EFFECT OF SEEDLING SIZE AND FIRST-ORDER-LATERAL ROOTS ON EARLY DEVELOPMENT OF NORTHERN RED OAK ON MESIC SITES

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Abstract—Northern red oak (*Quercus rubra*) seedlings were placed in three grades based on number of first-order-lateral roots. The grades were poor, medium, and good and had numbers of 0 to 6, 7 to 11 and ≥ 12, respectively. Eighty seedlings from each group were either underplanted or established in an adjacent clearcut on a high-quality mesic site in North Carolina. There were 240 seedlings outplanted on each area. The poor-graded seedlings were initially smaller than the medium and good seedlings with heights and root collar diameters of about 67 centimeters and 7.4 millimeters; 115 centimeters and 11.3 millimeters; and 138 centimeters and 13.4 millimeters, respectively. Survival was better overall with the underplanted seedlings at year 7, with the poor, medium, and good seedlings surviving at 75, 78, and 96 percent, respectively. Growth was unsatisfactory for all three grades. Survival on the clearcut was affected by a 17-year-locust (*Magicicada septendecim L.*) infestation and heavy stump sprout competition. Survival of the poor, medium, and good seedlings were 59, 63, and 66 percent, respectively. Height and stem caliper were very good for the medium and good seedlings. Only 3 seedlings from the 0-6 grade were free to grow at age 5, while 29 of the seedlings in the good grade were free to grow.

INTRODUCTION

Scores of manuscripts have reported on attempts to obtain northern red oak (*Quercus rubra*) regeneration on desirable mesic sites where the species is an important economic and ecological component of the forest. The basic tenets of most of this northern red oak research have been reported by Sanders (1971, 1972; Sanders and Graney 1993). That is, for this species to be a significant component of a future stand, they must be represented by specific numbers and size classes in the understory when the current stand is harvested. Stand structure is regulated by thinning of either (or both) the canopy and the understory to encourage the establishment and development of the smaller oak regeneration before the residual stand is harvested (Loftis 1983, 1990). Many of the regeneration attempts that have shown promise of providing adequate oak regeneration are on the more xeric sites, where northern red oak may not be the desirable oak species. Stable oak communities are not difficult to obtain or to maintain on xerophytic sites where site index is ≤60 (base age 50) (Lorimer 1993).

Kellison (1993) reported that obtaining oak regeneration is not a universal generic problem but, rather, is a specific problem of northern red oak on high-quality mesic sites. This serious problem is complicated by ignoring the effect of edaphic and environmental factors on the competitor species of this important oak species. The pertinent issue may be the desire to develop a generic management protocol that is simultaneously politically correct, scientifically sound, and universally applicable to all *Quercus* species regardless of edaphic and environmental constraints. This "Holy Grail" is unlikely to exist and if research and management continues to search for it, then Kellison's (1993) prediction of northern oak becoming the "California Condor" of the eastern deciduous forest may indeed become a reality.

Natural versus Artificial Regeneration

Oak research at the Institute for Tree/Root Biology (ITRB) was initiated a decade ago when we began screening northern red oak open-pollinated, half-sib progeny for first-order lateral roots (FOLR) development. The ultimate purpose of the research was to develop a seedling grading system to be used for assessing the future competitive ability of individual outplanted seedlings. We first had to develop a nursery protocol to grow high quality seedlings of this species, since a consistently reliable method had not been reported for any species of oak (Williams and Hanks 1976). Only a few organizations were even considering an option of artificially regenerating northern red oak because emphasis was on natural regeneration. The primary management emphasis was on mensurational aspects of stand manipulation, such as timing of thinning or removal of overhead canopy, rather than on the biological requirements of the species. (Loftis 1990, Johnson and others 1989).

Timing of regeneration cuts for northern red oak is difficult because of the periodic occurrence of good seed years and reduced acorn crop as the stand ages and passes its peak reproductive years. However, following a good seed year on most sites, small newly germinated northern red oak seedlings can be found in great numbers for several years (Loftis 1990). Few of these will survive on mesic upland sites for sunlight is usually significantly lower than the compensation point required by northern red oak seedling (Hodges and Gardiner 1993). Similar reliance on periodic acorn crops for seedling production in nurseries severely limits artificial enrichment planting opportunities that should accompany natural regeneration. Absence of a ready source of acorns has severely limited planned research on this species but recent results on acorn production from seed orchards have been encouraging.[2]

