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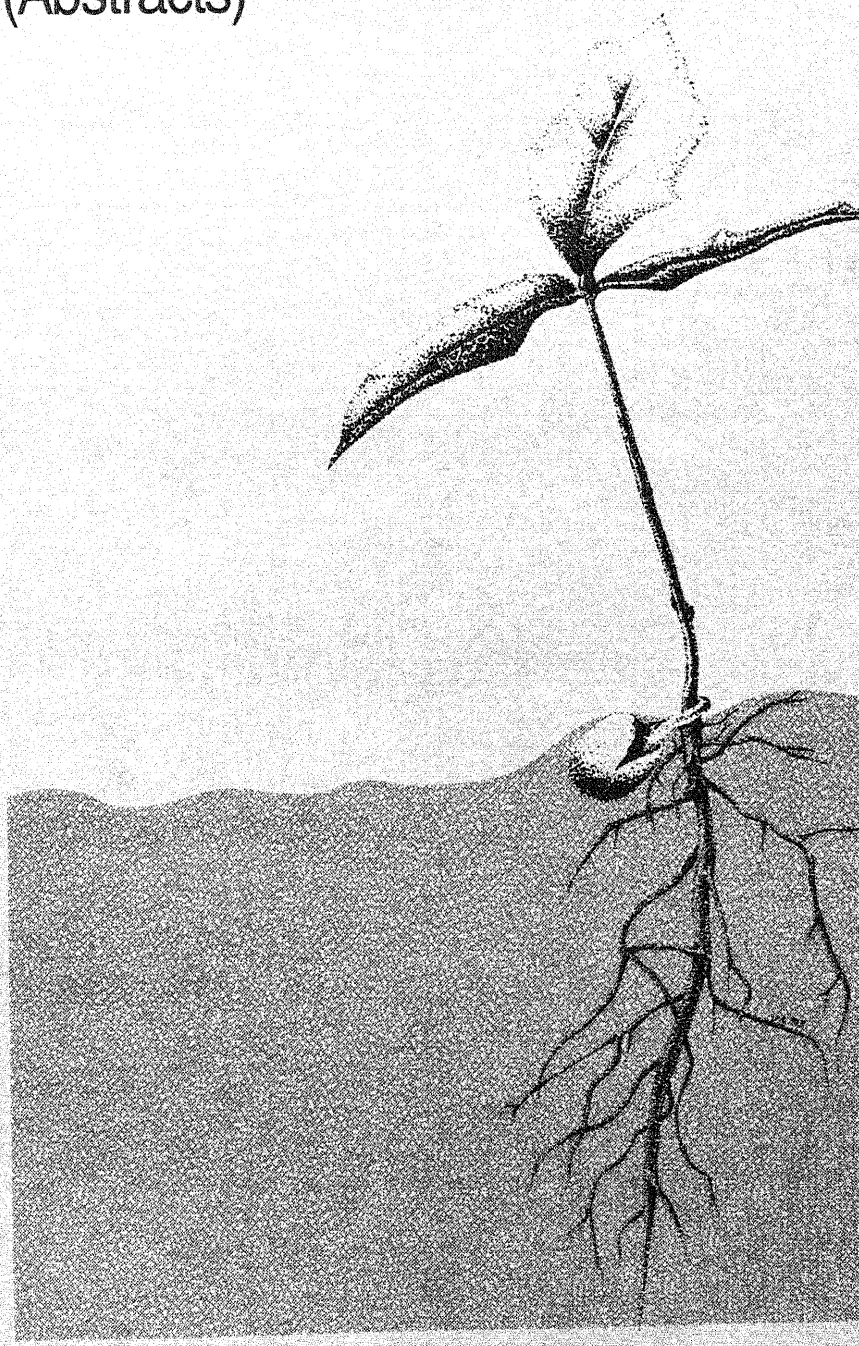
(Abstracts)



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Research results and ongoing research activities in field performance of planted trees, seedling propagation, physiology, genetics, acorn germination, and natural regeneration for oaks are described in 30 abstracts.

KEY WORDS: Plantations, progagation, regeneration.

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FIFTH WORKSHOP ON SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTINGS, AMES, IOWA, MARCH 4 and 5, 1992 (ABSTRACTS)

Edited by
Janette R. Thompson, Richard C. Schultz,
and J. W. Van Sambeek

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PREFACE

The fifth workshop on seedling physiology and growth problems in oak plantings was held at the Holiday Inn Gateway Center in Ames, Iowa on March 4 and 5, 1992 with more than 45 participants. The workshop continues to serve as an informal forum for researchers to exchange ideas and research results. Papers were divided into four general subject areas: (1) field performance of planted oaks, (2) seedling propagation and production, (3) oak physiology and genetics, and (4) natural and acorn germination regeneration. All abstracts prepared for the workshop are included in this technical report.

ACKNOWLEDGMENTS

Richard Schultz and Jan Thompson, workshop coordinators, gratefully acknowledge the assistance of the following session moderators: Robert Cecich, Jud Isebrands, Paul Johnson, Paul Kormanik, George Rink, Patricia Tomlinson, and Peter Williams. Support from the Department of Forestry, Iowa State University, and the North Central Forest Experiment Station is also gratefully acknowledged. Workshop participants appreciate the willingness of Jud Isebrands and coworkers at the North Central Forest Experiment Station in Rhinelander, Wisconsin, to host the sixth workshop in the fall of 1995.

REVIEW PROCEDURES

Each abstract in this general technical report was critically reviewed by at least two of the three editors. Revised abstracts were reviewed by each author and then submitted camera-ready to the North Central Forest Experiment Station, USDA Forest Service, for publication. Individual authors are ultimately responsible for the accuracy of their papers.

DISCLAIMER

Mention of pesticide, fertilizer, equipment or trade names does not imply endorsement of these products or their applications by the USDA Forest Service or Iowa State University.

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IMPACT OF DEER BROWSING, OVERSTORY DENSITY, AND COMPETITION ON SURVIVAL AND DEVELOPMENT OF PLANTED NORTHERN RED OAK SEEDLINGS

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In northwestern Pennsylvania, maturing oak stands on high-quality sites frequently fail to reproduce new stands with a significant component of northern red oak (Quercus rubra L.). In 1988, we initiated a study to identify the biological factors that control the establishment and development of oak seedlings, and to determine how these limitations might be manipulated to encourage red oak in second-generation stands.

Study installations were located within the Moshannon State Forest and within the Allegheny National Forest on the unglaciated section of the Allegheny Plateau in northwestern Pennsylvania. The basic experimental design included six 4-acre cutting plots replicated seven times. The overstory on two plots was cut to 60% relative density, two plots were cut to 40% relative density, and two plots were not cut. One plot of each overstory density was fenced to exclude deer. Half of each plot was broadcast-treated with glyphosate to control herbaceous cover and competing hardwoods. This arrangement of treatments produced twelve 2-acre plots. Following the cutting, twenty-four 2-0 red oak seedlings were planted on each plot, and evaluated annually for survival, height, and deer damage.

Interim results show that deer browsing has decreased seedling survival and height growth at both installations. At the Moshannon site, 97% of the unfenced seedlings were severely browsed, which reduced survival from 97 to 42%. At the Allegheny site, 84% of the unfenced seedlings were browsed, with a resulting decrease in survival from 96 to 85% after 2 years. At both sites, the annual increase in height of unprotected seedlings has been negligible. Overstory-density treatments affected seedling development only where seedlings were protected from deer browsing. Increased light levels increased growth of protected seedlings only during year 2. Where the overstory was reduced to 40%, strong competion from fast-growing hardwoods has developed and is beginning to overtop the planted oak seedlings. Light levels had no effect on survival of protected or unprotected seedlings. Control of competition with glyphosate did not influence seedling height or survival in either of the two years.

