EFFECT OF SEEDLING SIZE AND FIRST-ORDER LATERAL ROOTS ON EARLY DEVELOPMENT OF NORTHERN RED OAK ON A MESIC SITE: ELEVENTH-YEAR RESULTS

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Abstract–The effect of initial first-order lateral root (FOLR) groupings of northern red oak (*Quercus rubra*) seedlings on a high quality mesic site was followed for eleven years on a shelterwood and a clearcut area. The initial FOLR number groups were empirically determined as low (0 to 6), medium (7 to 12), and high (12). The shelterwood overstory was removed before the beginning of the eighth growing season and a circle (0.9 meter radius) was released around individual oaks in the clearcut. Individuals in the clearcut responded favorably to release, with some obtaining 6 to 8 meter in height by age 11. After the same period mean height from the shelterwood plantings was about 60 centimeter more than their initial height in 1990. It appears that large thrifty northern red oak seedlings can be established in properly controlled clearcut areas provided post harvest control of stumps is completed in a timely fashion. The shelterwood system with artificial regeneration does not appear to be a viable regeneration alternative as tested here.

INTRODUCTION

The basic tenets for northern red oak (NRO) (*Quercus rubra*) regeneration have been described by Sanders (1971, 1972). Working on lower quality sites in the central states, he clearly established that successful regeneration depended almost exclusively on the presence of advanced oak reproduction when the mature stand was harvested. On sites where the research was completed, faster growing competing species were a minor problem at best. However, obtaining the necessary advanced oak reproduction proved to be time consuming and difficult. Research after Sanders' was directed at various methods of obtaining adequate advanced reproduction by attempting to combine both natural and various combinations of artificial regeneration (Johnson 1993, Loftis 1983). This later research was applied to high quality mesic sites as well as sites comparable to those on which Sanders' research was completed. The use of the shelterwood system to encourage the development of advanced natural regeneration became the norm on these higher quality sites as clearcutting in any form became vilified by many uninformed individuals. In addition, various combinations of root/top pruning of nursery stock were extensively tested to improve their growth performance and, to increase the number of NRO after shelterwood was removed.

Eventually, it became apparent that competition from faster growing species made it very difficult to maintain a viable presence of NRO on the desirable mesic sites and NRO's future on these sites became questionable (McGee and Loftis 1986). Kellison (1993) most recently suggested that if new technology was not soon developed then NRO may become the "California Condor" of the eastern deciduous forests.

The initial objective of this research was directed at determining whether the nursery fertility protocol developed at our research center could produce "advanced oak regeneration" in the nursery in a single growing season. A secondary objective was to determine if a first-order lateral root (FOLR) grading systems previously used for sweetgum could be modified to select the best oak seedlings for outplanting in both a clearcut and shelterwood operation 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 (*Lirodendron tulipfera*) 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 NRO enrichment planting was a small segment of a larger harvested area. The shelterwood area

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Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

was immediately across the road from the clearcut area and had essentially the same species composition. For the underplanting, basal area was reduced by 30 percent to 20.44 meter^2/hectare, primarily by removing the intermediates and suppressed trees from the canopy level and all 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 Institute of Tree Root Biology's (ITRB) Whitehall Experimental Nursery, Athens, GA during the 1989 growing season, using a hardwood nursery protocol (Kormanik and others 1994). The seedlings were lifted during February 1990 and outplanted in March 1990. When lifted, the seedlings were placed in one of three groups, low, medium, and high, based upon FOLR numbers. First-order lateral roots were defined as roots with basal diameter exceeding 1 millimeter along the first 30 centimeter of taproot below the root collar. The low, medium, and high 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 15 centimeter and taproots were pruned to 30 centimeter before seedlings were outplanted.

The clearcut and shelterwood areas were each considered as randomized block design. Eight blocks were laid across the contour in each of the two areas and 10 trees from each FOLR group were shovel planted at 1.5 meter by 3.1 meter spacing in adjacent rows. The spacing was maintained with only minor adjustments due to large stumps. All standing trees, regardless of size in the clearcut area were felled before planting but no subsequent vegetation control measures were taken until the seventh growing season. Mechanical control in the shelterwood area removed all subcanopy trees as well as specific canopy trees overlapping naturally regenerated northern red oak seedlings on the periphery of the planted area. No subcanopy oak was present, but none of the naturally regenerated oak in the main canopy was removed when shelterwood was established. No statistical analyses were performed to compare clearcut with shelterwood because each was an independent randomized block experiment. In addition, no statistical comparisons were done for FOLR groupings due to the presence of stump sprouts and different degree of insect infestation between the two areas.

