STOCKTYPE AND HARVEST GAP SIZE INFLUENCE NORTHERN RED OAK REGENERATION SUCCESS

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Abstract—Four different northern red oak (*Quercus rubra* L.) stocktypes (standard- or low-nursery-density bareroot seedlings and 11.4 or 18.9 L container seedlings) were outplanted into large-, medium-, and small-harvested gap openings (0.400, 0.024, and 0.100 ha, respectively) and closed-canopy control plots in southern Indiana. Two-year survival, height, and diameter were each lower in small gaps and control plots, but there were no differences between medium and large openings. Container seedlings had reduced survival compared to bareroot stock, which was attributed to root damage incurred during overwintering. Diameter growth of container seedlings was greater than that of bareroot stock, though height growth did not differ. Both initial and final height and diameter were greater for container than bareroot stock. Container stock in the two larger gap-opening treatments established a dominant, free-to-grow status. These results illustrate the potential suitability of certain gap opening sizes and stocktypes to promote oak regeneration after harvesting.

INTRODUCTION

Northern red oak (*Quercus rubra* L.) is an important forest tree species of the Central Hardwood Forest Region, providing valuable timber, wildlife habitat, and recreation resources. Oak species have been present in this region for over 7,000 years (Davis 1981) and have dominated these forests through pre-settlement time (Dyer 2001). Trends toward reductions in both disturbance intensity and fire return intervals over the past approximately 100 years have shifted the proportion of small- to mid-size growing stock toward more shade-tolerant species (Abrams 1992), which will likely decrease the proportion of oak in future mature stands. Thus, ensuring adequate oak regeneration is a major concern of forest managers in this region.

Even-aged regeneration is the accepted system for successfully regenerating oak (Roach and Gingrich 1968, Sander and Graney 1992). Following a harvest disturbance, natural regeneration of oak may be successful if adequate oak advance regeneration or stump sprouting potential is present on the site and sufficient basal area is removed during harvest (Sander and Graney 1992).

In the Central Hardwood Region, disturbance areas are relatively small since much of the harvesting involves single-tree selection. Additionally, forest land is often divided into small ownership parcels, further limiting the area to which disturbance may be applied. In Indiana, for example, approximately 150,000 non-industrial private forest landowners own 85 percent of the 1.8 million ha of forests (Tormoehlen and others 2000). Many landowners are reluctant to clearcut and may favor creating small circular group openings to provide adequate light to regenerate oak. Though the recommended diameter of these openings is 1 to 2 times the height of the surrounding dominant trees (Sander and Graney 1992), relatively few studies have examined response of planted seedlings to an array of gap opening sizes.

Most hardwood tree plantings in Indiana involve afforestation plantings of bareroot seedlings (Jacobs 2003, Jacobs and others 2004). These plantings have had variable success, with mean survival during the first 5 years estimated at 65 percent and < 50 percent of seedlings considered free-to-grow by age 5 (Jacobs and others 2004). Inconsistent plantation establishment success of oaks has often been associated with competing vegetation, damage from animal browse, and poor seedling quality (Jacobs and others 2004, Johnson and others 2002).

Artificial oak regeneration may be improved by using large, vigorous, bareroot seedlings (Jacobs and others in press, Johnson and others 2002, Schultz and Thompson 1997). Additionally, advances in nursery production techniques for forest tree seedlings have resulted in the availability of new stocktypes that may further improve oak regeneration success. For instance, use of container seedlings reduced water stress of planted northern red oak seedlings on a mine reclamation site (Davis and Jacobs 2004). Dey and others (2004) found that use of large (i.e., 11 to 19 L) container stock may enhance early plantation development of oaks on floodplain sites. The potential for large container stock to improve oak regeneration success in harvested gap openings has not been thoroughly examined. Thus, our objectives were to (1) examine potential for large container stock to enhance northern red oak establishment success in harvested gap openings compared to traditional bareroot stock and (2) determine the effect of gap opening size on seedling establishment success.