This study clearly shows that it is futile to plant northern red oak in northwestern Pennsylvania without protecting the seedlings from deer. In addition, reducing the overstory density below about 60% will stimulate strong competition from other faster growing hardwoods which can overtop the slower growing oak seedlings in two growing seasons.

FIRST YEAR SURVIVAL AND GROWTH OF UNDERPLANTED NORTHERN RED OAK SEEDLINGS IN SOUTH CENTRAL IOWA

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A study was initiated in 1991 to determine survival and growth of undercut 1-0 northern red oak (Quercus rubra L.) seedlings underplanted in mixed hardwood stands following removal of all non-oak species. The study was located in two upland mixed hardwoods locations of 2.3 ha each. The site index for both locations was 21.3 m with an average stocking level of 14.1 to 15.9 m^2/ha after cutting. Fifteen square blocks, 46 m on each side, were laid out in August 1990 with seven of the blocks receiving herbicide. In the winter of 1990-1991, all non-oak trees were removed and their stumps were treated with Tordon RTU. Treatment areas were established during the spring of 1991. In the areas to be underplanted, ten seedlings from each of the following root classes were planted: 0 to 4, 5 to 9, and 10 or more first-order lateral roots (greater than 1 mm). Each root class was planted in a randomly assigned row. Tubex tree shelters were randomly placed on the first group of five or second group of five seedlings in each row.

Based on first year results, spraying, tree shelters, and the number of lateral roots appear to be important in the establishment of underplanted red oak seedlings. Spraying significantly reduced undesirable seedling competition by 42%. Seedlings planted in tree shelters had 128% better average height growth, and had a 7% better survival rate than seedlings without shelters. Seedlings with 10 or more first-order lateral roots outperformed seedlings with 5 to 9 first-order lateral roots by 70% and seedlings with 0 to 4 first-order lateral roots by 369% in average height growth. Survival of seedlings for all root classes at the end of the establishment year was 90% or greater, except for seedlings without tree shelters having 0 to 4 first-order lateral roots which averaged only 78%.

Undercut seedlings grew less in average height growth than seedlings that were not undercut. Possible reasons are that sorting the seedlings into root classes may have masked effects of undercutting. In addition, undercut seedlings may have used their stored carbohydrates to restore their root system, where seedlings that were not undercut may have used their stored carbohydrates in height growth.

PROTECTING NORTHERN RED OAK SEEDLINGS WITH TREE SHELTERS

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Maintenance of oak species is a major silvicultural challenge in many upland oak forests of the eastern United States. Natural regeneration is lacking in most forests, or if present, it is generally small and not vigorous. Nor do planted oak seedlings usually grow well. The problem is compounded in northwestern Pennsylvania by excessive browsing by large populations of white-tailed deer. Tree shelters are rigid, plastic tubes (10 to 15 cm in diameter and 1.2 to 1.8 m tall) placed around individual seedlings to protect them from deer browsing. They are reported to promote both seedling height growth and survival.

This study examines growth and survival of planted and naturally seeded northern red oak (Quercus rubra L.) seedlings and seedlings from planted acorns within tree shelters or individual chickenwire fences, and those planted with no protection (controls) under a shelterwood-cut upland oak stand. After 2 years, planted control seedlings averaged 20.8 cm in height with 71% survival and were significantly shorter than protected seedlings. Seedlings planted in tree shelters and fences averaged 26.8 cm in height and 61% and 92% survival respectively. Only 16% of acorns planted within shelters produced seedlings and these averaged 14.6 cm in height. None of the seeded controls or those planted within chickenwire fences survived. Small mammals destroyed most of the planted acorns. Whether they were protected or not, natural seedlings did not differ in height among treatments. Top-clipped natural seedlings averaged 14.5 cm in height and were significantly shorter than unclipped seedlings, which averaged 16.8 cm.

EFFECTS OF TREE SHELTERS AND WEED CONTROL ON BLUE OAK GROWTH AND SURVIVAL

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Blue oak (Quercus douglasii Hook. and Arn.) is one of several species of native California oaks that is regenerating poorly in some locations. Two of the most important factors limiting both natural recruitment success and field performance of planted seedlings are 1) limited soil moisture induced by competing plants, and 2) browsing or insect defoliation. This study compared the effects of Tubex tree shelters to standard screen cages on the field performance of blue oak seedlings. Response of seedlings to varying levels of weed control including a control (no weed control) and weed-free circles with diameters of 2, 4, and 6 feet were also examined. Twenty 1-0 container seedlings were planted for each of the eight treatment combinations in February 1991. From planting until the end of summer, weeds in the circles were removed by hoeing. The survival, height, height increment, caliper and caliper increment were evaluated at the end of the first field growing season. Data were analyzed using analysis of variance for a randomized split-plot design.

After one year, seedlings protected with tree shelters were taller than those in screen cages (46 vs 29 cm), had greater height increment, and greater survival (90 vs 71%). However, there were no differences in caliper or caliper increment between these groups. In general, seedlings receiving no weed control or 2-foot diameter circles had less height, height increment, caliper and caliper increment than those with 4- or 6-foot diameter weed-free circles. However, there are no significant differences between the pairs in these two groups. There were also no significant differences in survival between the four weed control treatments, although the control and 2-foot diameter treatments had the smallest averages. There was, however, an interaction between weed control and type of protector for height increment. Seedlings with good weed control tended to grow much taller in shelters, while those with little or no weed control remained stunted regardless of the protection used.

Our study indicates that tree shelters can promote increased survival and height growth of blue oak seedlings. However, shelters had no affect on caliper and consequently the seedlings tended to be tall and spindly. It is not yet clear how this will affect subsequent field performance or the ability of the seedlings to grow upright once the shelters are removed. The size of weed control also affected performance, with 4-foot diameter circles best in terms of costs and benefits.

MICROCLIMATE AND GROWTH OF OAK SEEDLINGS GROWN IN TREESHELTERS INSIDE AND OUTSIDE OF A SHADEHOUSE

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Northern red oak (Quercus rubra L.) and black oak (Q. velutina Lam.) seedlings were grown inside and outside of a shadehouse for 165 days to determine the effect of treeshelters and shade on shoot and root growth. The underlying reason for installing the experiment was to determine how young hardwood seedlings enclosed in treeshelters might respond in a forest understory.

There was no location effect on seedling growth for either species. Except for height, growth parameters measured were usually greater for seedlings grown without treeshelters than with them. Also, with few exceptions, the magnitude of this growth difference was greater for northern red oak than for black oak. The diameter of northern red oak seedlings grown with treeshelters was smaller than the diameter of seedlings grown without treeshelters. Height growth differences attributed to treeshelters did not affect shoot dry weight of either species. Mean taproot volume of northern red oak without treeshelters was 52% greater than the volume of red oak with treeshelters. Likewise, taproot volume of black oak without treeshelters was 38% greater than black oak with treeshelters. For both species, the fine root volume was also greater for seedlings without treeshelters than for seedlings with treeshelters.

The mean relative humidity was higher and mean temperature was lower inside the shadehouse than outside the shadehouse. Inside the shadehouse, the relative humidity inside the treeshelters during each measuring period was higher than outside of treeshelters for both species. However, this was not the case in treeshelters outside the shadehouse. For northern red oak, the relative humidity was slightly higher in treeshelters in mid-July, but significantly higher outside than inside of treeshelters during the early August and mid-August measuring periods. For black oak, the mean relative humidity inside of treeshelters outside the shadehouse was lower than inside the treeshelters at all measuring periods. Temperature, on the other hand, followed the same pattern for both species and was always higher inside treeshelters than outside of them both inside and outside of the shadehouse.

