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Using tree shelters to improve the initial performance of huisache (*Vachellia schaffneri*) plants in reforestation projects

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ABSTRACT

Objective: To evaluate the impact of tree shelters on the survival and early growth of huisache seedlings (*Vachellia schaffneri* (S. Watts) Hermann) in semiarid regions featuring soil conservation structures.

Design/Methodology/Approach: The experimental design comprised two planting conditions: (1) within areas where soil was retained by conservation works, and (2) outside such structures. These were combined with two protection treatments: (1) seedling protection using light-transmissive polyethylene tubes, and (2) no protection. Survival and growth metrics were monitored during the first year post-planting.

Results: While the tree shelters did not significantly affect survival rates, they markedly reduced herbivory by defoliating insects. Additionally, seedlings with protection exhibited enhanced height growth. Although the protective effect on diameter growth was less pronounced, it was notably significant under the planting condition outside the soil conservation structures. Defoliation, while not impacting survival, had an adverse effect on seedling growth.

Limitations/Implications: These findings carry practical significance for reforestation initiatives aimed at rehabilitating degraded semiarid landscapes.

Findings/Conclusions: Tree shelters enhance the initial establishment and growth performance of seedlings in reforestation efforts within semiarid environments.

Keywords: forest restoration, herbivory, seedling survival, growth.

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INTRODUCTION

The restoration of native vegetation in semiarid environments poses a significant challenge due to limited moisture availability, elevated temperatures, and intense solar radiation conditions that are particularly harsh in eroded and degraded areas with low soil productivity (Klik *et al.*, 2018; Yirdaw *et al.*, 2017). These ecological constraints severely

limit both natural and assisted regeneration of plant species, especially woody vegetation (Grossnickle, 2018; Lewandrowsky *et al.*, 2021). Furthermore, in reforestation projects, juvenile plants are especially vulnerable to herbivory by harmfull fauna (García-Obeso, 2003), domestic livestock (Wadud *et al.*, 2024), and defoliation by insects (Nickele *et al.*, 2012), all of which compromise plant establishment. A widely adopted strategy to prevent such damage is the installation of perimeter fencing in intervention areas. However, in Mexico, many reforestation efforts take place on grazing lands, where extensive livestock farming prevents the exclusion of large areas. Under such conditions, individual protection of newly planted seedlings emerges as a viable alternative, enabling more efficient resource utilization (Pérez *et al.*, 2022). Currently, various tree shelter models are used in reforestation efforts (Oliet *et al.*, 2023; Piñeiro *et al.*, 2013).

Depending on their structure and construction materials, these shelters have proven effective in enhancing plant performance by mitigating solar radiation, desiccating winds, and frost damage (Abe, 2022; Bergez & Dupraz, 2009). Additionally, they can improve soil moisture by channeling condensed water towards the root system (del Campo *et al.*, 2006). These benefits have been documented across different ecosystems and forest species (Oliet *et al.*, 2019; Padilla *et al.*, 2011; Rojas-Arévalo *et al.*, 2022; Valenzuela *et al.*, 2018). Nevertheless, tree shelters may also alter the aerial allometry of plants (Bainbridge, 1994; Mohsin *et al.*, 2021). Despite their advantages, the individual protection of plants in restoration projects within Mexico's semiarid ecosystems remains infrequent, largely due to the lack of knowledge regarding their effects on the initial performance of key ecological species (Sosa-Castañeda *et al.*, 2019). Assuming the cost of adopting this ecotechnology may be justifiable, as it significantly reduces the need for plant replacement, thereby lowering associated replanting costs and mitigating early growth losses during the critical first year after planting.

Another crucial factor in plant establishment is soil preparation at the planting sites (Löf *et al.*, 2012; Villar-Salvador & Oliet, 2021). In reforested semiarid regions, soil and water conservation structures are commonly constructed to reduce erosion, promote infiltration, and enhance the retention of organic matter and nutrients within captured sediments (García-Gallegos *et al.*, 2023; Welemariam *et al.*, 2018).

