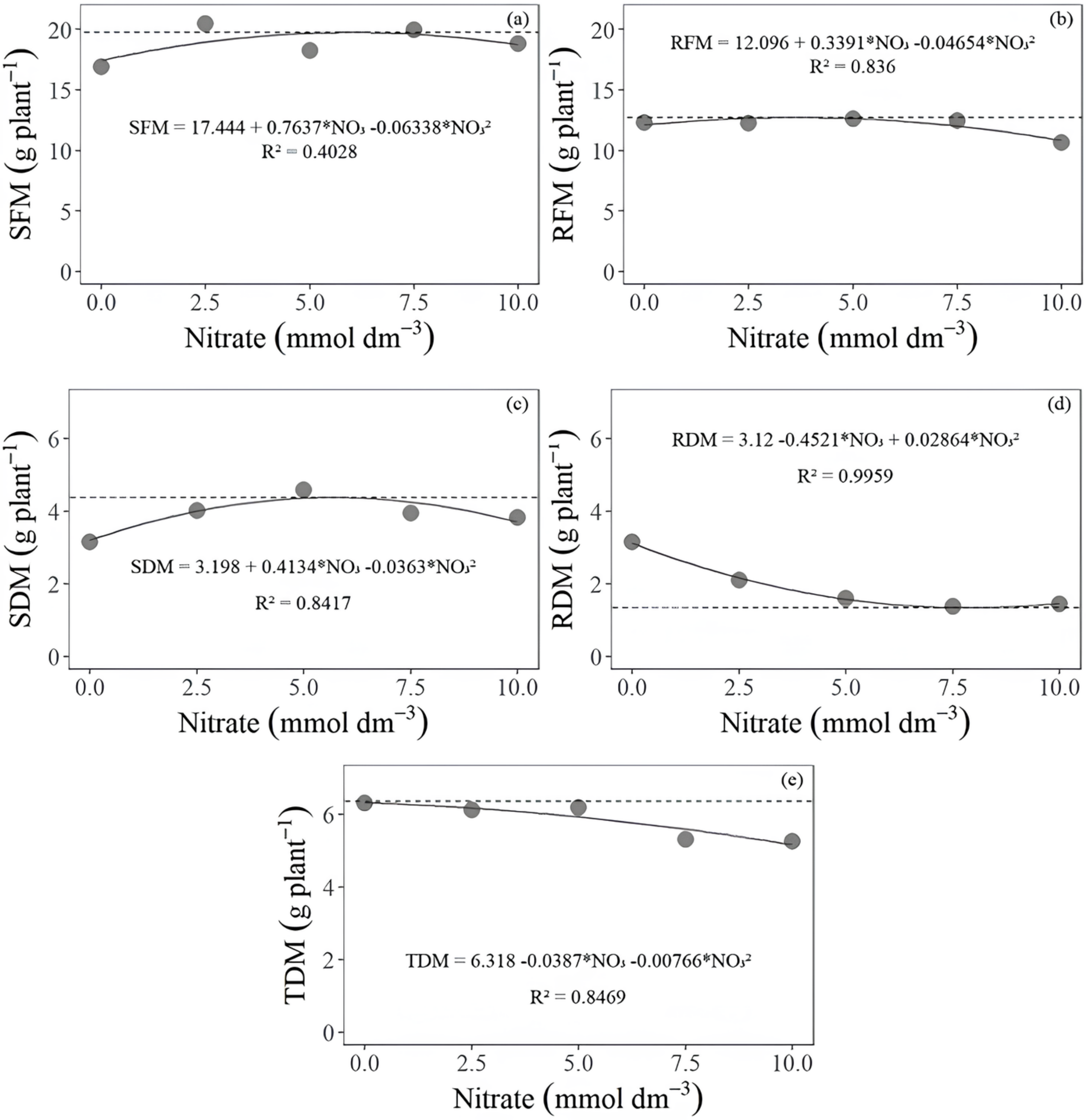

Figure 2. Regression analysis showing the relationship between nitrate concentrations and the growth parameters of *Prosopis juliflora* seedlings: (a) shoot fresh mass (SFM), (b) root fresh mass (RFM), (c) shoot dry mass (SDM), (d) root dry mass (RDM), and (e) total dry mass (TDM).