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Development of Northern Red Oak Seedlings

We will not include a discourse on acorn production but will assume the acorn has germinated. After germination, seedlings may survive a few years but light intensity near the forest floor on mesic sites is often below the compensation point for northern red oak. Seedlings seldom develop more than 2 or 3 leaves and the terminal buds remain very small. However, because of small openings in the canopy and sporadic understory, individuals can survive for a number of years under these suboptimal light conditions. They frequently break bud several weeks before canopy closure and may be able to partially replenish root reserves depleted during bud break. Although complete information is lacking, those seedlings reaching more than 1 meter in height might be considered advanced reproduction that can benefit from partial release. These partially released trees may develop slowly and after 9 years have a basal diameter increase of 0.86 centimeter with insignificant height growth (Loftis 1990). Thus, before as well as after this release, growth is far from satisfactory and newly germinated species like yellow poplar (*Lirodendron tulipfera*) or the already established competing vegetation rapidly overtops all but the tallest of the slower growing northern red oak seedlings. However, northern red oaks are notoriously slow to respond to initial release, and the heavy competition on mesic sites is far more severe than on the xeric sites. Thus, initial clearcutting or a series of release and regeneration cuts to release this species may be unsatisfactory as long as the reproduction is being overtopped.

The purpose of this study was to determine how large northern red oak seedlings stratified by FOLR numbers react to competition in a clearcut and an understory planting on a high-quality mesic site.

METHOD

Two adjacent areas on the USDA Forest Service's Grandfather Ranger District on the Pisgah National Forest, 12 miles northwest of Marion, NC, were used in this study. The site index for yellow poplar was approximately 100 (base age 50). The main crown canopy was a mixture of northern red oak, white oak (*Q. alba*), red maple (*Acer rubrum*) and yellow poplar. The clearcut area to be used for enrichment planting was a small segment of a larger harvested area.

The area to be underplanted was immediately across the road and consisted of the same species composition as the clearcut area. For the underplanting, basal area was reduced by 30 percent to 20.44 square meters per hectare (88 square feet per acre) primarily by removing the intermediates and suppressed trees from the canopy level as well as those individuals occurring in the subcanopy level.

Acorns were collected from the Forest Service's Wataqua seed orchard in eastern Tennessee. The seedlings were grown at the ITRB Whitehall Experimental Nursery during the 1989 growing season, using the hardwood nursery protocol reported elsewhere (Kormanik and others 1994a). The seedlings were harvested during February 1990 and outplanted in March 1990.

When lifted, the seedlings were placed in one of three groups, poor, medium, and good, based upon FOLR numbers. FOLR numbers were defined as roots with basal diameter exceeding 1 millimeter along the first 30 centimeters below the root collar. The poor, medium, and good groups had FOLR numbers of 0 to 6, 7 to 11, and ≥ 12, respectively. Root collar diameters (RCD), and heights, were recorded for each seedling. Each lateral root was trimmed to approximately 13 centimeters and taproots were pruned to 30 centimeters before seedlings were outplanted.

Eight blocks were laid across the contour and 10 trees from each grade were shovel planted at 1.5 meters by 3.1 meters spacing in adjacent rows. The design was a split-split plot with eight blocks. Each block contained 10 trees from each grade, giving a total of 240 seedlings per treatment. The spacing was maintained with only minor adjustments. All standing trees in the clearcut area were felled before planting but no subsequent vegetation control measures were taken. Mechanical control in the underplanting area removed subcanopy trees as well as trees overlapping naturally regenerated northern red oak seedlings. Essentially no subcanopy remained after basal area reductions had been completed.

Survival data were obtained after the first growing season in 1990. Survival, RCD, and HGT were also obtained after the fifth year (1994). Competing vegetation density was recorded from three positions in each block during the fifth-year remeasurement. Five artificially regenerated trees were excavated after the fifth growing season from both the clearcut and underplanting areas to examine root development characteristics. Survival, diameter at breast height (d.b.h.), and heights were also obtained after the seventh growing season (1997).

RESULTS AND DISCUSSION

Two unanticipated factors significantly affected the results. The first was a massive infestation of the 17-year locust (*Magicicada septendecim L.*) that severely damaged almost all 240 seedlings in the clearcut toward the end of the second growing season. Very few naturally regenerated or coppiced trees were affected in the clearcut and none of the oak seedlings in the understory planting were attacked. The second factor was that the intense competition from untreated stumps of Carolina silverbell (*Halesia carolina*), red maple, and yellow poplar seedlings proved to be more significant than anticipated.

