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GROWING, SELECTING, AND ESTABLISHING 1-0 *QUERCUS RUBRA* AND *Q. ALBA* SEEDLINGS FOR RAPID GROWTH AND EARLY ACORN PRODUCTION ON FORESTED LANDS IN THE SOUTHEASTERN UNITED STATES

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Introduction

Northern red oak (*Quercus rubra* L., NRO) and white oak (*Q. alba* L., WO) are among the most valuable oak species in the eastern United States and throughout the eastern provinces of Canada. They have a broad geographic distribution; yet no single regeneration mechanism can explain their presence in current stands. Both species are declining in numbers and importance on high quality mesic sites throughout their range. Many scientists feel NRO may become threatened or endangered on these sites unless new regeneration techniques are developed (Kellison 1993). The status of WO is not as critical because it can develop on poorer sites than NRO. Nevertheless, its competitive position on high quality sites is precarious.

These two species often coexist in natural stands in the US. Many oak-dominated stands originated because of human activity or biological catastrophes such as the chestnut blight caused by *Cryphonectria parasitica* ((Murr.) Barr). This disease resulted in the decimation of American chestnut (*Castanea dentata* (Marsh.) Borth.). Also, past land use, harvesting practices, and fires have enabled these oaks to occupy broad geographic and physiographic ranges (Abrams and Norwacki 1992). Currently, whether NRO stands are harvested, or whether the trees have succumbed to other disturbances such as gypsy moth (*Lymantria dispar* L.), new stands are not becoming established. However, a method used for [illegible] on low quality sites [illegible] dominant and co-dominant trees at age 50) reliably produces new stands composed of stump sprouts and individuals of seedling origin (Sander 1972). The procedure consists of thinning the mature stands to specific densities, then allowing oak seedlings to regenerate under the canopies. Once the desired seedling densities and sizes are obtained, the overstory canopy is removed. This shelterwood technique popularized the term "advanced oak regeneration" and specified the widely accepted minimum seedling stem height of 1 m in the eastern and central US. Others tried to modify Sander's low-quality site shelterwood prescription for use on high quality mesic sites. The results showed that shade tolerant species, as well as yellow poplar (*Liriodendron tulipifera* L.), responded well to these shelterwood modifications, but oaks did not (Loftis 1983).

Sander's (1972) system proved effective on the low-quality sites, especially with WO, because faster growing competitors to the oaks were absent or at minimal levels on these sites. A disadvantage was that at least 10-20 years might be needed to build up the necessary advanced oak regeneration. To shorten this regeneration cycle, attempts were made to incorporate artificial regeneration on the low-quality upland sites, as well as on high-quality mesic sites (Johnson 1993). On high-quality sites, however, severe competition from faster growing and/or more shade tolerant species (Barton and Gleeson 1996; Crunkilton et al. 1992) and the absence of high quality oak planting stook prevented artificial regeneration from being a practical endeavor. As needs of diversified management options gained in importance, the declining numbers of these two important species became of considerable concern among forest managers. This situation has lead to a resurgence of interest in oak management throughout the US.

Our goal in this oak research was to develop a reliable regeneration technology for establishing several species of oak on high-quality mesic sites in the southeastern US National Forest lands. The goal of this management technology placed equal consideration to timber values and to mast production needed for wildlife management efforts. As was amply demonstrated during the 2003 International Oak Society meeting, there are countless other landscape uses of oak that can employ other specific morphological attributes. These other attributes are not necessarily suitable for successful forest regeneration where vegetation competition can be severe.

