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Facilitation in Brazilian semiarid zone: remnant trees show a positive effect on caatinga regeneration

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ABSTRACT

Arid and semiarid ecosystems display several environmental filters naturally restricting plant community composition. Such filters become more severe after some disturbance and may thus hamper the survival of young plants. The role of remnant trees in succession needs to be better understood to identify patterns and functional traits that might facilitate natural regeneration in drylands. This study evaluated the role of remnant trees in the succession process in the *caatinga* vegetation (Brazilian seasonally dry tropical forest), testing the effect of a typical tree, the juazeiro (*Ziziphus joazeiro* Mart.) in richness and abundance of seedlings in areas of abandoned pasture, in Northeastern Brazil. A perimeter was outlined around each plant (n = 20) with a diameter equivalent to each tree crown; all seedlings of woody species up to 0.5 m in height, within that perimeter, were collected and identified. Control areas with the same dimensions were delimited in adjacent locations (n = 20) without the influence of remnant trees, followed by the same data surveys. Mean species richness was of 7.8 ± 4.8 under the juazeiro canopies, compared to 2.3 ± 1.9 in the control areas. Species abundance was also greater under the presence of *Z. joazeiro*, with an average of 16.9 ± 4.8, against 4.1 ± 4.2 individuals in the controls. Among the abiotic factors evaluated, it is suggested that soil and air temperatures may show a greater influence on the recruitment of seedlings, benefiting natural regeneration under *Z. joazeiro*. *Z. joazeiro* ramnant trees appear to facilitate the natural regeneration of tropical drylands. We suggest considering the use of these plants as catalysts for the nucleation process in the restoration of the *caatinga*.

1. Introduction

Natural regeneration in drylands is limited by environmental filters that naturally restrict the composition of the community (Lebrija-Trejos et al., 2010). Environmental filters, such as low precipitation, high temperature and excessive radiation, become more severe after some disturbances (Holmgren and Scheffer, 2001; Paterno et al., 2016) and may hamper the survival of young plants (Moura et al., 2021).

In the Brazilian *caatinga* (a seasonally dry tropical forest), the natural regeneration process is still poorly understood. Recently published studies have shown the importance of positive interactions, pointing to the role of some nurse plants as catalysts in the successional process (Vieira et al., 2013). The facilitation patterns promoted by nurse plants are already widely known in other semi-arid ecosystems worldwide (Bertness and Callaway, 1994; Callaghan et al., 2016; Callaway, 1995; Tirado et al., 2015).

Nurse plants can act in different ways, serving as perches or offering resources such as food and shelter for seed dispersers (Dias and Scarano, 2005), or creating physical or biological conditions for the establishment of other species throughout the succession by acting as nurse plants (Tirado et al., 2015, Gómez et al., 2004).

Unlike fast-growing pioneer species, which begin the process of succession (Connell and Slatyer, 1977), in the typical nurse-protege interaction as the term is used in current literature, the nurse generally remains a component of the ecosystem (Brooker et al., 2008; McIntire and Fajardo, 2014). Furthermore, the nurse does not need to be a pioneer. The nurse is often a remaining tree, spared from being cut down for economic or cultural reasons. Sometimes the nurse can be a

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regenerate from aboveground buds (Barros et al., 2021; Vanderlei et al., 2021), which regenerates quickly when an area of traditional agriculture is abandoned.

The role of remnant trees in ecological succession needs to be better understood to identify patterns and functional traits that might facilitate natural regeneration in drylands. Natural regeneration is generally a cheaper and more effective strategy for dryland restoration. Remnant trees able to promote facilitation can act as catalysts of the succession process in *caatinga* areas (Moura et al., 2021; Vieira et al., 2013), acting as nucleators (Reis et al., 2014), thus being strong allies of natural regeneration. As already reported by other authors for arid and semiarid areas of the planet (Brooker et al., 2008; Chelli et al., 2019), positive interactions can trigger the recruitment and establishment of young plants (Fagundes et al., 2018; Tewksbury and Lloyd, 2001), alleviating the effects of low water availability and high temperatures.

In the present study, we evaluated the secondary succession, promoted by remnant trees of the juazeiro (*Ziziphus joazeiro* Mart.), a typical Caatinga species, usually kept in pastures because it provides shade for cattle. *Z. joazeiro* is also able to resprouting from its stem base after clear cutting, so it is very frequent in areas undergoing natural regeneration.

