
Effects of Flooding Regime and Seedling Treatment on Early Survival and Growth of Nuttall Oak

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Abstract

Effects of flooding on survival and growth of three different types of Nuttall oak (*Quercus texana* Buckl.) seedlings were observed at the end of third and fifth growing seasons at Yazoo National Wildlife Refuge, Mississippi, U.S.A. Three types of seedlings were planted in January 1995 in a split-plot design, with four replications at each of two elevations on floodprone, former cropland in Sharkey clay soil. The lower of the two planting elevations was inundated for 21 days during the first growing season, whereas the higher elevation did not flood during the 5-year period of this study. The three types of 1-0 seedlings were bare-root seedlings, seedlings grown in containers (3.8 × 21-cm plastic seedling cones), and container-grown seedlings inoculated with vegetative mycelia of *Pisolithus tinctorius* (Pers.) Coker. Survival of all the three seedling types was greatest at the lower, intermittently flooded elevation, indicating that drought and related effects on plant competition were more limiting to seedling survival than flooding. At the lower elevation, survival of mycorrhizal-inoculated

container seedlings was greater than that of noninoculated container seedlings. Survival among bare-root seedlings and inoculated container seedlings was not significantly different at either elevation. At the higher, nonflooded elevation, however, bare-root seedling survival was greater than the survival of container seedlings without inoculation. Differences were significant among the inoculated and the noninoculated container seedlings, with higher survival of inoculated seedlings at both elevations, though differences were only significant in year 3. At the end of the fifth year, height of bare-root seedlings was significantly greater than the heights of both types of container-grown seedlings at both planting elevations. Because seedlings grown in the plastic seedling cones did not survive better than the bare-root seedlings at either planting elevation, the bare-root stock appear to be the economically superior choice for regeneration in Sharkey soil.

Key words: bare-root, container, flooding, inoculation, mycorrhizae, seedling.

Introduction

Approximately 7 million hectares of bottomland hardwood forests in the Lower Mississippi River Valley, U.S.A., have been converted to other uses since the mid-1800s (Tiner 1984; Mitsch & Gosselink 1993). Most wetland forests in the region were cleared, drained and/or graded, and tilled for row-crop agriculture (MacDonald et al. 1979; Keeland et al. 1995). Many of the cleared floodplain soils were found to be marginal agricultural lands with a history of crop failure (NRCS 2002). Since the inception of the Wetlands Reserve Program authorized by the Food Security Act of 1995, attempts to reestablish forest cover have increased on marginal public and private agricultural lands in the Lower Mississippi River Valley (Schoenholtz et al. 2001). Heavy-seeded species, particularly oaks, have been favored in most reforestation

projects in this region because of their high value to wildlife (Stanturf et al. 1998).

Success of reforestation projects on Lower Mississippi River Valley farmed wetlands has been mixed, with seedling mortality and poor growth often attributed to extended drought or flooding (Kennedy & Johnson 1984; Allen & Burkett 1996; Gardiner et al. 2004). Poor planting or sowing practices, poor seed or seedling quality, and herbivory by small mammals have limited the success of seedling establishment at many sites (Allen et al. 2001; Stanturf et al. 2001).

Soil saturation and periodic-to-continuous flooding of bottomland hardwood forested wetlands are major factors affecting the occurrence (i.e., seed germination and seedling survival) and growth rate of hardwood species (Kennedy & Johnson 1984). Several studies have shown that early oak seedling survival can be influenced by initial seedling root quality, for example, number of lateral roots (Parker et al. 1986; Ruehle & Kormanik 1986; Thompson & Schultz 1995). Primary and lateral root development is more extensive in container-grown seedlings than in bare-root seedlings (Dixon et al. 1981a, 1981b). Work by Humphrey (1994), Williams et al. (1998), and Howell (2001) suggests that container oak seedlings may survive better than bare-root seedlings on floodprone sites. Other

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comparisons of early seedling survival on floodprone sites have shown no significant difference in the survival of container or bareroot stock (Williams & Stroupe 2001; Sweeney et al. 2002; Dey et al. 2003).