Initial research with northern red oak

In the early 1980's, concern grew about the failure of NRO and WO to regenerate on high quality mesic sites through their ranges in North America. One of the questions asked was whether ectomycorrhizal fungi could improve establishment of these oaks as much as has been repeatedly demonstrated with various coniferous species (Marx 1991). From the beginning, research clearly demonstrated that various ectomycorrhizal fungi would readily colonize oaks under controlled, sterile conditions. However, the 1-0 stock produced did not attain the size desired for artificial regeneration use. For several years, countless oak seedlings were grown at the experimental nursery maintained by the Institute of Tree Root Biology of the US Forest Service under different nursery protocols. As seedling quality gradually improved, it became evident that a better method of evaluating seedling quality would have to be developed. The traditional mycorrhizal index used so successfully in conifer studies (Marx 1991) was inadequate for oak seedling quality evaluation. What was readily apparent was that seedlings could have comparable mycorrhizal indices, but be significantly different in seedling development and outplanting performance. Gradually, it became clear that while the percentage of feeder roots colonized by ectomycorrhizal fungi was important to seedling development, the number of first-order lateral roots (FOLR) was the essential factor in determining seedling field performance. Simply stated, higher FOLR numbers resulted in more mycorrhizal short roots for absorbing soil moisture and nutrients. However, in spite of nursery soils being artificially inoculated with specific ectomycorrhizal fungi, the nursery protocols used then rarely produced 1-0 oak seedlings with the necessary minimum root collar diameters (8 mm) and heights (0.8 m) for outplanting.

Development of a nursery base-line fertility protocol

During the initial phase of working with oaks, we found that few seedlings had more than three growth flushes the first year in the nursery beds. Tight terminal buds were usually present by late July. Over a period of three to four years we developed a nursery baseline fertility protocol that characteristically produced many 1-0 seedlings with five to seven flushes. Final heights and root collar diameters could exceed 1.0 to 1.25 m and 12 mm, respectively. With slight modifications, this protocol is effective for most hardwood species and has been used on 17 other species of oaks. Briefly, the extractable soil nutrient concentrations are adjusted to maintain Ca at 500, K at 130, P at 100, Mg at 75, Cu at 0.3-3, Zn at 3-8, and B at 0.4-1.2 ppm. From 900 to 1350 kg/ha of NH_4NO_3 is top-dressed in increasing increments over the growing season. From 50 to 170 kg N/ha is applied at 10-14 day intervals until 6 to 7 weeks before the first frost is expected (Kormanik et al. 1994).

With this baseline fertility procedure, approximately 30 to 35 days are required for the sequence of bud set, bud swelling, bud break, stem elongation, leaf expansion, leaf maturation, and bud set in various oak species in our area (Sung et al. 2002, 2004). Irrigation is provided throughout the growing season when rainfall is less than 2.5 cm per week and is reduced after mid-October. Irrigation is stopped when the leaf abscission zone develops after several frosts.

Initial attempts on up-scaling seedling production to larger commercial forest seedling nurseries proved [illegible] who had successfully grown conifers for many years were reluctant to modify their nursery procedures to accommodate the biological requirements of oaks. Currently commercial up-scaling of this nursery protocol has been successfully used in three different forest tree nurseries.

Biological considerations in oak seedling production

Perhaps the most common cause of nursery failures in producing seedlings [illegible] the standard for outplanting is mishandling of the acorns. Only sound, weevil-free acorns which have not been desiccated should [illegible] production. Acorns are recalcitrant and when permitted to desiccate, they will either not germinate or, if they do germinate, will produce inferior grade seedlings. This is especially true for WO which rapidly desiccates upon radicle protrusion. This rapid radicle elongation is, of course, most pronounced with WO since no stratification period is required for germination. [illegible] that protrude and elongate in storage are readily broken, a circumstance that can result in multiple taproots. Seedlings exhibiting this condition frequently develop poorly, both in the nursery and after outplanting for at least six years (PP Kormanik, personal observation).

A major consideration in producing quality oak seedlings in our geographical area is to maintain the 30 to 35 day [illegible] the main seedling canopy is 0.75 to 1.0 m. Buds should not be permitted to become dormant until the desirable height is obtained. If either the irrigation or nitrogen top dressing schedules are ignored, the buds can become dormant, and then it can be extremely difficult to stimulate bud break again. In fact, permitting premature bud set and sowing acorns which may have been desiccated are the major causes of substandard seedling sizes. The development of WO is significantly slower than that of NRO and seedlings frequently need more seasonal top dressing and irrigation than NRO seedlings to obtain sizes desirable for artificial regeneration.