Juazeiro has already been cited as a potential nurse plant by other authors, due to it being an evergreen tree, equipped with thorns (Carrión et al., 2017). We discuss, therefore, the possible effect of *Z. joazeiro* as “nurse plant”.

We addressed the following predictions: (1) The microclimatic variables differ under the canopy of *Z. joazeiro* in relation to the open (control) areas, and (2) Seedling richness and abundance of tree species increase under *Z. joazeiro* canopy. We further discuss restoration strategies to enforce the use of nurse plants effect, that may be a keystone in the regeneration native vegetation in abandoned pastures in Caatinga.

2. Material and methods

2.1. Study area and study plant

The study areas are located in a region where shifting cultivation and pasture rotation predominate, sometimes with the use of fire to prepare the soil for the planting of new fields or pastures. The areas chosen to analyze regeneration had been abandoned for over a year and there was no intention of the owners to use them during the research period. The sampling design was established in abandoned pastures in five smallholders, located between the coordinates 9°22’ – 9°37‴ S and 37°03’ – 37°20’ W and at altitudes ranging from 223 m to 286 m (Fig. 1). These properties included pasture areas abandoned for over a year in the semiarid zone of the State of Alagoas, in the Northeast of Brazil. Four trees were sampled per smallholder, and they were at least 30 m apart.

Soil fertility varies, with a predominance of sandy soils, classified as regosols (Santos et al., 2018). The rainy season occurs from May to August, and precipitation ranges between 300 mm and 500 mm per year. The natural vegetation of the area consists of Caatinga formations (Brazilian seasonally dry tropical forests), Currently, the region is highly anthropized, occupied by many smallholders and few remaining fragments in different stages of regeneration.

Ziziphus joazeiro Mart. Is an arboreal species, reaching up to 16 m, morphologically characterized by a straight or tortuous trunk, heavily branched and armed with stout thorns. This species was chosen as a likely nurse species due to its morphophysiological characteristics (Carrión et al., 2017), the presence of thorns that provide protection against herbivores, its lack of palatability and the fact that it is an evergreen species, possibly contributing to the alleviation of extreme microclimatic conditions. In this way it may act as a nurse in a process of secondary succession.

2.2. Sampling design, data collection and data analysis

A total of 20 remnant juazeiro trees were selected to conduct the surveys. To meet the inclusion criteria, juazeiro trees must have had a crown projection with a minimum diameter of 2 m and be isolated, at least 30 m away from another adult tree, in abandoned pasture areas, without the presence of animals. This criterion isolated the influence of the canopy of other trees both in the plot under the juazeiro and in the control plot. The perimeters of the canopy cover of the trees were measured. A control area with the same perimeter was plotted at a distance of 5–8 m in the north direction of each remnant tree. All seedling (up to 0.5 m in height) below the canopy and control area were sampled (Fig. 2). Observations were made of the root parts of the seedlings to rule out the possibility that it was a ramet. The seedlings were classified by morphotype and counted for quantitative analysis.

To collect the microclimatic data, two digital thermo-hygrometers (ITHT 2250, n = 20, 10 measurements for under canopy areas (Fig. 3A) and 10 measurements for open areas were used for measuring air relative humidity and temperature, soil thermometer was used to

