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Article

Survival and growth of two forest species based on the initial morphology after planting

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Abstract:

Successful reforestations depend on several factors; seedling quality is one of them, since it is decisive for its establishment after planting. The objective of this study was to assess of two morphological conditions of the seedlings, based on the height and diameter, the survival and the initial growth of *Pinus cooperi* and *Pinus engelmannii*, planted in *Agua Zarca*, *Otinapa*, *Durango*. The seedling distribution was carried out under an experimental design of random blocks, with four repetitions per treatment. 13 months after planting, *Pinus engelmannii* only exhibited significant differences ($p<0.05$) in survival and height, with the best results in the seedling with the high morphological condition; the differences between treatments in survival were of 50.0 %, while the difference in height was of 3.37 cm and 4.87mm in diameter. In *Pinus cooperi*, only the height variable showed significant differences ($p<0.05$), with a separation between values of 6.7 cm, while the difference in survival was 2.5 %, with more than 90 % survival in both qualities, and the differences in diameter were less than 1.0 mm. In all cases, the seedlings with the highest morphological attributes obtained the highest values. Regarding the survival between species, without considering the morphological condition of the seedlings, the final differences were of 51.2 %, with the best percentages for *Pinus cooperi*, the species that best adapted to the conditions of the planting site.

Key words: Height, morphological attributes, diameter, *Pinus engelmannii* Carr., *Pinus cooperi* Blanco, reforestations.

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Introduction

An important aspect in successful forest plantation programs is the use of high-quality seedlings with a high survival capacity (Grossnickle, 2012). Furthermore, as the environmental and edaphic conditions become more restrictive, the individuals must have a greater capacity of response (Villar, 2003). The use of high-quality seedlings favors success in plantations under climate change conditions (Vallejo *et al*., 2012). In Mexico, a cause of the high mortality rates (57 % one year after planting in the 2004-2015 period) is the inadequate quality of the seedlings, which contributes 9.2 % of the overall mortality (Prieto *et al*., 2016). Another important factor are the deficiencies occurring during the planting process (Burney *et al*., 2015), which have negative consequences beyond the first establishment phases (Villar, 2003).

High-quality seedlings are those which adapt to the plantation site with the morphological and physiological attributes with which they are produced (Wilson and Jacobs, 2006; Landis *et al*., 2010), under the ecological and edaphological conditions of the place where they establish (Ramírez-Contreras and Rodríguez-Trejo, 2004; Rodríguez, 2010; Bernaola-Paucar *et al*., 2015); this adaptability is reflected in the high survival and initial growth rates (Orozco *et al*., 2010). However, this variable also depends on the genetic origin of the seed, which has implications for its adaptation (Landis *et al*., 2010; Burney *et al*., 2015).

Other important factors for the success of plantations are the preparation of the soil, the plantation date, the availability of moisture, the specific characteristics of the site, and the control of weeds (Navarro *et al*., 2006; Bernaola-Paucar *et al*., 2015; Palacios-Romero *et al*., 2017).

The production of seedlings with morphological characteristics in accordance with the characteristics of the reforestation sites (height, collar diameter, above-ground part:root ratio, robustness index) (Birchler, 1998; Ritchie *et al*., 2010) requires, among other things, an adequate technical process for planting, appropriate growing media and nutrition, as well as adequate risk, pest and disease prevention and control, and management of the production environment (Prieto-Ruiz *et al*., 2007).

So far, such aspects of nursery cultivation as fertilization, substrate and containers, the specific conditions of the planting sites and the species to be planted have been little studied (Robles *et al*., 2017).

There is currently no single criterion based on the morphological aspects that explains the variation in the results after planting; however, the diameter has been recognized as an important initial characteristic of nursery-grown plants, as it promotes survival (Tsakaldimi *et al*., 2013) and tolerance to adverse weather and biological conditions in field (Prieto *et al*., 2011), given that its capacity can be partly attributed to the ratio of the initial diameter, to the volume of the root and the primary roots (Jacobs *et al*., 2009).

The purpose of the present study was to assess the effect of the initial morphological condition of the plant, based on the height and the collar diameter, on the survival and initial growth of *Pinus cooperi* Blanco and *Pinus engelmannii* Carr. planted in *Agua Zarca, Otinapa, Durango, Mexico*. The hypothesis is that the morphological attributes play a major role in the adaptability of the studied species to the plantation site.