Survival data were obtained after the first growing season in 1990. Survival, RCD, and height were also obtained after the 5th year (1994) and potentially dominant individual oak in the clearcut were identified. Competing vegetation density was recorded from three positions in each block during the 5th year measurement. Five artificially regenerated trees were excavated after the 5th growing season from both the shelterwood and clearcut areas to examine root development characteristics.

All artificially established individuals in both areas were measured prior to the 7th growing season. In the beginning of the 7th growing season (1997), the clearcut was released with a silvicide by establishing circles of 0.9 meter radius around each remaining dominant or co-dominant planted NRO seedlings. The shelterwood release was delayed until the 8th year prior to the spring flush. Prior to crown removal, all surviving NRO seedlings were conspicuously identified by flagging on the stems and tags attached at ground line to permit post harvest identification. The felling was such that whenever possible the tops were felled toward the outer boundary in an attempt to minimize damage to the surviving seedlings. In winter following shelterwood removal and completion of one growing season, individuals were placed into six groups as follows: 1. dead; 2. undamaged; 3. top one-third stem damaged; 4. top two-thirds stem damaged; 5. stem missing, sprouting from root collar; and 6. stem flat on ground, sprouting along entire length. The entire study was re-measured at this time and again after 3 years post release in January 2001.

RESULTS AND DISCUSSION

Basically, even with supposedly high quality seedlings, the shelterwood method proved to be unsatisfactory on this high quality site. Comparable results have been reported and have resulted in the misconception that artificial regeneration is not a viable option for NRO on those quality sites (Johnson 1993, McGee and Loftis 1986).

Performance of NRO seedlings in the clearcut, was very good even after a very shaky beginning. Indeed, several unanticipated factors significantly affected this experiment. The first, was a massive infestation of the 17 year locust (*Magicicada septendecim*) that severely damaged almost all 240 seedlings in the clearcut toward the end of the second growing season. However, only the artificially regenerated oak seedlings in the clearcut were affected while none of the oak seedlings in the shelterwood were attacked. No other species were damaged by this locust infestaticn. The second factor was the intense competition from untreated stumps and newly germinated seedlings of Carolina silverbell (*Halesia carolina*), red maple, and yellow poplar in the clearcut which continued unabated throughout the pre-release seven growing seasons. The final item, occurred one year post harvest when a leaf mining maggot (*Agromyza viridula*) attached the newly emerging leaf of only the NRO individuals in the clearcut. These maggots essentially eliminated a growth response during the first year post release. In contrast, the individuals in the shelterwood were free of disturbing factors.

Seedling Survival

Survival following the first season was 100 percent in both the clearcut and shelterwood understory plantings for all three FOLR groups of seedlings (table 1). 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 height and lost much of the height advantage over newly germinated competitor species. Mortality rate accelerated during the third season but

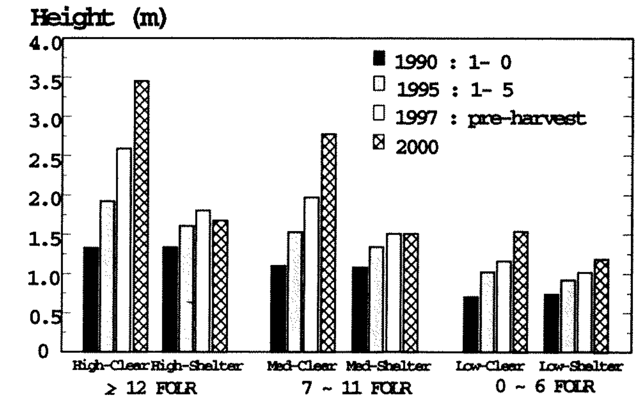

Figure 1–Percentage tree damage by grade in shelterwood planting after shelterwood removal.

stabilized by the initial re-measurement at age 5 (table 1). Seedling FOLR grouping really had no effect upon survival in the clearcut as survival was determined primarily by effects of the locust damage. Intense stump sprout competition also increased mortality in the clearcut site.

