Floresta e Ambiente 2021; 28(4): e20210044
https://doi.org/10.1590/2179-8087-FLORAM-2021-0044
ISSN 2179-8087 (online)

Floram
Floresta e Ambiente

ORIGINAL ARTICLE – Silviculture

Nutrient Reduction in the Initial Growth of Caatinga Tree Species

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Abstract

This study aimed to evaluate the influence of nutrient omission on the growth and phytomass production of three tree species native to the Caatinga biome cultivated in degraded Chromic Luvisol samples, under greenhouse conditions. The experiments were conducted from april to june 2015. Three experiments were set up corresponding to three tree species [*Myracrodruon urundeuva* (Allemão), *Caesalpinia ferrea* (Mart. *ex* Tul.), and *Amburana cearensis* (AC Smith)], in a completely randomized design with eight treatments referring to the addition or not of nutrients to the soil and four replications. The results revealed that Fe and Zn supply was essential for the initial establishment of *M. urundeuva* and *A. cearensis* in Chromic Luvisols. For *C. ferrea*, which has a higher growth rate, fertilization with N, P, and S sources is necessary in addition to Fe and Zn in order to increase its establishment potential in these areas.

Keywords: Deforestation, native species, recovery of degraded areas, nutritional deficiency.

1. INTRODUCTION AND OBJECTIVES

In the Brazilian semi-arid region, where the Caatinga biome is predominant, firewood and charcoal represent important energy sources for both home and industrial use, especially for bakeries, soap shops, and potteries, which has contributed to the indiscriminate removal of native species and the increasing pressure on the remaining floristic lining of this biome (Sousa Neto et al., 2017). Plant extraction associated with fires exposes the soil to erosive agents, constituting the leading causes of desertification processes in the northeastern semi-arid region of Brazil (Barros & Chaves, 2014; Efthimiou et al., 2020). Martins et al. (2019) state that the intense degradation of the Caatinga drastically reduces plant biomass production and increases direct soil exposure, resulting in reduced abundance and diversity of species and changes in soil fertility, thus increasing soil erosion.

This situation is further aggravated by the lack of scientific information on regional native species, contributing to a comparatively lower replacement rate of felled species than the suppression rate and resulting in marked degradation of natural resources (Galindo et al., 2008). Thus, it is necessary to establish alternatives to reverse this scenario, reintroducing removed native species and reducing the rate of degradation of the Caatinga biome.

In the Caatinga reforestation process, it is essential to know the main nutritional limitations in relation to the soil and the response of tree species to the often-adverse fertility conditions of these soils due to degradation. Furthermore, each species may require particular amounts of a given nutrient and different mechanisms to overcome such limitations (Scheer et al., 2017). One way to conduct this study is to use soil samples from the degraded environment and verify the isolated effects of nutrient omission in this sample and the same soil with fertilization on the initial growth of native species. In this regard, Chromic Luvisols are one of the most representative soil classes in the Caatinga biome, usually showing a high concentration of exchangeable bases but with severe limitations regarding the levels of organic matter, nitrogen, sulfur, and phosphorus (Naylor et al., 2020; Ramirez & Corona, 2020).

Among the tree species native to the Caatinga, the most prominent are *Myracrodruon urundeuva* (Allemão), *Caesalpinia*

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ferrea Mart., and *Amburana cearensis* (A. C. Smith), given their multiple uses in the production of herbal medicines, furniture, urban afforestation, and recovery of degraded areas (Pacheco & Silva, 2019).

For this reason, these species are among the most exploited in this biome, especially *M. urundeuva* and *A. cearensis*, which are on the list of endangered species (MMA, 2021). However, there is a lack of information on the growth rate and limiting nutrients of these species during their initial establishment in sparsely degraded soils.

Therefore, this study aimed to evaluate the influence of nutrient omission on plant growth and phytomass production in three tree species native to the Caatinga biome cultivated in degraded Chromic Luvisol.

2. MATERIALS AND METHODS

The study was carried out in a protected environment (greenhouse), were conducted from april to june 2015 at the Center of Science and Agri-Food Technology (CCTA) of the Federal University of Campina Grande (UFCG), in the municipality of Pombal, Paraíba, Brazil. Pombal is located in the western region of the State of Paraíba, at the following coordinates: 6º47'2" S and 37º48'01" W (Figure 1), with an elevation of 194 m (Beltrão et al., 2005). The climate of the region was classified as BSh according to the Köppen classification (1948), representing a hot and dry semi-arid climate with mean rainfall of approximately 750 mm/year and mean annual evaporation of 2.000 mm.