UNDERCUTTING AND SHOOT CLIPPING INFLUENCE FIELD PERFORMANCE OF NORTHERN RED OAK FIVE YEARS AFTER OVERSTORY REMOVAL

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Northern red oak (Quercus rubra L.) seedlings undercut in the nursery and top-clipped before planting outperformed seedlings not receiving those treatments. Three nursery undercutting treatments were compared: (1) no undercutting, (2) undercut the first year, and (3) undercut the first and second years. The top clipping treatments were: (1) not clipped and (2) tops clipped 20 cm above the root collar after spring lifting and before planting. The 2-year-old seedlings were outplanted under four shelterwoods, two in Missouri and two in Indiana. The shelterwoods were reduced to 60 percent stocking before planting. Three growing seasons after planting the shelterwood was removed.

Five years after shelterwood removal, survival differed significantly ($p<0.05$) among treatments based on chi-square analyses. On the average, survival was highest for undercut seedlings with clipped tops (76%) and lowest for seedlings receiving neither treatment (53%). Averaged across locations and treatments, survival of top-clipped seedlings was 72% and survival of undercut seedlings was 67%. Survival among the four outplanting locations differed significantly, and ranged from 60% to 80%.

Average heights of surviving planted trees five years after shelterwood removal differed among locations. In the two Missouri locations, the tallest seedlings were those receiving no treatments (1.90 m and 2.32 m). In the two Indiana locations, the tallest trees were those with clipped tops that were undercut once (one location) or twice (the other location) and averaged 2.20 m and 2.61 m, respectively. When both survival and height were considered, the "best" treatments were those where undercutting was coupled with top-clipping.

TWO-YEAR PERFORMANCE OF PLANTED OAK SEEDLINGS IN RELATION TO OVERSTORY DENSITY AND UNDERSTORY VEGETATION CONTROL

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Regeneration of northern red oak (Quercus rubra L.) is important to maintain forest diversity, provide wildlife habitat, and to support future timber demand. The growth potential of northern red oak is normally high in full sunlight, but vegetative competition may be intense and limit available moisture, nutrients, and light to seedlings. While vegetative competition may be reduced by partial shade provided by shelterwoods, the lower light intensities may also reduce the growth and performance of oak seedlings. An oak regeneration study was established in 1990 to determine the effect of overstory density and understory competition control on the performance of bareroot and containerized northern red oak seedlings.

We examined three overstory densities, 50% and 25% crown covers, and a clearcut. The study was enclosed with an electric fence to exclude deer. Each main plot is 0.3 hectare (0.75 acre) in size and replicated three times. One half of each main plot was sprayed with glyphosate (Roundup) herbicide in September 1989. Seedlings were auger planted in 10-cm diameter holes in May, 1990 at 2.4 m x 2.4 m (8 ft) spacings. The (1-0) bareroot seedlings were 31 cm tall with a root collar diameter of 7.6 mm and a minimum of ten lateral roots (>1 mm in diameter). The containerized seedlings were grown in a polyhouse in 10 x 36 cm polyethylene containers and were 29 cm in height with a root collar diameter of 5.7 mm.

After two growing seasons the mortality of bareroot and containerized seedlings combined was very low (1.4%). The bareroot seedlings had significantly greater growth in the clearcut (24.7 cm) and the 25% crown cover (24.6 cm) compared to the 50% crown cover (19.6 cm). Height growth of bareroot seedlings in the sprayed areas was greater than those growing in the non-sprayed areas. The spraying effect was most pronounced in the clearcuts. Height growth of the containerized seedlings was 30.2 cm in the clearcut, 29.3 cm in the 25% overstory and 24.2 cm in the 50% overstory, but these differences were not statistically significant. Two-year height growth for the containerized seedlings averaged 28.0 cm compared to 23.0 cm for the bareroot seedlings. The total height of all seedlings after two growing seasons averaged 56.1, 56.9 and 51.7 cm for the clearcut, 25% and 50% crown covers, respectively.

Survival of the planted northern red oak seedlings after two growing seasons is excellent when high quality stock is utilized. Seedling growth is "best" in the clearcuts although not significantly greater than in the 25% crown cover. Herbicide spraying was more advantageous in the clearcuts than in the shelterwoods.

DEVELOPMENT FOLLOWING RELEASE IN A DIRECT-SEEDED NUTTALL OAK PLANTATION: 11-YEAR RESULTS

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Early growth of many bottomland oaks is slow and many oaks eventually become overtopped by trees of other species. Precommercial removal of these larger competitors in a young stand might encourage the development of a higher proportion of free-to-grow oaks as the stand matures. To test this hypothesis, a study was initiated in 1980 to evaluate effects of seven release treatments designed to favor the development of 11-year-old, direct-seeded Nuttall oaks (Quercus nuttallii Palmer) in competition with naturally regenerated non-oaks of the same age.

The plantation was established in the spring of 1969 on a cleared Sharkey clay flat within the Delta Experimental Forest in west-central Mississippi. Nuttall oak acorns were direct-sown in rows 10 feet apart; seed spots within rows were spaced at 5-foot intervals. Following the 11th year, seven release treatments were applied: (1) cut all non-oaks 15 ft and taller (C15+), (2) deaden all non-oaks 15 ft and taller (D15+), (3) cut all non-oaks 20 ft and taller (C20+), (4) deaden all non-oaks 20 ft and taller (D20+), (5) cut all non-oaks 25 ft and taller (C25+), (6) deaden all non-oaks 25 ft and taller (D25+), and (7) untreated control (CTRL).

Average Nuttall oak stem diameter, height, number of trees/acre, and percentage of trees in free-to-grow status 11 years after applying release treatments are as follows:

Treatment	DBH (in.)	Height (ft.)	# Oak trees per acre	Free-to-grow oaks (%)
C15+	3.6	38	489	56
D15+	3.8	38	527	62
C20+	3.6	37	430	55
D20+	3.8	38	462	60
C25+	3.2	35	468	46
D25+	3.0	33	462	41
Control	2.9	33	382	38

Released oaks of all treatments were taller and larger in diameter than oaks in untreated control. The proportion of free-to-grow oaks was also greatly increased by the release treatments. The degree of improvement in growth and crown position increased with increasing intensity of treatment. Oaks subjected to the most intensive treatments (C15+, D15+, C20+, and D20+) showed a marked improvement in growth, and particularly, in the proportion of free-to-grow oaks, as compared to unreleased oaks.

THREE-YEAR SURVIVAL AND GROWTH OF NORTHERN RED OAK SEEDLINGS WITH RESPECT TO ROOT GRADE

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The purpose of this study was to determine if initial root system morphology of one-year-old seedlings would influence survival and growth of northern red oak (Quercus rubra L.) seedlings. Nursery-run bare-root northern red oak seedlings from the Iowa Department of Natural Resources State Forest Nursery in Ames were graded according to numbers of large first-order lateral roots (roots greater than 1 mm in diameter) and outplanted on nine plots at three sites in central Iowa in the spring of 1987.

Survival, stem height, and basal diameter were measured annually each fall for three years. Also beginning in the fall of 1987, six trees per plot were carefully excavated each year for three years, preserving as much of the root system as possible. Excavated seedlings were measured to determine height, diameter, number of roots, and oven-dried root and shoot dry weights.

Survival, height growth, and diameter growth were significantly greater for seedlings with 10 or more large first-order lateral roots at the time of planting than for seedlings with 4 or fewer lateral roots. Based on analyses of partial correlations, seedling survival and growth were significantly related to initial root grade. Measurements of harvested trees indicated statistical differences between seedlings with fewer than 4 large laterals and seedlings with 10 or more for most shoot and root characteristics. Poor height growth for all seedlings at the end of three years was attributed to drought conditions, animal damage, and inadequate control of competing vegetation.

Combined results for seedling survival and growth indicated that northern red oak seedlings with 5 or more large first-order lateral roots have a greater probability of success both in terms of establishment and competitive early growth than northern red oak seedlings with less than 5 large first-order lateral roots.