In the shelterwood most seedlings from all three FOLR groupings were intact at the 5th year measurement (table 1). A total of 20 trees had not survived in the shelterwood at age 5. Of these 20, 16 were low FOLR group, two in the medium group, and two in the high group. Survival remained relatively constant from the 5th to the 7th growing season for the high FOLR group but the individuals from the medium FOLR group were reduced in number to a greater extent than those from the clearcut (table 1). Survival did not change appreciably between the 5th and 7th year in the clearcut planting area. Release resulted in no accelerated mortality only for high group in the clearcut in the 11th year. Shelterwood removal resulted in considerable mortality in all three FOLR groupings. It also resulted in stem damage that is affecting the competitive potential of the surviving seedlings. The survival as well as the damage categories recognized after canopy removal are shown in figure 1. Less than one-third of the individual stems were undamaged and all others experienced considerable stem damage that will in both the short and long-term affect their survival (figure 1).

Table 1—Northern red oak survival percentages by first-order lateral root groupings from clearcut and shelterwood plantings

	----------Clearcut-------			------Shelterwood-----		
Survival rate	High[a]	Medium	Low	High	Medium	Low
1st year	100	100	100	100	100	100
5th year	68	66	63	98	98	80
7th year	66	63	59	96	78	75
11th year	63	55	48	86	60	68

[a]High = 12; Medium = 7-11; Low = 0-6 first-order lateral root number.

Competitive Status of Natural Regeneration

Most of the naturally regenerated oak seedlings in the clearcut and shelterwood were less than 30 centimeter tall when the study was initiated and few were alive by age 7. Although we did not make an exhaustive survey, naturally regenerated NRO seedlings were rarely observed at year 7 or 11. We do not know whether this situation occurred due to limited mast production or insufficient sunlight for seedling development or both. In neither the shelterwood nor the clearcut, would natural northern red oak regeneration development have been sufficient for this species to be more than a minor or occasional component on this high-quality mesic site. Artificial regeneration in the clearcut has altered this possibility through at least age 11, and indicates artificial regeneration may play a role in maintaining a viable population of NRO on these high quality mesic sites.

Shelterwood

One of the objectives of a shelterwood is to limit sunlight that would encourage development of competing species yet provide sufficient sunlight for the NRO seedlings to become established. The original basal area reduction was effective through the 7th year, such that no low or mid-crown canopies had developed. However, even the high FOLR grade seedlings have not developed satisfactorily either before or post canopy removal. Height growth was minimal and RCD through the 5th year remained essentially unchanged from their initial caliper. The 7th year DBH measurements were unimpressive. The poor performance resulted in the decision to remove the shelterwood before the accelerating decline of individuals worsened. Prior to release, low FOLR group of seedlings was the smallest and they were spindly, although some of these above 1.0 meter might be considered "advanced" reproduction. (Loftis 1983, Sanders and Graney 1993). Characteristics of all shelterwood seedlings is that only a few leaves developed annually throughout the 7 years. Even on the largest seedling, seldom have we observed more than 20 to 30 leaves. Tip dieback has occurred several times on most of the seedlings but dieback to ground level was not observed prior to release. Partial dieback was not associated with any particular FOLR group. Poor vigor of the low and medium FOLR grades appeared to be responsible for mortality that occurred between the 5th and 7th year. The seedlings within a specific FOLR grouping were uniform in size and mortality did not appear to be related to their initial sizes.