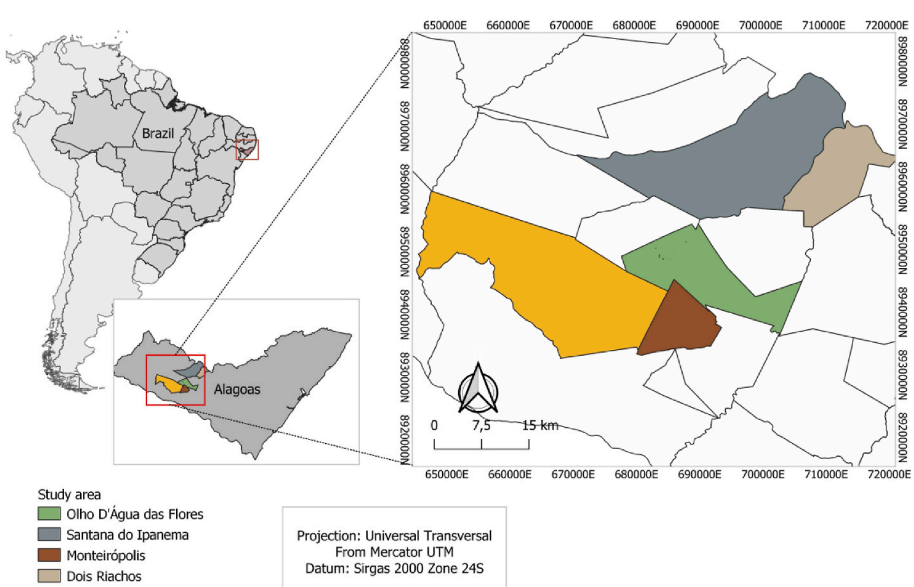

Fig. 1. (A) Location of the study area in the Northeast of Brazil.

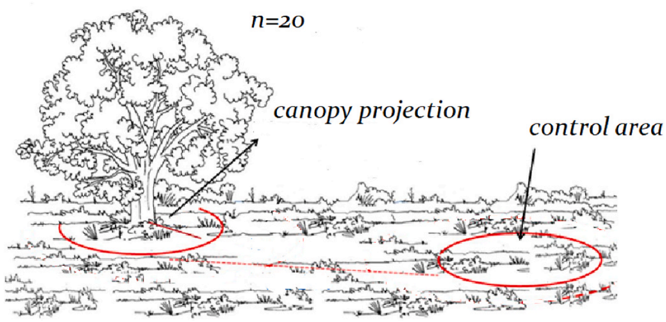

Fig. 2. Sample design: plot sunder the canopies of the juazeiro and in the control areas.

measure the temperature and digital Lux meters (Light Meter HD 450) were used for measurements of light intensity (Fig. 3B).

The measurements were made in pairs, always placing one instrument under the canopy and one in the control area, so that the measurement could be taken at the same time. The instruments were placed on the soil surface at a distance of 1 m from the trunk of the sampled trees. Measurements were taken every hour, from 6:00 a.m. to 5:00 p.m., thus covering all of the daytime period with light availability. The physical data were collected once during dry season (December). We performed paired Student's t-test comparing the values from each tree sampled with its control open area.

To investigate differences between seedling richness and abundance under *Z. joazeiro* canopy cover and in open areas, we performed paired Student's t-test comparing the values from each tree sampled with its control open area. All analyses were performed in R v.3.0.1 (R Core Team, 2021).

3. Results

A total of 301 seedlings were counted, 251 under the *Z. joazeiro* canopy and 50 in control areas. These seedlings belonged to 27 different morphotypes. The richness of morphotypes ranged from 3 to 17 under the canopy of *Z. joazeiro* trees (average 7.85 ± 4.81 standard deviation) and from zero to 6 in the open control areas (2.3 ± 1.9). The total number of seedling varied from 7 to 38 under *Z. joazeiro* canopy (16.9 ± 4.81) and from zero to 6 in the open areas (4.1 ± 4.2).

The seedling morphotypes richness average difference between each pair of under the canopy and open area unities was 5.5 (±3.1 standard deviation), and is statistically different from zero under the paired *t*-test (Fig. 4A, $n = 20$, $t = 5.40$, $df = 19$, $p < 0.001$). Similarly, the seedling abundance average difference between each pair of under the canopy and open area unities was 12.7 ± 7.1 and is also statistically different from zero under the paired *t*-test (Fig. 4B, $n = 20$, $t = 5.36$, $df = 19$, $p < 0.001$).

The effects of remnant tree on environmental microclimates were also strong (Fig. 5). The mean air temperature was 8.3 °C lower under the remnant trees than in the control areas ($n = 10$, $t = -7.3753$, $df = 11$, $p < 0.001$), and the mean light intensity was 54.2 lux lower than the controls ($n = 10$, $t = -5.1762$, $df = 11$, $p < 0.001$). The mean soil temperature was also lower than in the control areas. However, the data for relative humidity were not significantly different between the *Z. joazeiro* trees and open areas ($n = 10$, $t = 1.555$, $df = 11$, $p = 0.148$).