SHELTERWOOD HARVESTING AND UNDERPLANTING TO ENHANCE THE NORTHERN RED OAK COMPONENT OF SHALLOW-SITE FORESTS IN CENTRAL ONTARIO: 6-YEAR RESULTS

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Northern red oak (Quercus rubra L.) is commonly found growing as a minor component of low quality sugar maple (Acer saccharum Marsh.) stands on sandy loams of shallow-to-bedrock ridgetops in central Ontario. Our study compared the effects of controlling competition on the performance of both 1+0 and 1+1 northern red oak stock underplanted in a shelterwood cut. Competition was controlled by prescribed burning and herbicide application.

Initial harvesting removed 40% of the overstory and left a residual basal area of 13.8 m^2/ha (60 ft^2/acre). The experimental design tested all possible combinations of stock type (1+0, 1+1) and competition control (herbicide, prescribed burning, none). Northern red oak seedlings (n=64) were planted in each experimental cell in the spring of 1986. Glyphosate was applied at a rate of 2.0 g/l (a.i.) around each tree after leaf flush from 1986 to 1991. The prescribed burn was executed in the spring of 1987 and effectively killed a high proportion of the maple competition. The residual overstory was removed in the fall of 1989 and the burn treatment was re-applied in 1990.

Prescribed burning initially increased oak seedling height growth over the control and herbicide treatments. In the latter, the 1+0 stock outperformed the 1+1 stock in annual shoot growth for the first 3 years. The smaller 1+0 stock responded to increased available light while the larger 1+1 stock was generally above competing herbaceous vegetation when planted.

By 1990, the trees were starting to respond to the altered light regime resulting from the final harvest. Seedlings grown in the absence of competition control had higher total height growth than those subjected to either burning or herbicide. We speculate that 1) competition control made seedlings more susceptible to browsing by deer or damage by heavy snow and ice accumulation or 2) the competitive ability of northern red oak on these sites is such that, once established, it will respond exceedingly well to even late release. Competition control may have negatively impacted the seedlings by introducing drought stress. Monitoring over the next several years should indicate whether or not competition control is worth the added cost.

SEEDLING MORPHOLOGY RELATED TO GROWTH AND SURVIVAL OF NORTHERN RED OAK

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Northern red oak (Quercus rubra L.) is one of the highest value timber species in the Central Hardwood Forest. While northern red oak plantings exhibit relatively low mortality rates, seedling growth rates are highly variable. Efforts to predict the success of red oak seedling plantings have met with limited success. Research with sweetgum indicated that the number of first-order lateral roots (FOLR) can be a reliable predictor of seedling growth. This research was undertaken to determine if survival and growth of northern red oak seedlings are related to the number of FOLR and/or other seedling morphological characteristics.

Three plantations were established in west central, south central and southwest Indiana. Seedlings were placed in one of four categories based on the number of FOLR: 4 or less, 5-8, 9-12, and 13 or more FOLR. Seedlings were planted with post-hole diggers (no root pruning) or with a KBC planting bar (taproot and lateral roots pruned to 20 cm). After the first growing season, a subsample of seedlings at each planting was excavated to determine the morphological development after one growing season.

Two year net height growth was not significantly different among seedling classes for the post-hole planted seedlings. Regression analysis revealed that at one location no initial seedling morphological characteristics were significantly correlated with height growth. At a second site, a positive correlation existed between net height growth and the ratio of lateral root volume to stem volume. At the third site, net height growth was positively correlated with the ratios of lateral root volume to stem volume and lateral root length to stem length. Bar planted seedlings exhibited different growth trends. At two sites, seedlings with more than 13 FOLR exhibited greater dieback than seedlings in the other classes. Net height growth following outplanting was negatively correlated with initial seedling height.

Examination of the excavated seedlings revealed large decreases in the numbers of FOLR, FOLR length, and FOLR volume for all seedling classes regardless of planting method. This study suggests that northern red oak seedling growth can not be accurately predicted based on the numbers of FOLR. Results indicate that a rather complex interaction of morphological characteristics exists for northern red oak which can influence seedling growth following outplanting.

AGROFORESTRY METHODS FOR OAK ESTABLISHMENT

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Agroforestry practices have application in the establishment of oak plantations, especially on old field sites that are notoriously difficult for hardwood establishment. Agroforestry is defined as land use systems and practices where woody perennials (trees, shrubs, etc.) are deliberately integrated with crops and/or animals on the same land-management unit. The integration can be either in spatial mixtures or in a temporal sequence. The three main approaches discussed below are intercropping, naturalization, and silvipastoral methods. Our research on oak has primarily used northern red oak (Quercus rubra L.); however, the methods used should be applicable to a range of oak species.

Intercropping involves planting trees in configurations that accommodate the production of agricultural crops among the trees. It is similar to hardwood establishment methods that involve intensive site preparation and competition control. The main similarities are that competing plants are eliminated prior to planting and annual cultivation precludes the establishment of perennial weeds. In many cases, intercropping is economically superior as high establishment costs can be offset with revenue from agricultural production. Our research has shown that northern red oak and other hardwoods have grown better when intercropped with late-developing crops like corn and soybeans than with small grains like barley or wheat. Growth differences are likely a response to early season moisture competition from the developing intercrop.

The conversion of conifer plantations to hardwood forests is another agroforestry system that is useful in oak establishment. This process mimics natural succession or shelterwood systems as the conversion is facilitated by managing the conifer overstory to encourage natural or planted oak seedling establishment.

Oak establishment in pastures can be accomplished using silvipastoral methods where the livestock can be used as competition control while providing a return to the landowner. Control of livestock access is critical to the success of a silvipastoral project and seedling protection may be necessary during the early years of a plantation.

WATER OAK: A VIABLE COMPONENT IN THE SOUTHERN HARDWOOD FOREST?

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Water oak (Quercus nigra L.) is one of the most frequently occurring species in the southern hardwood forest. The species is found on a variety of sites, ranging from floodplains of major rivers to those of small intermittent streams in the upland pine forest types. Often water oak is confused with other closely related, but generally lower quality species such as obtusa oak (Q. obtusa (Willd.) Ashe), laurel oak (Q. laurifolia Michx.) and willow oak (Q. phellos L.).

During the past two decades, we have established a number of water oak plantings. Problems associated with these plantings were high mortality, dieback, transplant shock, and poor ability to compete with natural regeneration. The USDA Conservation Reserve Program (CRP) increased the demand for water oak planting stock and also has stimulated the use of direct seeding with this and other oak species. Problems with regeneration success have resulted in research that is designed to answer some of the planting problems associated with southern oaks and particularly water oak.

Poor survival, dieback, and transplant shock can be generally traced to late lifting and planting of seedlings, poor root/shoot ratio, and improper handling of seedlings before planting. Water oak should be lifted before the third week in February in north Louisiana, properly cold stored, and planted as soon as possible. If seedlings have excessive aboveground growth this can be top pruned with no damage to the seedling and no net loss of height by the end of the first growing season. Water oak is a resilient species and even when transplant shock causes dieback to the root collar, many seedlings will sprout and develop into excellent trees.

DROUGHT RESPONSE OF NORTHERN RED OAK SEEDLINGS USING COMPUTER-CONTROLLED IRRIGATION

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Plant-water stress mechanisms of northern red oak (Quercus rubra L.) seedlings were studied using a new approach to drought induction. This method uses the plants themselves as water-use indicators and a computer-controlled irrigation system. This system incorporates environmental and species specific factors related to water requirements without the use of empirical models. In this study, northern red oak seedlings were drought stressed to evaluate how well the system determined the physiological responses.

