Reforestation Success in Central México: Factors Determining Survival and Early Growth

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Abstract

Successful reforestation programs are requisite components of any forest industry; failure to establish new forests can lead to deforestation. The objective of this project was to examine factors influencing reforestation success in Central México, encompassing the Federal District and State of México. Seven plantations, established in 1995 with five conifer species, were monitored for 2 yr. Survival after 2 yr ranged from 15 percent to 86 percent. Most of the mortality was related to human activities, including fire, livestock grazing, and agricultural cultivation. Nevertheless, seedling quality was an important component of both seedling survival and subsequent growth. A minimum seedling diameter of 4 mm (0.16 in.) is required for adequate survival, but the target seedling diameter should be 6 mm (0.25 in.) for *Cupressus* and 8 mm (0.32 in.) for *Pinus* to ensure highest survival and growth.

El éxito de la reforestación en la Región Central de México: Factores que determinan la sobrevivencia y crecimiento temprano de las especies

Resumen

El éxito de los programas de reforestación es un componente indispensable en la industria forestal, ya que representa una fuente importante de abastecimiento de materia prima, por lo que su fracaso ocasiona problemas económicos graves; además del impacto negativo que sobre los ecosistemas tiene la pérdida de la cobertura vegetal (desforestación). En el presente estudio, se analizaron los factores que determinan la sobrevivencia y crecimiento temprano de cinco especies de coníferas, mediante dos años de monitoreo en siete sitios de plantación localizados en el Valle y Estado de México en 1995. Del segundo año de evaluación, la sobrevivencia de la planta fué del 15 al 86 por ciento. La mayor mortandad se relacionó con actividades humanas como son: quemas no controladas y cambios en el uso del suelo con fines agrícolas y pecuarios. Un factor importante tanto para la sobrevivencia, como para el crecimiento de las plantas en campo fue la calidad de la planta producida en los viveros. La sobrevivencia óptima de la planta se presentó en individuos con diámetros de tallo superiores a 4 mm (0.16 in.). Sin embargo, para asegurar la mayor sobrevivencia y crecimiento, se recomienda que el diámetro de plántula ideal para *Cupressus* sea de 6 mm (0.25 in.) y para *Pinus* sp. de 8 mm (0.32 in.).

Introduction

México is the 14th largest country in terms of land mass and forest cover with nearly 142 million ha (355 million ac), 55.3 million (138 million ac) of which are covered with forests or woodlands (SEMARNAP 1998a). Unfortunately, 250,000 to 600,000 ha (625,000 to 1,500,000 ac) of forest land are lost every year to deforestation (WRI 1994). A recent national inventory (SEMARNAP 1998b) estimated 25.4 million ha (63.5 million ac), or nearly 50 percent of the forest land, have suffered some degradation through conversion to agriculture, illegal harvesting, or other changes in land use. Greater reforestation efforts are needed to offset deforestation (Torres and Magaña 2001).

Federal, state, and community forestry programs produce nearly 400 million seedlings each year (Anonymous 1997), most in polybags filled with forest soil or a mixture of forest soil and sand or aged sawdust. Seedlings are grown for 8–20 mo, depending on species and the reforestation program, before outplanting during the rainy season (late May–September). Occasionally, seedlings may be held over for an additional year if seedlings are too small or if planting crews or sites are unavailable. In some cases, these holdover trees may be transplanted to a larger polybag if resources allow.

Until recently, there was little information on the survival of seedlings planted in reforestation programs in México. Generally, survival has averaged less than 50 percent throughout the country (Anonymous 1997); a recent national survey of 1998 reforestation activities found survival averaged 47 percent (Bello and Cibrián 2000), ranging from 39 percent for seedlings supplied by state nurseries to 67 percent for seedlings grown by social organizations. Even within a region, survival can vary. Survival of various conifers in the state of Michoacan averaged 34 percent (Madrigal and Piedad Garcia 2000), *Abies religiosa* in the state of Hidalgo averaged 40 percent, and conifers in the Federal District of México averaged 48 percent (Sierra and Rodriguez 1991).