Allen et al. (2001:55) suggest that oak seedlings grown in containers are preferable "on harsher sites" and may have a higher survival probability because their roots are protected by the same soil that they were grown in at the nursery. This soil reduces shock associated with transplanting and ensures that the seedling roots remain moist for a longer period after planting. Container seedlings, however, are more costly to produce and plant than bare-root seedlings, and information is needed to help land managers evaluate the practical use of container seedlings on large tracts.

The roots of seedlings that become established in forests commonly contain mycorrhizal fungi that are essential to survival and growth on drought-stricken and nutrient-poor sites (Spurr & Barnes 1992). These fungi facilitate the transport of water and nutrients to seedling roots (Allen 1990; Read 1991). Mycorrhizae are obligate plant symbionts; land clearing, cropping, and fallow influence mycorrhizal species type and abundance in soils (Johnson & Pfleger 1992). Black oak (*Quercus velutina* Lam.) seedlings inoculated with *Pisolithus tinctorius*, a common mycorrhizal fungus in southern forests, increased lateral root development (Dixon et al. 1981a, 1981b) and leaf area (Daughtridge et al. 1986), which may enhance survival and growth. However, the persistence of mycorrhizae and their effects on seedling survival in intermittently flooded soils are poorly understood (Jurgensen et al. 1997).

Objectives

This experiment was designed to determine if there is a difference in the effects of seasonal flooding, seedling stock type (bareroot and container), and mycorrhizal inoculation on Nuttall oak seedling survival and height in Sharkey soil. We specifically tested whether there were differences in survival and height among the three stock types (bareroot, container, and no inoculation) at two elevations depicting different flooding regimes (flooded or low and not flooded or high). Sharkey soil (very fine, montmorillonitic nonacid, thermic Vertic Haplaquepts) is a dominant soil type of the floodprone Lower Mississippi River Valley alluvium (Pettry & Switzer 1996).

Here we contrast the survival and height of each stock type during the third and fifth growing seasons after planting at two field elevations, one of which is periodically flooded. An assessment of seedling survival and herbivory by rodents during the first growing season was described by Burkett and Williams (1998). Chlorophyll concentration in leaf tissue, net photosynthesis rates, leaf water potential, transpiration, and diffusive resistance rates for each seedling type at each planting elevation during the first growing season have also been described previously, as well as soil

moisture and plant competition at each planting elevation (Burkett 1996). Seedling stem diameter, height, dry weight, lateral root development, nutrient and carbohydrate concentration in root and stem tissue, and root volume were measured prior to planting (Burkett 1996).

Methods

Bareroot and container seedlings were cultivated using common nursery methods. Thirteen kilograms (30 pounds) of Nuttall oak acorns were obtained from a seed source in the delta area of Mississippi in late April 1994 and placed in cold storage. Acorns were soaked overnight in tap water, and those that floated were discarded. The remainder were placed in plastic bags and refrigerated at 1.7°C, turned every other day, and checked for spoilage. In late May, the acorns were individually sown in 164-cm³ (3.8 × 21 cm) plastic seedling cones (Ray Leach "Cone-tainer" Nursery, Canby, OR, U.S.A.). A 1:1 homogeneous mixture of autoclaved peat moss and construction-grade vermiculite was used as a planting medium. After seeds were sown and thoroughly watered, the containers were placed on tables in a greenhouse on the Stephen F. Austin State University campus in Nacogdoches, Texas. Seedlings were fertilized biweekly with a 20:20:20 commercial fertilizer mix. Magnesium sulfate (5 mL/11.37 L of water) and liquid iron (5 mL/11.37 L of water) were also applied every other week. Seedlings were watered as needed. In late June, containers with fully developed seedlings were placed on trays (49 seedlings/tray) and moved to outdoor tables covered with 50% shade cloth.