The computer-controlled irrigation system estimates evapotranspiration of container-grown plants by monitoring randomly selected plants within a container block to determine "as needed" or baseline application rates. A simple percentage calculation of this baseline application rate was then used to establish reduced watering regimes. Northern red oak seedlings were randomly placed into five treatment groups (25 seedlings per group) with two replications. Four treatments were irrigated using the control system (baseline, 80%, 60% and 40% of baseline) while the fifth was irrigated by the nursery supervisor using standard nursery practice. Data collected throughout the test period included irrigation and leachate rates, air temperature and humidity, solar radiation, photosynthetic gas exchange, predawn water potential and root and shoot dry weight.

A comparison between baseline computer control and standard nursery practice showed a 95% reduction in water use and leachate rates with no difference in stem height, dry mass or number of leaves. Water use efficiency and photosynthetic rates tended to be lower for the baseline treatment plants compared to the drought regimes. The water limited treatments promoted a shift in the shoot:root ratio favoring root growth and development of a more fibrous root system.

The physiological response to mild drought conditions provides insight into the survival mechanisms of this species. Under mild drought stress, northern red oak seedlings maintain normal photosynthetic rates but shift carbon allocation to the root system, thus allowing for greater exploitation of soil water. From a practical viewpoint, the ability to induce an increase in root growth without affecting shoot growth would be a useful nursery practice. In addition, the commercial development of the computer-controlled irrigation system would be a useful tool for nursery growers and urban foresters to reduce water use and leachate rates without reducing overall plant growth.

NORTHERN RED OAK SEEDLINGS PRODUCED AT THREE NURSERY BED DENSITIES WITH AND WITHOUT UNDERCUTTING: 4-YEAR FIELD RESULTS

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Artificial regeneration in the Central States requires seedlings that are able to compete against heavy weed competition on sites exposed to high winds, excessive drying, and intense direct solar radiation. These seedlings must have a large root system that is able to produce many fine roots after field planting. Such a root system for northern red oak (Quercus rubra L.) should consist of five or more permanent first-order lateral roots if the outplanted seedling is expected to survive and become a competitive grower. Many oak seedlings produced in bare-root nurseries do not have the minimum number of first-order lateral roots even though they may have a suffient shoot.

A study was conducted in forest tree nurseries of Illinois, Indiana, Iowa, Missouri, and Ohio to determine the effect of bed density and undercutting on the number of permanent first-order laterals on 1-0 northern red oak seedlings. Bed densities of 32, 64, and 128 seedlings per square meter were used. Undercutting was done at a 15 cm depth when the taproots were from 0.6 cm to 1.3 cm in diameter.

Decreasing bed densities and undercutting increased the number of first-order lateral roots on 1-0 northern red oak seedlings. Decreasing bed densities also increased seedling height and stem caliper for both undercut and uncut seedlings. The undercutting treatment decreased both seedling height and stem caliper. At the end of the fourth year in the field, height and diameter growth are significantly related to the initial number of first-order lateral roots.

Planting seedlings with large root systems is not the only solution to successful field performance. The 1988 plantations were planted in a drought and mortality as a whole was less than 10%. The success of these plantings depended on the careful planting of the larger stock. Successful planting requires specialized hardwood planting machines and/or machine powered augers and good weed control. It is not possible to plant hardwoods with the typical pine planting equipment and expect a good response. In summary, a successful plantation is one in which seedlings survive and grow and depends on seedlings with more than 5 first-order lateral roots, careful planting, and weed control.

FIRST ORDER LATERAL ROOT DEVELOPMENT AND STEM CHARACTERISTICS OF 1-0 SEEDLINGS FROM NINETEEN SPECIES OF SOUTHERN OAKS

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The Southeastern Forest Experiment Station and Region 8, of the USDA Forest Service, and the Department of Energy initiated a long-term research program on clarification of factors affecting initial establishment and subsequent growth of heavy seeded hardwoods. This research involves detailed studies on how edaphic and climatic factors interact with metabolic processes. Also, we are studying specific anatomical/morphological and physiological adaptations that may account for apparent site specificity of some species across a multiple of rhizosphere conditions.

Our first step was to determine whether a single nursery prescription for growing the many different heavy-seeded species was possible. Based upon 5-year data for northern red oak (Quercus rubra L.) and white oak (Q. alba L.) seedlings grown in the Institute of Tree Root Biology's experimental nursery, it appeared likely that a single nursery prescription would succeed if uniform nursery soil conditions were maintained. Research to date with northern red oak indicates that first-order lateral root development of seedlings grown under specific conditions could be used as a biological grading criteria to predict early plantation performance.

The second step was to evaluate root development of seedlings from nineteen different oak species in two Georgia Forestry Commission nurseries using a uniform fertility and water management prescription. The primary traits of concern were height, diameter, and frequency distribution of seedlings when stratified by FOLR for all nineteen oak species.

All seedlings were grown at densities of 62 seedlings per square meter. The preplant soil nutrient status for P, Ca, K, and Mg was 90, 500, 80, and 50 ppm, respectively. In early spring, soils were irrigated or had rainfall of 2.5 to 3.0 cm/week. Beginning in July, irrigation was not used until irrometers registered -70 centibars for 2 days. A total of 392 kg/ha of nitrogen was applied in 6 to 8 separate applications starting with 17 kg/ha and gradually increased to 56 kg/ha. Nursery beds were undercut the first week in February. Seedlings of each species were lifted in the spring to obtain measurements made on approximately 150 seedlings from each seedlot. Results were reported at the workshop and can be obtained from the author at the above address.

NITROGEN AND PHOSPHORUS FERTILIZATION AFFECT THE MYCORRHIZAL SYMBIOSIS AND GROWTH PARAMETERS OF NORTHERN RED OAK SEEDLINGS

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Acorns of northern red oak (Quercus rubra L.) were sown in 1.9 liter containers filled with Plainfield fine sand previously inoculated with vegetative mycelium from one of three species of ectomycorrhizal forming fungi, Pisolithus tinctorius, Hebeloma crustuliniforme or Laccaria laccata obtained from Mycorr Tech Inc., Pittsburgh, Pennsylvania. A modified Hoagland's solution was added weekly after shoot emergence to provide nitrogen levels of 0, 100 and 200 ppm, and phosphorus levels of 0, 50 and 100 ppm.

Both P. tinctorius and H. crustuliniforme successfully colonized the oak seedling roots; however, L. laccata did not colonize the roots of northern red oak seedlings. Seedlings that were inoculated with P. tinctorius were taller and had greater root, stem and foliage biomass than the other inoculation treatments or the control. Although H. crustulinifore colonized the roots of northern red oak seedlings, the resulting mycorrhizae were not effective in increasing the physical attributes of the seedlings. The largest seedlings were obtained at high levels of N and P in the soil media. Mycorrhizal colonization was significantly decreased at these high levels of soil fertility.

SEEDLING QUALITY AS AFFECTED BY SEED SOURCE AND NURSERY PRACTICES

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Current nursery practices for rearing northern red oak (Quercus rubra L.) seedlings result in a wide variation in quality. The objective of our two-year study was to determine the biological and environmental effects of seed source and nursery practices on seedling quality and uniformity. The study was conducted at the Wilson State Nursery in Boscobel, WI in cooperation with the Wisconsin Department of Natural Resources. The study seedlings were outplanted so that observations can be made on their growth and development after several years in the field.

Acorns from four superior seed trees (or stands) and from public collections were planted at a bed density of 9 acorns per square foot in a split/split plot design to test the effects of seed source, undercutting, and a soil amendment. In addition, seed spacing effects were assessed by making comparisons to blocks of seedlings raised under the current nursery practices (from public collection seed). Effects of treatments were quantified by determining emergence rate and percent, as well as seedling height and caliper at the end of the growing season.