The root-to-shoot ratio exhibited quadratic polynomial behavior, where the increase in nitrate concentrations initially led to an increase in the evaluated parameter. However, higher concentrations of the fertilizer (7.5 and 10.0 mmol dm $^{-3}$) resulted in a decrease in the observed values. The derivative analysis of the equation modeling this relationship revealed that the optimal concentration of 6.37 mmol dm^{-3} maximized the parameter values (approximately 5.02 g), which were higher than the highest mean obtained in the experiment (approximately 3.14 g).

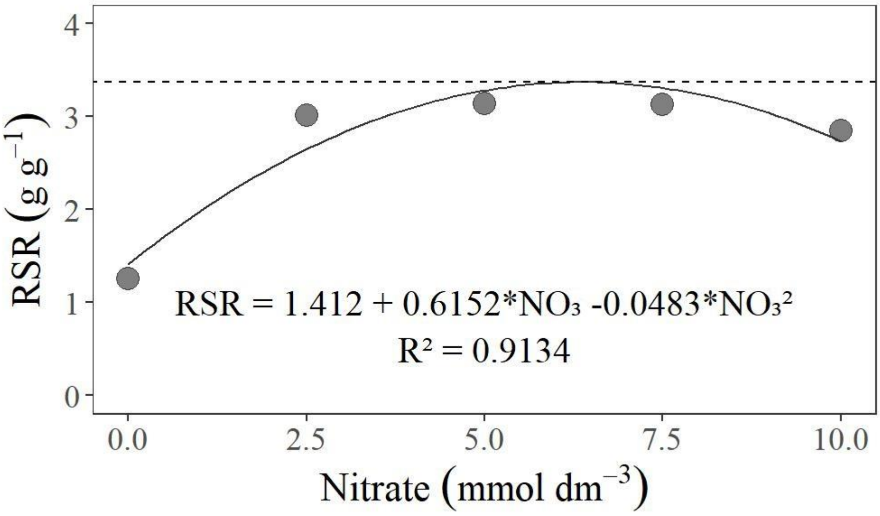

Figure 3. Regression analysis illustrating the root-to-shoot ratio (RSR) of *Prosopis juliflora* seedlings in response to varying nitrate concentrations.

In the control (0.0 mmol dm^{-3}), the highest average value of the Dickson Quality Index (DQI) was observed (approximately 0.391) (Figure 4). In detail, the relationship between seedling quality and nitrate concentrations exhibited non-linear behavior. Initially, the values decreased with increasing nitrate concentrations, reaching the lowest value (approximately 0.301) at around 7.82 mmol dm^{-3} of nitrate. Beyond this point, there was a slight increase in the index with higher $N^{-}NO^{3-}$ concentrations. These results indicate that both very high and very low nitrate concentrations are not ideal for seedling quality, and that the highest quality seedlings were observed in the control, with the absence of fertilizer.

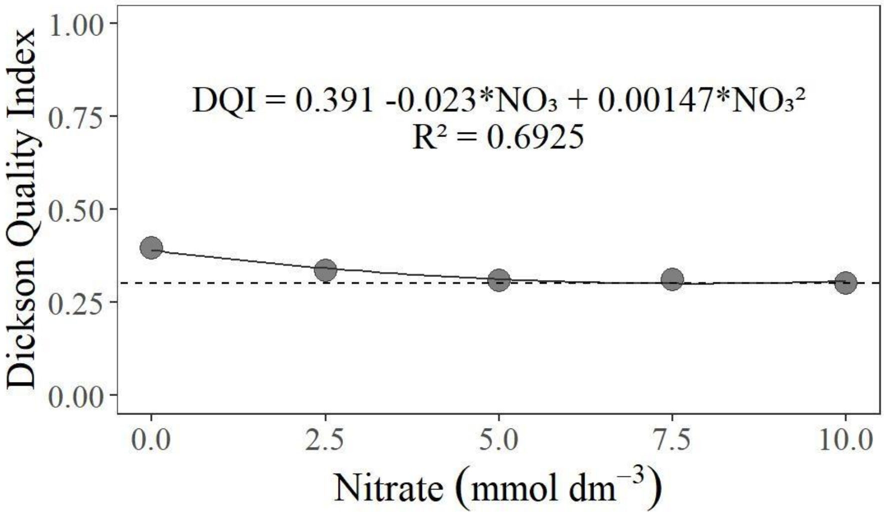

Figure 4. Regression analysis of the Dickson Quality Index (DQI) for *Prosopis juliflora* seedlings in response to varying nitrate concentrations.