Maintenance of soil moisture has proven to be essential even long after fall leaf coloration occurs. In early December, even though the green chlorophyll coloration appears diminished, photosynthesis in NRO and WO continues at 30 to 60% of the summer activity until 4 to 6 weeks after the first frost, when abscission layers finally develop (SS Sung, personal observation). During this period, growth has stopped and starch is being stored in taproots and stems. If soil moisture is not effectively managed, the leaves may wilt and the accumulation of starch reserves needed in the spring is seriously impacted.

Development of a biologically based seedling grading system

When consistent seedling production meeting the desired standards was achieved, a biologically-based seedling grading system was developed using FOLR numbers similar to that used earlier for loblolly pine (*Pinus taeda* L.) (Kormanik et al. 1990) and sweetgum (*Liqudambar styraciflua* L.) (Kormanik 1986). Heritability estimates for FOLR numbers were as high as 0.898 and 0.918, with standard errors as low as 0.153 and 0.073 for NRO and WO, respectively (Kormanik et al. 1999). Seedlings with more FOLRs usually grow more in height and root-collar diameter than those with few or no FOLRs. Thus, we developed a minimum acceptable seedling morphological grading standard for outplanting in a forest situation. For both NRO and WO the standard is 6 FOLR, 8 mm root-collar diameter, and 0.75 m height. There is a significant difference in morphological development between the best 20% and the poorest 20% of the seedlings, even from among the best half –sibling (half-sib) progeny groups as shown in Figure 1. Usually about 40 to 60% of seedlings from most properly handled seedlots meet the specifications.

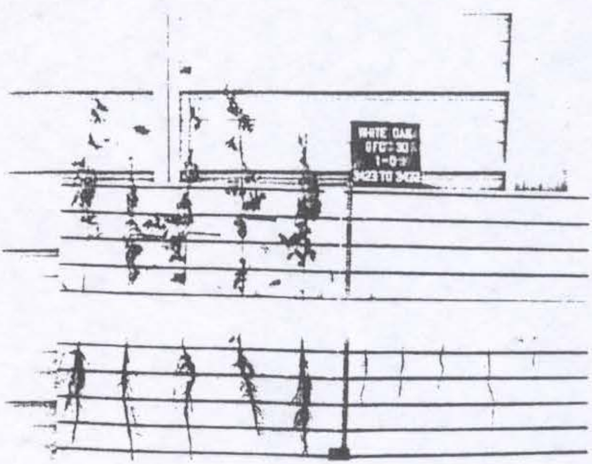

Figure 1. 1-0 *Quercus alba* seedlings grown with a nursery baseline fertility protocol in the southeastern US. Seedlings on the left of the meter stick were

Outplanting of northern red oak and white oak

One of the most frequent causes of poor growth and development of NRO and WO seedlings is maintaining too dense an overhead canopy. There has long been a misconception that, even though stem development is poor in understory conditions, seedling root systems are rapidly expanding and will be of benefit when the seedlings are eventually released. We have found this not to be the case. We have examined countless oak seedlings outplanted under different light conditions and excavated them to examine root development after several years. One of the studies is shown in Figure 2 where one-year-old (1-0) NRO seedlings were planted either under a hardwood canopy with a 7 m^2 basal area or in a clearcut site. The FOLRs of the underplanted seedlings began to atrophy and within a few years only the taproot remained (Figure 2A). At this point, canopy removal may afford little benefit to the deteriorating seedling, and recently developing competing vegetation will dominate the site after release. In contrast, seedlings planted in a clearcut site have grown immense root systems (Figure 2B).