In particular, stone bunds not only improve the soil's physical and chemical properties and increase fertility (Atinafu *et al.*, 2024; Klik *et al.*, 2018), but also facilitate the natural colonization of herbaceous and shrub species, and support the establishment of forest plantations with temperate species (Ponce-Rodríguez *et al.*, 2019). However, it remains unclear whether the conditions generated by these structures can serve as suitable microsites for successful seedling establishment in semiarid environments. In Mexico, arid zones cover approximately 40% of the national territory and encompass extensive areas affected by deforestation and degradation (González-Medrano, 2012). From 2001 to 2022, the country experienced an average annual gross deforestation of 208,746 hectares, of which 13.51% occurred in arid and semiarid ecoregions (CONAFOR, 2024). In response, various reforestation programs have been implemented, often accompanied by soil and water conservation practices (CONAFOR, 2023). Nevertheless, one-year post-planting survival rates remain below 57%, primarily due to drought and herbivory

(Prieto & Goeche, 2016). *Vachellia schaffneri*, a leguminous tree species, is commonly found in xerophytic thornscrub communities across central and northern Mexico (González-Elizondo *et al*., 2007). However, its intensive use as forage, fuel, and a source of tannins has led to significant fragmentation of its natural populations (Monroy-Ata *et al*., 2007). Ecologically, *V. schaffneri* contributes organic matter under its canopy and, as a nitrogen-fixing species, it is particularly well-suited for restoring degraded soils (Gómez-Acata *et al*., 2019). This study focuses on assessing how tree shelters influence the survival and early growth of *Vachellia schaffneri* seedlings in semiarid lands with soil conservation structures. The central hypothesis posits that tree shelters reduce herbivory damage and consequently enhance seedling survival and growth, especially under the microsite conditions created by soil conservation works. The findings may have practical implications for guiding future strategies in the restoration of degraded arid environments.

MATERIALS AND METHODS

Study area description

The research was conducted in a rangeland area of the Ejido Lázaro Cárdenas (Garabitos), located in the municipality of Durango, Durango, Mexico (24° 01’ 05.1” N, −104° 45’ 53.9” W, at 1,990 meters above sea level). The site is situated on a south-facing hillside with a 15% slope. The climate is classified as temperate semiarid with summer rainfall, characterized by an average annual precipitation of 475 mm and a mean annual temperature of 17 °C. The surrounding native vegetation consists of shrubland and grassland, with dominant woody species such as huisache (*Vachellia schaffneri*), mesquite (*Neltuma laevigata*), and peach cactus (*Opuntia durangensis*), along with a diverse array of grass species in the herbaceous stratum. The soil is shallow (<25 cm), stony, and has been subject to water erosion due to reduced herbaceous cover caused by overgrazing. In 2011, soil conservation structures were implemented on-site, consisting of 30 cm-high dry-stacked stone walls arranged along contour lines, spaced 25 meters apart. These structures have successfully retained sediment, contributing to soil accumulation and erosion control.

Planting and protection treatments

For the plantation establishment, one-year-old *V. schaffneri* seedlings were used, grown in 380 mL polyethylene tube containers. The growing substrate consisted of a mixture of 50% composted pine bark, 30% peat, 10% perlite, and 10% vermiculite, enriched with 7 g/L of Multicote® slow-release fertilizer (NPK 18-6-12) with a release duration of nine months. The seedlings were propagated from mass-collected seed harvested from natural stands within the municipality of Durango. Prior to sowing, thermal scarification was applied by immersing the seeds in 90 °C water for one minute. The plantation was established using a bifactorial experimental design with two planting conditions: (1) on soil retained by the conservation structure, and (2) at a site without such structures, located midway between the stone bunds (Figure 1A). These were combined with two seedling protection treatments: (1) with protection using a polyethylene tube (milky white) with 45% light transmittance (Figure 1B), and (2) without a protective tube. The tree shelters measured 61 cm in height and 10.5 cm in diameter.

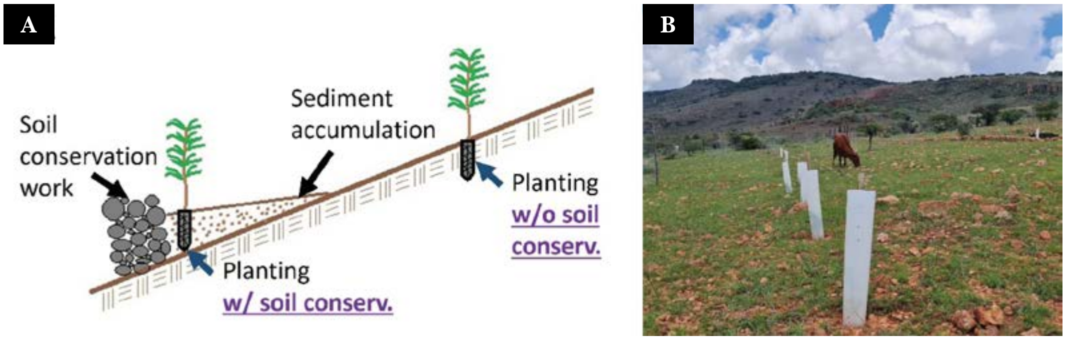

Figure 1. Illustrative diagram of two plantation microsites (A): with and without construction work, and appearance of the tree shelters once installed (B), factors that were evaluated in huisache plants (*Vachellia schaffneri*).