Materials and Methods

Characteristics of the study area

The study was carried out in the privately-owned plot known as *Agua Zarca*, located 5 km away from the town of *Otinapa, Durango,* Mexico, at the coordinates 24°03’20” N and 105°00’41” W, at an altitude of 2 350 m (Secope, 2003). The site is located in the middle of a transitional forest between semi-arid zones and a temperate forest. The predominant vegetation consists of *Pinus engelmannii*, *P. leiophylla* Schl. *et* Cham., *P. cooperi*, *P. teocote* Schiede ex Schltdl. and *Quercus* sp. The specific area is characterized by being an open, vegetation-free space, previously used for bovine livestock grazing. The plot has zenithal sun exposure.

The mean annual precipitation is 650 mm (SECOPE, 2003); the mean temperature, 14.6 °C; the average minimum temperature of 6.1 °C and the average maximum temperature of 21.1 °C, with a mean relative humidity of 59.1 % data obtained *in situ* with a portable Davis™ weather station. The soil has a loamy texture (43 % sand, 38 % silt y 19 % clay), with an average pH 7.3 and 2.63 % organic matter.

Plant production

The vegetal material occurred at the *Praxedis Guerrero* forest nursery, located 12 km away from the city of *Durango*, in the state of *Durango*. (23°56’57.1" N and 104°34'07.6" W), at an altitude 1 880 m (Inegi, 2017), and administered by the Department of Natural Resources and Environment of the Government of the State of *Durango*.

The seedlings grew in detachable rigid plastic tubes with a conic shape, an upper diameter of 5 cm, a length of 21 cm and a volume of 165 mL. The substrate used was a mixture of composted pine bark (50 %), peat moss (25 %), vermiculite (13 %) and agrolite (12 %).

During the preparation of the substrate, 5 kg m^{-3} of the Multicote^{TM} controlled release fertilizer (8 to 9 months) with the formula 18N-6P_2O_5-12K_2O+2MgO+ micronutrients were used. The seed of both species came from natural stands with an annual precipitation of 800 to 900 mm, at altitudes of 2 200 to 2 500 m.

Preparation of the terrain and planting

The terrain was prepared with a Savannah^{TM} rake; the ground was ploughed with a subsoiler that penetrated 50 cm at the center of the planting line, with two side disks coupled to the rake, forming a 30 cm high and 1 m wide central ridge, favoring moisture retention. The separation between the planting lines was 3 m, while the distance between plants on the same line was 1 m. The hole was dug with a high-carbon steel shovel, which made it possible to turn the ground over 30 cm in width and 40 cm in depth. Before planting, 7 g of the Multicote^{TM} controlled release fertilizer (8 to 9 months) with the formula 18N-6P_2O_5-12K_2O+12MgO+ micronutrients were laid at the bottom of each hole, regardless of the treatment. The plantation was carried out on July 15, 2015.

Assessed treatments and experimental design

The assessed species were *Pinus engelmannii* and *Pinus cooperi* aged 11 months. Based on the diameter and height, two morphological conditions of the plants were considered (Table 1). These criteria were based on the Mexican standard NMX-AA-170-SCFI-2016 (Secretaría de Economía, 2016). Plants with the best morphological attributes were rated as "high morphological condition", which is recommended for planting, while plants rated as "low morphological condition" had inferior characteristics to those suggested in the standard cited above. The distribution of the seedlings was carried out according to a random block

experimental design. Each treatment consisted of four repetitions, and the experimental unit comprised 10 seedlings.

Table 1. Average morphological characteristics, by seedling quality, of the assessed species.

Species	Morphological condition	Diameter (mm)	Height (cm)
Pinus engelmannii	High	6.5	Not considered*
Pinus engelmannii	Low	5.0	Not considered*
Pinus cooperi	High	4.5	10-14
Pinus cooperi	Low	3.0	15-25

*Because of its cespitose condition at the initial stages of its growth, the standard NMX-AA-170-SCFI-2016 does not consider this criterion.

Assessed variables

During the development of the assay, the average maximum, medium and minimum temperatures and the relative moisture were registered using a portable Davis™ weather station. Furthermore, based on three soil samples from the first 30 cm of depth, the texture, pH and organic matter content were determined; the analyses were performed at the Laboratory of the National Centre for Disciplinary Research on Water, Soil, Plants and Atmosphere Relations (Cenid RASPA) of INIFAP *(Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias*).