These survival rates are low compared to those in the United States, where survival averages over 70 percent with a much larger reforestation program (Weaver and others 1981**)**. Furthermore, individual companies can have survival consistently approaching 90 percent (South and Mitchell 1999). Unfortunately, these statistics on Mexico's reforestation, while providing an indication of survival, include little information on causes or timing of mortality. For example, Sierra and Rodriguez (1991) did not attribute any mortality to poor seedling quality. Most mortality was attributed to "drought" (13 percent) or "unknown" (10 percent), both of which could be significantly related to seedling or planting quality. Bello and Cibrián (2000) attributed 22 percent of mortality to "seedling quality" (undefined) and 7 percent to "planting quality." However, 29 percent of mortality was attributed to "drought."

A better understanding of causes of plantation mortality could lead to improved nursery production practices and reforestation practices (Randall and Johnson 1998). The objective of this project was to determine the causes of mortality in recently planted plantations in Central México.

Materials and Methods

The study sites were located in the Federal District and the state of México around México City at elevations above 2,000 m (6,550 ft). These two governmental entities planted over 70 million seedlings in 1995–1996 (Anonymous 1997). Established plantations in each region were evaluated during the monsoon season (June–September 1995), which corresponds to the planting season in México.

Experimental units consisted of 3–5 circular plots [0.005–0.01 ha (0.0125-0.0250 ac)] per plantation (Neumann and Landis 1995). For convenience in reading, species used and plot details are given in the Results section following. Seedlings were identified and height and groundline diameter measured. Size (height and ground line diameter) after planting and planting depth and firmness of each seedling were evaluated. The closest seedling to the north side of the plot was excavated for assessment of root quality (planting depth, number of laterals, and taproot deformation [either by transplanting in the nursery or outplanting in the field]). The plots were revisited 3–5 times over the next 26 months. Causes of mortality and changes in vigor and size were recorded.

Results and Discussion

***Abies religiosa* (oyamel).** The San Miguel Balderas plantation in the state of México was a privately owned pasture on about 15 percent slope. *Abies religiosa* seedlings were grown in large polybags [12 cm × 35 cm (4.75 in × 13.8 in)] for 2 yr and planted for Christmas tree production. Seedlings were planted on 1.5 m × 1.5 m (5 ft × 5 ft) spacing about July 6, 1995, and five survival monitoring plots were established on July 27, 1995. Four of the five excavated seedlings had evidence of new root growth, but one seedling (20 percent) had a poor rootball, and four (80 percent) were loosely planted. There also was evidence of grubs in one rootball (20 percent).

In spite of loose planting, survival was 98 percent after 4 mo, but after 26 mo it was only 15 percent. Three of the plots were damaged by fire (arson), although only one plot was actually destroyed by fire (table 1). Two of the burned plots, plus a third plot, were plowed and converted to agriculture (the previous land use). The remaining plot appeared healthy, but growth was poor, averaging less than 1 cm (0.4 in) of new growth after 26 mo. There was a weak positive relationship (r^2=0.55) between diameter growth and height growth (data not shown). Seedlings that shrunk in diameter suffered shoot dieback, while those with diameter growth also exhibited height growth. The poor growth may have been due to the loose planting.

***Cupressus lindleyii* (cedro blanco).** *Loma de Medio Predio plantation.* The Loma de Medio Predio plantation in the state of México was a privately owned pasture on 0 percent slope. One-year-old seedlings of *C. lindleyii* were grown in polybags [9 cm × 25 cm (3.5 in × 10 in)], and planted for commercial post production. Seedlings were planted about July 25, 1995, on 1 m × 1 m (3.3 ft × 3.3 ft) spacing. Three survival monitoring plots were established on July 26, 1995. Weeds were controlled manually at least once during the subsequent year.