For each combination of planting condition and protection treatment, 20 seedlings were established, distributed across four replicates of five individuals each, totaling 80 plants in the experiment. Planting was carried out during the first week of October 2023, using a standard hole method with dimensions of 40×40 cm and a spacing of 2.5 meters between plants.

At the individual plant level, survival, herbivory damage (expressed as a percentage), and growth parameters (height and stem diameter) were monitored at three time points: late winter (February 2024), early summer (July 2024), and autumn (October 2024, 12 months after planting). Additionally, in the final evaluation, plant branching was assessed by counting the number of primary branches and measuring the length of the basal branch (LBB) to detect potential changes in shoot allometry. During the monitoring period, total recorded rainfall at the site was 501 mm, with an average temperature of 20.7 °C. Mean daily maximum and minimum temperatures were 30.7 °C and 12.1°C, respectively. During the spring and summer months, temperature fluctuations inside the tree shelters were evaluated. A temperature increases of up to +6 °C was observed within the tubes compared to ambient external conditions, particularly during the hottest part of the day (12:00 to 17:00 h). Conversely, in the early morning hours (6:00 to 9:00 h), temperatures inside the tubes were up to 5 °C lower than external temperatures (Figure 2A). Similarly, the photosynthetic photon flux density (PPFD) inside the tubes was, on average, 55% lower than the PPFD measured outside (Figure 2B).

Statistical analysis

Statistical analyses were performed using R software, version 4.4.1 (R Core Team, 2024). The effects of the tree shelters and planting microsite (position relative to the conservation structure) on the response variables were evaluated through two-way ANOVAs. Survival data and herbivory percentages were analyzed using generalized linear models (GLMs) with a binomial distribution. Similarly, the number of branches recorded at the end of the evaluation period was analyzed with a GLM employing a Poisson distribution.

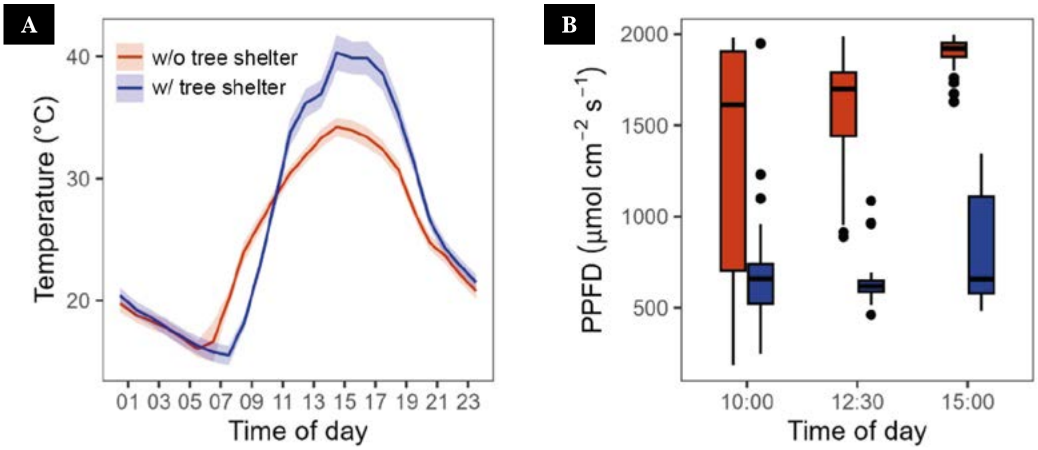

Figure 2. Air temperature (A) and photosynthetic photon flux density (B) on the outside (red) and inside (blue) of the tree shelters used for the individual protection of huisache plants (*Vachellia schaffneri*).

Growth data (stem diameter and height) were analyzed using repeated measures ANOVA through mixed-effects models, with protection treatment, microsite, and time (months after planting, MAP) included as fixed effects, and individual plant treated as a random effect. When the effect of any factor or interaction was statistically significant, a Tukey's *post hoc* test was conducted at $\alpha=0.05$. Assumptions of normality and homoscedasticity of residuals were verified using the Shapiro-Wilk and Levene's tests, respectively.

