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Germination and growth of the Sonoran Desert native trees under different agricultural conditions

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ABSTRACT

Objective: To evaluate the germination, survival, and growth of Sonoran Desert native trees, in a fertile agricultural soil, with irrigation and protection against herbivory.

Design/Methodology/Approach: For six months, the germination, survival, and growth of five tree species (*Parkinsonia microphylla*, *Olneya tesota*, *Prosopis velutina*, *Guaiacum coulteri*, and *Parkinsonia florida*) were evaluated in agricultural soil, with and without drip irrigation, avoiding herbivory.

Results: The irrigated species *O. tesota* and *P. velutina* had the highest germination percentage (χ^2=398.941, p<0.0001). Plant survival was above 62% (χ^2=21.196, p<0.0035), except for *G. coulteri* and *P. florida* without irrigation, which did not survive. At six months, *P. florida* recorded the greatest height (p<0.0001), while all the species without irrigation and *G. coulteri* with irrigation recorded the lowest heights. Likewise, *P. velutina*, *P. florida*, and *O. tesota* (p<0.0001) registered the greatest canopy cover at six months, while non-irrigated plants of all species and irrigated *G. coulteri* had the least cover.

Limitations/Implications: Further agronomic studies are necessary to enable the successful establishment of commercial forest plantations, increasing knowledge about environmental problems.

Findings/Conclusions: The five species of native plants studied can be established by direct sowing, in agricultural soil and with drip irrigation.

Keywords: Forest plantations, ecological restoration, ecosystem services.

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INTRODUCTION

The state of Sonora, in northwestern Mexico, has a highly diverse flora composition (Van Devender *et al.*, 2010). Most of the state is located within the Sonoran Desert (Shreve and Wiggins, 1964) and there is still a great lack of knowledge about its biodiversity. For example, the growth potential of various plant species has not been yet documented (CONAFOR, 2010). In arid and semi-arid zones, plant growth is slower than in humid zone ecosystems. Growth limitation is the consequence of two key factors that determine

Image by Dinah Rodriguez Anaya at Pixabay both the structure and the function of these ecosystems: firstly, the low availability of water for plants (Noy-Meir, 1973; Zhou, 2009) and, secondly, the low availability of nutrients in the soil (Whitford, 2002). As a third stressor, herbivory also interferes with plant growth and survival in these natural ecosystems (Bainbridge *et al.*, 1993; Ward, 2009).

The biodiversity of the Sonoran Desert is not exempt from current global challenges, such as overexploitation, climate change, and desertification (Van Devender *et al.*, 2010). Despite this worldwide problem, the restoration of degraded lands has not been extensively studied in arid and semi-arid environments (Bainbridge *et al.*, 1993). An alternative to partially mitigate the current environmental problems is the establishment of commercial forest plantations, which help to recover degraded land, capture carbon, and obtain satisfiers from ecosystems in a sustainable manner (CONAFOR, 2010; Li *et al.*, 2012).

Most of the experiments with native desert plants are carried out with local rainfall and some with a small supplementation of irrigation water (Bashan *et al.*, 2012), but not with drip irrigation. This technology increases the efficient use of water in ecosystems where this resource is limited, avoiding loss through evaporation and guaranteeing the availability of water for plants (Taylor and Zilberman, 2017). Few studies about the revegetation of deserts with native plants use irrigation as a treatment; even less studies use drip irrigation and few mention the height and canopy growth of the plants studied (Hessing and Johnson, 1982; Cox *et al.*, 1984; Abella and Newton, 2009; Woods *et al.*, 2012; Taylor and Zilberman, 2017).

Most of the studies about the forest species development in arid zones have been carried out in Africa or Asia (Duku *et al.*, 2016; Farahat and Linderholm *et al.*, 2015; Jiao *et al.*, 2021), where the possibilities of irrigation with urban effluents were analyzed, as an opportunity to reuse water. However, it is very important to determine the growth potential of native plants to help decision-makers in charge of ecological restoration programs or to establish commercial forest plantations; in both cases, obtaining more ecosystem services from arid and semi-arid zones would improve the balance between environmental benefits and those of landowners (Wormald, 1995; CONAFOR, 2010; Djanibekov *et al.*, 2012; Boreux *et al.*, 2013; Sánchez-González *et al.*, 2017; Zeng *et al.*, 2018).

The objective of this work was to evaluate, during a six-month period, the germination, survival, and potential growth of the Sonoran Desert native trees in an agricultural soil and with drip irrigation; additionally, the said trees did not face the water availability limitation of natural ecosystems and they were protected from herbivory.