Three assessments were carried out: 1.5, 8 and 13 months after planting; the recorded variables were: a) survival, based on the living and dead seedlings per experimental unit, b) height, in centimeters, measured with a ruler (Truper® 14387), and c) collar diameter, in millimeters, registered with a digital vernier caliper (SURTEK® 122204).

Statistical analysis

Variance analyses were performed for each assessment date and for each variable; where significant statistical differences were found, the mean test was applied (Tukey, 0.05). For the survival variable, the percentage values were transformed using the arcsine function.

Results and Discussion

Survival

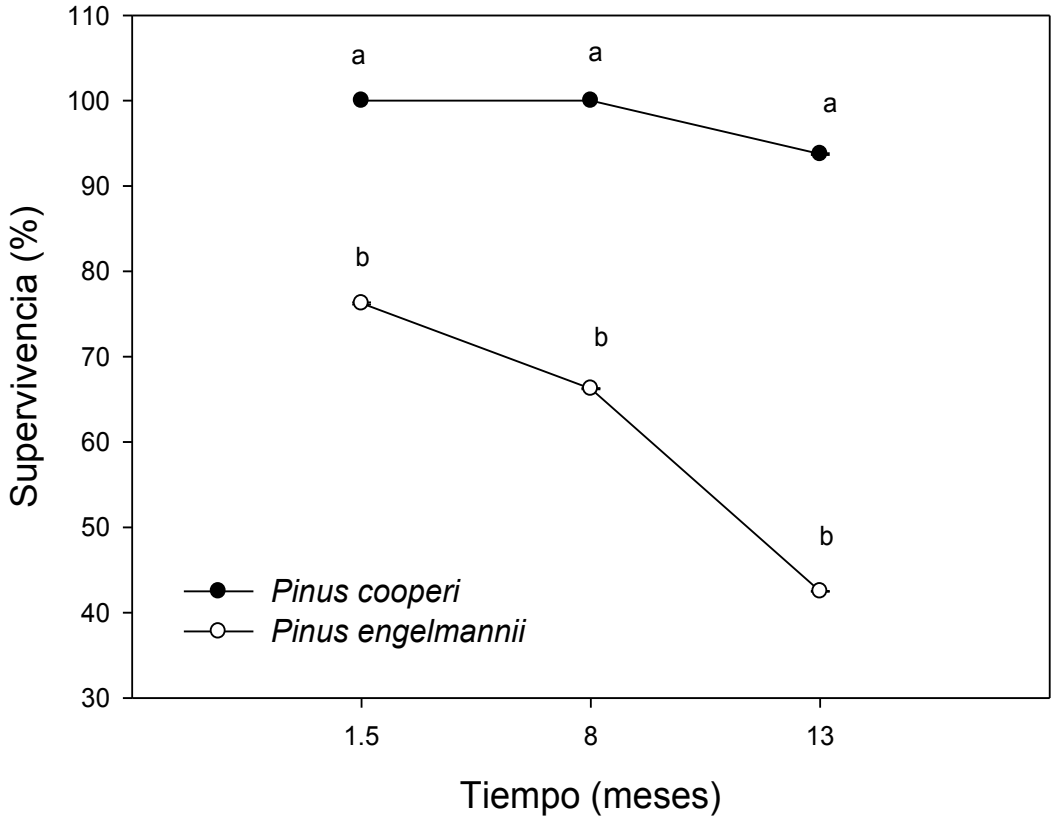
The survival of *Pinus engelmanni* 1.5, 8 and 13 months after planting exhibited significant differences ($p<0.05$) due to the morphological conditions of the individuals, with differences of 22.5, 32.5 and 50 % between treatments in each evaluation. The best results were obtained in seedlings with the superior initial morphological condition (Table 2). In the case of *Pinus cooperi*, the survival showed few changes, regardless of the diameter and the height at planting, for total survival occurred at 1.5 and 8 months after planting, while at 13 months the difference between treatments was 2.5 %, and therefore the species remained in the same statistical group ($p > 0.05$), with values above 90 % for both treatments (Table 2).