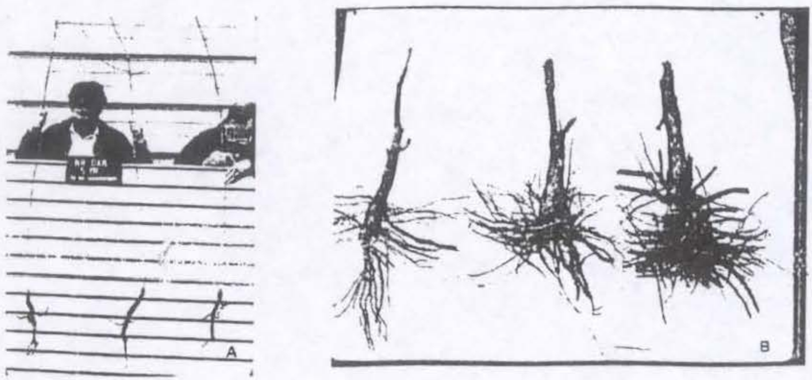

Figure 2. (A) Plants of *Quercus rubra* underplanted in a stand with a 7 m^2 basal area after five years; (B) Roots of *Q. rubra* planted in a clearcut site after five years. All individuals were of comparable size as 1-0 planting stock.

In another experiment, NRO and WO seedlings grown in full sun for two years allocated much more biomass, in absolute amounts and in percentages of total biomass, to lateral roots and to leaves than did seedlings grown under 70% [illegible] cohorts growing in the understory seldom survive more than just a few years. Examination of their root systems typically shows the same root atrophy we observed in our understory planting studies.

On high quality mesic sites, mixtures of NRO and WO dominate the site if overhead competition is eliminated during the first three years after planting (Table 1). Depending on the site, if the woody sprout competition is controlled for three years, [illegible] need only minimal control because the tree crowns will rapidly close when seedlings are planted at 3.5 x 3.5 m spacing.

Table 1. Fourth year performance of a mixed *Quercus rubra* (NRO) and *Quercus alba* (WO) stand in Brasstown Ranger District of the Chattahoochee National Forest, Blairsville, Georgia, USA. The stand was established with 1-0 seedling stock in March 1999.

Species	Survival, %	Height, cm			Diameter at breast height, mm		
		Mean	Max	Min	Mean	Max	Min
Quercus rubra	99	293	440	45	23	44	0
Quercus alba	95	246	410	10	15	39	0

The advantage of these rapidly growing oak seedlings is that their exceptional early vigor may activate genes that control flowering response (Zimmerman and Brown 1971). Thus, by selecting the largest individuals with the largest root system, we have been able to develop individual seedlings that begin acorn production at a very early age. However, not all individuals with large FOLR numbers are precocious acorn producers. We have established a second generation NRO seed orchard from an existing 20-year-old planting that contains a number of individuals that are consistent acorn producers. Approximately one third of the half-sib progeny from this second generation planting have produced multiple acorn crops between year 6 and their current age of 11. Furthermore, good acorn production has been achieved from a second generation WO planting. Some WO seedlings have been consistent acorn producers since age 6. Half-sib progeny from some of these early acorn producers are now well established in a third generation seed orchard and are being monitored for precocious acorn production. Most importantly, from a forest management perspective in the US, trees that have the best form and are fastest growing appear to produce acorns at an early age. Early acorn production is very critical for the management of NRO and WO on even small woodlands in the US. While oak timber has great economic value, much emphasis is now placed on hard mast production for wildlife management considerations.

Conclusions

Selecting oak seedlings possessing the best root systems and the most desirable stem characteristics for outplanting in natural forested areas can also lead to acorn production in less than 10 years. Major problems in obtaining large, vigorous seedlings are acorn desiccation prior to sowing and allowing early bud set in the nursery. The latter is caused by inconsistent top dressing and irrigation practices following seed germination. Our results indicate that NRO and WO thrive best in the absence of competing vegetation and in full sunlight. The commonly held belief that young NRO and WO seedlings thrive in the understory prior to overstory removal may not be scientifically accurate and should be [illegible]. Although more defining research is needed to fully understand oak carbon metabolism under varying overhead canopy [illegible] current research indicates that root atrophy occurs under sub-optimal light conditions.

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