According to Pearson's linear correlation (r), all correlations between the variables were non-significant, where nitrate showed a moderate to strong negative correlation with most variables, such as shoot dry mass and root dry mass. Additionally, it exhibited a positive correlation with the absolute growth rate and the root-to-shoot ratio (Figure 5).

Figure 5. Pearson's genetic correlation coefficient (r) for growth, biomass, and quality variables of *Prosopis juliflora* seedlings. * $p \leq 0.05$ by t-test. Where: nitrate (NO^{3-}), absolute growth rate (AGR), shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), root-to-shoot ratio (RSR) and Dickson Quality Index (DQI). The circle's color represents the direction of the correlation: red for negative and blue for positive. The circle's size and color intensity reflect the strength of the correlation.

For the absolute growth rate, positive correlations were observed with shoot fresh mass and root fresh mass. Regarding the fresh biomass of the seedlings, positive correlations were found between fresh shoot and root biomass and the absolute growth rate, reinforcing that growth is simultaneously promoted by these variables.

Strong positive correlations were observed between dry biomass and total dry mass, indicating that increases in shoot dry mass tend to be associated with increases in root dry mass and total dry mass. Dry biomass also showed a strong negative correlation with the root-to-shoot ratio and nitrate concentrations.

Regarding the root-to-shoot ratio, the correlations were negative with all variables except nitrate concentrations. For the Dickson Quality Index, it showed a negative correlation with almost all variables, except for the absolute growth rate, where a slight positive correlation was observed.

The principal component analysis (PCA) revealed a separation of PC1 and PC2, representing 84.59 % of the total variance in the data. PC1 was positively correlated with root fresh mass, total dry mass, root dry mass, and the Dickson Quality Index, and negatively correlated with the absolute growth rate, shoot dry mass, root-to-shoot ratio, and shoot fresh mass. In contrast, PC2 showed positive correlations with all variables (Figure 6).

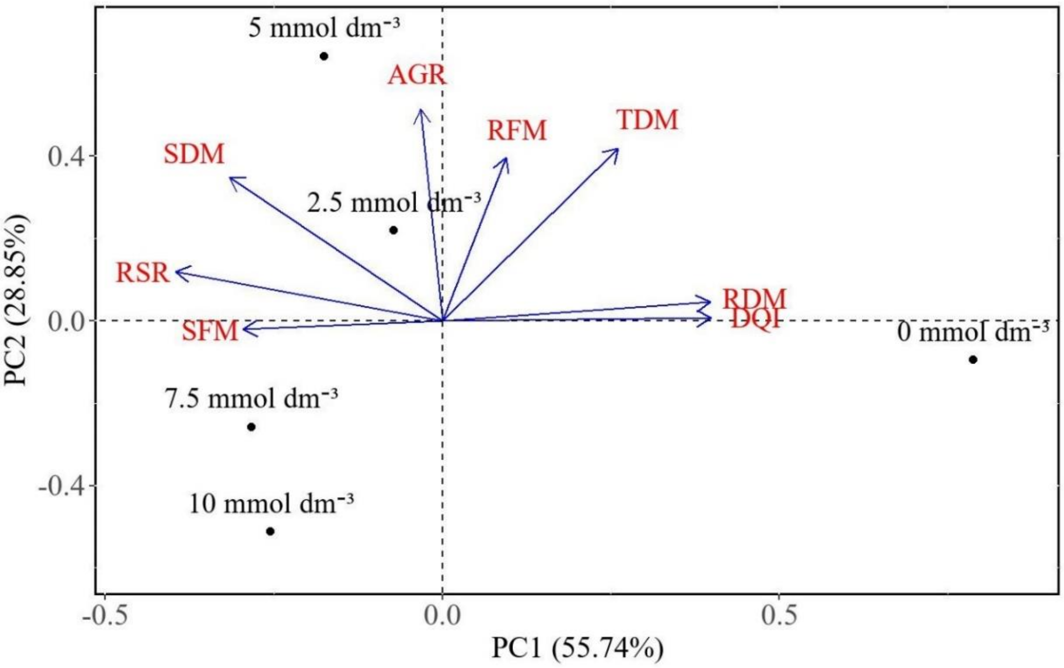

Figure 6. Principal Component Analysis (PCA) illustrating the relationships among growth, biomass, and quality variables of *Prosopis juliflora* seedlings. Where: absolute growth rate (AGR), shoot fresh mass (SFM), root fresh mass (RFM), shoot dry mass (SDM), root dry mass (RDM), total dry mass (TDM), root-to-shoot ratio (RSR) and Dickson Quality Index (DQI).