MATERIALS AND METHODS

Study Site

The study was conducted at the Southern Indiana Purdue Agricultural Center near Dubois, IN. Four different forest stands with relatively uniform site conditions within a stand (i.e., slope, aspect, dominant tree species, pre-harvest basal area, etc.) were identified. Aspect differed among the stands, ranging from north, east, south, or southwest. The pre-harvest stands contained a substantial proportion of both red and white oak.

Circular gap opening treatments were randomly allocated within each stand; treatments consisted of a large (0.400 ha),

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medium (0.100 ha), or small (0.024 ha) opening and a 0.100-ha control (no harvest). Harvest gap-diameters were 73.2, 36.6, 18.3, and 0 m, respectively. Since heights of adjacent dominant trees were in the range of 25 to 35 m, the medium- and large-gap openings represented the approximate recommended range of 1 to 2 times the height of the surrounding dominant trees (Sander and Graney 1992). Harvesting was conducted during the winter of 2002-2003. Trees were harvested using chain saws; merchantable logs were cut to length and skidded from the site by tractor. All stems < 5 cm d.b.h. were cut and stumps treated with herbicide.

Plant Material and Study Establishment

Northern red oak seedlings were planted into the site in spring 2002. Stocktypes consisted of low (LD) and high (HD) nursery-bed-density bareroot seedlings, or small (SC) and large container (LC) seedlings. Bareroot seedlings were obtained from the Indiana Department of Natural Resources Vallonia Nursery near Vallonia, IN. Seedlings were grown during 2001 using standard nursery practices (Jacobs 2003) at either the operational nursery-bed spacing of 75 seedlings m^{-2} (HD) or at a density of 21 seedlings m^{-2} (LD), which was achieved by thinning during early spring. Seedlings were lifted in fall, 2001, and cold stored (2 °C) prior to transport to the planting site. Container stock consisted of 11.4 (SC) or 18.9 L (LC) seedlings that were operationally grown during 2000-2001 at the Woody Warehouse near Lizton, IN. Seedlings were initially grown in 650 cm^3 pots and transplanted into larger pots for the second year of growth. Container seedlings were transported to the field site in late 2001 and overwintered outside in the growing pots.

All seedlings were planted in spring, 2001, using shovels. Due to the uneven size of the gap openings, the number of planted seedlings varied within an opening. Additionally, to ensure that adequate numbers of seedlings were available for the study, planting density varied by opening treatment ranging from 7.6 × 6.7 m for the large opening, 4.6 × 4.6 m for the medium opening and control, and 3.6 × 3.6 m for the small opening. This resulted in a total number of 60, 40, 40, or 20 seedlings planted for the large, medium, control, and small openings, respectively. An equal number of seedlings were planted per stocktype treatment within a particular gap opening size. Immediately following plantings, seedlings were measured for height and root-collar diameter (RCD). Following the first two growing seasons, seedlings were assessed for survival and re-measured for height and RCD.

Experimental Design and Data Analysis

The study was established as a randomized complete block design with factorial treatment structure (4 gap openings × 4 stocktypes). Each of the four forest stands comprised a replication. A sampling unit consisted of each individual seedling, and the experimental unit for data analysis was the mean response value for a treatment within a replicate. Data were analyzed using Analysis of Variance (ANOVA). When significant ($P < 0.05$) treatment differences were detected in the ANOVA, Tukey's highly significant differences test was used to separate treatment means at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Harvest Gap Openings

First- and second-year seedling survival differed significantly among gap size openings (table 1). Seedlings planted into large and medium openings had second-year survival of 68 to 78 percent, while survival in the small opening was 50 percent and that in the control was only 23 percent (fig. 1). Gap openings similarly affected total height and RCD, as well as RCD growth (table 1). No significant differences were detected between the large and medium openings, but seedlings in the small opening had significantly lower total height and RCD compared to the large and medium openings (fig. 2). Seedlings in the non-harvested control plot had the lowest mean total height and RCD (fig. 2). These results help confirm the contention of Sander and Graney (1992) that gap diameters should be at least 1 to 2 times the height of adjacent dominant trees. Smaller gaps create a large ratio of perimeter to opening area (Johnson and others 2002), thereby limiting the amount of light that seedlings receive. A threshold level exists beyond which growth is affected; this level was reached in our study in the 0.100-ha openings.