Accounting for seedling response post release by FOLR grouping was difficult. This is because seedling damage did not appear to be related to their heights. Thus, when evaluating the shelterwood treatment, we combined all individuals, regardless of initial FOLR groupings for comparing initial seedling heights with 7th year pre-release and 3 years post harvest (table 2). All initial mean heights met or exceeded stem morphological conditions considered acceptable for advanced regeneration of NRO. Oak regeneration is not satisfactory in this shelterwood with a maximum growth response of only 60 centimeter

Table 2—Initial, seventh year pre-harvest and eleventh year post-harvest mean heights and stem condition of northern red oak 3 years after shelterwood removal

	Before Shelterwood Removal		Post-harvest
2000 Stem condition	Initial Ht 1990 (cm)	7th Year Ht 1997 (cm)	11th Year Ht 2000 (cm)
Dead	95	140	0
Undamaged	101	141	163
Top 1/3 stem damaged	105	139	115
Top 2/3 stem damaged	117	160	96
Stem missing - sprouting from root collar	108	145	84
Stem flat on ground - sprouting along length	141	193	103

for 11 years (table 2). These results are typical for NRO responses in a shelterwood and have contributed to artificial regeneration being a questionable recommendation.

Trees excavated from the shelterwood 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 or newly developed seedlings will develop a vigorous root system and be competitive when the stand is harvested even if top is damaged during canopy removal. It has been reported that 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 in NRO and white oak seedlings (Kormanik and others 1995, Sung and others 1998) as well as in loblolly pine trees (Sung and others 1996). Eventually, however, taproots begin to deteriorate and seedling mortality occurs. This unfavorable root deterioration was not observed on the individuals excavated from the clearcut area where photosynthetic active radiation was at least 1500 micromole/meter^2/second. The shelterwood had photosynthetic active radiation levels of less than 5 percent of this.

The pre-release seventh year mean height increases since shelterwood establishment for the high, medium, and low FOLR groups were 50, 40, and 30 centimeter, respectively (figure 2). The tallest seedlings were 280, 200, and 170 centimeter for each FOLR group, respectively. Three years post harvest showed the mean heights remained essentially the same or were reduced somewhat following shelterwood removal (figure 2). All seedlings under the shelterwood developed poorly and pre-release data indicate few seedlings were large enough to obtain DBH measurements. Three years post release DBH development was still unsatisfactory mirroring the lack of RCD growth for the first 5 years under the shelterwood (figure 3).

Clearcut

At age 5 when potential future dominant individuals were selected, the tallest individual from the high, medium, and low FOLR groupings were respectively 5.1, 4.6 and 2.4 meter. However at age seven and before release, only the selected individuals from the high and medium groups were still free-to-grow. Post release response was apparent with 6 to 8 meter trees being present by age 11 with mean heights of the high and medium FOLR grouping being 3.5 and 2.7 meter, respectively (figure 2). Post release DBH development, was impressive with almost a doubling in DBH over a 3 year period (figure 3). This response was in spite of the leaf maggot infestation during year one post release that seriously reduced leaf photosynthesis potential for that entire growing season.

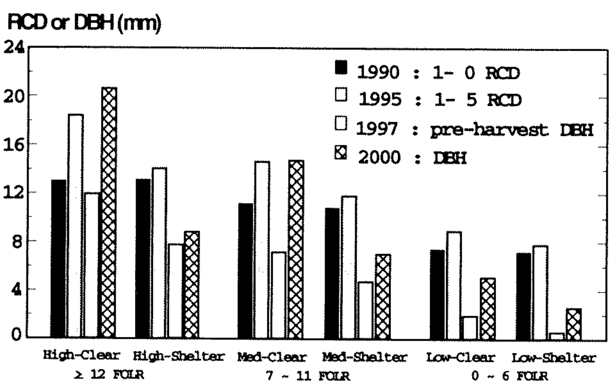

Figure 2–Height of northern red oak planted on clearcut site and under shelterwood.

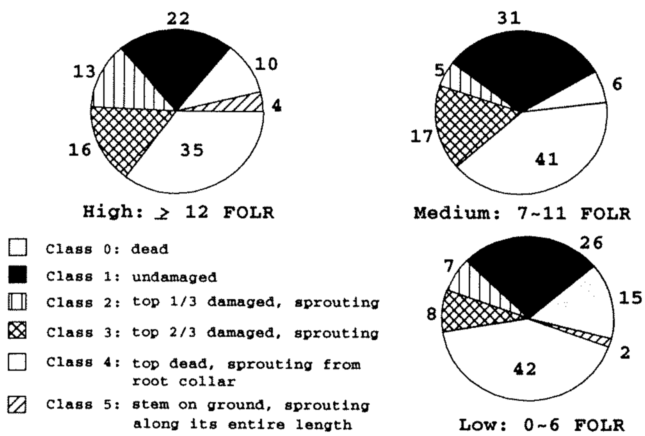

Figure 3–Diameter of northern red oak planted on clearcut site and under shelterwood.