Seedling Survival

Survival following the first season was 100 percent in both the clearcut and understory plantings for all three FOLR groups of seedlings. The second year, locust damage was so extensive on seedlings in the clearcut that their long-term survival appeared to be in doubt. Many stems were severely damaged over half to two-thirds of their heights by the end of the second growing season. In the understory, all seedlings from all three FOLR grades were intact (table 1). A total of only 20 trees had not survived in the understory at age 5. Of these 20, 16 were in the poor (0 to 6) FOLR group, two in the medium (7 to 11) group, and two

Table 1—Northern red oak survival by first-order-lateral root groupings[a] from clearcut and understory plantings

Survival rate	Clearcut			Understory		
	Good	Medium	Poor	Good	Medium	Poor
1st year	100	100	100	100	100	100
5th year	68	66	63	96	96	96
7th year	66	63	59	96	78	75

[a] Good = ≥12; medium = 7-11; poor = 0-6.

in the good (≥12) group. When stands were remeasured after the seventh growing season, more mortality had occurred in both the medium and poor FOLR grades but essentially all in the good grades were still surviving in the understory (table 1).

Mortality in the clearcut was more severe (table 1) due to the result of both the intense competition from stump sprouts and the residual effect of the locust damage. Survival did not change between the fifth and seventh year in the clearcut planting area.

Growth, Vigor, and Competitive Status of Regeneration

Most of the naturally regenerated oak seedlings were less than 30 centimeters tall when the study was initiated and few of these were found by age 7. Although we did not make an exhaustive survey, newly developed seedlings were rarely observed. We do not know whether this situation occurred due to limited mast production or insufficient sunlight for seedling development. In neither the understory planting nor the clearcut area, would natural northern red oak regeneration development have been sufficient to be more than a minor component on this high-quality mesic site. Artificial regeneration, however, has altered this possibility through at least age 7.

Underplanting

The original basal area reduction has been effective through the seventh year, in that no low or mid-crown canopies have developed. However, even the best FOLR grade seedlings have not developed satisfactorily. Height growth has been minimal and RCD increases through the fifth year have remained essentially unchanged from their initial caliper; the seventh year d.b.h. measurements are tracking that of the RCD development (figs. 1A, 1B). The poor (0 to 6) FOLR group of seedlings remains the smallest and is spindly, although some—those taller than 1.0 meter—might be considered "advanced" reproduction. Characteristic of all underplanted seedlings, regardless of FOLR grade, is that only a few leaves develop annually. Even on the largest seedling, we have seldom observed more than 20 to 30 leaves. Tip dieback has occurred several times on most of the seedlings and is not associated with any particular FOLR grade. Low vigor of the poor and medium FOLR grades appeared to be related to the mortality that occurred between the fifth and seventh year. The seedlings within a specific grade were uniform in size and appear to be related to their initial sizes.

Trees excavated after year 5 showed that FOLR numbers had declined for each seedling examined. This was relatively unexpected. Underplanting or shelterwood regeneration assumptions are that the released seedlings will develop a vigorous root system and be competitive when the stand is harvested. As reported in other species, unfavorable edaphic or environmental conditions such as low light intensity can result in a reduction in FOLR numbers and vigor with a preferential carbon allocation to the taproots at the expense of the lateral roots (Sung and others 1996; Kormanik and others 1994b; Sung and other, in press). This may be the situation here since photosynthetic active radiation was at least 1500 $\mu E/m^2/s^2$ in the original clearcuts but less than ca. 5 percent in the understory.[3]

At age 7, the mean height increases since underplanting for the good, medium, and poor FOLR grades were 50, 40, and 30 centimeters, respectively (fig. 1A). The tallest seedlings were 280, 200, and 170 centimeters for each FOLR grade, respectively. In the understory, FOLR grades had little effect upon RCD increments through the fifth year and the poor FOLR grade had few seedlings large enough to obtain d.b.h. measurements at the seventh year (fig. 1B).

Clearcut

Large differences were observed in all growth parameters among FOLR root grades in the clearcut area. Survival was not related to root grade and seedling size per se. All seedlings remained free to grow during their first year, but competition for sunlight became intense between years 2

[3] Data on file at the USDA Forest Service, Institute for Tree/Root Biology, Athens, GA 30601.