Stocktypes

Stocktype affected survival during both growing seasons (table 1), with container seedlings having significantly lower survival than bareroot stock during each growing season (fig. 1). Bareroot stock had 68 to 70 percent survival after the second growing season, compared to a range of 44 to 52 percent mean survival for container stock (fig. 1). Although LC had greater survival than SC during the first growing season (64 versus 48 percent), differences were non-significant after the second growing season (fig. 1).

We attributed the reduced survival of container stock primarily to differences in overwintering procedures. While bareroot stock was stored in a controlled cooler environment throughout winter, container seedlings were subjected to winter freeze-thaw events during outdoor storage adjacent to the site. Roots are more sensitive than shoots to cold temperatures, and at time of planting we noticed substantial root damage to some container seedlings. This likely contributed to the reduced survival of container stock. Furthermore, a significant gap opening × stocktype interaction effect was detected for survival (table 1). This was a reflection of

Table 1—Analysis of variance results for effects of gap opening and stocktype treatments on survival, shoot height, and root-collar diameter (RCD) response variables

Response variable	Gap size	Stocktype	Gap size X stocktype
		P-value	
Survival – year 1	< 0.0001	< 0.0001	0.0002
Survival – year 2	< 0.0001	< 0.0001	0.0038
Height - initial	0.1387	< 0.0001	0.4267
Height – growth	0.4837	0.2128	0.1353
Height – final	< 0.0001	< 0.0001	0.1039
RCD - initial	0.7449	< 0.0001	0.0523
RCD – growth	< 0.0001	< 0.0001	0.7524
RCD – final	< 0.0001	< 0.0001	0.6740

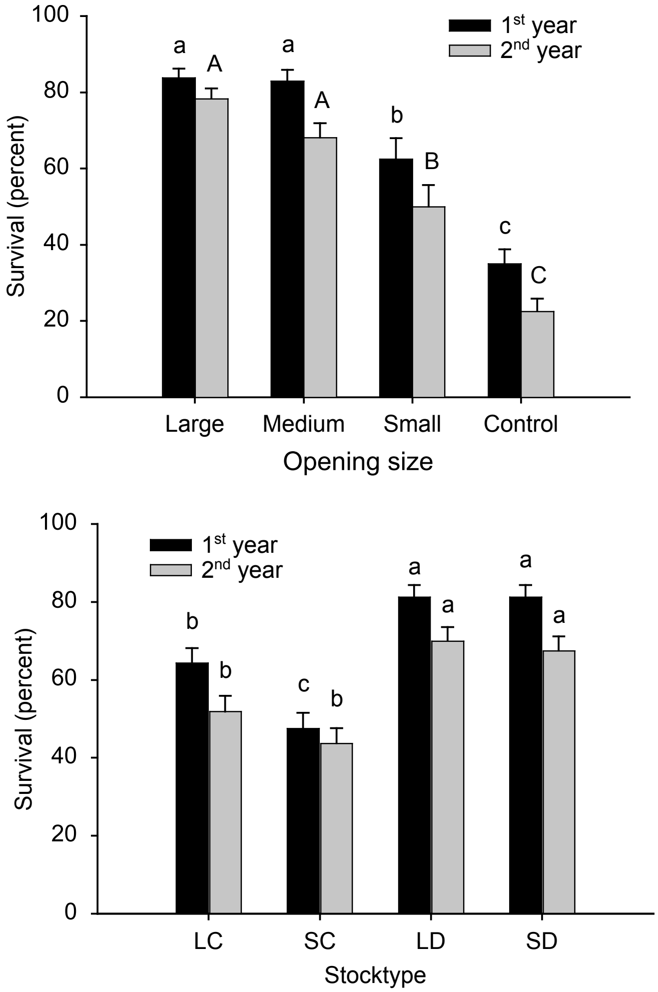

Figure 1—First- and second-year northern oak seedling survival as affected by gap size (top) and stocktype (bottom). Gap treatments consisted of large (0.400 ha), medium (0.100 ha), or small (0.024 ha) openings and a control (no opening). Stocktype treatments included 18.9- or 11.4-L container stock (LC and SC, respectively) or low- or high-density bareroot stock (LD and HD, respectively). For either gap size or container treatments, treatments with similar letter groupings within a sampling year were not statistically different at $\alpha = 0.05$.

