OAK SEEDLINGS: *QUALITY* IMPROVED AVAILABLE NOW— *GENETICALLY* IMPROVED AVAILABLE SOON

S.E. Schlarbaum
Department of Forestry, Wildlife & Fisheries
The University of Tennessee
Knoxville, TN 37901-107 1

P.P. Kormanik
USDA Forest Service
Southern Research Station
Carlton Street
Athens, GA 30602

T. Tibbs
USDA Forest Service
Southern Research Station
1720 Peachtree Road
Atlanta, GA 30367

L.R. Barber
USDA Forest Service
Southern Research Station
P.O. Box 2680
Asheville. NC 28802

Technology for obtaining natural oak regeneration on low quality upland sites, e.g. site indices of 60-65 or less, was developed in the Central States region and has been successfully applied throughout the eastern United States (Sander and Graney 1993, Clark 1993, Sander 1972). Modification of this technology for use on high quality mesic sites, productive coves and bottomlands generally has not been successful, and alternative technology for regeneration on high quality sites needs to be developed (Clark 1993). On these better sites, competition from faster growing tree species and other vegetative components develop more rapidly than oak, regardless of species, when adequate sunlight reaches the forest floor.

Much has been written about natural regeneration problems of oaks on high quality sites, and entire symposiums have been directed toward attempting to clarify the problem (Loftis and McGee 1993). Despite repeated attempts, only very limited success has been achieved on good upland sites (Fosbroke 1987). Several basic factors underly natural oak regeneration, some of which have been ignored or minimized. These factors are (1) variability of site requirements among oak species, (2) periodicity of acorn crops, (3) shade intolerance, and (4) slow initial growth.

Site requirements of oak species. There are over two dozen oak species considered to be of importance in forest and wildlife management (Bums and Honkala 1990). The common usage of oak as a generic term often masks specific site requirements of individual species (Smith 1993) and infers that oak regeneration is a common problem to all oak species on all sites. In reality, this generalization can only be applied to a few species of oak (e.g. northern red oak (*Quercus rubra* L.) and white oak (Q. *alba* L.)) growing on certain sites (e.g. high quality mesic or bottomland).

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Periodic@ of acorn crops. In natural conditions, the occurrence of large acorn crops is cyclical in a number of species (Sork and Bramble 1983) and can be a major obstacle to regeneration. Furthermore, studies have shown that fewer than 30 percent of the crop may result in viable seedlings (Beck 1970). Successful germination and initial survival is dependent upon many factors including initial viability, acorn and seedling predation, and environmental conditions.

Slow growth of oak seedlings. Through getmination characteristics, the white oak species group (*Leucobalanus*) has a distinct advantage over the red oak species group (*Erythrobalanus*) in initial establishment. White oak acorns germinate rapidly and then are protected by leaf fall. Under favorable conditions, the radicles become well established infhe organic layer and soil surface and thereby, assist in preventing desiccation of the cotyledons. Therefore, it is not unusual to find a carpet of white oaks on the forest floor in the spring season following a large white oak acorn crop. Red oak acorns, in comparison, lay on the forest floor for extended periods without germinating. During this long exposure period, the danger of excessive moisture loss is a constant threat and can prevent germination even in good seed years (Korstian 1927). Additionally, the risk of predation that could affect germination is greater. In contrast to white oak, a profusion of red oak seedlings are rare, even in spring seasons after a heavy acorn crop. Despite this advantage, white oak seedlings initially grow slower than red oak seedlings.

The characteristically slow growth of newly established oak seedlings will eventually result in suppression on good mesic sites, i.e. site index >65. The suppression may be due to competition from aggressive competitors, e.g. yellow-poplar (*Liriodendron tulipifera* L.) in an open site (clearcut or natural disturbance), or from increased loss of reserves from reduced levels of sunlight if a partial canopy (shelterwood) remains over the site. Suppression is a minor problem on poor sites, where seedlings can compete with surrounding vegetation.

Repeated examination of seedlings in reduced light levels reveals the gradual demise at the population level (Sung et al. 1997). Under a full canopy, where less than 5 percent of full sunlight reaches the forest floor, decline can be readily predicted. Photosynthesis cannot replenish metabolic losses in young seedlings with limited root reserves. The tenaciously surviving seedlings generally resemble newly germinated ones in having seldom more than 2-5 leaves develop and corresponding root collar diameters less than 3 mm. In some situations where partial sunlight reaches the forest floor in its daily cycle, a few seedlings may survive. Even if suppressed seedlings are released through thinning procedures or harvesting, they have a low probability of achieving a competitive growth rate and eventually becoming a significant component of the next stand on high quality sites.