During the 1991 season, selecting known seed sources and decreasing bed density yielded seedlings with dramatically greater height and caliper: height and caliper were increased by approximately 50% and 30%, respectively. Bed density alone contributed to increases of about 40% and 20% in seedling height and caliper, respectively. Bed density did not affect percent of seed that emerged, but did increase the variability in both emergence and seedling characteristics. Similar results were observed in 1990 for bed density and seed source effects. In the 1990 study, seedling height and caliper were reduced by undercutting, but not in the 1991 study. Amendment with peat did not significantly affect height or caliper during either year.

Compared to current nursery practices, consistent increases in seedling quality and uniformity can be achieved by selecting known seed sources and planting seed at a bed density of about 9 acorns per square foot.

PHOTOSYNTHATE ALLOCATION PATTERNS IN CHERRYBARK OAK SEEDLINGS GROWN UNDER THREE LEVELS OF SHADE

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Cherrybark oak (Quercus falcata var. pagodaefolia Ell.) is considered one of the most desirable oaks for both timber and mast production of the dozen or so that occur in southern bottomland hardwood forests. Problems in the management of these forests include the inability to adequately regenerate cherrybark oak. Scientists have indicated there is a need for more basic information on oak seedling biology as a way to better understand regeneration successes and failure. Therefore, two experiments were conducted on the photosynthate allocation patterns in intact and clipped cherrybark oak seedlings grown under 0, 53, and 80% shade.

In Experiment No. 1 conducted in May 1990, 1-Lag intact and clipped seedlings (34 per treatment) were exposed to $^{14}CO_2$ for 30 minutes and harvested 48 hours later. Results indicate that shoots of clipped seedlings had a greater relative specific activity (RSPA) of recovered ^{14}C than intact seedling shoots, regardless of shade treatment. RSPA for shoot and first-flush leaves increased for both intact and clipped seedlings with increasing level of shade, indicating a greater emphasis on light gathering capabilities with decreasing levels of light. Little difference occurred in RSPA for shoots in exported ^{14}C between intact and clipped seedlings grown in full sunlight. Conversely, RSPA of clipped seedling shoots under shaded conditions was double that of intact seedling shoots.

In Experiment No. 2, three-year old intact seedlings were grown for one year under 80% shade and then exposed to $^{14}CO_2$ for one hour in September 1989. One-half of these seedlings were clipped in February, 1990. Equal numbers of intact and clipped seedlings were assigned to the three shade treatments. In May 1990, four seedlings per treatment were then harvested during 1-Lag to determine RSPA. Few differences were found in the RSPA of recovered ^{14}C between shoots and roots of intact and clipped seedlings. Intact seedlings had greater root RSPA in full sunlight while clipped seedlings had greater shoot RSPA in 80% shade. Regardless of seedling or shade treatment, first flush stems had about two times greater RSPA as compared to corresponding first flush leaves. This agrees with previously described patterns of shoot development in oak seedlings in which rapid stem growth preceded rapid leaf growth.

RESPONSES OF CONTAINER-GROWN SHUMARD OAK, SWAMP CHESTNUT OAK, AND GREEN ASH TO THREE LEVELS OF LIGHT AND TWO SOIL TYPES

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Re-establishment of the heavy-seeded component of coastal plain bottomland hardwood forests after Hurricane Hugo is of primary importance to recover biodiversity of coastal plain forests. Past research has shown that light-seeded species usually dominate in the natural regeneration of hardwood stands. Our objectives included determining effects of three levels of sunlight (full, 70%, and 30% sun) on the gas exchange properties and growth characteristics of heavy-seeded Shumard oak (Quercus shumardii Buckl.) and swamp chestnut oak (Q. michauxii Nutt.) and light-seeded green ash (Fraxinus pennsylvannica Marsh.) when grown on an Alfisol (Hockley) and an Ultisol (Bethera) in plastic pots.

Photosynthetic rates of the two oak species were not affected by the shade treatments, while photosynthetic rate of green ash was reduced in the heaviest shade treatment. Only stomatal conductance of swamp chestnut oak was influenced by the shade treatment. Green ash grown in the Alfisol averaged the highest rates of gas exchange, whereas the oaks were unaffected by soil type. Gas exchange rates varied throughout the growing season with a peak in photosynthetic rate for swamp chestnut oak and green ash in July. Shumard oak did not vary significantly in photosynthetic rate during the growing season; however, stomatal conductance declined for all species from a peak in July to their minimum in August.

Swamp chestnut oak grown in the Ultisol produced the greatest height increment and exhibited some shade treatment effects on height early in the growing season. Shumard oak grew the least in the full sun treatment when grown in the Alfisol and grew the most in the 70% and full sun treatments in the Ultisol. Green ash height growth exhibited little response to shade or soil treatment. Green ash stem diameter differed between the two soil types only in the 70% sun treatment, where diameter increment in the Alfisol was almost twice that of the Ultisol.

RELATIONSHIP BETWEEN ENVIRONMENT AND GROWTH OF NORTHERN RED OAK SEEDLINGS

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Growth of northern red oak (Quercus rubra L.) was compared for seedlings raised in pots in a growth chamber (16 hr, 80°F day: 70°F night), a polyhouse, and a natural environment (field). Seedlings were raised through 2 flushes in year 1 and through 3 flushes when repeated in year 2. Seedling development took longer in the field than in the growth chamber both years. The developmental rate of two-flush seedlings raised in the polyhouse was similar to that of field-raised seedlings in year 1. The developmental rate of three-flush seedlings in the polyhouse was similar to that of growth chamber-raised seedlings in year 2. This year to year difference in polyhouse seedling growth provided a means of discriminating among environmental conditions related to seedling developmental rate.

Daily average temperature and average daily minimum temperature were greater in the growth chamber than in the field during both seasons. Total degree days necessary to achieve any given developmental stage was consistently lower for seedlings grown in a growth chamber than for field-raised seedlings both years. Despite differences in the seedling developmental rates among environments, daily average temperature, minimum temperature, and total degree days in the polyhouse were similar to those in the growth chamber during both years.

In the first year, total dry weight of two-flush seedlings raised in the field and polyhouse was greater than that of seedlings raised in the growth chamber. In contrast, total dry weight of three-flush seedlings raised in either the polyhouse or growth chamber was greater than that of seedlings raised in the field during year 2. Thus, dry weight accumulation was unrelated to developmental rate. Leaf area of seedlings followed the same pattern as the developmental rate.

Carbon distribution was examined in year 1 for seedlings in pots and in a typical nursery bed situation. The first flush of leaves were labeled with $^{14}CO_2$ at different developmental stages. The percent of the ^{14}C exported during 48 hrs from the first flush leaves to developing second flush shoots or to roots was similar for all environments when plants were examined at the same developmental stage whether in raised in pots or in the nursery bed. During development of the second flush, approximately 90% of ^{14}C-assimilates exported from the first flush leaves were transported to the developing shoot. In contrast, in the absence of active shoot growth, nearly all the ^{14}C-assimilates exported were found in the roots. Thus, results obtained from growth chamber raised seedlings and from seedlings raised in pots are applicable to nursery and field situations.

TWO-YEAR FIELD RESULTS IN A PROGENY TEST OF NORTHERN RED OAK

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Failure of planted northern red oak (Quercus rubra L.) seedlings to initiate and maintain rapid juvenile height growth is considered to be a primary cause of planting failure. The Pennsylvania tree improvement program for northern red oak is designed to select parental genotypes that exhibit rapid early height growth patterns. The selection goal is to identify families that attain 4.5 feet height within three years after outplanting. Parental genotypes producing progeny at or above target height performance will serve as a source for future commercial seed collection.