In early July, every other tray of seedlings was inoculated with vegetative mycelium of *Pisolithus tinctorius*. One-half (5 g of fungal mycelia) of a commercially available inoculum kit was applied in a drench following procedures recommended by the distributor (Mycorr Tech, Inc., Pittsburgh, PA, U.S.A.). Trays with inoculated seedlings were placed on separate tables in the shade house and inoculated again in August and December 1994. The shade house cover was removed during mid-September. Seedlings were transported in a covered van to the planting site in Sharkey County, Mississippi, in early January 1995.

Bareroot seedlings, graded 46 cm (18 inch) or larger, were obtained from the same seed source and seed lot as the container-grown seed. They were lifted from the nursery bed in early January and transported in sealed shipping bags to the planting site on the same day.

Morphology of the three seedling types was compared prior to planting. The inoculated container seedlings had significantly more primary (i.e., first order) lateral roots greater than 0.5 mm than the noninoculated container seedlings. The inoculated container seedlings had twice as many lateral roots greater than 5 mm than did the bare-root seedlings, but the volume of the bareroot seedling roots (mostly taproot) was roughly four times the total volume of either container stock type (Burkett & Williams

1998). Root volume, stem diameter at the root collar, stem dry weight, and height were not significantly different among the container stock types.

Field experiments were conducted at Yazoo National Wildlife Refuge (lat 32°57'39"N, long 90°43'54"W) in the delta region of west-central Mississippi. The planting site was located on a tract of farmed wetlands that was annexed to the Refuge in Sharkey County, Mississippi, 2.5 km east of the community of Anguilla. The field had been planted with soybeans for several years, but repeated crop failure due to inundation resulted in the transfer of the land title to the Federal government in 1993. The tract was scheduled for wetland restoration by the U.S. Fish and Wildlife Service in 1994 when it became part of the Yazoo National Wildlife Refuge. A soil survey of the tract by the Soil Conservation Service in 1994 indicated that the soil type at the site is Sharkey clay. Sharkey soils are poorly drained, very slowly permeable clay soils that formed in clayey alluvium on the floodplains and terraces of the Mississippi River. When dry, this soil commonly develops cracks as wide as 10 cm and several centimeters deeper than wide (Scott & Carter 1962). An elevation survey of the planting site delineated two elevation contours representing different flooding regimes: 28.1-m mean sea level (LOW) and 29.4-m mean sea level (HIGH).

During March–April of the first growing season (1995), rainfall in west-central Mississippi was considered normal to above normal (SRCC 1995b). It was during this period that the lower of the two planting elevations was inundated for 21 days (Fig. 1). Low rainfall during the latter half of the first growing season (June–September 1995) produced unusually dry conditions (SRCC 1995a). Hence, the seedlings were exposed to relatively wet conditions during the early part of their first growing season, but as precipitation decreased and temperature increased during August and September, they were exposed to unusually

dry conditions. Average monthly precipitation was again lower than average during the first half of the second growing season (1996) (SRCC 1996). Rainfall was normal to above normal during the last half of the second growing season and through 1997, but in 1998 and 1999, drought conditions persisted in this area of Mississippi from March to December (NOAA 2002).

The percentage of soil moisture at both planting elevations was determined using five shallow cores (approximately 15 cm deep) augered at random locations between plots at each planting elevation in June 1995. Mean soil moisture at the LOW and HIGH planting elevations was 24 and 22% total weight, respectively (Burkett 1996). The lower of the two planting elevations flooded twice for a total of 21 days between 8 March and 1 May of the first growing season (1995). During subsequent years, the lower elevation was inundated periodically but to a lesser degree than in 1995. During our study the higher elevation zone was not inundated.

Plant competition at each planting elevation during the first growing season was compared by describing the percentage of cover by species, overall height, and above-ground total biomass. A list was compiled of all species that made up 5% or more of the total area in a 1-m² plot located at the center of the spaces between each whole plot. After competing species were identified, their percent cover and overall height were measured. All above-ground plant material was then clipped at ground level, placed in paper bags, dried in a drying oven at 60°C for 2 days, and then weighed on a Mettler balance.