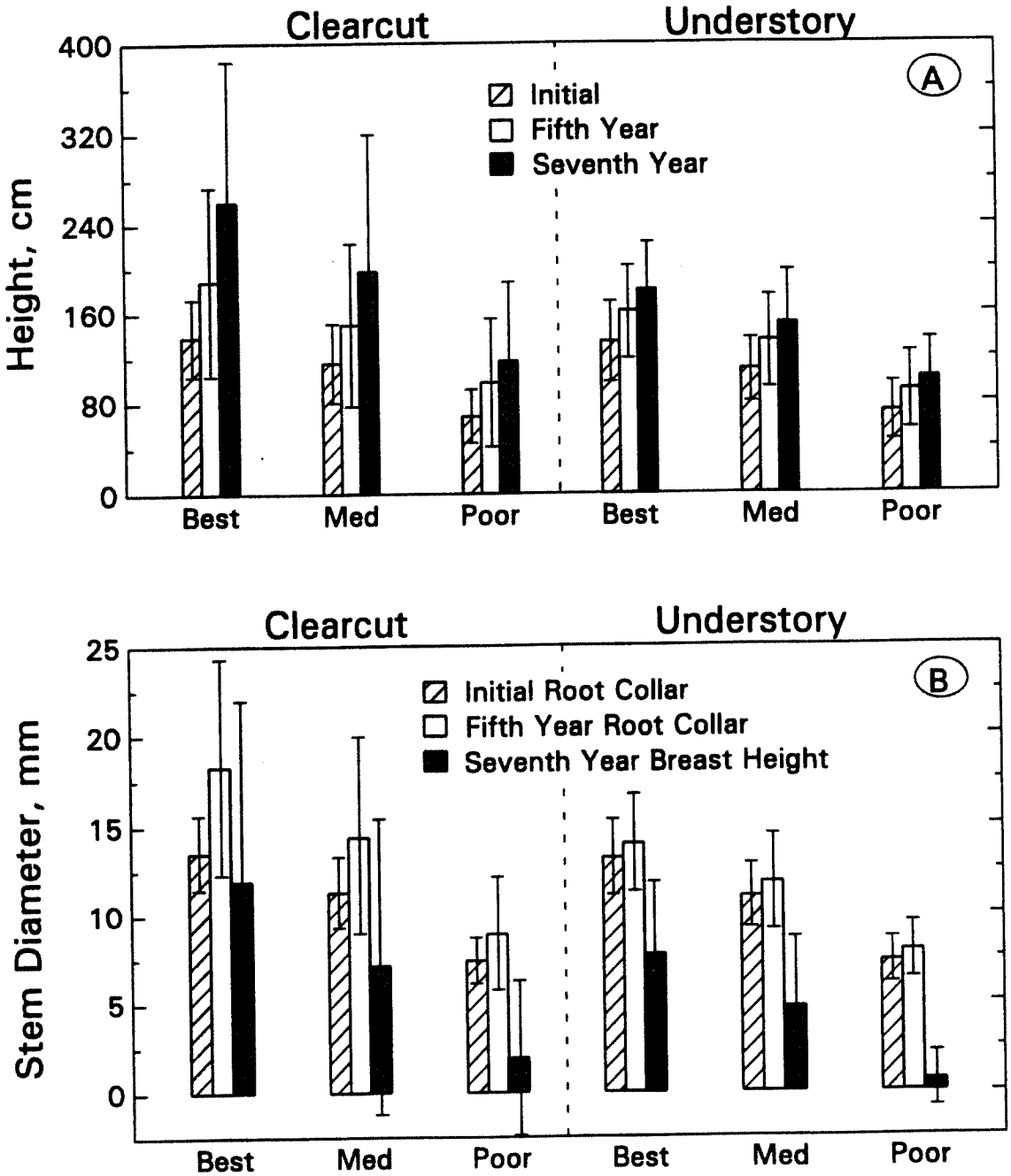

Figure 1—Initial-, fifth-, and seventh-year diameters and heights of root graded (Good = ≥12 first-order-lateral roots; medium =7-11 first-order-lateral roots; poor = 0-6 first-order-lateral roots) northern red oak in a clearcut and adjacent underplanting. Figure 1A heights; 1B diameters.