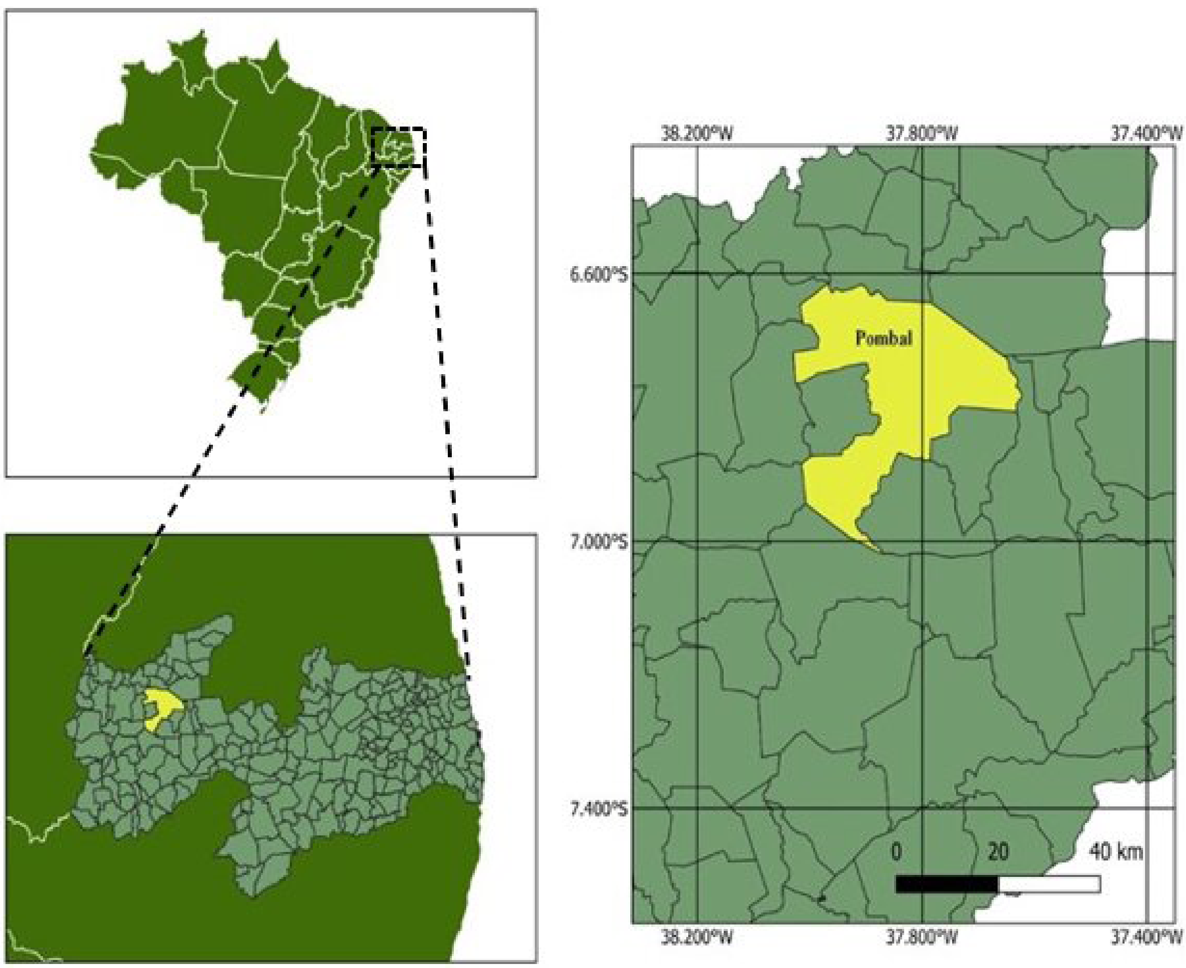

Figure 1. Geographic location of the municipality of Pombal, State of Paraíba, Northeastern Brazil, where the study was conducted.

Chromic Luvisol samples were used in this study (Embrapa, 2018). The samples were obtained randomly in the 0 - 40 cm layer, in an area with strong laminar erosion belonging to the Pombal Campus of UFCG, with very sparse tree vegetation consisting mainly of *Mimosa tenuiflora* (Jurema-preta). After collected in the surface layer (0 - 40 cm), the soil samples were air-dried, ground, and sieved through a 2 mm mesh sieve, followed by analysis (Table 1) according to the methodology proposed by Embrapa (2011).