MATERIALS AND METHODS

The experiment was developed in the Experimental Field of the Departamento de Agricultura y Ganadería of the Universidad de Sonora (DAG Unison), in Hermosillo, Sonora, Mexico, which is located at 29° 00' 55" N and 110° 07' 59" W. The mean annual temperature is 25.2 °C. The maximum temperature is registered in the month of June (39-41 °C) and the minimum is registered in the month of January (7-10 °C). The average annual rainfall is 378 mm, with August being the wettest month (100 mm) and May, the driest month (2.5 mm) (INEGI, 2014; SMN, 2019). The experimental agricultural area consists of an open field, from which fauna and domestic animals are excluded.

The main physical and chemical properties of the soil were determined up to a 30-cm depth (Table 1). Although the fertility in arid ecosystems is exceptionally low, no fertilizer was added (Cox *et al.*, 1984; Whitford, 2002).

Germination in agricultural soil

Seeds of five native plant species were collected at DAG Unison, with the proper collection permits from SEMARNAT (Table 2). One-hundred seeds of each species were germinated and maintained with drip irrigation. Likewise, in the same agricultural soil, 100 additional seeds of each species were sown and kept without irrigation; the purpose was to determine if they can germinate only with rainwater. The seeds were germinated directly in 40-cm wide raised furrows, separated by 1 m. One seed of each plant species was sown every 20 cm on 20-m long furrows. Sowing depth was twice the size of the seed. Sowing was carried out on June 4, 2018. The seeds were dry sown and then drip irrigation was applied to the raised furrows under the said treatment. A 1-cm irrigation sheet was applied per week. With >20 mm rainfall, weekly irrigation was suspended.

The study period comprised six months from June 2018. Seed germination was checked three days a week, dead seedlings were counted, and the possible cause of death was noted. Precipitation was recorded with a physical rain gauge in each rain event of the study period.

Experimental design

A bifactorial experimental design was planned, naming the species as the first factor and the irrigation treatment as the second factor. The levels of the first factor were the five native plant species. The levels of the second factor were drip irrigation and exclusively rainwater. One hundred repetitions per treatment were established.

At six months, the germination percentage, survival percentage, and height and width of the canopy were evaluated.

Table 1. Physical and chemical characterization of the soil.

pH	E.C. dS m^{-1}	O.M. %	NO_3^-	PO_4^-	K	Ca	Mg	S	Fe	Cu	Zn	Mn
			mg kg^{-1}									
7.73	0.56	0.20	17.6	132.4	126.0	1830.0	160.0	71.0	2.0	2.5	0.6	0.8

E.C.: Electric conductivity. O.M.: Organic matter.

Table 2. List of native plant species used in this study.

Common name	Scientific name	Seeds with irrigation	Seeds without irrigation
Guayacán	*Guaiacum coulteri* A.Gray	100	100
Palo fierro	*Olneya tesota* A. Gray	100	100
Palo verde azul	*Parkinsonia florida* (Benth. ex A. Gray) S. Wats.	100	100
Palo verde	*Parkinsonia microphylla* Torr.	100	100
Mezquite	*Prosopis velutina* Woot.	100	100

Plant canopy height and cover

Six months after germination, 25 plants were randomly sampled per species, except for some species where the total number of individuals alive was sampled, which was noted in the corresponding place. A tape measure was used to obtain plant height and leaf canopy width data.

Statistical analysis

Statistical analyzes were performed with the JMP version 10 software (SAS Institute, 2000). With the germination and survival data, contingency tables were developed using the chi-square test (χ^2) (Infante and Zarate de Lara, 2000). The rest of the information about the plants height and canopy cover was contrasted by analysis of variance. Tukey's test was used a posteriori. In all cases, a ≤5% statistical significance was established.

RESULTS AND DISCUSSION

Table 3 shows the germination and survival results. The five species showed germination, except *O. tesota* without irrigation. The species that had the highest germination percentage were *O. tesota* and *P. velutina*, both under irrigation with 85 and 72%, respectively. Meanwhile, *P. microphylla* with and without irrigation and *G. coulteri* with irrigation showed a 29-43% germination. The lowest germination values were found in the seeds under the non-irrigated treatment.