Seedlings were well planted with new root growth evident. Smaller seedlings usually were missing the lower one-half of the rootball. Survival was 97 percent after 4 mo and 86 percent after 26 mo (table 1). The major cause of mortality was rabbit damage (6 percent). Insect damage was common on most seedlings, evidenced by lesions on the root collar

Table 1. Initial seedling morphology and causes of mortality (mean ± standard deviation) for the seven plantations evaluated in the Valle de México.

Species	*A. religiosa*	*C. lindleyii*		*P. ayacahuite*		*P. patula*	*P. pseudostrobus*
Plantation	San Miguel Balderas	Loma de Medio Predio	San Bartolo Ameyalco	San Banabé Ocotepec	Rancho Don Nati	Los Mena	La Esperanza
Height (cm)							
Initial	44.5 ± 10.8	33.4 ± 9.1	33.0 ± 13.2	41.4 ± 9.9	28.5 ± 2.8	32.0 ± 11.8	21.5 ± 6.4
Final	46.8 ± 11.7	131.0 ± 21.7	105.7 ± 26.3	54.7 ± 13.9	99.4 ± 9.0	42.7	24.5 ± 10.3
Diameter (mm)							
Initial	7.1 ± 1.7	3.9 ± 0.8	3.8 ± 1.2	6.6 ± 1.4	9.7 ± 0.5	5.0 ± 0.7	6.3 ± 1.5
Final	11.7 ± 1.1	21.7 ± 1.7	14.8 ± 4.0	12.4 ± 3.0	35.2 ± 3.3	n.m.	6.0 ± 1.8
Survival (%) at							
4 mo	98	97	100	93	95	44	100
10 mo	78	89	92	89	33	33	27
26 mo	15	86	84	67	15	27	n.a.
Mortality (%)							
Seedling quality	1	2.8	10	10	0	0	3
Planting quality	1	2.8	0	9	0	35	3
Rodent damage	0	5.6	0	4	8	7	0
Insect damage	0	2.8	0	1	1	0	0
Grazing damage	0	0	0	0	35	0	0
Fire	20	0	0	0	0	0	67
Cultivation	63	0	0	0	0	0	0
Fertilizer damage	n.a.	0	n.a.	n.a.	n.a.	7	n.a.
Unknown	0	0	6	9	41	24	0

n.a.=not applicable.

n.m.=not measured.

and stem. Occasionally, trees were girdled completely below the root collar, resulting in 3 percent mortality. Nevertheless, survival and growth were excellent. Seedlings averaged 131 cm (4.3 ft) in height after 26 mo. There was no correlation between initial seedling size and subsequent growth.

San Bartolo Ameyalco ejido. The San Bartolo Ameyalco ejido in the Federal District planted *C. lindleyi* for erosion control. Seedlings were grown in polybags [6 cm × 25 cm (2.4 in × 10 in)], and planted on 2 m × 2 m (6.5 ft × 6.6 ft) spacing under a mature pine-fir forest on July 25, 1995. Three survival monitoring plots were established. Seedlings were well planted.

Survival was 100 percent after 4 mo and 84 percent after 26 mo. Seedling quality (small diameter) accounted for most of the mortality (table 1). Growth was excellent, and final height averaged 106 cm (3.5 ft) after 26 mo. Final survival and height were correlated with initial seedling diameter (figure 1A). Seedlings with at least 4 mm (0.16 in) diameter had excellent survival, but growth continued to increase with increasing diameter for seedlings with an initial diameter of 8 mm (0.32 in).