Table 1. Chemical and physical attributes of the soil sample used in the experiments.

pH	P	SOM	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	$Al^{3+} + H^+$	SB	CEC
H_2O	mg dm^{-3}	g kg^{-1}			$cmol_c$ dm^{-3}					
7.12	7.06	17.04	0.22	0.23	3.5	8.4	0.1	3.47	11.9	15.37
Sand		Silt	Clay		Particle density		Soil bulk density		Porosity	
	g kg^{-1}					g cm^{-3}			m^3 m^{-3}	
716.8		152.8	130.4		2.74			1.40	0.49	

pH_{H2O}: soil pH at 1:2.5 soil: water ratio; P, K^+, Na^+: Mehlich-1 extractor; SOM: soil organic matter by the Walkley-Black method; Al^{3+}, Ca^{2+} Mg^{2+}: KCl 1.0 $molL^{-1}$ extractor; SB: sum of bases = Ca^2 + Mg^{2+} + K^+ + Na^+; Al^{3+} + H^+: calcium acetate 0.5 $molL^{-1}$ extractor at pH 7.0; CEC = cation exchange capacity at pH 7.0 = SB + H^+ + Al^{3+}.

Three experiments, one for each species (*Myracrodruon urundeuva*, *Caesalpinia ferrea*, and *Amburana cearensis*) were set up in a completely randomized design with eight treatments corresponding to the addition or not of nutrients to the soil (T: without fertilization; C: complete fertilization; -N: without nitrogen; -P: without phosphorus; -K: without potassium; -S: without sulfur; -Fe: without iron; and -Zn: without zinc) and four replications, totaling 32 experimental units per experiment (or per species). The experimental plot consisted of a pot with 10 dm^3 of soil containing one plant. The plastic pots were 15 cm in diameter at the base, 20 cm at the top, and 25 cm high.

The complete fertilization treatment (C) was based on Sousa et al. (2012), with the following levels in mg dm^{-3}: N = 250, P = 200, K = 250, Ca = 200, Mg = 50, S = 50, B = 0.5, Cu = 1.5, Fe = 5, Mn = 4, Mo = 0.15, and Zn = 5.0, using analytical sources. The other treatments were established by omitting the corresponding nutrient during fertilization. The macronutrients sources used were urea [$CO(NH_2)_2$], potassium nitrate (KNO_3), dicalcium phosphate ($CaHPO_4$), sodium phosphate ($NaHPO_4$), potassium chloride (KCl), magnesium sulfate ($MgSO_4.7H_2O$), calcium chloride ($CaCl_2.2H_2O$), and magnesium chloride ($MgCl_2.6H_2O$). For micronutrient sources used were copper sulfate ($CuSO_4.5H_2O$), manganese sulfate ($MnSO_4.7H_2O$), Fe-EDTA, zinc sulfate ($ZnSO_4.7H_2O$), boric acid (H_3BO_3), and ammonium molybdate [$(NH_4)_6Mo_7O_{24}.4H_2O$]. Potassium and nitrogen levels were split into three applications of 83.3 mg dm^{-3}.

Sowing was carried out by placing three seeds per pot. The seeds were germinated in 200 mL plastic cups filled with a sandy soil substrate and organic compost from a degraded area at a volumetric ratio of 1:1. The seedlings were thinned to one plant (the most vigorous) per pot 15 days after sowing, when showing one pair of definitive leaves.

Irrigation was performed with a constant water volume determined based on the evapotranspiration of the control treatment. The irrigation volume applied (Va) per container was determined as the difference between the average weight of the container in a condition of 100% water availability and the average weight of the pots before irrigation. Field capacity was determined by saturating the soil and subjecting it to drainage, subsequently weighing the containers when the excess water volume was drained away.

Plant height and stem diameter were measured every two weeks for 60 days after transplanting. Plant height was measured from the base of the plant to the height of the youngest leaf using a centimeter ruler. Stem diameter was measured at 1 cm from the soil with an ULTRA TECH ® stainless steel digital caliper in the same periods established for measuring plant height. Subsequently, the collected plant material was separated into roots, stems, and leaves, washed in distilled water, packed in paper bags, dried in a forced-air oven at 65°C until constant weight, and weighed on a precision balance accurate to 0.0001 g to obtain the values of leaf, stem, and root dry mass and the total dry mass.