The seedlings treated with the absence of nitrate (0.0 mmol dm^{-3}) were associated with positive PC1 values and exhibited higher dry root biomass and a higher Dickson Quality Index. For intermediate nitrate concentrations (2.5 and 5.0 mmol dm^{-3}), located near the center, an intermediate distribution of growth and biomass characteristics was observed. In contrast, the higher nitrate concentrations (7.5 and 10.0 mmol dm^{-3}), associated with negative values of PC1 and PC2, had a negative impact on certain growth characteristics, such as shoot fresh mass for both components and the root-to-shoot ratio and shoot dry mass for PC1 (Figure 6).

Discussion

Overall, the results indicate a negative or null effect of nitrogen fertilization at the dosages used on the development of aerial parts of *P. juliflora*, such as height, stem diameter, absolute growth rate, and dry biomass. These findings suggest that the seedlings' response to the dosages was irrelevant in the development of these variables. Furthermore, these results are consistent with the Dickson Quality Index and the robustness index, which also showed no significant statistical differences among the variables.

Similar results were reported by Soares et al. (2021), who observed that nitrogen application had no significant effect on the growth of *Ceiba speciosa* seedlings. Schulz et al. (2021), when applying nitrogen fertilization to *Luehea divaricata* seedlings, also observed no significant effects on height and stem diameter. Thus, nitrogen fertilization elicits varying responses across forest species, influenced by factors such as geographic location, the nitrogen source employed, and the dosage applied which may or may not contribute to their development (Fernandes et al., 2019; Soares et al., 2021). In this case, nitrogen fertilization would result in unnecessary expenses since it does not cause significant effects on the development of *P. juliflora* seedlings.

A possible explanation for the observed results lies in the evaluation period, which may have been insufficient to demonstrate the effects of applied nitrogen concentrations. This hypothesis is supported by studies from other authors who monitored some species over longer periods, specifically 120 and 125 days for *Mimosa caesalpiniifolia* and 125 days for *Tabebuia serratifolia* (Gonçalves et al., 2013; Goulart et al., 2016). In these studies, positive responses of the species to various sources and concentrations of nitrogen were observed.

Additionally, it is important to note that *P. juliflora*, belonging to the Fabaceae family, establishes a symbiotic association with bacteria that fixes atmospheric nitrogen (Bissa et al., 2024; Fall et al., 2021). These bacteria include genera such as *Rhizobium*, *Sinorhizobium*, and *Allorhizobium* from the Rhizobiaceae family; *Bradyrhizobium* from the Bradyrhizobiaceae family; *Mesorhizobium* from the Phyllobacteriaceae family; and *Azorhizobium* from the Hyphomicrobiaceae family. These associations are particularly suited to soils with low fertility (Benata et al., 2008). According to Wen et al. (2021), the process of biological nitrogen fixation can reduce or even eliminate the need for nitrogen fertilizer application for plant development enhancement.

This characteristic further highlights the independence of *P. juliflora* from external nitrogen supplies, representing a significant advantage for producers as it reduces the need for additional expenses on chemical inputs. The natural adaptation of *P. juliflora* to its environment and its ability to efficiently utilize available resources present a promising perspective for its cultivation in a sustainable and economical manner, with long-term benefits.

In this context, an inversely proportional effect was identified between root dry mass, total dry mass, and the Dickson Quality Index in relation to the concentrations of nitrate applied. Probably these conditions compromised the symbiotic interaction with nitrogen-fixing bacteria, and that the amount of nutrient applied exceeded the species' needs, resulting in this reduction.

However, it was observed that in the root-to-shoot ratio, increasing nitrate concentrations initially led to an increase in the assessed parameter. This phenomenon is supported by Anis et al. (2021) and Rawal et al. (2022), who assert that increasing nitrogen doses can lead to decreased nutrient efficiency, as the amount applied may surpass the specific crop’s nutritional needs. According to Godoy et al. (1997), this occurs because there can be a negative relationship between plant development and the levels of nitrogen present, due to interactions and competition among biochemical pathways in metabolism.