In the fall of 1988, acorns from 40 open-pollinated northern red oaks were made from across the state and sown in a replicated design in a nursery bed. Parental selections were representative of average to above-average trees for size and form. In 1990, the seedlings were lifted as 1-0 bareroot stock and out-planted on a 1.5 m x 1.5 m spacing at three test locations. Test design was an randomized complete block design with 5-tree row plots and 5 replications. Locations 1 and 2 are representative of the Ridge and Valley region of Pennsylvania and location 3 is representative of the Allegheny Plateau. All test locations were protected against deer browsing by a five-wire electric fence, and herbicides were used to control competing vegetation before and after planting.

After two growing seasons, survival across sites ranged from 96.1 to 99.3 percent; however no significant family variation for survival was detected. Both statistical and biological significance were observed for family height growth variation at all sites. Mean height of all seedlings were 51.5, 80.1, and 39.2 cm for location 1, 2, and 3, respectively. Ranges of mean family heights were 39.5 to 72.9 cm for location 1, 60.5 to 102.9 cm for location 2, and 26.6 to 45.2 cm for location 3. At the best site, 12% of the trees are growing more than 46 cm per year with as many as 32% of the trees in some families doing so. The family x location interaction was significant, but this was primarily due to the relative uniformity of families at location #3 where 42% of the trees showed deer browsing compared to less than 1% at other locations.

These early results indicate that genetic selection for early height growth is a practical technique to enhance planting success. Continued progeny testing is planned for 1992, 1993, and 1994. A total of 180 parent trees will be screened for early height growth at completion of the project.

GENETIC VARIATION IN THE TAXONOMIC TRAITS OF THE NORTHERN RED OAK COMPLEX IN THE LAKE STATES

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The northern red oak complex in the northern Lake States region consists primarily of two Quercus species: northern red oak (Q. rubra L.) and northern pin oak or Hill's oak (Q. ellipsoidalis E. J. Hill). Trees with intermediate morphological traits exist suggestive of hybridization between the two species. Two separate studies were conducted in northern Wisconsin to examine the relationship between northern red oak (NRO) and Hill's oak (HO) and whether hybridization occurs between the two species.

Our first study examined the morphological and isozyme variation of oak populations on the Apostle Islands in Lake Superior (Bayfield County, WI). The Apostle Islands offered a unique opportunity to study distinct and isolated oak populations across a gradient of islands from the mainland peninsula to the outermost island. A detailed morphometric analysis of these oaks showed that there was a continuum of leaf morphology along a transect from the mainland peninsula to the Outer Island. The continuum was reflected in both leaf size and shape, with leaves on the mainland more HO-like and leaves on the Outer Island NRO-like, and with intermediate types on the intermediate islands suggestive of hybridization. Our isozyme analysis of leaves, winter buds, and acorns for 21 enzyme systems yielded no species-specific alleles to distinquish between NRO, HO, and their hybrids. Isozyme analysis showed low levels of heterozygosity indicating low gene flow among island populations with acorns being twice as homozygous (inbred) as adults. Apparently, in the early life history of the stands, gene flow among island populations was less restrictive than in present closed stands.

Our second study was a nursery common garden study where acorns from NRO, HO, and intermediate type trees were planted to determine morphological and mensurational variables of resultant seedlings. There were large differences in seedling quality among seed sources. Mother trees with NRO-like traits yielded seedlings that were taller, had larger caliper, and had more lateral roots than either the intermediate or HO-like mother trees. The HO seed sources always had the lowest seedling quality.

Our studies show that there are large morphological differences within the northern red oak complex in the Lake States. Morphometric analysis are suggestive of hybridization between NRO and HO, but genetic studies are less clear.

HEIGHT VARIATION IN A MULTI-SITE OPEN-POLLINATED WHITE OAK PROGENY TEST

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A multi-site progeny test of white oak (Quercus alba L.) was established at three locations in the spring of 1984. The progeny test was arranged in a randomized complete block design with 71 open-pollinated families in 8 blocks using 4-tree plots of 1-0 seedlings. The open-pollinated families represented acorn collections from 15 stands in Indiana, one from southern Illinois, and one from southern Missouri. Plantings were located on the Starve Hollow State Forest and Harrison-Crawford State Forest in southern Indiana and on the Shawnee National Forest near Makanda in southern Illinois.

All sources of variation in a combined-location analysis of variance of 5-year height data were statistically significant. The among-site variance component was the single largest in this analysis and accounted for 62.3 percent of total variance. This was followed by the among replication within site component (16.5 percent) and the within plot (i.e., among individual trees/plot) component (16 percent). Although the among-family component accounted for only 1.9 percent of total variance, the narrow-sense heritability for 5-year height was estimated to be 0.356, which is comparable to the heritability for juvenile tree height of most other commercially valuable tree species. There was no biologically significant genotype x environment interaction, as reflected by a site x family component approaching zero. At this age there was little correlation in family rankings among sites.

Of the three planting sites from Indiana and Illinois included in this multi-site progeny test, the tallest white oak trees were at the site closest to Indiana Department of Natural Resources' Vallonia Nursery (2.2 m vs 0.6 and 1.0 m). The Vallonia site is the most favorable in terms of soil texture, depth, soil moisture, and nutrient availability. In addition, the the faster height growth at this site may also reflect benefits from the most intense weed control during the establishment phase. The implication is that white oak is site sensitive and very responsive to outplanting aftercare.

FLOWERING AND FRUITING OF YOUNG NORTHERN RED OAK GRAFTS IN INDIANA

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A tree improvement program using the sublining breeding strategy was initiated in Indiana in 1985 for northern red oak (Quercus rubra L.). A total of 150 clones were included in the program and grafted ramets of each clone were established in one of 5 different subline sites at the Vallonia State Nursery in southern Indiana.

Widespread flowering was observed in the spring of 1990, which provided an opportunity to document the flowering and subsequent acorn development. A total of 166 of the 838 ramets surveyed in late April produced either staminate or pistillate flowers, or both (19.8%). Of these 166 ramets, 152 ramets producing pistillate flowers. Pistillate flowers were found on only 72 of the 150 clones. Over 40% of the pistillate-flowering ramets exhibited symptoms of graft incompatibility. Graft incompatibility in northern red oak is characterized by severe swelling of the scion (or "overgrowth"), vigorous rootstock suckering, and poor shoot growth. Of the 152 pistillate-flowering ramets surveyed in April, 11 died due to severe graft incompatibility, resulting in 141 ramets capable of producing seeds. All 141 ramets were surveyed in June of 1991 for the presence of acorns. Immature acorns were present on a total of 55 ramets (39.0%). Only 27 out of the 141 pistillate-flowering ramets produced harvestable seed by October of 1991 (19.2%). The average harvest per ramet was 14.7 acorns.

In 1991, a total of 52 ramets from 33 of the 150 clones produced either staminate or pistillate flowers, or both. Of these 52 ramets, 27 ramets were surveyed as showing signs of graft incompatibility (51.9%). These data indicate that flowering and fruiting in northern red oak is more dependent on clonal origin and on stress due to graft incompatibilities than on ortet age.

INFLUENCE OF AGE CLASS AND SITE QUALITY ON REGENERATION AND SURVIVAL RATES OF OAK SEEDLINGS

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Four upland ecosystems in central Wisconsin which vary in site quality and contain a significant oak component were monitored for 3 years. The oak composition changed from northern pin oak (Quercus ellipsoidalis E. J. Hill) on the two drier sites, to northern red oak (Q. rubra L.) and white oak (Q. alba L.) on the intermediate site, to northern red oak only on the mesic site. Although northern red oak made up 35% of the overstory basal area on the mesic site, only three northern red oak seedlings were found during the entire study period.

The flux for oak regenerants averaged over both age classes and all years was a 3.9% decrease on the most xeric site, a 39.3% increase on the slightly more moist xeric site, and a 14.0% increase on the intermediate site. The overall fluxes for red maple (Acer rubrum L.) were -1.5% and -25.4% in the more moist xeric and the intermediate sites, respectively. The most common arboreal species on the mesic site was sugar maple (Acer saccharum Marsh.) which exhibited an overall flux of -25.4%.