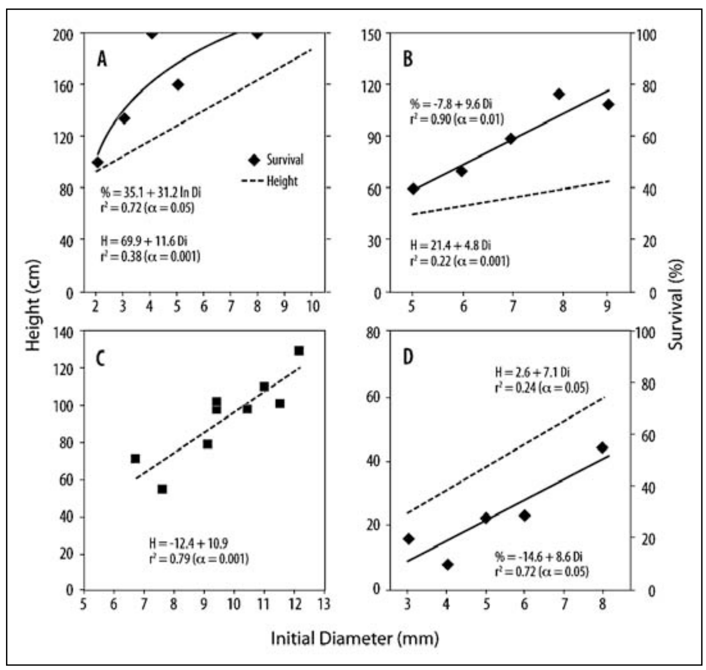

Figure 1. Relationship between initial seedling diameter and survival and height after 26 mo of (A) *Cupressus lindleyii* at San Bartolo Ameyalco, (B) *Pinus ayacahuite* v. *veitchii* at San Bernabé Ocotepec, (C) *Pinus ayacahuite* v. *veitchii* at Rancho Don Nati (height only), and (D) *Pinus patula* at Los Mena.

***Pinus ayacahuite* v. *veitchii* (generic common names, pino or ocote).** *San Bernabé Ocotepec ejido*. San Bernabé Ocotepec ejido in the Federal District planted *Pinus ayacahuite* v. *veitchii* seedlings for erosion control. Seedlings were grown in 6 cm × 25 cm (2.4 in × 10 in) polybags and outplanted at 2 m × 3 m (6.5 ft × 9.8 ft) spacing under mature pine forest. Seedlings were planted about July 25, 1995, and three survival monitoring plots were established. Seedlings were well planted.

Survival was 93 percent after 4 mo, but only 67 percent after 26 mo. Seedling and planting quality were the major causes of mortality (table 1). Growth after 26 mo was poor, averaging 11 cm (4.3 in). This is a drier site than San Bartolo Ameyalco, which was planted with *C. lindleyii*, and seedling establishment may have been more difficult under a mature forest. Survival and growth were linearly correlated with initial seedling diameter (figure 1B). Seedlings larger than 7 mm had the best survival and growth.

Rancho Don Nati. Rancho Don Nati was a privately owned pasture in the state of México on about 25 percent slope. The area was grazed heavily by goats at time of planting in July 1995. Seedlings were grown in large polybags [12 cm × 35 cm high (4.75 in × 13.8 in)], and planted at 1.5 m × 1.5 m (5 ft × 5 ft) spacing for Christmas tree production. Five survival monitoring plots were established on July 24, 1995. Most of the excavated seedlings had evidence of new root growth (60 percent) and grubs in the rootballs (80 percent). One seedling (20 percent) was planted shallowly, and another (20 percent) was barerooted due to small seedling size. There was no evidence of grubs on one plot, which was a steep, rocky site.

Survival was 95 percent after 3 mo, but only 15 percent after 24 mo. The major cause of mortality was grazing by goats (table 1). Only Rep 5, planted in steep, rocky soil, had surviving seedlings (77 percent). This site had a large percentage of "unknown" mortality (41 percent) that may be attributable to a combination of freeze damage, heavy grub infestation in the rootball, and grazing. Most of the excavated seedlings had evidence of root feeding, and most planting holes had grubs present. The origin of the grubs is not known. Seedling growth, but not survival, was correlated with initial seedling diameter (figure 1C).

***Pinus patula*.** Los Mena was a privately owned pasture in the state of México on 0-percent slope. Two-year-old *Pinus patula* seedlings were planted on 2 m × 3 m (6.5 ft × 9.8 ft) spacing for pole production. Seedlings were grown in gussetted 9 cm × 25 cm (3.5 in × 10 in) polybags, resulting in an open bag diameter of about 10 cm (3.9 in), and planted July 1995. Each seedling received about 5 g (0.2 oz) surface-applied urea immediately after planting. Five survival monitoring plots were established on July 24, 1995. Most (3 of 5) of the excavated seedlings had evidence of shallow planting, and 20 percent had poor rootballs. There also was evidence of grubs in one rootball (20 percent).