In the control areas, higher temperature peaks were observed between 10:00 a.m. and 4:00 p.m., with temperatures ranging between 42 °C and 45 °C. In the same period, a maximum temperature of 36 °C was recorded under the *Z. joazeiro* canopy at 1:00 p.m. (Fig. 5). In the soil, the maximum temperature was 42.5 °C in the open areas, against 32.5 °C, under the *Z. joazeiro* canopy (Fig. 5). The light intensity reached its highest peaks (as expected) in the control areas, with the highest

Fig. 3. (A) Adult Juazeiro tree with the projection of shadow from its crown during the dry season, Juazeiro rarely loses its leaves, even during drought.

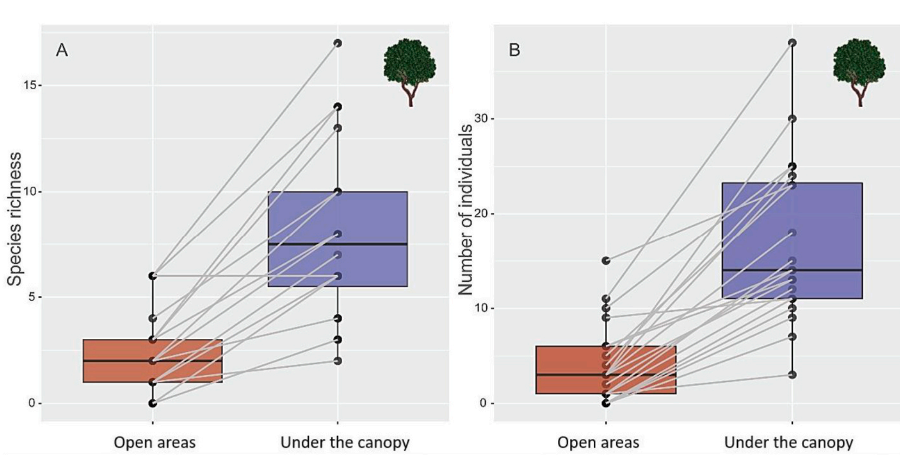

Fig. 4. Species richness (A) and number of individuals (B) under the canopy of the *Z. joazeiro* and in the control areas.

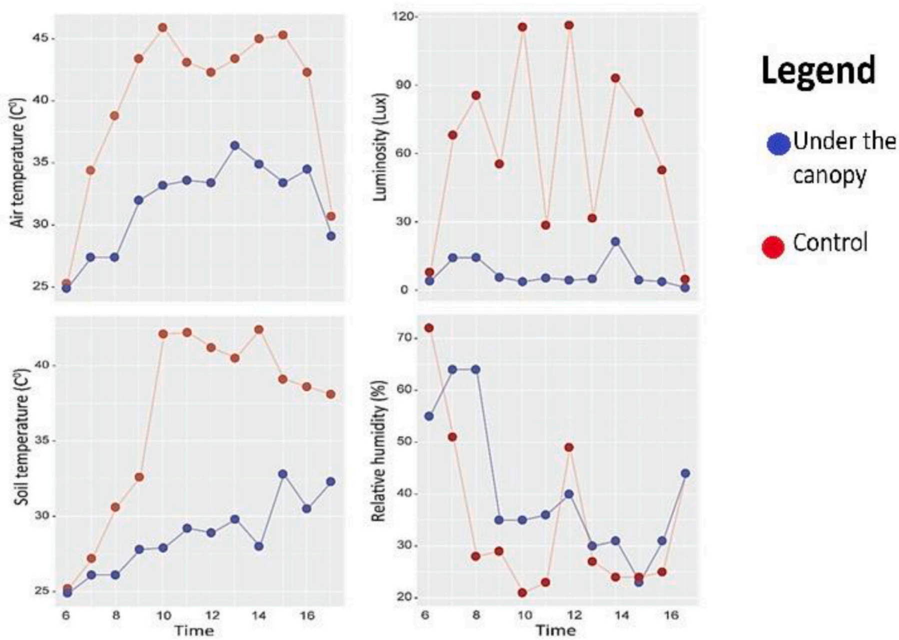

Fig. 5. Air temperature, soil temperature; luminosity and relative humidity, under the canopy (blue) of *Z. joazeiro* and in the control area (red).

values of 115.5 lux and 116.3 lux recorded at 10:00 a.m. and 12:00 p.m., respectively. Under the *Z. joazeiro* canopy, the light intensity level did not vary significantly, remaining lower and constant during the period of greatest insolation between 10:00 a.m. and 3:00 p.m. (Fig. 5). The level of relative humidity decreased rapidly soon after 6:00 a.m. in both environments, with a steeper decline in the areas outside the *Z. joazeiro* canopy. During the period of highest light intensity and temperature, the relative humidity remained low, reaching 21% (at 10:00 a.m.) in the control area and 23% (3:00 p.m.) under the canopy (Fig. 5).

