ESTABLISHING NORTHERN RED OAK ON A DEGRADED UPLAND SITE IN NORTHEASTERN PENNSYLVANIA: INFLUENCE OF SEEDLING PEDIGREE AND QUALITY

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Abstract.—Enrichment plantings using large oak seedlings of regional sources may promote superior survival and growth compared to direct seeding or standard nursery seedling material. This study evaluated the survival and growth of planted 1-0 northern red oak (*Quercus rubra* L.) seedlings among 11 families and 3 seedling size classes (small, average, and premium). Seedlings were planted in April 2005 in a deer exclosure in a failed clearcut in Pike County, PA. After 7 years, survival averaged 84 percent and was greater in the premium than either the small or average size classes in 2 of the 11 families. Total height and ground-level diameter of premium seedlings were greater in five and eight of the families, respectively, than seedlings in either the average or small size classes. Results suggest that selecting premium seedlings from certain mother trees can improve planted seedling survival and growth and have ramifications for seed orchard construction.

INTRODUCTION

The reduction in oak regeneration throughout much of the eastern United States can be attributed to changes to disturbance regimes (Abrams 2003, Crow 1988), browsing by overpopulated deer herds (Rooney and Waller 2003), increased competition by fire-intolerant species (Abrams 1992), interference from invasive species such as hay-scented fern (*Dennstaedtia punctilobula* [Michx.] T. Moore) (Horsley 1988, McWilliams et al. 1995), and mortality from the nonnative gypsy moth (*Lymantria dispar dispar* L.; Kegg 1971). Advance regeneration of desirable timber and wildlife hardwood species, including oaks, is inadequate throughout most of Pennsylvania (McCaskill et al. 2013; McWilliams et al. 1995, 2007), and recruitment of oaks after harvest has been very poor (Marquis et al. 1976).

When natural regeneration of oaks is inadequate, enrichment planting can be a useful tool to produce desired levels of oak stocking. Success of oak plantings is a function of genetic factors, site quality, site conditions at the time of planting, competition, planting methods, and stock quality (Burdett 1990, Dey and Parker 1997, Dey et al. 2008, Kormanik et al. 1995). Indicators of high quality stock include number of 1st-order lateral roots, root collar diameter (RCD), root volume, and stem height (Dey and Parker 1997, Jacobs et al. 2005, Kormanik et al. 2002). High quality oak seedlings generally grow faster than smaller seedlings, can better compete with other vegetation, and can better survive damage and dieback. These advantages give large seedlings a better chance of surviving repeated browsing by white-tailed deer (*Odocoileus virginianus Miller*). Northern red oak (*Quercus rubra* L.) seedlings with RCDs larger than 8-10 mm (c.f. Dey and Parker 1997) and stem height taller than 50 cm (Johnson 1981) have been recommended for successful establishment on productive sites.

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Previous work to evaluate success of oak-enrichment plantings in forested settings has focused on establishment on highly productive sites (e.g., Kormanik et al. 2002, Morrissey et al. 2010) or sites in the South or Midwest (e.g., Kormanik et al. 2002, Morrissey et al. 2010, Schuler and Robison 2010, Spetich et al. 2000, Thompson and Schultz 1995). Highly productive sites, which generally have greater soil moisture and nutrient availability than xeric sites, have been particularly challenging for regenerating oak because of the abundance of faster-growing shade-intolerant species such as yelow-poplar (*Liriodendron tulipifera* L.) (Morrissey et al. 2010). Few studies have evaluated planted oak establishment with little or no preplanting site preparation on xeric or poor quality sites in the Northeast. Although oak is easier to regenerate on poor quality sites because severe competition is lacking, regeneration is still questionable if the area has a high deer population. The interaction between deer browsing and competing vegetation (e.g., hay-scented fern) limits the establishment and advancement of oak seedling cohorts (de la Cretaz and Kelty 2002). Deer exclosure fences and nonselective herbicide application to remove competing vegetation are effective management options for promoting oak regeneration. The cost of deer fencing is extremely high, however; woven wire fencing costs $2 or more per linear foot (Penn State Extension 2006) and requires fairly regular maintenance. Therefore, for most private landowners deer fencing lends itself to only small acreage.

Most studies evaluating success of oak-enrichment plantings focus on early survival and growth, rarely following the trees beyond the first 5 years. Here we present 7-year results of a long-term study to compare survival, height, and diameter of 1-0 northern red oak seedlings of three seedling size classes from 11 families. The objective is to understand the interaction among seedling genetics and seedling quality in an enrichment planting of northern red oak on a low-productivity upland site.