Experimental Design

This study was designed as a randomized, complete block split-plot experiment with four replications. Along each elevation, four 22.8 × 7.6-m sections (replicates) were



Figure 1. Photograph of planting site (lower elevation, facing east) at Yazoo National Wildlife Refuge as floodwaters were receding in late May 1995.

designated and spaced 7.6 m apart. Each replicate was divided into three 7.6 × 7.6-m plots, and each plot was randomly assigned one treatment type in a split-plot design. In early January 1995, 30 seedlings were planted uniformly with a 1.5-m spacing within each treatment plot. In total, 240 seedlings of each type (BAREROOT, CONTAINER, and INOCULATED CONTAINER) were planted. Seedling survival and height measurements were taken during the third and fifth years after planting.

Analysis of variance (ANOVA) of the categorical data (SAS Institute, Inc., Cary, NC, U.S.A.) was conducted to compare survival among the three seedling treatments at the two elevations (HIGH or not flooded and LOW or intermittently flooded). For the significant main effects and interactions, two separate CATMOD analyses were performed by using the nested-by-value effects approach, one to investigate the elevation differences in survival within each level of treatment (i.e., ELEV[TMT = B] refers to elevation differences within the bareroot treatment) and the other to determine treatment differences in survival within each level of elevation (i.e., TMT[ELEV = H]). Multiple comparisons were applied to isolate significant differences in survival, with adjusted alpha level for each model (α/n). A two-way ANOVA (SAS Institute, Inc.) was used to evaluate differences in seedling height. All statistical analyses were conducted at the level of significance $\alpha = 0.05$.

Results

Survival

Survival in the first growing season was difficult to assess. In early June 1995, the average survival of both container-grown types exceeded 96%, whereas that of bareroot types averaged only 45% (Burkett & Williams 1998). By the end of the first growing season, 97% of the seedlings planted at the site had been clipped slightly above the root collar by small rodents. Resprouting is common in rodent-damaged hardwood seedlings; by April 1996, many of the seedlings had initiated new shoot growth. Rodent herbivory was abundant at the site during 1996 or subsequent years, although some herbivory and resprouting was observed between years 3 and 5. Percentage of survival of the seedlings per replicate and overall survival for each treatment type for the third and fifth years after planting are presented in Table 1.

Although most seedlings were clipped near the root collar by rodents during the first growing season (Burkett & Williams 1998), roughly half resprouted during subsequent growing seasons. For the BAREROOT treatment, there was approximately 40–70% recovery by sprouting in the third year, with higher survival percentages in the LOW than in the HIGH elevation. The CONTAINER treatment demonstrated mixed recovery, with a marked difference between the HIGH (0–10% survival) and LOW (37–73% survival) planting elevations. The INOCULATED CONTAINER treatment demonstrated the

Table 1. Percentage of live seedlings for each treatment type (by each replicate and over the four replicates as “overall”) at the high (not flooded) and low (flooded) planting elevations and total over both elevations, after the third and fifth year growing seasons, based on all seedlings originally planted (30 per plot).

Treatment	Third Year Survival (%)			Fifth Year Survival (%)		
	High	Low	Total	High	Low	Total
Bareroot (B)						
Replicate 1	17	70	43	20	63	42
Replicate 2	30	63	47	33	57	45
Replicate 3	43	53	48	37	53	45
Replicate 4	40	57	48	37	60	48
Overall	33 ^b	61 ^{c,d}	47 ^b	32 ^b	58 ^{c,d}	45 ^b
Container (C)						
Replicate 1	0	67	33	0	63	32
Replicate 2	0	73	37	10	77	43
Replicate 3	10	37	23	13	37	25
Replicate 4	7	47	27	7	43	25
Overall	4 ^a	56 ^c	30 ^a	7 ^a	55 ^c	31 ^a
Inoculated container (I)						
Replicate 1	0	77	38	0	80	40
Replicate 2	50	90	70	33	87	60
Replicate 3	17	60	38	17	57	37
Replicate 4	27	67	47	17	73	45
Overall	23 ^b	73 ^d	48 ^b	17 ^{a,b}	74 ^d	45 ^b

