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EFFECT OF HERBIVORY ON THE REFORESTATION OF FOUR SPECIES OF THE FABACEAE FAMILY IN DETERIORATED AREAS

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ABSTRACT

Reforestation plays an important role in attempting to reverse ecosystem degradation in arid regions, where natural rainfall variability makes ecological restoration difficult. The aim of this work was to evaluate the survival and growth of four native species of the Fabaceae family (*Prosopis velutina* Wooton, *Havardia mexicana* (Rose) Britton & Rose, *Parkinsonia microphylla* Torr., and *Olneya tesota* A. Gray), with and without protection against herbivory in a degraded arid land in Sonora, Mexico. A three-level factorial design was established according to the protection treatments (PET and mesh, 20 and 30 cm in height, respectively) and a control (without protection). The variables of survival and height were evaluated 6, 12, and 24 months after transplant. Computer packages were used for the statistical analyses, establishing 5 % significance. Survival was highest in the plants with protection, with 100 % for the first year, both for PET and mesh, in comparison with a survival rate of 16.6 % for the unprotected control plants. The second year, the highest survival rate was found in plants protected by a mesh (41.6 %), whereas plants protected with PET and the control had the lowest survival rates, both with 8.3 % ($\chi^2 = 5.674$, $p \leq 0.058$). The height of plants was affected by herbivory. Plants protected by mesh reached a greater height (29.4 cm) in comparison with the PET treatment, with 17.4 cm, and the control, with 3.1 cm ($p < 0.0001$). The growth of native forage fabaceae (leguminous) tree species in Sonora is extremely slow and relies on both herbivore protection and above-average rainfall years. This work presents the use of low-cost herbivory protection strategies to increase the survival and height of plants 2 years after being established.

Keywords: Sonora desert, *Prosopis velutina* Wooton, *Havardia mexicana* (Rose) Britton & Rose, *Parkinsonia microphylla* Torr., *Olneya tesota* A. Gray, survival.

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INTRODUCTION

The degradation of arid environments has, for decades, been a very serious problem on a global scale (Turner *et al*., 2016). Human activities have contributed towards the degradation of lands, which may worsen and promote desertification. Practices such as the clearing of trees have negative impacts on the biodiversity and increase soil vulnerability towards disruptions such as droughts, which exacerbate the problem (Eswaran *et al*., 2019). Arid ecosystems have been described as very vulnerable to disruptions due to the long drought periods (Shreve and Wiggins, 1964) that affect the establishment of new plants every season and the survival of trees (Walton, 2017). Despite their ability to adapt to arid areas, the low availability of water causes stress in plants, limiting their establishment and potential growth (Walton, 2017). This is also influenced by soil fertility and the pressure exerted by herbivory on trees in their earlier stages. Herbivory in the degraded soils of the coast of Hermosillo, Mexico, has recently been proven to affect the survival of *Parkinsonia microphylla* Torr. seedlings, one year after transplanting (1.8 %), without any type of protection (Sosa-Castañeda *et al*., 2019; Moreno *et al*., 2017).

A recurring strategy to recover degraded soils is reforestation with native species (Celaya-Michel *et al*., 2020). This makes it necessary to identify species adapted to local conditions, searching for those with the greatest possibilities of reaching the reproductive stage (Walton, 2017). Generally, recovery occurs after the establishment of plants, which favors carbon-capturing mechanisms and the increase in the organic matter of soils (Turner *et al*., 2016). During the time of recovery with the present species, characteristic communities of arid zones are formed, such as the fertility islands created by some trees and shrubs, mainly from the Fabaceae family (Shreve and Wiggins, 1964).

In order to provide plants for reforestation activities in degraded areas a greater chance of survival, physical protection methods are used (Sosa-Castañeda *et al*., 2019; Moreno *et al*., 2017). Some examples are metal, plastic, and PVC (polyvinyl chloride) mesh tubes (CONAFOR, 2010). Based on the above, the survival and growth of four tree species of the Fabaceae family, native to the Sonora desert, were evaluated, with and without protection against herbivory in degraded areas 6, 12, and 24 days after transplanting. The hypothesis presented was that the protection against herbivory increases plant survival and height.