METHODS

Experimental Material

Seeds from 11 open-pollinated northern red oak mother trees were used in this study. Acorns were harvested from mother trees located in natural forested stands at the U.S. Military Academy reservation, West Point, NY, and proximal area in fall 2003. Mother trees were located at least 0.40 km apart to avoid collecting closely related material. The acorns were planted at the Georgia Forestry Commission's Flint River Nursery in Byromville, GA, in December 2003 at a density of 65 seeds/m^2. Fertilization and irrigation of the seedlings followed guidelines developed by Kormanik et al. (1994). The 1-0 seedlings were lifted in late January 2005 and transported to Knoxville, TN, where they were stored in a cold room (~1 °C). Total height and root collar diameter of each seedling were measured and seedlings were individually tagged. Finally, seedlings were visually sorted into three size classes within each family: small, average, and premium, according to height and RCD (Clark et al. 2000) (Table 1). Before starting the grading process, we chose several seedlings that appeared to represent small, average, and premium sizes for each family and used them as model seedlings for each size group by the planting crew (Clark et al. 2000). We used the minimum height (50 cm) (Johnson 1981) and RCD (8-10 mm) (Dey and Parker 1997) recommended for northern red oak seedlings as the standard for our average seedling size class. One family (family 1) was divided into average and premium size classes only, because small seedlings were lacking.

Table 1.—Height (± standard error) and ground-level diameter (g.l.d.) of seedlings at planting and after seven growing seasons. N total at planting was 759 seedlings.

Family	Quality	Initial height (cm)	7-year height (cm)	Initial g.l.d. (mm)	7-year g.l.d. (mm)
1*	Average	66 ± 4	163 ± 24	8.1 ± 0.4	24.4 ± 2.9 b
	Premium	89 ± 4	200 ± 22	10.8 ± 0.6	33.1 ± 2.6 a
6	Small	50 ± 6	177 ± 28	7.2 ± 0.4	27.0 ± 3.8
	Average	71 ± 5	221 ± 27	8.6 ± 0.4	30.8 ± 3.5
	Premium	68 ± 4	210 ± 22	10.1 ± 0.6	33.4 ± 2.6
7*,†	Small	54 ± 6	97 ± 27 b	6.9 ± 0.4	17.1 ± 3.5 b
	Average	79 ± 5	156 ± 27 b	8.9 ± 0.6	22.1 ± 3.4 ab
	Premium	95 ± 4	235 ± 21 a	12.1 ± 0.5	30.9 ± 2.3 a
8	Small	39 ± 5	181 ± 22	6.9 ± 0.5	31.0 ± 2.7
	Average	52 ± 3	195 ± 19	8.6 ± 0.4	32.0 ± 1.9
	Premium	62 ± 3	217 ± 19	10.2± 0.4	34.1 ± 1.9
9*,†	Small	37 ± 2	130 ± 16 b	6.9 ± 0.3	19.9 ± 1.1 b
	Average	44 ± 2	154 ± 17 ab	8.1 ± 0.3	23.3 ± 1.4 ab
	Premium	45 ± 3	162 ± 19 a	9.4 ± 0.4	24.9 ± 1.9 a
10*,†	Small	39 ± 2	141 ± 16 b	7.1 ± 0.2	21.3 ± 1.2 b
	Average	44 ± 2	140 ± 17 b	8.4 ± 0.2	21.3 ± 1.4 b
	Premium	51 ± 2	173 ± 17 a	9.5 ± 0.2	25.6 ± 1.4 a
11*,†	Small	48 ± 2	129 ± 18 b	6.9 ± 0.4	17.3 ± 1.7 c
	Average	53 ± 2	151 ± 17 b	8.1 ± 0.3	23.0 ± 1.6 b
	Premium	71 ± 2	202 ± 16 a	10.1 ± 0.4	29.6 ± 1.3 a
12*	Small	36 ± 3	134 ± 19	7.0 ± 0.4	20.1 ± 1.9 b
	Average	43 ± 3	143 ± 20	8.5 ± 0.4	22.0 ± 2.1 ab
	Premium	49 ± 3	150 ± 18	9.6 ± 0.4	24.0 ± 1.7 a
14*	Small	40 ± 3	122 ± 21	7.2 ± 0.4	18.7 ± 2.4 b
	Average	44 ± 2	128 ± 19	7.9 ± 0.3	20.6 ± 2.0 ab
	Premium	55 ± 4	158 ± 22	9.5 ± 0.4	25.6 ± 2.5 a
15*,†	Small	60 ± 7	117 ± 33 b	8.1 ± 1.0	16.7 ± 4.9 b
	Average	63 ± 3	185 ± 20 a	9.3 ± 0.4	29.6 ± 2.1 a
	Premium	76 ± 3	185 ± 19 ab	11.5 ± 0.5	27.8 ± 1.9 a
16	Small	45 ± 4	160± 22	7.2 ± 0.5	24.2 ± 2.7
	Average	63 ± 4	196 ± 21	8.6 ± 0.4	28.4 ± 2.4
	Premium	84 ± 3	185 ± 21	10.1 ± 0.4	31.1 ± 2.4