Total values, analyzed separately by year, are not significantly different if the superscripts are the same. Comparisons of overall values across elevations are aggregated for each year. Analysis of overall survival was performed on actual survival counts and not percentages.

best recovery (up to 90%) (Tables 2 & 3). The fifth-year survival data were very similar to the third-year data, with some additional resprouting as well as some die-backs (Fig. 2).

Results of the categorical ANOVA (PROC CATMOD, SAS Institute, Inc. 1990) testing seedling treatments and elevation for both the years are presented in Table 2. There were significant differences in survival ($p < 0.05$) among the three treatment types, the two elevations, and the treatment–elevation interactions (Table 2). Table 3 summarizes the analyses of contrasts. For both third- and

Table 2. ANOVA (CATMOD) of the effects of elevations and treatments on survival, after the third and fifth years.

Year	Source	df	χ^2	Probability
Third	TREATMENT	2	29.78	0.0000*
	ELEVATION	1	178.79	0.0000*
	TMT × ELEVATION	2	9.83	0.0073*
	RESIDUAL	0**	—	—
Fifth	TREATMENT	2	18.17	0.0001*
	ELEVATION	1	185.32	0.0000*
	TMT × ELEVATION	2	14.46	0.0007*
	RESIDUAL	0**	—	—

*Significant at $\alpha = 0.05$.

**Saturated model with no residual error.

Table 3. Selected multiple contrasts from two nested-by-value effects models of ANOVA (CATMOD).

Contrast	df	Third Year		Fifth Year	
		χ^2	Probability	χ^2	Probability
TMT B-C	1	17.67	0.000*	11.54	0.001*
TMT B-I	1	0.16	0.691	0.01	0.919
TMT C-I	1	24.00	0.000*	14.63	0.000*
TMT B, ELEV H-L	1	20.84	0.000*	18.39	0.000*
TMT C, ELEV H-L	1	109.53	0.000*	83.94	0.000*
TMT I, ELEV H-L	1	79.02	0.000*	118.06	0.000*
ELEV H, TMT B-C	1	36.29	0.000*	24.03	0.000*
ELEV H, TMT B-I	1	2.50	0.114	7.49	0.006
ELEV H, TMT C-I	1	19.57	0.000*	4.69	0.030
ELEV L, TMT B-C	1	0.61	0.434	0.27	0.604
ELEV L, TMT B-I	1	4.28	0.039	6.85	0.009
ELEV L, TMT C-I	1	8.23	0.004*	9.93	0.002*

TMT B = bareroot, TMT C = container, TMT I = inoculated container, ELEV H = high elevation, and ELEV L = low elevation.

*Significant for corresponding model, at $\alpha = 0.05/\text{number of contrasts}$.

fifth-year data, overall survival in the CONTAINER treatment was significantly lower than that in other two treatments (contrasts TMT B-C and TMT C-I), whereas survival in the BAREROOT seedlings did not differ significantly from the INOCULATED CONTAINER seedlings (contrast TMT B-I).

Survival at the higher of the two planting elevations was generally poor. By the end of the fifth growing season, overall survival of bareroot seedlings (32%) was approximately twice as high as the survival of INOCULATED CONTAINER seedlings (17%) and almost 5-fold greater

than survival of CONTAINER seedlings (7%) at the HIGH elevation. As indicated in Table 3, survival was significantly greater at the LOW, intermittently flooded elevation for all treatment types (group of contrasts TMT #, ELEV H-L, i.e., the contrast between survival at the HIGH and LOW elevations for a treatment such as BAREROOT). Furthermore, for the higher, nonflooded elevation (ELEV H, TMT #-# contrasts), CONTAINER treatment survival was significantly lower than both other treatments in the third year but only lower than BAREROOT treatment in the fifth year. At both elevations (ELEV L and H, TMT #-# contrasts), INOCULATED CONTAINER treatment survival was significantly higher than CONTAINER treatment survival during the third year. By the fifth year, however, the superior survival of the inoculated container seedlings was only significant at the lower planting elevation. Also at the lower elevation, the BAREROOT treatment survival percentage values fell between both container treatments, and they did not differ significantly from either container treatment.