Studies have shown that two growth characteristics of oak seedlings may be primarily responsible for the initial slow growth. Although these growth characteristics have been identified, there have not been sufficient studies to provide more than a limited description. Newly established oak seedlings allocate a significant proportion of their photosynthates to early root expansion at the expense of early height growth. The second characteristic is a stress reaction that newly released oaks experience and may endure for an extended 2-3 year period. During the transition period from germination to dissipation of stress, newly germinated competitors and stump sprouts rapidly overtop the newly released oak seedlings. The oak seedlings then undergo gradual senescence as metabolic losses exceed photosynthetic input and seedling dieback and/or mortality eventually follow.

BIOLOGICAL LIMITATIONS TO NATURAL OAK REGENERATION

It has long been reported that obtaining regeneration of oak under an oak canopy, regardless of species, has been difficult (Kellison 1993). Kellison (1993) concludes that efforts to get oaks to succeed themselves on upland mesic sites may be unnatural and may result in reduction in future stand quality. Due to the above growth characteristics of oak seedlings, it is doubtful that any partial thinning to encourage oak regeneration, e.g. shelterwood, will be successful if subsequent competition control is not used.

Given the bleak outlook for natural regeneration of oaks via seedlings on good upland sites, is there any value in discussing the virtues of artificial regeneration ? We believe there is hope for artificially regenerating oaks, based upon recent advances in nursery technology and a better understanding of oak seedling physiology (Kormanik et al. **1994a;** Sung et al. 1997).

ARTIFICIAL REGENERATION OF OAKS THROUGH ENRICHMENT PLANTING

Seedling physiology and nursery protocols. Until recently, forest tree nurseries produced oak seedlings in a similar fashion **as pine** seedlings. The emphasis was to facilitate planting, and the resulting small size almost ensured that the **seedlings** were overtopped soon after outplanting and thus suffered the same fate as the small natural seedling **component.** This production mentality is slowly changing due to the **repeated** failures of upland **oak** plantings in southeastern North American and the development of new nursery protocols based on seedling physiology (Kormanik et al. 1994b). Application of these nursery protocols on oak species results in 1-O seedlings of 11 meter in height with root collar diameters exceeding 8 mm. In contrast, seedlings of this size may take 10-l 5 years to produce in the forest.

Oak seedlings from bulked **seedlots** or genetic families that are produced under these nursery protocols show a wide range in variation for height, number of flushes, root collar diameter and number of **first-order** lateral-roots **(FOLR)** (Ruehle and Kormanik 1986). Therefore, seedling grading is a necessary component of the production system to ensure distribution of only the best quality seedlings, i.e. seedlings that have the potential to compete with surrounding vegetation.

Perhaps the greatest difficulty facing oak regeneration on high quality mesic sites is the failure to appreciate the importance of carbon cycling within the seedling. Severe pruning of root systems to facilitate planting (e.g. pruning of the tap root to less than 8 inches) is counterproductive, as is top pruning to reduce shipping costs. A significant reduction of the root system correspondingly reduces the amount of energy available for initial growth after the dormant season. Top pruning reduces the total seedling height and makes the seedling more susceptible to overtopping and suppression. Research has shown that top or root pruned seedlings can survive and exhibit satisfactory growth rates on low quality sites after outplanting (Weigel and Johnson 1997). However, when the site index is high enough to favor yellow-poplar, these practices are deleterious to survival and growth in the long term.

Field studies using graded oak seedlings. Recent reports demonstrate that by planting the top 50 percent of a nursery seedling crop, based on FOLR numbers, results in a height advantage over most of the competing vegetation on mesic or bottomland sites for up to 5 years (Kormanik et al. 1995, Kormanik et al. 1997). This **5-**year period has been sufficient time for the oaks to develop a massive root system needed to sustain height growth.

Currently, there are a small number of studies established throughout southeastern North America using graded oak seedlings. The majority of these plantings contain northern red oak, although white oak and cherrybark oak studies have been established. In northern red oak, second year heights of 2-3 m are not uncommon and fifth year heights of 5-6 m have been obtained. In general, survival'has been excellent. Myriad problems have been encountered in these plantings, ranging from deer browse; vole, insect and frost damage; and an unplanned fire (Lay et al. 1997). These challenges to successful oak regeneration, plus the eventual competitive challenge from stump sprouts and yellow-poplar, will be the subjects of future silvicultural research on these specific study areas.