RESULTS AND DISCUSSION

Survival and damage from herbivory

At 12 months post-planting, overall survival decreased to 87.3% ($\chi^2=8.24$, $p=0.004$). The protective tube had no statistically significant effect on plant survival ($\chi^2=1.51$, $p=0.218$). Seedlings with protection showed a survival rate of 91.7%, while those without protection had a survival rate of 81.0%. Additionally, the effect of planting location relative to the soil conservation structure was marginally significant ($\chi^2=3.01$, $p=0.083$). Plants established within the conservation structure exhibited a survival rate of 82.1%, whereas those planted outside had a survival rate of 91.1%. Although there was no significant evidence of herbivory by small mammals (*e.g.*, hares or rabbits) or domestic livestock, damage caused by defoliation from leaf-cutting ants (*Atta* sp.) was observed, particularly in late winter and early spring. In this regard, the tree shelters was found to reduce defoliation (Figure 3); however, this reduction was statistically significant only in the microsite outside the soil conservation structure (interaction: Structure×Protection; $\chi^2= 6.023$, $p=0.014$). The higher incidence of defoliation in plants located within the conservation structures may be associated with the proximity of these microsites (*i.e.*, stone bunds), which can create favorable habitats for insect populations, increasing their abundance and, consequently, the plant's vulnerability to defoliation, even when protection is in place (Pérez *et al.*, 2022). Nonetheless, due to the high resprouting capacity of *V. schaffneri*, no direct impact of defoliation on plant survival was observed.

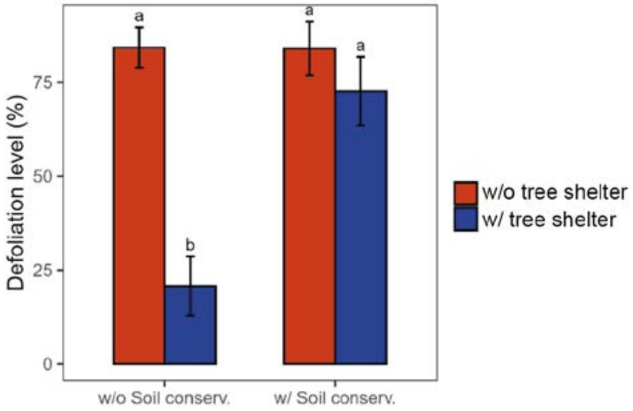

Figure 3. Percentage of defoliation in *Vachellia schaffneri* (huisache) seedlings under two planting conditions (microsites): (1) without soil conservation structures and (2) with soil conservation structures, and two protection scenarios: (1) without tree shelters and (2) with tree shelters. Different letters within each microsite condition indicate statistically significant differences (Tukey, α=0.05).

Growth

The protective tube had a highly significant effect on height growth (F=20.4, p<0.001), whereas planting location relative to the soil conservation structure did not show a significant effect (F=1.59, p=0.212). The influence of the protective tube became especially evident beginning in the spring growth season (interaction: Time × Protection; F=16.9, p<0.001). After one year, protected plants reached nearly 60% greater height compared to unprotected ones, which exhibited negligible growth (Figure 4A).

Similarly, the tree shelters had a positive, albeit more moderate, effect on stem diameter growth (F=3.96, p=0.048). The soil conservation structure alone did not significantly affect diameter growth (F=0.62, p=0.433). However, by the end of the study, a significant three-way interaction was observed (Time×Protection×Structure; F=5.29, p=0.023), indicating that the positive effect of the protective tube on diameter growth was significant only in seedlings planted outside the soil conservation structures (Figure 4B).