Survival was 44 percent after 3 mo, and only 27 percent after 24 mo. Major causes of mortality were shallow planting and fertilizer damage at time of planting (table 1). Grazing caused an additional 7 percent mortality, and 24 percent was due to "unknown" causes (possibly related to planting quality). Surviving seedlings initially suffered 2 cm (0.8 in) dieback, which may have been due to fertilizer burn. Both survival and height were positively related to initial seedling diameter (figure 1D).

***Pinus pseudostrobus*.** La Esperanza was a native forest restoration planting following a wildfire on communal property in the state of México. The forest is routinely burned to improve pasture for cattle grazing. *Pinus pseudostrobus* seedlings were planted on 3 m × 3 m (9.8 ft × 9.8 ft) spacing under a mature forest. Seedlings were grown in polybags [6 cm × 25 cm (2.4 in × 10 in)], and planted on July 26, 1995. Three survival monitoring plots were established. All seedlings were planted correctly, but 2/3 of the excavated seedlings only had a partial rootball. Survival was 100 percent after 3 mo, but only 27 percent after 10 mo, as 2/3 of the site was destroyed by fire in April 1996. Height growth of surviving seedlings averaged 3 cm (1.2 in) while diameter shrunk to 6.0 mm (0.24 in), due to heavy grass competition. This site was abandoned after 10 mo.

Factors affecting survival and growth. Only the *Cupressus* plantations had adequate survival (mean = 85 percent). The other plantations averaged only 30 percent. The primary cause of seedling mortality was human activity (figure 2). However, the direct activity varied among plantations (table 1). Fully 67 percent, and possibly as much as 85 percent, of the mortality was attributed to such activities (in decreasing order) as burning, cultivation,

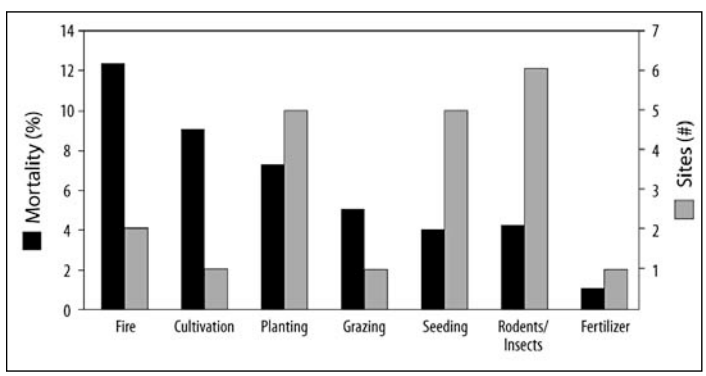

Figure 2. Principal causes of mortality and its frequency on the seven plantations evaluated in the Valle de México and State of México, 1995.

poor planting quality and livestock grazing. Four of the seven plantations were destroyed. The sites that had the best survival and growth were those too steep to support either crop production or grazing. These factors are easily corrected if reforestation becomes a priority for the communities or landowners.

As reforestation becomes a priority for México, land managers must develop minimum size standards for seedling production. As the United States has moved to adopting a minimum diameter of 4 mm, survival has increased. Quality seedlings generally are better suited to withstand the stresses following planting, such as grazing, poor planting, or insect attack. Seedlings with larger diameter at time of planting survived better, regardless of species (figure 3A). Seedlings with initial diameters less than 3 mm had about 40 percent survival, whereas seedlings with diameters larger than 6 mm had over 60 percent survival. These results are similar to findings in the United States with different production systems (Mexal and Landis 1990; Mexal and South 1991).