Table 3 shows that species with ≤15% germination values may require some type of seed scarification. This is the case of *P. florida*, whose seeds can last for several years in the soil before germinating, in the absence of scarification (Phillips *et al.*, 2015). Other authors report that different methods —such as mechanical scarification with sulfuric acid, temperatures alternation (Connor *et al.*, 2008), or immersion in hot water (Bainbridge, 2012)— benefit the germination of the seeds of genus *Parkinsonia*. Naturally, many species are consumed by animals that scarify or condition the seeds for better germination, after they pass through their digestive tract (Shreve and Wiggins, 1964; Whitford, 2002). Meanwhile,

Table 3. Germination (χ^2=398.941, p<0.0001) and survival (χ^2=21.196, p<0.0035) of the native plants studied.

Species	Treatment	Germination, %	Survival, %
G. coulteri	Without irrigation	4.00	0.00
O. tesota	Without irrigation	0.00	NA
P. florida	Without irrigation	1.00	0.00
P. microphylla	Without irrigation	29.00	65.52
P. velutina	Without irrigation	10.00	80.00
G. coulteri	Irrigation	43.00	62.79
O. tesota	Irrigation	85.00	65.88
P. florida	Irrigation	15.00	93.33
P. microphylla	Irrigation	43.00	83.72
P. velutina	Irrigation	72.00	79.17

new ironwood seeds germinate without problems (Shreve and Wiggins, 1964). *O. tesota* did not germinate without irrigation; this could be the consequence of the extraction of seeds by small rodents (Connor *et al.*, 2008) and insects such as ants, which has been observed in other studies (Celaya, personal obervation).

The rains in the study area recorded an accumulated value of 446 mm during the six months analyzed (Figure 1), which surpasses the average annual rainfall of 378 mm (INEGI, 2014). The highest precipitation was mainly concentrated during the months of July, August, September, and October, which are the months in which tropical cyclones take place. These extraordinary rains may have influenced the germination and survival of the species without irrigation and showed what happens in a year with above-average rainfall (Table 3). Therefore, the germination results in the non-irrigated areas of this work could be more severe in years in which droughts cause water stress.

Plant survival (Table 3) was higher than 62%, except for *G. coulteri* and *P. florida* without irrigation, which did not survive. In studies about *P. velutina*, *P. microphylla*, and *P. florida* in Baja California Sur, within the Sonoran Desert, irrigation was added up to the equivalent of 300 mm of rainfall per year. The annual survival rates surpassed 80% (Bashan *et al.*, 2012); these data are similar to those obtained in this study for the same three species. However, the survival expectancy without irrigation is only around 2% (Bainbridge *et al.*, 1993).

Herbivory damage was recorded during the six months of the study. When the first rains occurred, small rodents and ants extracted seeds —mainly of *O. tesota* without irrigation. Apparently, in the treatments with irrigation, seeds germinated faster, reducing the animals' opportunity to extract ungerminated seeds. After several months of growing, some plants were eaten by moles (Talpidae); this phenomenon was observed through the drying of the plant and total cuts at the stem base level. However, no more than 5% of the experimental population of *O. tesota*, *P. velutina*, *P. microphylla*, and *P. florida* died due to herbivory.

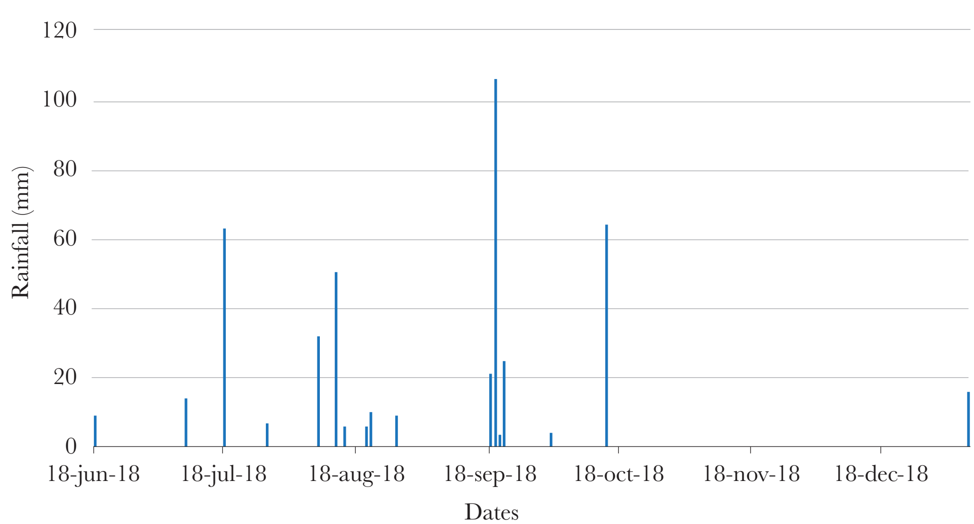

Figure 1. Precipitation during the study period in the Departamento de Agricultura y Ganadería, Universidad de Sonora (DAG Unison), in Hermosillo, Sonora, Mexico.