Consistent supply of acorns. Currently, most forest tree nurseries depend upon acorn collections from natural stands to generate oak seedlings. As previously indicated, acorn production is cyclical with variation among the oak species. In poor seed years, nursery managers often solicit acorns from any source, regardless of potential problems with local adaptation. Seedling-based seed orchards, however, maybe a solution to this situation. lust as new technology has eliminated seedling quality as a hurdle to **artificial** regeneration, development of oak seed orchards may minimize the problem of long and unpredictable years between viable acorn crops-a prerequisite to a viable artificial regeneration program.

Research on the biology of acorn production is currently underway in a 24-year old northern red oak seedling orchard on the Watauga Ranger District of the Cherokee National Forest (Schlarbaum et al. 1993). This seed orchard was originally a Tennessee Valley Authority progeny test that reverted to the USDA Forest Service's control in the **early** 1980's. The Southern Region's Genetic **Resources** Program converted the orchard in 1987. Cooperative **studies a**mong the Forest Service, University of Tennessee and Tennessee Division of Forestry on insect predation a**nd d**iversity, flower and acorn production and seed quality were initiated in 1989 and continue today. The research has identified genetic families that bear acorns at an early age and individual trees within families that have producedcrops for 9 consecutive years. At age **20,** the orchard yielded enough acorns to produce over 300,000 **seedlings.**

Generic improvement in oak species. Genetic studies of oak species have been limited by some of the problems affecting regeneration. 'Seed collections for progeny tests have been hampered by variable acorn production in different portions of a species' range. Production of small planting stock, coupled with slow growth, has generated survival problems and high costs associated with plantation maintenance. Nevertheless, published **reports** have shown that growth is a heritable trait in the oak species that have been studied, and genetic gains are possible **(LaFarge** and Lewis 1987, Rink and Coggeshall 1995). Improvement of growth rates in seedlings translates to a competitive advantage in field plantings; critical to successful **regeneration** per the above discussion.

Currently, few clonal and seedling seed orchards of different oak species exist in North America (Schlarbaum et al. 1994). Although genetic gains can be calculated for each orchard, the key to realizing those gains is seed production by all genotypes. Observations on clonal and seedling seed orchards of northern red oak show genetic variation among families in flowering, frequency of flowering, and level of flowering (Schlarbaum et al. 1993). Management protocols to induce consistent flowering of all genotypes have not been developed. An additional factor affecting crop production is protection from pests (Barber 1994, Grant et al. 1994). With the exception of northern red oak, virtually nothing is known about pest management in seed orchards of different oak species. The integration of genetically improved oaks ultimately will be dependent upon current and future seed orchard management research.

ENRICHMENT PLANTING AS OPPOSED TO PLANTATION FORESTRY

Plantation forestry is economically desirable and biologically important for pine on many sites. It may not be ideal, however, for many high quality **mesic** sites supporting valuable hardwoods. Many different biologically diverse hardwood species develop rapidly after harvesting on such sites. This diversity acts as a biological buffer against significant natural calamity from a host specific insect or disease epidemic that can map havoc on a forest comprised of a single species or a group of closely related species.

Using the above nursery and grading protocols, it is feasible to introduce the best nursery stock to high quality sites and anticipate survival and competitive growth with less desirable species. These selected hardwood seedlings usually are equal to or larger in size than natural seedlings following a regeneration cut from 10 years ago. In one such enrichment planting, **five** species of **hardwoods—(*Quercus falcata var. pagodifolia* Ell.),** swamp chestnut oak **(*Quercus michauxii*** Nutt.), water hickory **(*Carya aquatica*** (Michx. f.) Nutt.), green ash

(*Fraxinus pennsylvanica* Marsh.) and sweetgum (*Liquidambar styraciflua* L.)[1]—were simultaneously established in one area with each species' survival exceeding 90 percent after four years. All species are competitively growing among seedlings of other species from natural regeneration. Depending on how diverse a species population is desired, no more than 60-80 individuals of desirable species have to be outplanted per acre.

Although research on enrichment planting to supplement natural reproduction is in its infancy, the results have been favorable. However, it may require a change in regeneration mentality of the forestry profession for the benefits of enrichment planting to be realized.

CONCLUSIONS

For fifty years, oak regeneration studies have been replicated in time and place on high quality sites with less than even marginal success. The recognition of the biological limitations of oak seedlings has stimulated a multi-faceted research effort directed toward successful artificial regeneration on high quality mesic sites. Although the experimental field plantings are quite young and the need for addition silvicultural treatment is indicated, the high survival and excellent growth offer encouragement for further research on silvicultural procedures. Development of these procedures should permit maintenance of a viable oak component on these sites. Integration of genetically superior stock should further ensure an oak presence on all sites in eastern North American forests.

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