* Families with differences in 7-year g.l.d. among quality classes (α = 0.05).
† Families with differences in 7-year height among quality classes.
Different letters within column and family indicate significant differences.

Study Area

This study was established on the Delaware State Forest in Blooming Grove, PA (41°25'N, 75°03'W, elevation 420 m). This area is part of the glaciated low plateau section province of northeastern Pennsylvania and is dominated by oaks, primarily white oak (*Quercus alba* L.), northern red oak and chestnut oak (*Q. prinus* L.), hickory (*Carya* spp.), white pine (*Pinus strobus* L.), pitch pine (*P. rigida* Mill.), and red maple (*Acer rubrum* L.). The soils at the site are of the Manlius Series characterized as strongly acidic, rocky-silt loam with low soil moisture retention. The stand was clearcut in 1975 as part of a commercial harvest to regenerate oak and other economically desirable hardwood species. Preferential browsing by overabundant white-tailed deer inhibited hardwood seedling regeneration and instead facilitated the establishment of a thick understory of sweet fern (*Comptonia peregrine* [L.] J.M. Coult) and ericaceous shrubs (primarily *Vaccinium* spp.). An 8-ha 2.4-m tall woven-wire deer fence was erected on the site in 2005 before planting to protect the experimental material from deer browsing.

Experimental Design

The study was designed to examine the effects of family and seedling quality on seedling survival and growth. Seedlings were planted in two plots approximately 150 m apart. Within the plots, seedlings were planted in an incomplete block design with four seedlings in each block: one small, one average, and one premium size class of 11 families, along with one bulked seed lot. The bulked seed lot seedlings were not included in the analysis presented in this paper. A total of 1,067 seedlings (759 included in the results presented here) were planted in a 2.4-m × 2.4-m grid on each experimental site on April 12 and 13, 2005. Seedlings were planted with a Jim Gem KBC© bar, which was modified by adding 5 cm to each side of the blade. This created a blade that was 15 cm at the top and tapered to the tip.

Measurements

Height and ground-level diameter (g.l.d.) of seedlings were measured at the time of planting and annually thereafter. Survival was tallied at the end of the 7th growing season.

Statistical Analysis

All analyses for this study were processed using SAS 9.3 software (SAS Institute 2011). Seedling response was analyzed using a mixed model analysis of variance to determine significant effects of family and seedling size class on height and g.l.d. after 7 years. Residuals were tested for normality and equal variance. Using a binomial distribution, PROC GLIMMIX was used to evaluate differences in survival among families and quality classes. Least squares means with Fisher's least significant difference mean separation are reported using a 5 percent significance level.

RESULTS

After 7 years 84 percent of the oak seedlings were alive and averaged 166 cm in height and 25.4 mm in g.l.d., 114.0 cm taller and 16.9 mm larger in g.l.d. than they were when planted. Compared to family 7, the family with the highest average 7-year survival (94 percent), seven families were statistically similar in survival and three families had lower survival ($P = 0.0005$, $F = 4.59$; Fig. 1). Within families, the premium seedlings showed higher survival over the average or small seedling size classes in 2 of the 11 families ($P = 0.02$; $F = 2.03$; Table 2).

Compared to family 6, the family with the greatest height after 7 years (202.5 cm), three other families were statistically similar and seven were smaller (Fig. 2; $P < 0.0001$, $F = 5.26$). Compared to family 8, the family with the greatest 7-year g.l.d. (32.3 mm), two of the families were similar and eight were smaller ($P < 0.0001$, $F = 7.73$; Fig. 3). Seven year height and g.l.d. were greater in the premium size class than in either the average or small size class in five and eight of the pedigreed families, respectively ($P < 0.0001$ for each, $F = 5.02$, 4.59, respectively; Table 1).