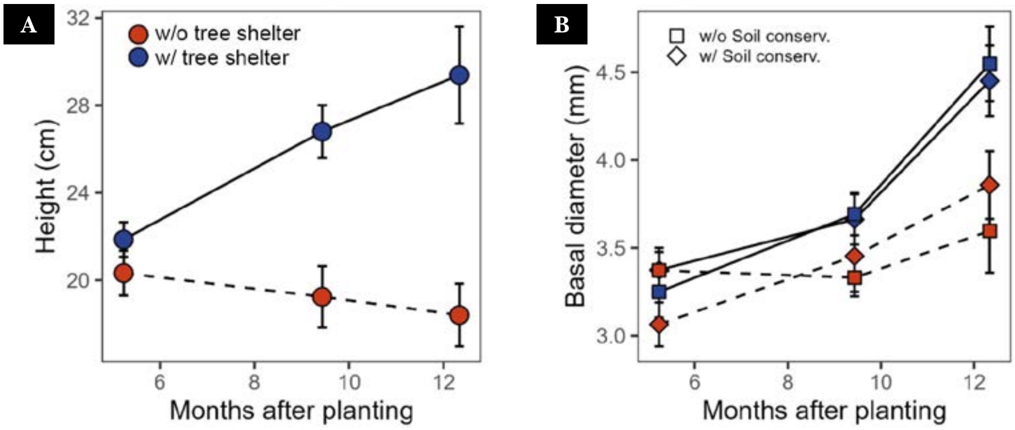

Figure 4. Height (A) and stem diameter (B) growth of *Vachellia schaffneri* seedlings under two protection scenarios: with tree shelters (blue) and without tree shelters (red), and their interaction with planting condition (B): (1) with soil conservation structure (diamonds) and (2) without structure (squares). MAP=Months after planting.

The positive effect of protective tubes on aerial plant growth can be attributed not only to their role in preventing herbivory but also to the favorable microclimatic conditions they create. On one hand, the tubes significantly reduce direct solar radiation, as observed in the present study (Figure 2B), thereby lowering the risk of photoinhibition-induced stress and its consequent limitation on growth (Oliet *et al.*, 2019; Rojas-Arévalo *et al.*, 2022). On the other hand, the tubes may help generate a favorable soil moisture microenvironment by capturing both rainfall and dew that forms on the tube walls (del Campo *et al.*, 2006; Oliet & Jacobs, 2007; Valenzuela *et al.*, 2018). In this study, dew capture was likely, given the observed drop in internal tube temperature during the early morning hours (Figure 2A), which was also visually confirmed during meassurement campaing.

Contrary to expectations, the microsite condition generated by the soil conservation structures did not substantially influence overall plant growth. However, diameter growth analysis revealed that this parameter was enhanced by the use of tree shelters, particularly in the condition without conservation structures, where soil moisture availability was presumably lower. In contrast, in seedlings planted within the conservation structures, the protective effect on diameter growth was less pronounced. This finding further supports the role of tree shelters in creating more favorable microenvironments, especially for enhancing soil moisture capture and retention (del Campo *et al.*, 2006). At 12 months after planting, seedling branching was also affected by the tree shelters, but only in terms of basal branch length ($F=38.5$, $p<0.001$), while the effect on the number of branches was marginal ($\chi^2=3.30$, $p=0.069$). In general, protected plants showed slightly greater branching (Figure 5A), and the length of the basal branch was twice as long as that observed in unprotected plants (Figure 5B).

Due to its shrubby growth habit, *V. schaffneri* tends to naturally branch from early developmental stages; however, this trait can be further stimulated by environmental disturbances (Teveni *et al.*, 2020). In this study, the microenvironmental conditions created by the tree shelters did not significantly affect the number of branches but did

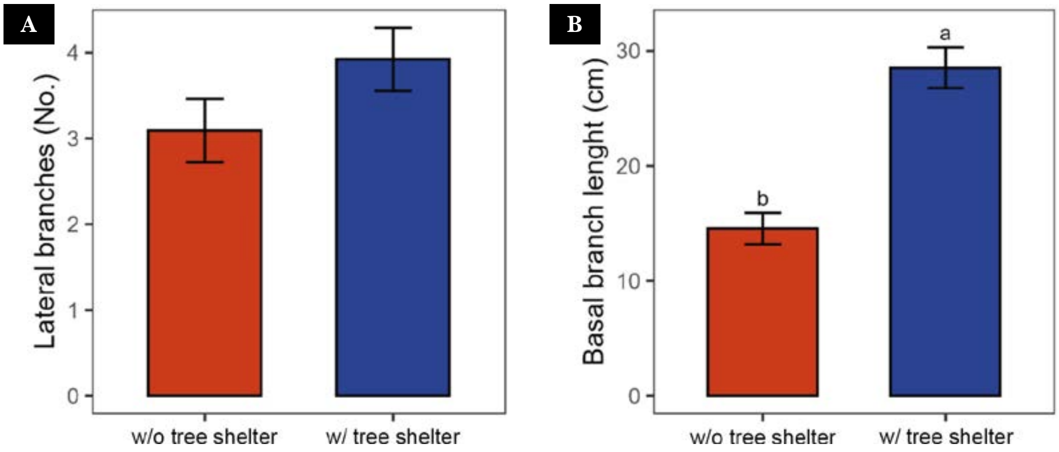

Figure 5. Number of branches (A) and basal branch length of *Vachellia schaffneri* (huisache) seedlings 12 months after planting under two protection scenarios: with tree shelters (blue) and without tree shelters (red). Different letters within each variable indicate statistically significant differences (Tukey, $\alpha=0.05$).