The Pearson correlation coefficient expresses the direction of the correlation, and its intensity is represented by a numerical value ranging from -1 to 1. In extreme situations, two traits may exhibit perfect negative linear correlation (r = -1) (i.e., as one variable increases, the other decreases) or perfect positive correlation (r = 1), or even no linear relationship (r = 0) (Cargnelutti Filho et al., 2010). Based on this, the results for the variables of growth, biomass, and seedling quality indicate that increased nitrate concentrations may result in a reduction in dry biomass but may facilitate more balanced growth between the shoot and root in some plant species. Each species may respond differently to fertilizer concentrations, highlighting the importance of finding an optimal concentration for each specific case.

Furthermore, it is observed that a higher absolute growth rate is closely linked to an increase in fresh biomass. However, dry biomass values are negatively influenced by a higher shoot-to-root ratio and by higher nitrate concentrations. This suggests that, although there is an increase in nitrogen availability that can promote shoot growth, there can also be an imbalance in biomass allocation, adversely affecting the accumulation of dry biomass.

The reduction in dry biomass of plants, when exclusively supplied with nitrate in larger proportions, has been documented in previous studies involving both grasses and dicotyledons (Almeida et al., 2024; Araújo et al., 2012; Oliveira Neto et al., 2023; Ribeiro et al., 2019). Apparently, the poor utilization of nitrate in the initial growth phase may be the primary cause of this reduction, even manifesting typical symptoms of nitrogen deficiency. Reduced growth when increasing the dosage of nitrate is attributed to the excessive accumulation of this form in the plant tissues during this initial phase, due to the low activity of the nitrate reductase enzyme.

The activity of the nitrate reductase enzyme is influenced by light and the water availability on the plant (Bian et al., 2018; Kaya, 2021; Nugraheni et al., 2019; Wang et al., 2023). Regardless of the seedlings' age, the concentration of nitrate in the environment also affects this activity. When there is a higher availability of nitrate, the enzyme works intensively to convert it into nitrite, and in its absence, it leads to stagnation (Reyes et al., 2018).

Tucci et al. (2009), studying the effects of nitrate on the production of *Swietenia macrophylla* seedlings, found that higher concentrations of nitrate contributed to a decrease in the root-to-shoot ratio, indicating a relatively greater root production with the increase of this anion concentration in the solution. The observed correlation between the shoot and roots, as well as the Dickson Quality Index, suggests that the applied nitrate concentrations are related to a reduction in biomass and quality measures of the seedlings. However, it is important to note that overall improvement in seedling quality may be linked to more efficient absolute growth. On the other hand, very high concentrations of nitrates seem to be associated with a significant decrease in biomass and quality of the seedlings, but it is necessary that fertilization promotes a balance between the shoot and root, resulting in enhanced absolute growth.

As observed by Guo et al. (2019), high levels of nitrate are associated with a significant reduction in seedling biomass, indicating an adverse effect on growth. However, it is crucial to consider that nutrient availability is essential for the healthy development of forest species seedlings. Seedling responses vary according to species, nutrient type, and applied concentration. In general, the appropriate addition of nutrients can increase biomass and improve seedling quality. On the other hand, excessive concentrations can lead to negative effects (Martini et al., 2020; Liu et al., 2023; Roy et al., 2022; Ramos et al., 2022).

The Dickson Quality Index is used to assess the quality of seedlings, combining important morphological parameters into a single metric. By considering the index, isolated evaluation of parameters, such as seedling height, which does not always reflect the best choice for planting, is avoided. Additionally, the robustness index, which is the ratio between height and diameter, relates to two growth indicators of seedlings through the robustness quotient. In this metric, a lower ratio indicates a more robust seedling. Conversely, high values suggest relatively slender seedlings, making them more susceptible to damage caused by handling, wind, drought, and frost, as pointed out by Avelino et al. (2021).

It is important to highlight that nitrogen fertilization promotes cell elongation, which can result in the formation of etiolated seedlings with excessive height growth and little robustness, making them unsuitable for planting and consequently reducing their success in the field (Taiz et al., 2017). Therefore, the Dickson Quality Index is a valuable tool in seedling selection because it helps to choose those that present a balance between height, stem diameter, and biomass distribution.

Conclusion

High nitrate concentrations do not enhance the growth of *P. juliflora* seedlings, with some variables displaying quadratic polynomial behaviors and optimal concentration ranges identified between 3.5 and 6.5 mmol dm^{-3}.

Given its adaptability to low-fertility conditions, *P. juliflora* emerges as an economical and sustainable alternative for the recovery of degraded areas in the Caatinga biome.

To refine management practices and maximize its productive and ecological potential in reforestation systems and land restoration, further studies with extended evaluation periods and a broader range of nitrate concentrations are recommended.

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