DISCUSSION

Overall, survival among the seedlings was high (84 percent, Table 2 and Fig. 1) and comparable to the only other 7 year northern red oak enrichment studies we found; 83 percent across three size classes in a study in North Carolina (Kormanik et al. 2002), and 72 percent across six browse protection treatments in a study in Connecticut (Ward et al. 2000).

In families 12 and 14, survival differed among size classes (Table 2 and Fig. 1); these were among the families with the lowest height and diameter after 7 years (Figs. 2 and 3). Family 12 and 14 seedlings averaged 141 and 140 cm in height and 22.2 and 21.9 mm in g.l.d., respectively, compared to 171 cm (height) and 26.2 mm (g.l.d.) averages for the remaining families. Families 12 and 14 were also among the shorter families at planting. For these families, the size advantage of the premium size class may have been more important for competing with other vegetation than for families with larger height and diameter at the time of planting.

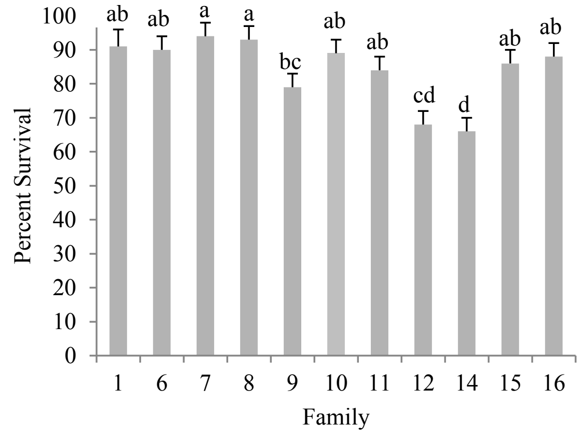

Figure 1.—Percent survival (± standard error) among families 7 years after planting. Bars with the same letter are not significantly different (α = 0.05).

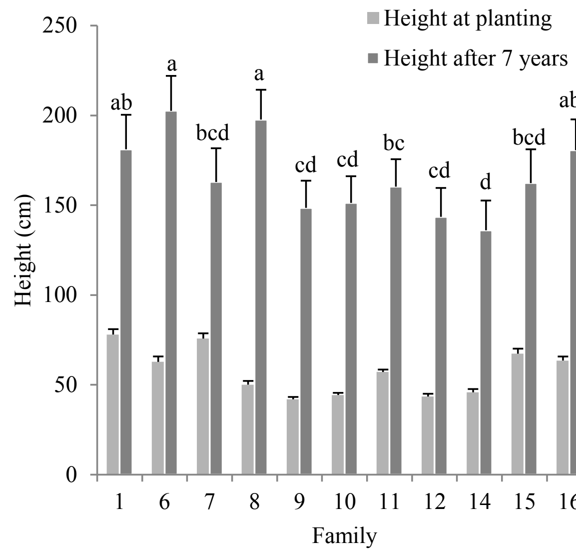

Figure 2.—Planting and 7-year height (± standard error) among families. Seven-year height bars with the same letter are not significantly different (α = 0.05).

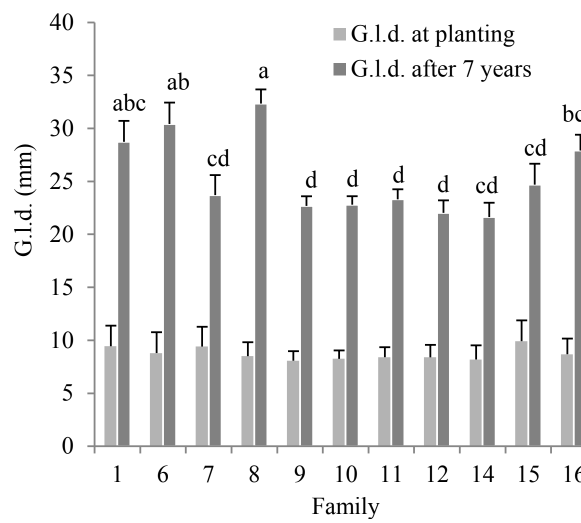

Figure 3.—Planting and 7-year ground collar diameter (g.l.d.; ± standard error) among families. Seven-year g.l.d. bars with the same letter are not significantly different (α = 0.05).