The data on plant height (H), stem diameter (D), shoot dry mass (SDM), root dry mass (RDM), and total dry mass (TDM) were used to calculate the root: shoot ratio and the Dickson Quality Index (DQI) based on the equation proposed by Dickson (Dickson et al., 1960):

Equation (1): $$DQI = \frac{TDM}{(H \mid D) + (SDM \mid RDM)}$$

Where DQI: Dickson Quality Index; TDM: total dry mass (g plant $^{-1}$); H: plant height (cm); D: stem diameter (mm); SDM: shoot dry mass (g plant $^{-1}$); RDM: root dry mass (g plant $^{-1}$).

Based on the plant height and stem diameter data, linear functions were adjusted according to the evaluation periods to obtain the plant growth rates. Analysis of variance and the Scott-Knott test were used for the other variables. Additionally, the growth rates in height and diameter were correlated with total dry mass production. The SISVAR software was used in the analyses (Ferreira, 2011), and the tests were carried out at the 5% level of significance.

3. RESULTS

Plant height and stem diameter were significantly affected by nutrient omission in the soil in the three species studied (Figure 2).

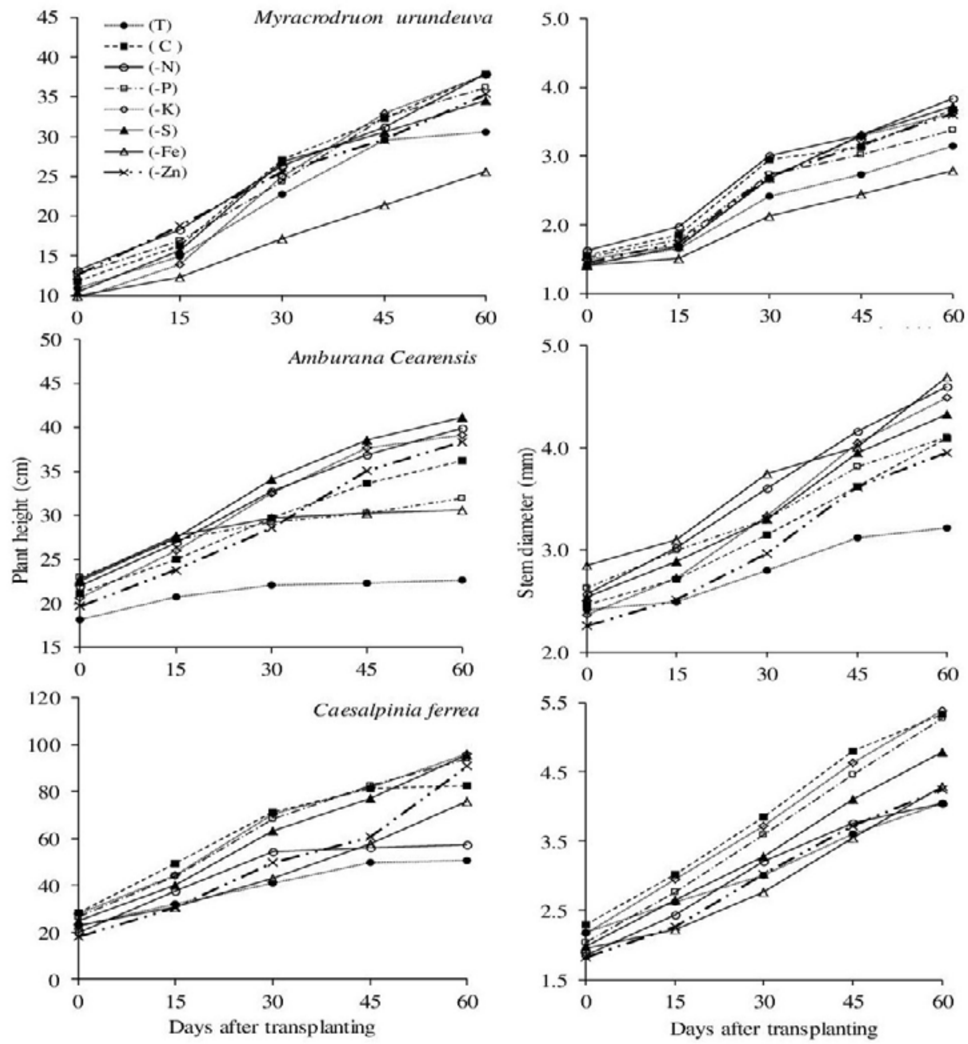

Figure 2. Evolution of plant height and stem diameter of native tree species from the Caatinga biome grown in degraded Chromic Luvisol samples for 60 days after transplanting. C and T correspond to complete fertilization and no fertilization, respectively. The other treatments correspond to the omission of the indicated nutrient.