Seedling Height and Plant Competition

Between the third and fifth years, seedlings in all the three treatments more than doubled in height (Table 4). At the end of the third and fifth growing seasons, the height of BAREROOT treatment seedlings surpassed the heights of both types of container-grown seedlings. For BAREROOT seedlings, average height at the HIGH elevation (190 cm) was significantly greater ($p < 0.05$) than the average height at the LOW elevation (159 cm) by the fifth year, whereas their average height did not differ significantly between elevations at the end of the third growing season. In both types of container-grown seedlings, the average height in the LOW elevation exceeded the HIGH elevation, although differences were not significant (Fig. 3).

The predominant species at the low elevation was *Iva annua* L., which covered an average 75% of the sampled plots (Table 5). No other species had more than 5% cover in the canopy of the competing vegetation at the low elevation during the first growing season. At the higher planting elevation, the plots had a dense growth of Johnson grass (*Sorghum halepense* (L.) Persoon). Powderpuff (*Mimosa strigillosa* Torr. and Gray) was slightly more prevalent at the higher elevation.

Discussion

Bareroot seedlings and container seedlings treated with mycorrhizal inoculation had similar survival 5 years after planting and outperformed the simple container-grown seedlings without inoculation. By the end of the fifth growing season, bareroot seedlings were taller than the other two seedling types at both planting elevations. The higher survival of all the three seedling treatments at the lower,

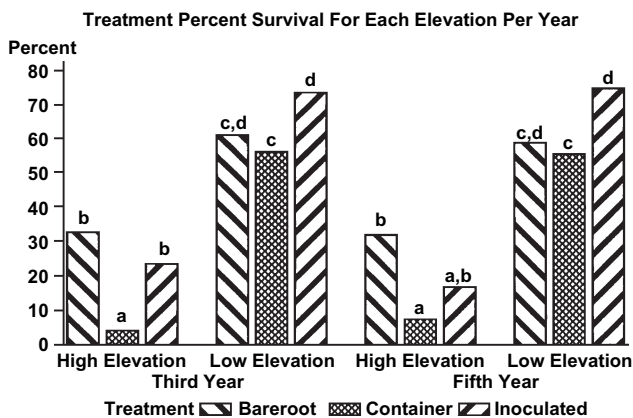


Figure 2. Percentage of seedlings of each treatment type that survived at the high and low planting elevations for the third and fifth years. Values with same letters within each year and elevation class are not significantly different.

Table 4. Average heights (SE) in centimeters are given for each treatment type (by each replicate and over the four replicates as “overall”) at the high and low planting elevations for third and fifth years.

Treatment	Third Year Average Height (SE)		Fifth Year Average Height (SE)	
	High	Low	High	Low
Bareroot				
Replicate 1	100 (8)	68 (7)	215 (12)	150 (13)
Replicate 2	62 (13)	68 (6)	172 (14)	150 (10)
Replicate 3	76 (12)	84 (8)	182 (18)	182 (13)
Replicate 4	71 (7)	76 (8)	201 (14)	156 (14)
Overall	74 (6) ^c	73 (4) ^c	190 (8) ^f	159 (6) ^c
Container				
Replicate 1	0	43 (6)	0	119 (9)
Replicate 2	0	53 (5)	128 (5)	128 (8)
Replicate 3	41 (20)	45 (7)	81 (24)	113 (9)
Replicate 4	47 (23)	61 (7)	101 (27)	139 (15)
Overall	44 (13) ^a	50 (3) ^{a,b}	101 (13) ^d	125 (5) ^d
Inoculated container				
Replicate 1	0	61 (4)	0	127 (7)
Replicate 2	34 (6)	61 (4)	131 (10)	136 (7)
Replicate 3	41 (9)	48 (7)	115 (17)	129 (10)
Replicate 4	30 (9)	65 (4)	121 (22)	135 (11)
Overall	34 (4) ^a	59 (2) ^b	125 (8) ^d	132 (4) ^d