Table 2. Survival of *Pinus engelmannii* Carr. and *Pinus cooperi* Blanco, at 1.5, 8 and 13 months after planting, in individuals with two morphological conditions in *Agua Zarca, Otinapa, Durango, Mexico.*

Species	Morphological condition	1.5 months	8 months	13 months
Pinus engelmannii	High	87.5 ±0.14 a	82.5 ±0.06 a	67.5 ±0.05 a
	Low	65.0 ±0.10 a	50.0 ±0.08 b	17.5 ±0.03 b
Pinuscooperi	High	100.0 ±0.0 a	100.0 ±0.0 a	95.0 ±0.09 a
	Low	100.0 ±0.0 a	100.0 ± 0.0 a	92.5 ±0.11 a

Values with different letters at the same seedling age indicate significant differences, according to Tukey ($p < 0.05$).

As for inter-species survival, without taking into account the initial morphological condition of the seedling, the differences were 23.7, 33.7 and 51.2 % for evaluations at 1.5, 8 and 13 months after planting, with the best results for *Pinus cooperi*. Survival in *Pinus engelmannii* diminished noticeably since the first evolution, and decreased to 42.5 % at 13 months after planting; *Pinus cooperi*, on the other hand, exhibited few changes, with total survival at 1.5 and 8 months, and a decrease of only 6.2 % at 13 months after planting (Figure 1).



Supervivencia = Survival; *Tiempo* = Time; *Meses* = Months

Values with different letters at the same seedling age indicate significant differences, according to Tukey ($p < 0.05$).

Figure 1. Survival of *Pinus engelmannii* Carr. and *Pinus cooperi* Blanco at 13 months after planting, with two different morphological conditions, in *Agua Zarca, Otinapa, Durango,* Mexico.

Survival in *Pinus engelmannii* was influenced by its initial morphological characteristics, with a 50 % final difference between treatments (67.5 % *vs* 17 %); according to Landis *et al.* (2010), the diameter at the neck has a direct proportional correlation with survival; this may have affected the seedlings with low morphological condition, which had diameters of 5.0 mm, i.e. smaller diameters than those recommended by the Mexican standard NMX-AA-170-SCFI-2016 (Secretaría de Economía, 2016) for this species, which are ≥ 6.0 mm; this diameter size was found only in seedlings with the best morphological attributes.

Benítez (2016) assessed *Pinus engelmannii* plantations in the location of *Durangueño, Canatlán, Durango*, a site with similar edaphic and climate conditions, located 70 km away from the study area, which exhibited an average survival of 65 % at 13 months after planting, *i.e.* a survival similar to that of seedlings with a high morphological condition, but inferior to that of plants with a low morphological condition. Tsakaldimi *et al*. (2013) predicted the survival of the *P. halepensis* Mill. plants, based on the initial morphology; these authors correlate it positively with the initial diameter of the seedlings.

In *Pinus cooperi*, the survival was of more than 90 % in both plant qualities (95 % *vs* 92.5 %), which indicates that the morphological condition was a factor with little influence on this variable, and that the plants adapted easily to the conditions of the site. Prieto-Ruíz *et al*. (2007) planted *Pinus cooperi* individuals under two quality conditions, and 12 months after planting the survival was 85 %, *i.e.* 10% lower than that observed in individuals of the low morphological condition in this study. This indicates that this species was appropriate for the site, as it had a high survival response. Furthermore, the diameter and the height had little impact on survival.

Since the edaphic and climate conditions and the land preparation were the same for both species, the adaptability factor is regarded as decisive for the results, causing the specific characteristics of the site to favor significant differences in the survival between species. Although both species occur in adjoining sites, *Pinus cooperi* is more abundant and common in lower lands a prevalent condition in the study site.

As for *Pinus cooperi*, although there were two initial morphological conditions of the plants, the characteristics of the site did not affect the survival of the individuals; this may be due to the fact that this taxon is common in open sites and in plateaus or valleys (Farjon, 2013a), a situation that occurred in the study area, while *Pinus engelmanni* generally grows on rolling hills with slight slopes with a higher relative humidity, in combination with other taxa (Farjon, 2013b); the drainage is easier, and the radiation rates are lower. These conditions were not prevalent in the site under assessment, and they influenced the inter-species results.

In this case, in which seeds of both taxa from sites with the best quality were used, *P. engelmannii* turned out to be more sensitive to unfavorable site conditions, because, as referred by Alia (2006), the interaction between the genotype and the environment, and the plasticity of the species, are factors that may influence the adaptability of the plants to a particular site.