4. Discussion

Remnant plants of *Z. joazeiro* improved the microclimatic conditions of the surrounding environment, creating a suitable environment to the establishment of seedlings.

Microclimate is a key driver of forest dynamics, so it is important to understand how microclimate varies along forests successional gradients (Máliš et al., 2023). The higher species richness and abundance found under the canopy, together with the lower air and soil temperatures and lower light intensity confirmed the two proposed hypotheses, showing that *Z. joazeiro* is most likely an important species in the natural regeneration of the Caatinga, ensuring the recruitment of other species.

The functional traits of *Z. joazeiro* may play an important role in its success as a nurse plant. One of the important nursing features of this species is that it is evergreen, which provides the species that grow under its canopy protection from high solar radiation and high temperatures even during the dry season, when most species lose their leaves. The low and irregular rainfall, concentrated in a few months is a characteristic of the Brazilian semiarid climate, which makes it difficult to recruit and establish seedlings of tree species. Some studies emphasize that in adverse environments, species that grow beneath other plants that have a potential as nurse plants are benefited by protection against high levels of solar radiation and extreme temperatures (Tirado et al., 2015, Gómez et al., 2004). The mean decrease in temperature of 8.3 °C and in light intensity of 54.2 lux under the *Z. joazeiro* canopy could thus be decisive for the establishment and survival of seedlings. Another likely "nurse" feature associated with *Z. joazeiro* is the fact that the species is not consumed by local herbivores (cattle and goats) as are other species in the region.

Apparently, the fact that the species is not palatable and is armed with thorns inhibits grazing by herbivores and benefits the species that grow under its canopy, similar to that reported by Bertness and Callaway (1994) and Brooker and Callaway (2009). However, the effects of palatability and thorns occurrence of the nursing plants on the survival of seedlings and herbivory should be better analyzed. Another extremely relevant aspect, which may be related to the perch effect of the *Z. joazeiro* tree, is zoochory. Having fruit dispersed by animals has been one of the traits highlighted by several authors (Guevara et al., 1986; Mitani and Osumi, 2022) as most important in the potential for nucleation of remnant trees. Although the perch effect was not directly analyzed in this study, we suggest that it may be a possible important mechanism of nucleation in the caatinga, which should be analyzed in new studies.

5. Conclusions and future directions

We understand that nurse plants, as is the case with *Z. joazeiro,* may contribute to the secondary succession process in areas that have suffered deforestation in the Caatinga vegetation. However, understanding the main mechanisms involved in the reduction of environmental filters and, consequently, the greater success of the seedlings, is an important step towards proposing more adequate restoration models for these areas, considering the potential of remnant trees in the secondary succession. Thus, the main limitation of this study is the lack of knowledge about functional traits of this species that are related to its potential as a nurse plant.

Understanding succession processes in this type of environment characterized by adverse conditions, mainly due to high temperatures and water deficit, is the first step to increase the success of restoration practices. To suggest the use of remnant trees as a conservation and restoration strategy, it is still necessary to advance in the following questions: (1) What is the relative effectiveness of different remnant species as potential facilitators of plant regeneration? (2) Which functional traits are related to higher efficiency of nurse plants? Moving forward in examining these issues can be an effective pathway to define practical strategies to recover degraded environments in underfunded and understaffed areas, such as the Brazilian Caatinga.

Ethics approval (include appropriate approvals or waivers)

Not applicable.

Consent to participate (include appropriate statements)

Not applicable.

Consent for publication (include appropriate statements)

Not applicable.

CRediT authorship contribution statement

Givanildo Bernadino de Araújo: Conceptualization, Investigation, Writing – original draft. **Marcos V. Carneiro Vital:** Formal analysis, Methodology, Writing – original draft. **João Vitor Campos-Silva:** Formal analysis, Validation, Writing – original draft. **Micheline Maria de Lima:** Conceptualization, Data curation, Investigation, Methodology, Validation. **Gilberto Costa Justino:** Conceptualization, Methodology, Writing – original draft. **Flávia Moura:** Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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