Values for each overall treatment elevation are not significantly different if the superscripts are the same, columnwise and between elevations. A dual superscript designation denotes values not significantly different from either, that is, in between, columnwise, and across.

intermittently flooded elevation suggests that drought stress may have been a factor in seedling mortality.

Deep cracks in the dry Sharkey soil were common in late summer. Cracks in the soil were observed at or near the base of many of the planted seedlings (Fig. 4), thereby increasing seedling vulnerability to root desiccation and moisture stress. The difference in soil texture and moisture retention in the potting medium compared to the

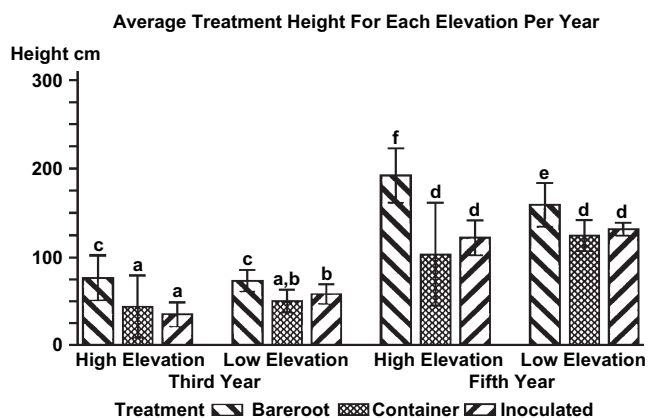


Figure 3. Average height of seedlings of each treatment type that survived at the high and low planting elevations for the third and fifth years. Values with same letters within each year and elevation calls are not significantly different.

Table 5. Mean percent cover and average height of competing vegetation during the first growing season at the two planting elevations on 17 August 1995.

Elevation (\bar{X} sea level)	Species	Cover (%)	Height (cm)
Low (28.1 m)	<i>Iva annua</i> L.	75	144
	<i>Polygonum punctatum</i> Ell.	5	110
	<i>Mimosa strigillosa</i> T. & G.	5	78
	<i>Campsis radicans</i> (L.) Seemann	5	25
	<i>Baltonia</i> spp.	5	96
High (28.9 m)	<i>Sorghum halepense</i> (L.) Persoon	90	154
	<i>Mimosa strigillosa</i> T. & G.	10	32
	<i>Euphorbia maculata</i> L.	5	5
	<i>Oxalis</i> spp.	5	10

Sharkey soil in which the seedlings were planted may have accounted for some root stress in the container seedlings. Pettry and Switzer (1996) reported that the moisture content of the upper 30–40 cm of Sharkey soil at field capacity and permanent wilting point was about 51.8 and 41.6 %, respectively, which is above the moisture level that we observed during the first growing season. The low moisture content that we measured at the study site supports the observation that the seedlings were experiencing



Figure 4. Photograph of bareroot seedling in dry, cracked soil.

severe soil water deficits during the first growing season after planting, leading to premature senescence, leaf abscission, and stem die-back.

The superior height growth of the bareroot seedlings at both elevations in this experiment may be an important factor in their continued survival. Large seedlings and saplings have an advantage over smaller seedlings in the event of shallow flooding because the crown of the taller seedling is at a lower inundation risk (Allen et al. 2001). Experiments with Nuttall oak in a nearby field (also planted in the same year, 1995) by Gardiner et al. (2004) indicate that vigorous early growth is critical for the successful establishment of Nuttall oak seedlings planted on former agricultural fields in the Lower Mississippi River alluvial floodplain.