Height of the aerial part and collar diameter

The height of the *Pinus engelmannii* plants at 1.5, 8 and 13 months after planting exhibited statistically significant differences between treatments ($p > 0.05$), with a final difference of 4.4 cm. However, at 13 months the increase with each treatment was nearly of 2 cm; this evidenced the fact that the initial differences persisted through time. The scarce growth in height with the two treatments is due to the cespitose condition of this species during the first stages of its life, characterized by a low rate of elongation of the epicotyls and an abundant production of needles, as well as a significant increase in diameter (Ávila *et al*., 2014; Rosales *et al.*, 2015); the same is true of other taxa, such as *Pinus montezumae* Lamb. (Calderón, 2006).

In the evaluations of *Pinus cooperi* there were significant differences ($p > 0.05$) between treatments in the height of the plants. At 13 months after planting, the individuals with a high morphological condition increased their height by 7.6 cm, while the seedlings with the lowest morphological condition grew only 5.2 cm taller. In both cases, the largest increase in height occurred between the second and the last evaluations (Table 3).

Table 3. Growth in terms of stem height and diameter at the neck of *Pinus engelmannii* Carr. and *Pinus cooperi* Blanco, at 1.5, 8 and 13 months after planting, in individuals of two different morphological qualities, in *Agua Zarca, Otinapa, Durango, Mexico.*

Variable/Species	Morphological condition	1.5 months	8 months	13 months
Pinus engelmannii				
Height (cm)	High	12.4 ±0.66 a	14.5 ±0.56 a	14.5 ±0.67 a
	Low	8.4 ±0.39 b	8.4 ±0.47 b	10.1 ±1.44 b
Diameter (mm)	High	9.8 ±0.36 a	17.1 ±0.74 a	21.1 ±1.29 a
	Low	6.8 ±0.37 b	10.2 ±0.65 b	16.2 ±1.31 a
Pinus cooperi				
Height (cm)	High	14.3 ±0.62 a	14.1 ±0.74 a	22.0 ±1.09 a
	Low	10.1 ±0.47 b	10.5 ±0.47 b	15.3 ±1.08 b
Diameter (mm)	High	8.7 ±0.21 a	10.9 ±0.26 a	14.4 ±0.40 a
	Low	6.9 ±0.20 b	9.6 ±0.31 b	13.5 ±0.56 b

Values with different letters for the same seedling age indicate significant differences, according to Tukey ($p < 0.05$).

Significant differences ($p < 0.05$) were found between treatments in the diameter at the neck of *Pinus engelmannii* at 1.5 and 8 months after planting, while no significant differences ($p > 0.05$) occurred at 13 months (Table 3). In individuals with a high initial morphological condition, the increase was 14.3 mm (6.5 to 21.1 mm), while low-quality individuals exhibited an 11.2 cm increase (5.0 to 16.2 mm). *P. cooperi* exhibited significant differences ($p > 0.05$) between treatments in all the evaluations. The collar diameter increased by 9.9 mm in seedlings with a high morphological condition, which grew from 4.5 to 14.4 mm, while in plants with a low morphological condition the increase was of the order of 10.5 mm (3.0 to 13.5 mm) 6.7 mm (Table 3).

Bayala *et al*. (2009) estimated the yield in field of five arboreal species by assessing the quality of the seedlings, and the diameter was one of the growth measures with the best performance in both the nursery and in-field phases.

According to Sigala *et al*. (2015), the characteristics of the container used in the nursery for *Pinus pseudostrobus* Lindl., in terms of type and size, as well as the exposure had an impact on the survival after planting. This shows that the success of a reforestation depends on various factors that go from the production conditions to the specific conditions of the sites where the seedlings are planted; however, the diameter of the individuals is one of the variables most commonly associated to plant survival.

Conclusions

The best initial morphological conditions of the *Pinus engelmannii* seedlings were positively related to the in-field survival and growth in height.

The initial morphological condition of the *Pinus cooperi* did not influence the survival of the plants; however, it did have an impact on the height and diameter of the seedlings with the best morphological condition.

Pinus cooperi adapted better to the conditions of the site where it was planted than *Pinus engelmannii*, the difference in survival being of 51.2 %.

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Conflict of interests

The authors declare no conflict of interest.

Contributions by author

José Ángel Prieto Ruíz: conception, design and establishment of the experiment, data collection, drafting and editing of the document; Adolfo Duarte Santos: establishment of the experiment, data collection and capture, and review of literature; José Rodolfo Goche Télles: interpretation of results and review of the manuscript; María Mónica González Orozco: establishment of the experiment, analysis of the database and review of the final document; Miguel Ángel Pulgarín Gámiz: review of the document.