The height growth rate of *M. urundeuva* was negatively affected by iron omission, followed by the omission of all nutrients (T) and sulfur only, respectively (Figure 2). For *A. cearensis* and *C. ferrea*, the T treatment was the most limiting to the growth in height, especially for *A. cearensis,* which also showed growth reduction due to iron and phosphorus omission 30 days after transplanting (DAT). Nitrogen was the second most limiting nutrient for *C. ferrea*, especially after 45 DAT. Regarding stem diameter (Figure 2), the nutrient omission treatments acted similarly, that is, the greatest limitation for *M. urundeuva* was caused by iron omission, followed by the T treatment, whereas for *A. cearensis* and *C. ferrea*, the T and -Zn treatments were the most limiting.

The linear functions obtained for plant height (Table 2), except for the T and -Fe treatments for *A. cearensis* and the –N treatment for *C. ferrea*, showed a coefficient of determination between 0.91 and 0.99. For stem diameter, in the three species tested, the coefficients were always greater than 0.95, indicating a good adjustment of the linear model.

Table 2. Linear functions obtained for plant height (h) and stem diameter (d) of natives species from Caatinga biome grown in degraded Chromic Luvisol samples as a function of the days after transplanting (T).

Treatments	Plant height (cm)		Stem diameter (mm)	
	Equations	R^2	Equations	R^2
	Myracrodruon urundeuva			
(-K)	h = 8.770+0.5025*T	0.9798	d = 1.392+0.0389*T	0.9615
(C)	h = 11.450+0.4545**T	0.9816	d = 1.533+0.0369T	0.9528
(-S)	h = 10.990+0.4208*T	0.9606	d = 1.3125+0.0416*T	0.9741
(-P)	h = 12.015+0.4168*T	0.9855	d = 1.506+0.0329**T	0.9549
(-N)	h = 12.920+0.4155*T	0.9950	d = 1.595+0.0385**T	0.9678
(-Zn)	h = 13.085 +0.3765**T	0.9940	d = 1.380+0.0385**T	0.9728
(T)	h = 10.965+0.3595**T	0.9585	d = 1.3705+0.0302*T	0.9757
(-Fe)	h = 9.275+0.2675**T	0.9908	d = 1.320+0.0246**T	0.9686
	Amburana Cearensis			
(-K)	h = 21.430+0.3257**T	0.9661	d = 2.275+0.0372*T	0.9896
(-Zn)	h = 19.355+0.3245**T	0.9918	d = 2.1615+0.0299*T	0.9816
(-S)	h = 23.075+0.3218**T	0.9793	d = 2.468+0.031**T	0.9888
(-N)	h = 22.465+0.3067*T	0.9874	d = 2.551+0.0346**T	0.9975
(C)	h = 21.440+0.2578*T	0.9918	d = 2.370+0.0279*T	0.9891
(-P)	h = 24.105+0.1408*T	0.9239	d = 2.609+0.0252**T	0.9936
(-Fe)	h = 24.540+0.1217*T	0.7913	d = 2.758+0.0307**T	0.9754
(T)	h = 19.035+0.0710*T	0.8190	d = 2.360+0.0149**T	0.9631
	Caesalpinia ferrea			
(-S)	h = 24.535+1.1905**T	0.9959	d = 1.9405+0.0473*T	0.9983
(-Zn)	h = 14.890+1.1708*T	0.9695	d = 1.7470+0.0422**T	0.9935
(-K)	h = 29.430+1.1583**T	0.9813	d = 2.1440+0.0541*T	0.9992
(-P)	h = 28.490+1.1542*T	0.9835	d = 1.9915+0.0545**T	0.9991
(C)	h = 34.650+0.935*T	0.9063	d = 2.2855+0.0525**T	0.9940
(-Fe)	h = 19.445+0.890**T	0.9802	d = 1.7558+0.040**T	0.9694
(-N)	h = 26.415+0.6228**T	0.8349	d = 1.9110+0.0382**T	0.9794
(T)	h = 24.785+0.4842**T	0.9511	d = 2.1465+0.0315*T	0.9961

** $P<0.01$; * $P<0.05$; $^{ns}P>0.05$ by the t-test. C and T correspond to complete fertilization and no fertilization, respectively. The other treatments correspond to the omission of the indicated nutrient.