Higher water availability at the low planting elevation appears to have promoted survival among all the three seedling treatments. Differences in herbaceous plant competition at each planting elevation can also be explained by differences in soil moisture, and plant competition probably played an important role in the higher seedling survival at the lower elevation. The canopy architecture of the more flood-tolerant *Iva annua* allowed more sunlight to reach the oak seedlings at the low field elevation than the dense growth of Johnson grass and Powderpuff at the high elevation. Gardiner et al. (2004) interplanted bareroot Nuttall oak seedlings with Cottonwood (*Populus deltoides* Bartr. ex Marsh.) at a nearby site in 1995. The Cottonwood canopy reduced total biomass accumulation by Nuttall oak seedlings by approximately 50%.

Reuhle and Wells (1984) found that fertilization of container seedlings can lead to unsatisfactory overdevelopment of *Pisolithus tinctorius* in pine seedlings, and Beckford et al. (1984) found similar effects in Northern red oak (*Quercus rubra* L.) seedlings. Although fertilization may have limited mycorrhizal development in this experiment, the increase in lateral root development of the inoculated seedlings was comparable to increases reported by other investigators who have inoculated container oak seedlings with the same species of mycorrhizae (Dixon et al. 1981b).

Prior to the rodent damage of the container-grown seedlings and bareroot seedling die-back in the first growing season, it was noted that the average survival of both container-grown seedlings was over 95%, suggesting initial success of the container-grown seedlings over the bareroot seedlings (34% average survival) (Burkett & Williams 1998). Resprouting played an important role in the survival of all the three seedling treatments, with bareroot and mycorrhizal-inoculated container seedlings recovering similarly during the first 3 years. This pattern continued into the fifth year, with survival of the noninoculated container seedlings significantly lower than that of the other two seedling treatments, especially at the higher elevation.

It appears that rodent herbivory combined with the flooding, herbaceous plant competition, and desiccation of seedlings during the first growing season created an excep-

tionally difficult environment for seedling establishment. Size of the containers used to culture the seedlings may have been an important factor in this setting. Howell (2001) noted a significant improvement of growth in oak seedlings grown in large pots compared to smaller ones when outplanted at a bottomland site in Georgia. Oaks that were cultured in 3- and 5-gallon (11.35 and 18.93 L, respectively) containers by using a method called RPMTM (Root Production Method) had superior diameter and height growth compared to bareroot seedlings when planted on former cropland in the Missouri River floodplain (Dey et al. 2003). The costs of producing, transporting, and planting seedlings cultured in large pots may be outweighed by their potential for superior growth in some circumstances.

Conclusions

At the end of the fifth growing season, survival of the bareroot seedlings was greater than that of the noninoculated container seedlings at the higher planting elevation. Survival of the bareroot seedlings was not different from that of the inoculated container seedlings at either planting elevation. Bareroot seedlings grew taller than the noninoculated and the inoculated container seedlings (47 and 34%, respectively) during the 5-year study. Seedling survival was greatest at the lower, wetter of the two planting elevations, suggesting that drought stress- and soil moisture-related effects on plant competition were more important factors than flooding stress on the seedlings planted at this site.

Bareroot oak seedlings are generally less expensive to purchase and plant than container-grown seedlings (Allen et al. 2001). Because the seedlings grown in the plastic seedling cones did not survive better than the bareroot seedlings at either planting elevation, the bareroot stock appear to be the economically superior choice for regeneration. Moreover, this study suggests that height growth was much greater in the bareroot seedlings, which may lead to improved survival in future years if prolonged flooding occurs or if rodent and/or deer herbivory were to become a problem. The noninoculated container stock did not survive as well as the bareroot or inoculated container seedling treatments at the drier elevation, nor did they grow as tall as the other two seedling treatments. Hence, this study indicates that the noninoculated seedlings are not likely to be as successful as the inoculated container seedlings in Sharkey clay soils with similar flooding regimes.

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