Seedling growth, like survival, was related to initial seedling diameter (figure 3B). Unlike survival, however, which seemed to be independent of species, species differed in growth response. *Cupressus* grew faster than *Pinus* species. With future growth in mind, 4 mm (0.16 in) should be the minimum standard for seedlings, and efforts should be made to increase seedling diameter to at least 6 mm (0.24 in) for *C. lindleyii* and 8 mm (0.32 in) for *Pinus* sp.

An integrated evaluation of both nurseries and plantations is required before major improvements can be implemented. Evaluating nurseries in isolation (Aldana 2000) is unlikely to result in much improvement in plantation establishment, unless guidelines relating nursery factors to field performance are developed. Even evaluating plantations

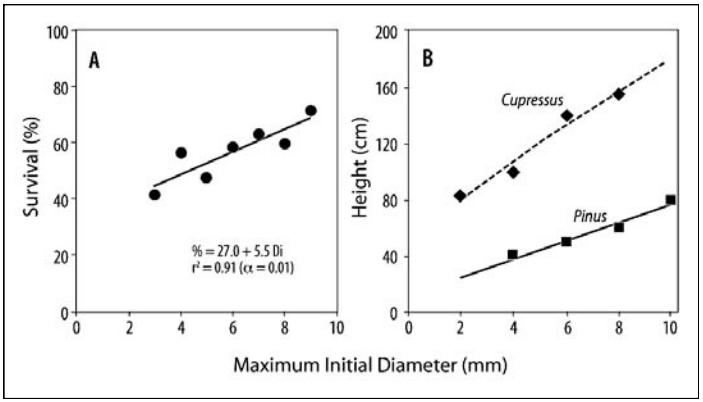

Figure 3. Relationship between initial seedling diameter and (A) survival (*Cupressus* and *Pinus* combined) and (B) final height of *Cupressus lindleyii* and *Pinus* sp. plantations after 26 mo in central México, 1995.

is not beneficial, however, if much time elapses between planting and evaluating. For example, a common cause of mortality in México is "drought" (Bello and Cibrián 2000; Sierra and Rodríguez 1991), but this could easily result from poor seedling quality, loose planting, exposure, or even late planting.

For the most part, polybag production systems have been denigrated (Josiah and Jones 1992), often with a lack of data substantiating the claims of poor performance. Likewise, few data support their continued use. Napier (1985) proposed a target seedling diameter of 3–6 mm (0.12–0.24 in) for conifers in Central America but provided no empirical data relating seedling size to performance. This study indicates polybag production systems can successfully be used to produce conifers for reforestation in México, and it appears that large-diameter seedlings [6 mm (0.24 in) for *C. lindleyii* and 8 mm (0.32 in) for several species of *Pinus*] would provide the greatest potential for success of conifer reforestation.

Polybag systems are not without problems. Typically, the growing medium is forest soil or a mixture of forest soil and sand. Soilless media, humus, compost, or pinebark could be substituted for all or part of the medium. This would reduce weight and destruction caused by soil collection. Often germinants are transplanted (pricked out) into polybags. This can easily result in taproot deformation, which can impact future tree survival and growth. This "problem" is not inherent to polybags and is solved by either direct seeding or careful transplanting. Even if seedlings are transplanted properly, root quality can be affected by lateral roots spiraling around the rootball or the taproot growing out of the polybag into the soil of the nursery bed. The taproot can be pruned by following guidelines to periodically lift the seedlings from the nursery bed. Root spiraling can be minimized by proper timing or, if the seedlings are held too long, by pruning the root prior to transplanting in the field.

This success is critical for México. In 1998, over 5,500 forest fires burned more than 31,000 ha (SEMARNAP 1998a). Unfortunately, reforestation success following these fires is poor (Robles and Angeles 2000) for both seedlings and seeding. Improved seedling production practices are urgently needed. Reforestation can be successful with polybag systems. Limited reforestation resources should not be expended on planting and replanting areas because of poor seedling quality, poor planting supervision, and a lack of commitment to forestry. Improving the quality of the seedlings and protection of reforested areas will reduce wasting valuable resources.

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