and 5 as stump sprouts and other seedlings rapidly developed. When the first remeasurement was made at year 5, evidence of significant dieback of many stems was clearly visible as a direct result of the second growing season attack by the 17 year cicada. At age 5, seedling sizes and competitive position were closely related to original FOLR grade, with the poorest grade trailing far behind the better two grades (figs. 1A, 1B). At that time, only 3 seedlings were free to grow in the poor grade, but 15 of the medium and 29 of the best grade were in this category. This latter number, 29, is especially significant as it represents about 50 percent of the surviving seedlings in this good FOLR grade. The tallest seedlings at ages 5 and 7 were strikingly different for each FOLR grade. At age 5, the poor, medium, and good FOLR grades' tallest seedlings were 235, 455, and 510 centimeters, respectively (see footnote 3). Only the medium and good grades continued to be free to grow at age 7. Many were beginning to experience severe competition from the faster growing Carolina silverbell and yellow poplar seedlings, and red maple sprouts.

At age 5, a thorough survey of competition in the clearcut revealed that the planted oaks were competing with 126,800 stems per hectare of 14 different deciduous hardwood species. However, it was the sprouts of the three

above-mentioned species and the yellow-poplar seedlings that had become the major competitors and had affected oak development the most. Vegetation was not resurveyed at age 7, but stem numbers did not appear to have declined from age 5.

During the seventh year, when crown competition in the clearcut area became intense, the number of leaves on the oak seedlings was quite high with 200 to 400 leaves being common on the better seedlings. The effect of leaf number was most evident during the initial 3 years when essentially all larger seedlings were free to grow. Northern red oak seedling development during the first 2 to 3 years is especially important and is dependent upon full sunlight for optimum establishment. We found that during years 1 and 2, major carbon allocation with northern red oak is directed to root maintenance and development with little stem elongation occurring. Without early establishment of an adequate root system, subsequent top growth is severely restricted and newly released or outplanted seedlings are soon overtopped.

Many of the naturally regenerated oak seedlings had died or had been suppressed by faster growing competitors between years 2 and 7. The reason is clear for this mortality and what was observed in this study is probably true on other mesic sites. The established oak seedlings did not immediately respond to release and few seedlings produced more than 3 to 5 leaves the first or second year. Growth during this first year was negligible as others have reported (Pope 1993). Newly germinated herbaceous vegetation, other tree species, and many sprouts soon overtopped these naturally regenerated northern red oak seedlings. By the second growing season, most of these naturally regenerated seedlings were completely overtopped and received phtosynthetic active radiation of less than 5 percent of full sunlight.

The large artificially regenerated seedlings essentially remained free to grow until the third and fourth years except when planted adjacent to stumps that sprouted vigorously. During this early period, the surviving seedlings developed a large root system that was not observed in underplanted individuals. The advantage of the large seedlings was quite obvious. The newly germinated competitors started at ground level and they seldom were more than 60 to 80 centimeters tall the first year. This was well below the height of the medium and good planted oak seedlings. Even the stump sprouts resulted in minimal competition during years 1 and 2 when the artificially regenerated oaks were establishing their root system. Thus, an early major, limiting factor of northern red oak characteristically encountered on high-quality mesic sites was moderated, i.e., access to full sun. However, it is expected that at least one release will be needed to sustain development of these free-to-grow individuals.

CONCLUSION

Large northern red oak with FOLR numbers ≥7 can be used effectively for enrichment planting on high-quality mesic sites following clearcutting. Large seedlings effectively compete against severe competition from newly germinated seedlings and other herbaceous vegetation, but by age 7 may need release from the more rapidly growing stump sprouts and yellow poplar seedlings. Planting immediately adjacent to untreated stumps of yellow-poplar, red maple, and Carolina silverbell can result in severe competition and mortality. Few individuals from the poor FOLR grade (0 to 6) were in a competitive position after year 2. Treatment of stumps adjacent to artificially regenerated seedlings may prove beneficial but was not tested.

Underplanted individuals released to a basal area of 20.44 square meters per hectare had a better survival rate than those in the clearcut, but grew little during these first 7 years. The seedlings repeatedly died back regardless of initial sizes and FOLR numbers. Excavation at age 5 from the understory, revealed most of the original FOLR have senescenced and root mass was smaller than when initially outplanted due to mortality of the FOLR.

Neither artificial nor natural regeneration techniques may prove effective for regenerating northern red oak on mesic sites unless mechanical or chemical competition control accompanies use of large nursery-grown seedlings. It is questionable whether advanced natural regeneration can be relied upon on mesic sites with the shelterwood method of regenerating this species.

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