The growth rates, represented by the slope of the plant height and stem diameter functions, varied greatly for both characteristics in the different treatments (Table 2). For *M. urundeuva* and *A. cearensis*, the lowest height growth rates were obtained with the T treatment and iron omission, whereas for *C. ferrea*, the T treatment was followed by N and Fe omission, which were the most limiting treatments for this variable. The lowest diameter growth rates for *M. urundeuva* were obtained with the T treatment and Fe omission, whereas for *A. cearensis* and *C. ferrea*, the lowest values were obtained with the T treatment. Overall, *C. ferrea* showed the highest growth rates, both in height and diameter.

SDM production by *M. urundeuva* was lower when only nitrogen or sulfur was omitted from the soil, while the other treatments resulted in similar values for this variable (Figure 3).

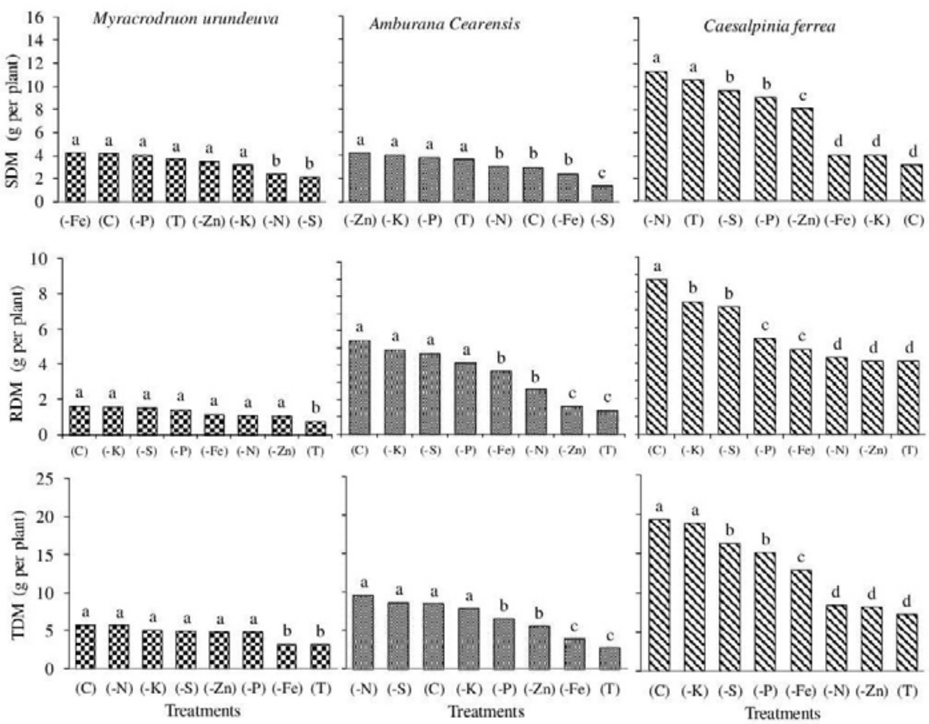

Figure 3. Shoot dry mass (SDM), root dry mass (RDM), and total dry mass (TDM) production of three tree species native from the Caatinga biome 60 days after transplanting. C and T treatments correspond to complete fertilization and no fertilization, respectively. The other treatments correspond to the omission of the indicated nutrient Means followed by the same letters do not differ at the 5% level of significance by the Scott-Knott test.

For *A. cearensis*, sulfur omission was the most limiting treatment to SDM production. In turn, for *C. ferrea*, complete fertilization or Fe or K omission resulted in the lowest values for these variables. For the three species studied, the lowest RDM values were obtained with the T treatment and with Zn omission, followed by N omission (Figure 3). The lowest TDM values obtained for *M. urundeuva* and *A. cearensis* were provided by the T treatment and Fe omission, whereas for *C. ferrea*, the lowest values were obtained with the T treatment and the treatments corresponding to Zn and N omission (Figure 3).

Among the studied species, *C. ferrea* stood out in terms of growth rates (Table 2) and dry mass production (Figure 3), including the treatment without any nutrient addition. In this perspective, regardless of the species or treatment, the TDM showed a good correlation with the height (Figure 4A) and diameter growth rates (Figure 4B), indicating that this is a good parameter to predict phytomass production in the tested species.