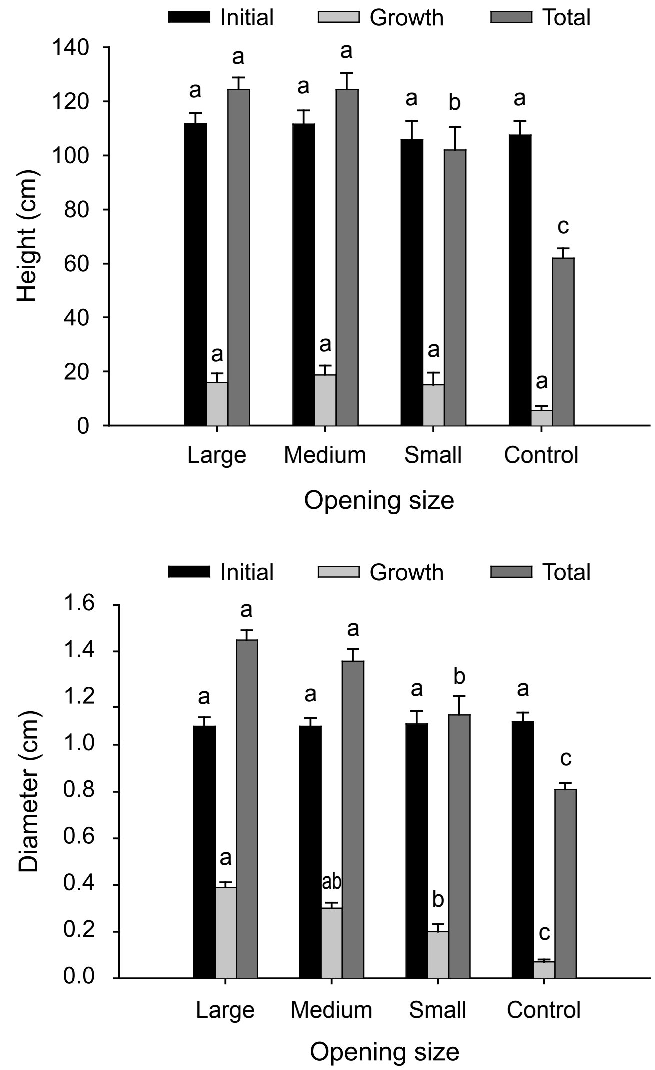

Figure 2—Initial, 2-year growth and total height (top), and root-collar diameter (bottom) as affected by gap size. Gap treatments consisted of large (0.400 ha), medium (0.100 ha), or small (0.024 ha) openings and a control (no opening). For either initial, 2-year growth, or total response, treatments with similar letter groupings within a sampling year were not statistically different at $\alpha = 0.05$.

increased mortality for container versus bareroot seedlings planted into non-harvested control plots. The larger container seedlings (fig. 3) likely had greater respiratory demand compared to bareroot stock, and low light levels within the control plots probably did not allow for adequate photosynthetic assimilation to meet basic physiological maintenance requirements. This effect further contributed toward the decreased mean survival of container seedlings when averaged across all gap openings.

Stocktypes varied in initial height and RCD (table 1), with container stock being significantly larger for both traits compared to bareroot stock. Initial mean height and RCD for container stock ranged from 165 to 169 cm and 1.4 to 1.6 cm, respectively, compared to 52 to 53 cm and 0.6 to 0.7 cm, respectively, for bareroot stock. Dey and others (2004) reported similar discrepancies in initial size of large container versus bareroot stock of pin oak (*Quercus palustris* Muenchh.) and swamp white oak (*Quercus bicolor* Willd.). Height growth during the two growing seasons was not affected by stocktype, though container seedlings had significantly greater RCD growth than bareroot seedlings (table 1, fig. 3). Oak seedlings tend to allocate significant resources toward root versus shoot growth during establishment (Johnson and others 2002), which serves as an adaptive mechanism to help resist drought. Since seedling root proliferation is well correlated with RCD (Jacobs and Seifert 2004), container seedlings were able to establish larger root systems for resource acquisition, which should continue to facilitate growth over time.