influence branch elongation. This differential effect may be linked to a phototropic response (Fiorucci & Fankhauser, 2017), which is common in light-demanding species during their juvenile stage, such as Vachellias. Specifically, the reduced light availability inside the tubes particularly near the base likely triggered the elongation of branches and stems as a mechanism to increase light capture. Nevertheless, this effect may diminish once the shoots exceed the height of the protective tube (Bellot, 2002). Moreover, both stem diameter growth and branch elongation were found to be associated with defoliation damage. These variables, measured at the end of the study, showed negative correlations with the percentage of defoliation observed during the spring (six months prior), with correlation coefficients of −0.56 (p=0.024) and −0.66 (p=0.005), respectively (Figure 6). Partial or complete defoliation is known to directly reduce leaf area, thereby diminishing the plant's photosynthetic capacity and limiting the accumulation of energy reserves (*i.e.*, carbohydrates) (Eyles *et al.*, 2013). Although recovery from defoliation is often rapid, resource allocation patterns can vary among plant organs. For instance, defoliated plants may prioritize allocating stored resources toward the production of new leaves rather than stem development (Wiley *et al.*, 2013). This explains why plants that experienced higher levels of defoliation showed reduced stem diameter growth (Figure 6A), partially masking the protective tube's effect on this variable during the initial months following defoliation (Figure 4B), especially considering that some protected plants were also affected by defoliation (Figure 3).

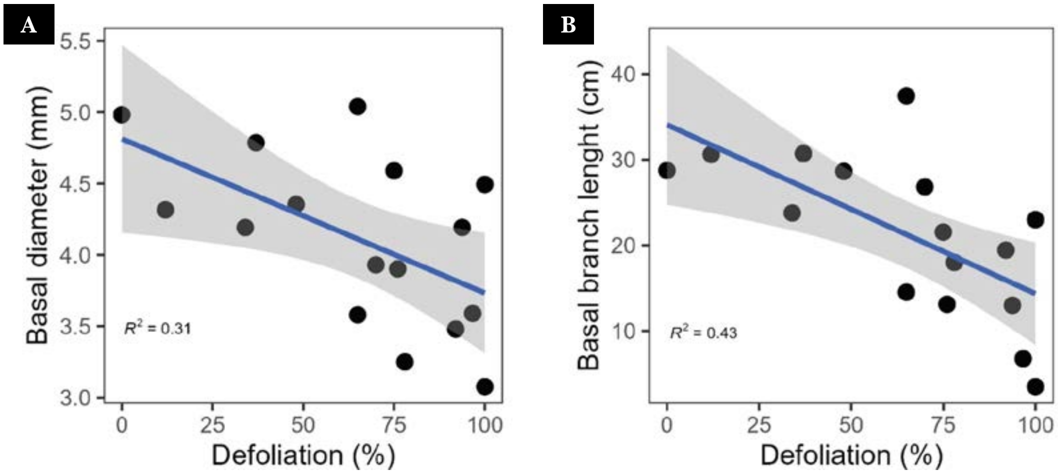

Figure 6. Relationship between spring defoliation percentage and basal branch diameter (A) and length (B) measured in autumn in huisache (*Vachellia schaffneri*) plants. The points represent the means per replicate, while the blue line and shaded area are the predicted data and confidence intervals, respectively.

CONCLUSIONS

The use of individual protective tubes in the reforestation of huisache (*Vachellia schaffneri*) effectively reduces herbivore damage and insect defoliation, while significantly enhancing plant growth during the first year after planting. Although soil conservation structures help create favorable microenvironments for seedling establishment, they may also promote the presence of insects and small fauna, thereby increasing the risk of herbivory regardless of the presence of protection. The findings of this study have practical relevance for the implementation of reforestation programs aimed at restoring natural populations of *Vachellia schaffneri*, particularly in degraded semiarid environments.

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