Treatment influence on the root: shoot ratio varied according to the species studied (Figure 5). For *M. urundeuva*, the treatments related to N, P, and Fe omission provided the highest values of this variable.

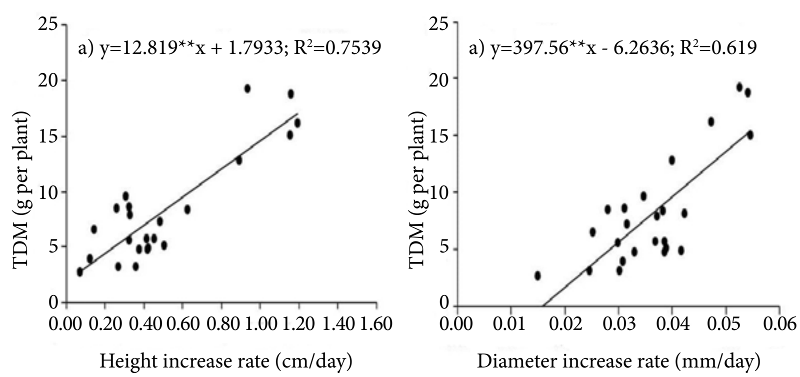

Figure 4. Correlation of the total dry mass production rates (TDM) with the height (A) and TDM with stem diameter growth rates (B) of natives species from Caatinga biome grown in degraded Chromic Luvisol samples. **: Significant at 1% by the t-test.

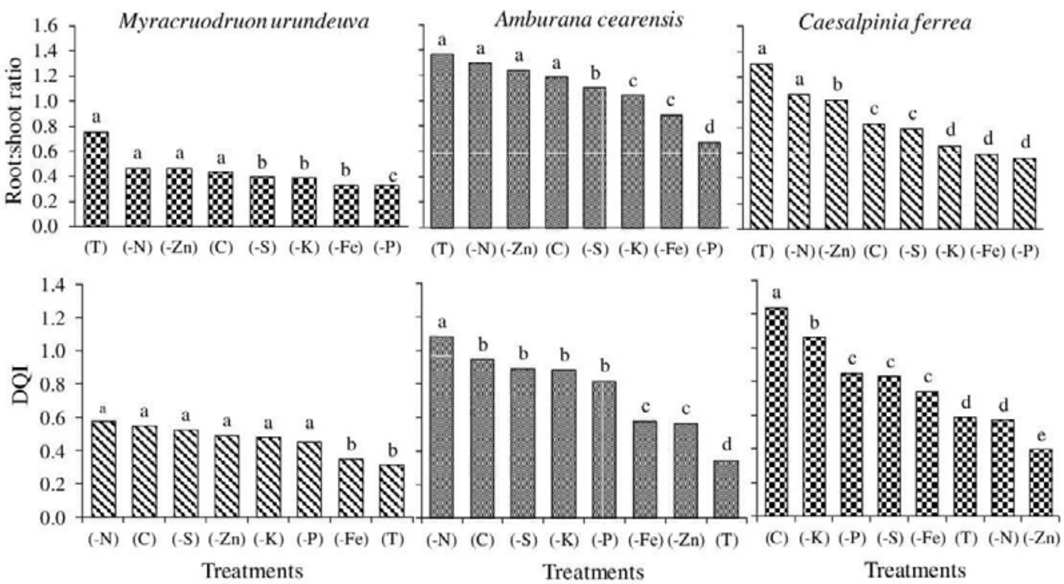

Figure 5. Root: shoot ratio and Dickson Quality Index (DQI) of species from Caatinga biome. C and T treatments correspond to complete fertilization and no fertilization, respectively. The other treatments correspond to the omission of the indicated nutrient.

Means followed by the same letters do not differ at the 5% level of significance by the Scott-Knott test.

For *A. cearensis*, there was a decrease in this relationship due to Fe and Zn omission and with the T treatment, whereas a decrease in the root: shoot ratio was observed for *C. ferrea* with P, Fe, and K omission (Figure 5).

The Dickson Quality Index (DQI) of *M. urundeuva* was lower with Fe omission and with the T treatment (Figure 5). For *A. cearensis*, the DQI was lower in the T treatment, followed by Zn and Fe omission, whereas for *C. ferrea*, the lowest DQI value was provided by Zn omission, followed by N omission and unfertilized soil (T).