Management Implications

Ensuring adequate oak regeneration following harvest is an important objective for many landowners. On some sites, reliance on natural regeneration is not likely to facilitate maintenance of a large oak component in the ensuing stand. Artificial regeneration may offer a means to help enhance oak regeneration on these sites.

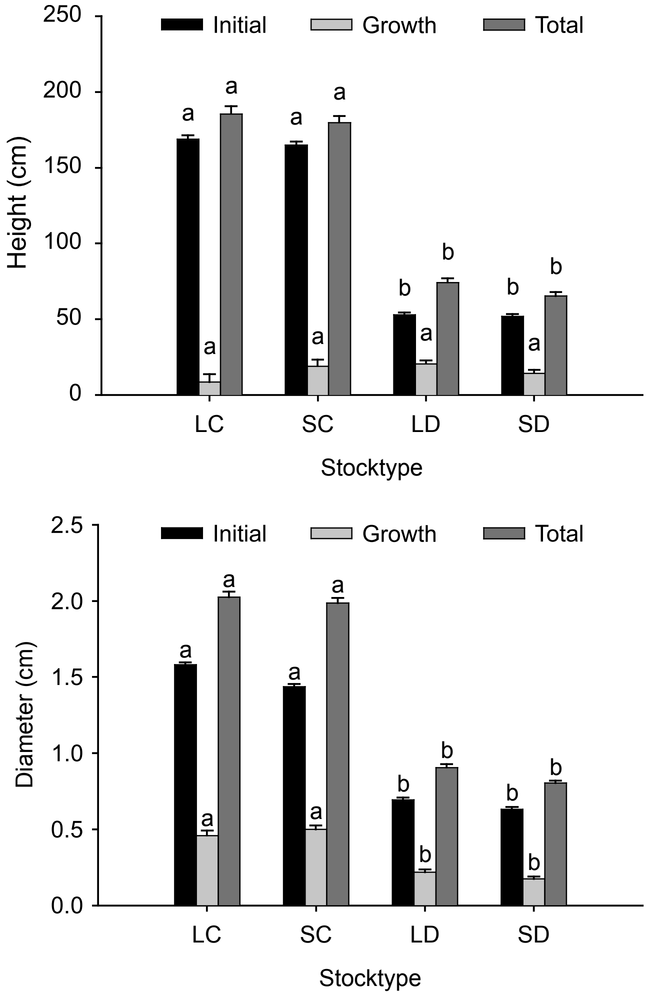

Figure 3—Initial, 2-year growth and total height (top), and root-collar diameter (bottom) as affected by stocktype. Stocktype treatments included 18.9- or 11.4-L container stock (LC and SC, respectively) or low- or high-density bareroot stock (LD and HD, respectively). For either initial, 2-year growth, or total response, treatments with similar letter groupings within a sampling year were not statistically different at $\alpha = 0.05$.

A clear advantage of using large container stock is that the planted seedlings are in a free-to-grow state (i.e., above levels of deer browse and competing vegetation) at time of planting. For instance, initial mean height for container stock in this study was > 165 cm. An obvious disadvantage is the higher seedling cost and increased transport and labor requirements to plant this large stock. Greater costs may restrict use of large container stock to specific sites where natural oak regeneration is unlikely to be successful or to small-scale reforestation projects for which landowners are willing to pay a premium to ensure maintenance of oak in the succeeding stand. When using container stock, it is critical to ensure that seedlings are overwintered properly to alleviate potential for damage as documented in this study. Since large container seedlings require substantial cooler space for winter storage, they are often operationally stored outside in a horizontal position with insulating cover.

Our data also suggests that there is little variation in northern red oak seedling establishment success within a gap opening range of 0.100 to 0.400 ha. As the forest canopy continues to converge over time in these gaps, we expect that these results may change. Additionally, we observed prolific yellow poplar (*Liriodendron tulipifera* L.) regeneration in the larger gap openings. Long-term evaluation of this site will be useful to determine if established oak seedlings are able to maintain dominance within the stand.

ACKNOWLEGDMENTS

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