MATERIALS AND METHODS

For this study, an area of 20 ha with a barbed wire perimetral fence intended for the rotational grazing of cattle was considered. The area is located in an arid region of Hermosillo, Sonora, Mexico (29° 00’ 53’’ N, 111° 07’ 56’’ O, altitude of 149 m). The weather is dry and warm, with annual mean temperatures of 25 °C and annual mean rainfall of 246.4 mm (García, 2004). The soil in the area is sandy loam in texture with a low nutrient availability (FAO, 2015).

The vegetation was originally xerophilous scrub, which was transformed into grasslands 40 years ago for cattle grazing. These lands suffered degradation and a loss of plant coverage. The current composition of species is very simplified, dominated by buffelgrass (*Pennisetum ciliare* (L.) Link), with the presence of mesquites (*Prosopis* spp.). The main feature indicating the degradation of the site is that 70 % of the soil is bare and compacted, where no new plants are established year after year.

Species under study

The tree species from the Fabaceae family *Prosopis velutina* Wooton (mesquite), *Havardia mexicana* Britton & Rose (Mexican ebony), *Parkinsonia microphylla* Torr. (yellow palo verde), and *Olneya tesota* A. Gray (ironwood) were chosen. These are native to the area, and their records indicate a certain tolerance to drought. These species are ecologically important as nurse plants and for their economic relevance to produce wood, lumber, coal, and forage in the state of Sonora (Turner *et al*., 1995; Celaya-Michel *et al*., 2020).

Transplanting and growth of plants

The plants used in this study were produced in a nursery. Permits for scientific gathering were obtained from the Ministry of the Environment and Natural Resources (SEMARNAT). In July 2019, a total of 36 90-day old seedlings were transplanted to avoid the root torsion experienced by phreatophyte plants when they are kept for long periods in pots. They were transplanted in the degraded grazing area under the following treatments: a) without protection, b) protected with PET, and c) protected with a mesh, with a 5 m separation between plants. The treatments were carried out with three plants per species, for a total of 12 plants per treatment and a total experiment sample size of n = 36. The plants were irrigated at the time of transplanting, followed by three additional irrigations every 15 days, each with 3 L of water per plant. Subsequently, they were no longer irrigated, and the water they got was seasonal rainfall.

For the treatment with protection with PET, plastic containers made of polyethylene terephthalate, made from reused 3 L soda containers, 30 cm in height and 12 cm in diameter, were buried to a depth of 10 cm. For the mesh protection treatment, a prefabricated black plastic mesh tube or cylinder with 8 mm openings (commonly sold in local hardware stores), 40 cm in height and 15 cm in diameter, was buried to a depth of 10 cm.

Experimental design

A three-level factorial design was established, which corresponds to the protection treatments and the control (PET, mesh, and no protection). The response variables evaluated were survival and height, which were evaluated during transplanting and 6, 12, and 24 months afterwards.

Statistical analysis

Generalized mixed linear models were used to evaluate the main factors that had an influence on survival. They were compared using Akaike's information criterion (Martínez *et al*., 2009), considering the effect of time (6, 12, and 24 months), treatment (without protection and protection with a mesh or PET), and species. The generalized mixed linear models and the Chi-square tests (χ^2) were performed in R 4.1.0 (R Core Team, 2021) using the lme4 package. Additionally, p values were simulated with the Monte Carlo test, using one million replications since it is a small sample (Infante-Gil and Zarate-de Lara, 2000). The information corresponding to the height of plants was contrasted using an analysis of variance. The Tukey test was used *a posteriori* using JMP 10 (SAS Institute, 2000). A statistical significance of 5 % or less was established.

RESULTS AND DISCUSSION

Survival

The statistical model that best described the survival of the plants throughout the experiment included the effect of time and the protection treatments (Table 1). Adding the factor "Species" to the model did not improve its performance, indicating that all species had a similar survival rate, or that a higher number of replications is required to evaluate their differences. This analysis suggests that the environmental conditions (evaluated here through the factor of time) and herbivory (through the treatments of protection) exert great pressure on the survival of the four species analyzed.

Table 1. Comparison of generalized mixed linear models to evaluate the main factors that affected the survival of plants throughout the experiment.

Model	Random factors	AIC*
Model 1	Individuals	149.122
Model 2	Time + Individuals	108.376
Model 3	Time + Treatment + Individuals in a treatment	91.618
Model 4	Time + Treatment + Specie + Individuals in a species	92.620

*AIC: Akaike information criterion.