Differences in 7-year diameter among size classes were found in 8 of the 11 families, and size class was important to height in five of the families. Many studies have found that larger northern red oak seedlings, when correctly handled and planted, survive and grow better than smaller seedlings on productive sites (Dey and Parker 1997; Jacobs et al. 2005; Kormanik et al. 1995, 2002; Thomson and Schultz 1995). Taller seedlings impart a height advantage important for competing with fast-growing species on highly productive forest sites (Dey and Parker 1997). Few studies have evaluated the effect of seedling size on less productive sites, such as our study site. Seedlings with larger diameters at planting tend to have larger root systems and more fine roots, which are vital for regaining root-to-soil contact after transplanting (Burdett 1990). Our study shows that initial seedling diameter is also important for subsequent seedling growth on less productive sites. Initial seedling height did not appear to be as important as initial diameter. This may be partly due to the large initial average height of our seedlings (45 cm). This is close to the 50-cm height recommended for oak plantings (Johnson 1981) and therefore may not have been representative of small seedlings that are produced by many tree nurseries. Also, the fast-growing shade-intolerant species that can outcompete oaks on mesic sites, such as red maple, serviceberry (*Amelanchier* spp.), and yellow-poplar, tend to grow less abundantly and rapidly on xeric sites; therefore, height may be less important to planted seedlings on these sites. Furthermore, sweet fern became established on our planting sites in response to the canopy removal in the mid-1970s and may have hindered establishment, survival, and growth of naturally regenerating tree seedlings, thereby conferring an advantage to the planted oak.

The differences in height and diameter among families are not surprising because of the substantial genetic variation for height growth within and between northern red oak seedling populations (Kolb and Steiner 1989). Variation in survival and size among the families over seven growing seasons and two plots suggest that collections from certain mother trees should be avoided because they produce poor quality seedlings. In several years we will evaluate their competitive ability based on growth and height relative to competing vegetation and will subsequently rogue inferior families. Superior families will be left and maintained as a seed orchard to provide acorns for the production of high quality seedlings for regional enrichment plantings.

Table 2.—Percent survival (± standard error) of size classes within each family 7 years after planting

Family	Quality	Percent survival
1	Average	82 ± 8
	Premium	100 ± 8
6	Small	88 ± 8
	Average	83 ± 8
	Premium	100 ± 8
7	Small	100 ± 8
	Average	89 ± 8
	Premium	95 ± 8
8	Small	100 ± 8
	Average	94 ± 8
	Premium	85 ± 8
9	Small	81 ± 8
	Average	83 ± 8
	Premium	75 ± 8
10	Small	84 ± 8
	Average	94 ± 8
	Premium	87 ± 8
11	Small	76 ± 8
	Average	84 ± 8
	Premium	91 ± 8
12*	Small	66 ± 8 b
	Average	51 ± 8 b
	Premium	86 ± 8 a
14*	Small	52 ± 8 b
	Average	51 ± 8 b
	Premium	94 ± 8 a
15	Small	83 ± 8
	Average	79 ± 8
	Premium	94 ± 8
16	Small	93 ± 8
	Average	92 ± 8
	Premium	78 ± 8

* Families with differences in 7-year survival among size classes within family ($\alpha = 0.05$).

Different letters within column and family indicate significant differences.

MANAGEMENT IMPLICATIONS

On low productivity sites where natural oak regeneration is lacking, enrichment planting using high-quality seedlings within deer exclosures is a feasible way to establish northern red oak. The Pennsylvania Bureau of Forestry maintains approximately 16,200 ha of deer fencing on state forest lands, providing ample opportunities for enrichment plantings throughout the state. Fencing and using tree shelters to prevent deer damage to seedlings is not economically feasible for most landowners. Some National Resource Conservation Service programs offer cost-sharing opportunities to help landowners plant and protect seedlings. Planting oak on sites with an expansive sweet fern layer may actually benefit the planted seedlings by reducing growth of natural regeneration. Seedlings of at least 60 cm in height and 8 mm in RCD are recommended for plantings on such marginal or poor sites. Selecting certain mother trees can improve overall seedling quality in the nursery and have ramifications for future seed orchard construction. Our results substantiate the importance of tree improvement programs such as the Tennessee Tree Improvement Program and the Hardwood Tree Improvement and Regeneration Center. In a period of increasing challenges stemming from the introduction and spread of nonnative pests and pathogens, and predicted range changes caused by climate change, the availability of locally adapted, high quality hardwood seedlings will become more important.

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