4. DISCUSSION

The lower plant growth rates obtained with the T treatment (omission of all tested nutrients) or with Fe omission are partly related to the combined effect of the soil chemical attributes, which showed a relatively high pH and low organic matter content (Table 1). In the T treatment, the high soil pH probably reduced Fe availability (Moro et al., 2013), whereas the low organic matter content probably reduced S and N availability (Lustosa Filho et al., 2017), thus decreasing the growth rates under these treatments. Valeri et al. (2014) observed that redwood (*Paubrasilia echinata*) cultivation without fertilization resulted in limited growth. On the other hand, in this study, K omission did not limit the growth rates of *M. urundeuva* and *A. cearensis* and little affected the growth rates of *C. ferrea*, which is justified by the relatively high content of this nutrient in the soil (Table 1). High K levels in Chromic Luvisols are very frequent (Oliveira et al., 2009), constituting a reflection of the source material of this nutrient, predominantly minerals such as potassium feldspars, micas, and vermiculites.

Among the studied species, *C. ferrea* showed the highest height growth rates, as observed in other studies (Sousa et al., 2012; Araujo et al., 2017; Silva, et al., 2020). This is especially relevant when it comes to recovering degraded areas using fast-growing species. However, when this species was cultivated with the omission of all tested nutrients, there was a 48% decrease in the height growth rate, indicating the need for previous fertilization in this soil.

The lower shoot dry mass production in *M. urundeuva* due to N and S omission and in *A. cearensis* due to S omission may be related to the role of these nutrients in protein synthesis and, therefore, in leaf production (Marschner, 2012). Pimentel & Guerra (2015) found different results when studying *A. cearensis* under field conditions in an agroforestry system, observing a decrease in the growth rate and the number of leaves of this species with N supply via cattle manure, which is probably related to the cultivation conditions or the characteristics of the manure used. For *C. ferrea*, however, N omission did not limit leaf dry mass production, which may be related to the greater nitrogen fixation capacity of this species.

Regarding total dry mass production, the T treatment and Zn omission were the most limiting treatments for the three species studied, especially regarding root dry mass, contributing to decrease the TDM. Zinc is essential to cell division and, therefore, to both shoot (Hassan et al., 2020) and root growth (Jain et al., 2013). This nutrient participates in the synthesis of tryptophan, a precursor amino acid of IAA (indolylacetic acid), and in the composition of ribosomes, essential for protein synthesis (Hassan et al., 2020). It is noteworthy that *A. cearensis* had the lowest TDM values but the highest root: shoot ratio. This occurs due to the xylopodium-type root system of this species, an important characteristic of plants adapted to water scarcity conditions (Almeida et al., 2014). The fact that P omission did not affect the TDM production of *M. urundeuva* may be related to its lower growth rate in relation to the other species, especially *C. ferrea,* given the lower need for this nutrient in metabolic processes (Marschner, 2012).

The root: shoot relationship in *M. urundeuva* and *C. ferrea* was favored by N and P omission. However, for *C. ferrea*, this effect only occurred with N omission and with the T treatment. Under nutrient deficiency, especially N and P, plants usually employ most photoassimilates for root production as a mechanism to overcome this deficiency (Péret et al., 2014). However, this did not occur with *C. ferrea*, indicating that this species uses a different strategy to adjust to phosphorus deficiency. The DQI values, regardless of treatment and species, ranged from 0.6 to 1.1, above the ideal minimum value of 0.2 (Berilli et al., 2018). According to Eloy et al. (2013), this index is one of the best indicators of plant quality as it associates robustness (H/D) with biomass production (SDM/RDM), avoiding, in the case of seedlings, mistakenly choosing taller and etiolated plants to the detriment of smaller ones, although with greater potential for survival and development in the field.

Finally, it is emphasized that, in the T treatment, in addition to the already mentioned limitations, nutrients such as Cu and Mn may have contributed to limit the growth rates and quality of plants, considering that, like Fe, their availability is negatively affected by high pH (Moro et al., 2013).

5. CONCLUSIONS

Prior fertilization with Fe and Zn sources is essential for the initial establishment of *M. urundeuva* and *A. cearensis* species in Chromic Luvisols.

For *C. ferrea*, which has a higher growth rate, fertilization with N, P, and S sources in addition to Fe and Zn is necessary to increase the establishment potential of this species in Chromium Luvisol areas.

Considering the relatively high soil pH, Mn and Cu supply is recommended to optimize the growth of the three species studied.

SUBMISSION STATUS

Received: 02 Jun. 2021.
Accepted: 09 Sept. 2021.
Associate editor: Eduardo Vinicius Silva

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