Six months after the experiment began, differences in survival became evident between treatments ($p \leq 0.05$) (Table 2), presenting a higher rate of survival between treatments with protection (mesh and PET). These differences were more evident after 12 months ($p \leq 0.0001$), whereas after 24 months, the differences between treatments were marginal ($p \geq 0.05$).

The survival percentages per plant species under study, 6 and 24 months after transplanting (Table 3), displayed no significant differences. However, after 12

Tabele 2. Chi-square analysis (χ^2) for the survival between treatments in a given time and values simulated by the Monte Carlo test.

Time	χ^2	p value	Simulated p value
6 months	9	0.01111	0.025
12 months	27.692	< 0.0001	< 0.0001
24 months	5.6749	0.05858	0.087

Table 3. Survival (%) by plant species under study 6, 12, and 24 months after transplanting, in three treatments (no protection, mesh and PET protection).

Time Transplant	Species	Protection None (%)	PET (%)	Mesh (%)
6 months	*Prosopis velutina*	66.67	100.00	100.00
$\chi^2 = 15.750$	*Havardia mexicana*	33.33	100.00	100.00
$p = 0.1507$	*Parkinsonia microphylla*	66.67	100.00	100.00
	Olneya tesota	100.00	100.00	100.00
12 months	*Prosopis velutina*	33.33	100.00	100.00
$\chi^2 = 29.354$	*Havardia mexicana*	0.00	100.00	100.00
$p = 0.0020$	*Parkinsonia microphylla*	0.00	100.00	100.00
	Olneya tesota	33.33	100.00	100.00
24 months	*Prosopis velutina*	33.33	33.33	66.67
χ^2 14.719	*Havardia mexicana*	0.00	0.00	0.00
$p = 0.1957$	*Parkinsonia microphylla*	0.00	0.00	66.67
	Olneya tesota	0.00	0.00	33.33

months, a difference was found ($\chi^2 = 29.354$, $p = 0.002$). All treatments with mesh and PET protection maintained a survival rate of 100 % and the plants without protection had a survival rate between 0 and 33 %.

Earlier studies in the same location reported a survival rate of 43 % with protection and 1.8 % without protection for *P. microphylla* one year after transplanting (Sosa-Castañeda *et al*., 2019). In the Sonora desert in Arizona, USA, the survival rate of *P. velutina* two years after transplanting was 67 %, whereas for *P. microphylla* it was 55 % with irrigation (3 L per plant every 15 d) between May and July (Abella *et al*., 2015).

The total rainfall in the first year after transplanting was 526 mm, and only 234 mm for the second year. This may have been a determining factor for the survival percentages after 6 and 12 months for all protected plant treatments to be of 100 % (Table 3). The opposite is true for the second year of study, between mid-2020 and mid-2021, when the lowest amount of monthly rainfall was registered, with even more months of drought, which was reflected on the death rate of plants, affecting survival in all treatments.

Plant heights

Differences were obtained (p < 0.0001) in the analyses of heights 6 months after transplanting (Table 4). The greatest heights were found in plants protected with meshes, followed by those protected by PET and plants without any protection. This difference continued to be significant (p < 0.0001) after 12 and 24 months, in the same order (Mesh > PET > no protection).

Table 4. Average plant height values (cm) per treatment, 0, 6, 12, and 24 months after transplanting, for the three treatments evaluated.

Time (months)	Treatment	Number of plants	Mean height (cm)	Standard deviation	*	p value
0	Mesh	12	29.492	10.701	A	0.6856
	PET	12	28.467	11.535	A	
	No protection	12	25.792	9.827	A	
6	Mesh	12	33.792	8.675	A	< 0.0001
	PET	12	20.167	12.329	B	
	No protection	12	4.767	6.651	C	
12	Mesh	12	31.800	5.917	A	< 0.0001
	PET	12	18.750	7.105	B	
	No protection	12	3.117	2.044	C	
24	Mesh	12	29.417	3.300	A	< 0.0001
	PET	12	17.433	3.152	B	
	No protection	12	3.158	2.385	C	

*Different letters indicate differences between treatments.