Large differences were observed in all growth parameters among FOLR groups in the clearcut but survival as explained earlier was not related directly to FOLR groups or seedling sizes. All seedlings remained free-to-grow during their first year since stumps had not yet sprouted nor had the newly germinating competitors attained a competitive position. However, between years two and five, rapid growth of stump sprouts and development of new seedlings competitors resulted in steadily increasing competition. When the first re-measurements were made at year five, the artificially regenerated NRO seedlings were competing against 126,800 stems/hectare from 14 different deciduous hardwood species. However, the most severe competition was from stump sprouts of yellow poplar, red maple, and Carolina silverbell which each year became more critical as their rapidly developing crowns began to complete with the slower developing NRO crowns.

The competing vegetation was not re-inventoried prior to release but stem numbers did not appear to have declined much because of the absence of obvious mortality. At pre-release, age 7, competition of the dominant canopy level was primarily due to the rapidly growing stump sprouts. However, NRO individuals were still competing successfully against naturally regenerated seedling. These established small naturally regenerated seedlings did not respond immediately to clearcut and few of them produced more than 3 to 5 leaves either the first or second year following the clearcut and thus, as reported by others, did not benefit from it (Pope 1993).

Many of the large artificially regenerated seedlings remained free-to-grow or codominant until about the end of the 4th growing season unless they were planted immediately adjacent to stump sprouts. These large NRO seedlings that were at least 1 meter tall had a clear early advantage over competitors that began at ground level. During this first year the artificially regenerated oak benefitted from full sunlight and developed a root system required to compete with a wide range of competitors as the new stand developed.

Release at age 7 not only stimulated the NRO seedlings dramatically (figures 2, 3), but also had a comparable effect on the stump sprouts outside the 0.9 meter radius around the released individuals. Three years post release resulted in yellow poplar stump sprouts adjacent to the released individuals developing DBH's of 15 to 20 centimeter and obtaining heights of 6 to 10 meter. They are now, at age 11, clearly invading the NRO growing space. It is encouraging, however, that the potential dominant individuals selected at age 5, are still maintaining crown position with competitors of seedling origin but would benefit from further release to permit broader crown expansion.

CONCLUSION

After 11 years evidence is substantial that large NRO seedlings with adequate FOLR numbers are competitive and can be established on high quality mesic sites. Treatment of stumps prior to enrichment plantings or establishing mast producing areas will be required because even the largest and most competitive seedling cannot compete against stump sprouts on these excellent sites. In the absence of stump sprouts following an effective clearcut and site preparation, large NRO seedlings may not need release until ages 5 to 7 and, perhaps again at 10 to 12 years. Potential dominant trees that were selected at age 5, retained that status after release at age 7. Individual NRO oak seedlings with fewer than 4 FOLR were generally not competitive. Locust borer damage on them could not be ascertained from this study.

As of age 11, response from the shelterwood has not been satisfactory regardless of FOLR grouping. Neither height growth nor stem caliper have been acceptable compared to the clearcut response. The shelterwood site will be remeasured at 5 years post release. This will afford a comparison to the original clearcut at age 5 to determine to what degree the potential competition has developed since the shelterwood was removed. It appears unlikely, based on the ecology at these mesic sites, that any shelterwood type could be depended upon to establish NRO regeneration: too little sunlight and NRO will not grow or sufficient sunlight and the competitors will multiple rapidly. The question of what is too much overhead cover remains an open question and how to regulate competition to maintain NRO in a competitive position is difficult to ascertain. Certainly full sunlight is the best choice for NRO regeneration.

Neither shelterwood nor clearcutting in conjunction with the best most competitive NRO seedlings available will likely succeed in establishing this species on the desirable mesic sites without both mechanical and chemical control of competitors applied in a timely and effective schedule. Continued restriction in harvesting and chemical control of competitors may indeed contribute to NRO attaining the status of "California Condor" in the eastern deciduous forests as some have predicted (Kellison 1993).

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