Age class greatly affected the net flux of most species. The average annual change for northern pin oak seedlings was a net increase of 1133 and 2667 seedlings/ha/yr on the xeric sites. The >1-yr-old regenerants suffered a 7.4 to 8.2% decline (439 to 1892/ha/yr). Expressed another way, the number of new seedlings which germinated and survived each year exceeded the mortality in the early cohort. New oak seedlings were rare on the intermediate site (<55/ha/yr), so no flux could be calculated while the >1-yr-old stems declined by an average of 8.3% (561/ha/yr). The corresponding fluxes for red maple were a decrease in 1989 and 1991 of 50.8% and a 327% increase in 1990 among the <1-yr-old class. Older maple regenerants showed an average decline of 27.0% (9162/ha/yr). Sugar maple on the mesic site showed significant decreases among the new seedlings -68.3% (21,924/ha/yr), but only a small drop (-4.8%, 1079/ha/yr) in the >1-yr-old class.

These analyses, coupled with climatic data, indicate that the population dynamics of arboreal regenerants during 1989-1991: (1) can vary from site to site for the same species, (2) includes significant levels of recruitment for northern pin oak and occasionally for red maple, (3) oak regenerants >1-yr-old decline by an average of 8% annually on the three driest sites, (4) are characterized by much larger inputs and decreases on the two more mesic sites, (5) are only weakly correlated with precipitation amounts, and (6) include extremely low rates of oak seedling establishment on the intermediate site and relatively low rates on the dry sites.

INTEGRATING OAK PLANTING WITH NATURAL REGENERATION POTENTIAL

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Oaks can be successfully planted in clearcuts and under shelterwoods. Because planting costs are high, it is important to plant no more trees per acre than needed to attain a future stocking goal. In planning for such plantings, the natural regeneration potential of desirable species should be determined. Then, this information can be used to calculate the number of planted oaks needed to attain the stocking goal. A model for assessing the natural regeneration potential of oak stands in combination with a model for predicting the field performance of planted northern red oak (Quercus rubra L.) provide a comprehensive regeneration system that is applicable to the Missouri Ozarks.

The concept has potential application to many ecosystems under even-age management. It is based on the premise that the composition, structure, and stocking of the future stand is predictable from site, overstory, and advance reproduction characteristics of the parent stand. The method also requires an estimate of the probability of "success" of an individual planted tree, where success is defined as the probability of a planted tree surviving and attaining dominance or codominance at a specified future stand age. The reciprocal of the success probability thus represents the number of trees that need to be planted to obtain on the average, one competitively successful tree. Models based on research in the Missouri Ozarks show that success probabilities of planted oaks rapidly increase as initial basal diameter (caliper) of planting stock increases. An analysis of costs shows that, for a given future stocking goal, it is more cost effective to plant fewer large seedlings with high success probabilities than larger numbers of seedlings with low success probabilities.

USING CANOPY PHOTOGRAPHS TO CHARACTERIZE THE LIGHT ENVIRONMENT BENEATH SHELTERWOODS

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Of all the factors involved in the regeneration process, the microenvironmental conditions within the seedling space is the one we can most easily alter silviculturally to favor specific tree species. We have some information on the average microenvironmental conditions beneath forest canopies; however, seedlings respond to the varying conditions within their specific locations, not just the mean. Characterizing the solar radiation environment within the seedling space can contribute significantly to our understanding of the regeneration process, since solar radiation is important directly for photosynthesis and indirectly for its effects on the temperature and moisture conditions beneath the canopy. The direct measurement of solar radiation and/or PAR can be both difficult and expensive, especially if the objective is to quantify the variation at a large number of seedling sites.

A seedling's "view" or exposure to the radiation environment can be captured with a camera equipped with either hemispherical (7.5 to 8 mm) or very wide angle (16 mm) lens looking upward toward the overstory canopy from a height at or near the seedling's canopy. With the increased availability of video analysis equipment and techniques, analyzing the canopy photographs is no longer an overly daunting task. We used a 16 mm lens to take upward looking black and white canopy photographs above 1200 regeneration plots within an oak shelterwood study. The photographs were converted to computer files via a flat-bed scanner and analyzed with a BASIC program to obtain the percentage of the view open to the sky within the entire photograph and the percentage open to the sky within the area outlined by the sun's paths at the vernal and autumnal equinoses during the growing season.

For 60 locations beneath a shelterwood cut to 40 percent stocking, the percent open within the entire view averaged 26 percent and ranged from 9 to 39 percent. Within the sun's path during the growing season, the percent open averaged slightly higher, 30 percent, and ranged from 9 to 52 percent. Beneath a shelterwood cut to 60 percent stocking, the average percent open within the entire view was 22 percent, ranging from 1 to 31 percent. Within the sun's path, the percent open averaged about the same (23 percent), but ranged from 1 to 43 percent.

RESTORATION OF A MIXED BOTTOMLAND HARDWOOD STAND AFTER A MAJOR DISTURBANCE

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On September 21, 1989, Hurricane Hugo destroyed an 85-acre mixed bottomland hardwood stand in the Santee Experimental Forest near Huger, South Carolina. Detailed basal area and species composition data on this stand as well as the parent stand provide the opportunity to evaluate several silvicultural treatments for increasing the red oak component of a bottomland hardwood stand.

A study was installed on the site in 1990 which consists of four treatments with increasing degrees of silvicultural manipulation and investment. Treatments range from no enhancement to cutting all stems greater than one inch DBH, herbicide control of undesirable hardwoods, and planting of cherrybark oak (Quercus falcata var. pagodaefolia Ell.) seedlings. Comparison of treatments after one year suggest that control of undesirable hardwood sprouts with herbicide application had a positive effect on oak regeneration. This ongoing project will monitor stand growth to observe the long term effects of these treatments on red oak regeneration.

ACORN PRODUCTION IN THREE MISSOURI OAKS

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Acorn production fluctuates significantly from year-to-year and from tree-to-tree; thus, forest managers are not able to reliably predict the availability of an acorn crop until shortly before seed crop maturity. Weather, genetics, nutrition, insects, and flower numbers have been implicated or hypothesized as affecting acorn production. This report discusses the relationship of pistillate flower numbers to acorn survival and compares flower ontogeny of three species of oak, northern red oak (Quercus rubra L.), black oak (Q. velutina Lam.) and white oak (Q. alba L.) from 1989 through 1991.

There was little year-year variation in the flower survival curves for the three oak species, regardless of the number of flowers at the time of pollination. In 1991, black and white oak produced only about one fourth the number of flowers as in the two previous years and northern red oak produced no flowers. This suggests an environmental influence on either flower initiation or differentiation up to the time of receptivity. However, genetic control of the flowering process is also implicated because of the constant tree-tree ranking in flowers produced.

A rapid abortion and abscission of flowers occurred in May and early June for all three species and in all three years. This time period corresponds to the time of pollen shed and pollination and of feeding by various species of treehoppers (Membracidae). Both northern red oak and black oak require two growing seasons to complete acorn development. In this study, northern red oak had almost completely aborted its flowers by mid-summer of the first growing season, while black oak still retained from 50 to 60 percent of its flowers. During the second growing season almost all the flowers on black oak were aborted in the spring during the fertilization period. Almost all of the remaining flowers survived to maturity.

White oak, which requires only one season for acorn development, aborted up to 100 percent of the flowers by mid-July or just after the fertilization period. Ovule development and embryogenesis in white oak were about 2 to 4 weeks ahead of black oak.

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INDEX TO OAK (Quercus) SPECIES INCLUDED IN ONE OR MORE ABSTRACTS

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.