Height right after transplanting displayed no significant differences (Figure 1, Table 4). However, beginning at 6 months, there were significant differences ($p \leq 0.01$), with height further reduced in plants without protection, followed by plants protected with PET at 12 and 24 months.

Earlier studies in the same location reported heights between 21 and 42 cm for *P. microphylla* with protection one year after transplanting and between 12 and 21 cm without protection (Sosa-Castañeda *et al*., 2019). Another study conducted in Baja California Sur, Mexico, with *P. microphylla* and *P. velutina* under greenhouse conditions, mentions plants with heights of 120 and 70 cm, respectively (Bashan *et al*., 2009). In soils degraded by mining activities in Sonora, Mexico, eight years after transplanting, values of 291, 267, and 113 cm were found for *P. velutina*, *P. microphylla*, and *O. tesota*, respectively (McCaughey-Espinoza *et al*., 2018).

It is necessary to continue studying low-cost strategies for reforestation to increase the survival and growth rates of species (CONAFOR, 2010; Moreno *et al*., 2017) in order to increase the area of recovered lands, avoid the risk of desertification, and thus to

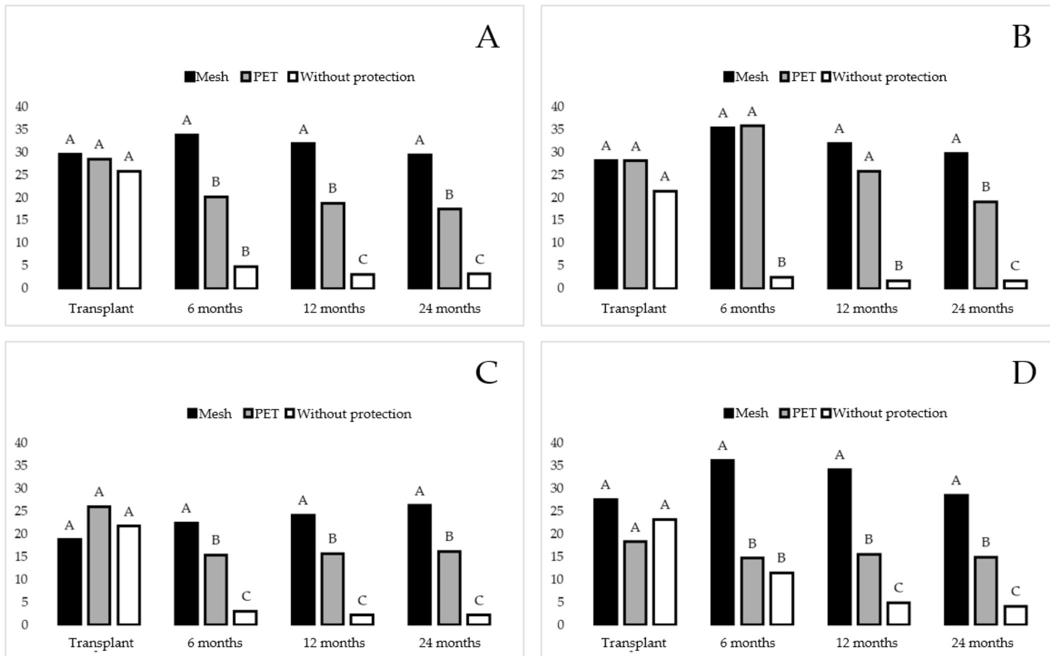

Figure 1. Changes in height (cm) per species, at transplant and 6, 12, and 24 months after transplanting. A: *Prosopis velutina* Wooton; B: *Havardia mexicana* (Rose) Britton & Rose; C: *Parkinsonia microphylla* Torr.; D: *Olneya tesota* A. Gray. Different letters indicate significant differences ($p \leq 0.01$) per species and sampling date.

obtain more services from the ecosystems (Turner *et al*., 2016). Low-cost protection against herbivory may increase the survival rates and growth of plants in reforestation activities in degraded areas. The results show that protection against herbivory favors plant survival and height 6, 12, and 24 months after transplanting.

CONCLUSIONS

The limitations in the establishment of the tree species evaluated in the arid and degraded soil of the Sonora desert are related to the herbivory and periods of drought. Mesh protection increased the survival rate and height of plants two years after they were transplanted.

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