Growth rate

Table 4 shows significant differences in height at six months of age ($p<0.0001$) among the species studied. The greater height was presented by *P. florida*, followed by *P. velutina*, *O. tesota*, and *P. microphylla*, while the lowest heights were recorded in plants without irrigation and *G. coulteri* with irrigation.

A transplant experiment with drip irrigation, close to our study area, but established on non-agricultural soil, reports *Ipomoea arborescens*, *P. florida*, *P. microphylla*, *P. velutina*, and *O. tesota* as species with the highest growth in 1.5 years, with 1.41, 1.41, 1.33, 1.31, and 0.69 m height, respectively, and the lowest growth for *G. coulteri* with 0.38 m (Mc Caughey-Espinoza *et al.*, 2017). These results match the trends shown in Table 4.

In the Sonoran Desert, during the first year and with 300 mm of annual rainfall, *Prosopis* sp., *Parkinsonia microphylla* Torr., and *Parkinsonia florida* grew up to 35, 50, and 130 cm, respectively (Bashan *et al.*, 2012). The height data recorded in this study after six months are similar to the results obtained for the same species, with values of 66, 44, and 101 cm, respectively.

The highest canopy cover values at six months were presented by *P. velutina*, *P. florida*, and *O. tesota* (Table 5), while the lowest values were found in plants without irrigation and *G. coulteri* with irrigation. There was no statistical difference among the three species with the largest canopy diameter; they showed a lower height than *P. florida*. The species

Table 4. Height of the species studied after six months of growth ($p<0.0001$).

Common name	Treatment	Number	Height (cm)
P. florida	With irrigation	14	102.0±21.5 a
P. velutina	With irrigation	25	66.9±28.6 b
O. tesota	With irrigation	25	60.9±21.9 b
P. microphylla	With irrigation	25	44.6±12.7 c
P. microphylla	Without irrigation	13	23.3±7.8 d
P. velutina	Without irrigation	8	20.8±9.1 d
G. coulteri	With irrigation	25	6.2±1.8 d

Means ± SD with different letter in the height variable are statistically different, Tukey ($p<0.05$).

Table 5. Canopy cover (cm) at six months of growth ($p<0.0001$).

Species	Treatment	Number	Canopy cover (cm)
P. velutina	With irrigation	25	67.8±24.9 a
P. florida	With irrigation	14	67.1±8.8 a
O. tesota	With irrigation	25	56.7±14.7 ab
P. microphylla	With irrigation	25	43.9±19.0 b
P. microphylla	Without irrigation	13	23.5±9.2 c
P. velutina	Without irrigation	8	20.0±11.2 cd
G. coulteri	With irrigation	25	5.3±0.9 d

Means ± SD with different letter in height are statistically different.

without irrigation and *G. coulteri* obtained the lowest canopy width values; these same species had a similar height behavior at six months (Table 4).

Results in the Sonoran Desert have shown low success rates with direct seeding (Bainbridge *et al.*, 1993). However, this study shows that irrigation, agricultural soil, and protection from medium and large herbivores may have contributed to the high survival rates (Table 3).

Further and longer studies with more species of trees that take into account the impact of agronomic practices (*e.g.*, irrigation, fertilization, and pruning) would provide more elements for improved commercial forest plantations in arid and semi-arid zones (Bainbridge *et al.*, 1993; CONAFOR, 2010), both with timber and non-timber species within the plant biodiversity of the Sonoran Desert. This first six-month approximation provides a good prospect about the feasibility of establishing native species plantations. Likewise, we have observed the behavior of germination and growth in a year of atypical rainfalls. The importance of this event lies in the fact that some climate change scenarios predict that these rain events may become more extreme as the years go by, either towards droughts or heavy rains. Having information on the response of native species to environmental variations allows us to select those that can tolerate or benefit during these atypical years.

CONCLUSIONS

It is feasible to establish the five native plant species studied by direct sowing, in agricultural soil and with drip irrigation. Survival in the first months of growth is strongly influenced by the availability of water. Similarly, plant height and canopy cover were different between species, which is determined by their growth rate. Further studies are required to learn more about agronomic elements and about the growth potential of these and other native plants, which will enable better decisions about the convenience and resources necessary to establish commercial forest plantations.

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