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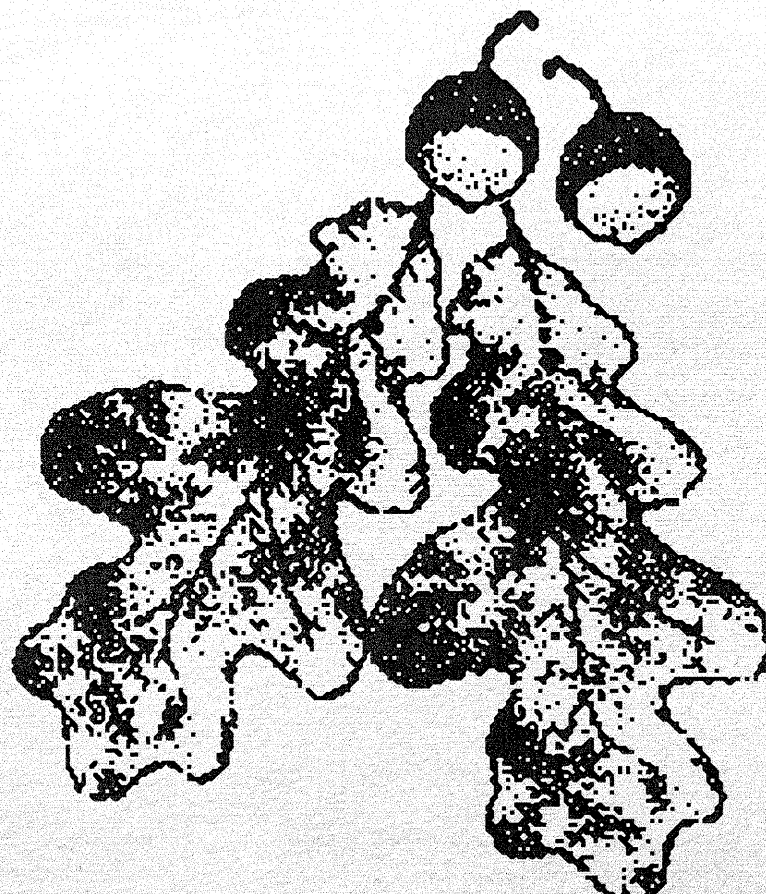
# Fourth Workshop on Seedling Physiology and Growth Problems in Oak Plantings

(Abstracts)



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# FOURTH WORKSHOP ON
# SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTINGS, COLUMBUS, OHIO, MARCH 1-2, 1989 (ABSTRACTS)

Edited by
J. W. Van Sambeek and M. M. Larson

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## PREFACE

The fourth workshop on seedling physiology and growth problems in oak plantings was held at the Olentangy Inn in Columbus, Ohio, on March 1-2, 1989. Like past workshops, it provided an informal forum for researchers to exchange ideas and research results. Invited and contributed papers were divided into four subject areas: (1) oak physiology and genetics, (2) oak seedling propagation and production methods, (3) field performance of planted oaks, and (4) natural regeneration of oaks. After much discussion, we decided to maintain our emphasis on problems associated with planted oaks.

## ACKNOWLEDGEMENTS

Merlyn M. Larson and John P. Vimmerstedt, workshop coordinators, gratefully acknowledge the assistance of the following session moderators: John D. Hodges, Jud G. Isebrands, Keith Jensen, Paul S. Johnson, Richard Schulta, Daniel K. Struve, and Jerry Van Sambeek. In addition, the workshop coordinators appreciate the support of the School of Natural Resources, Ohio State University; the Northeastern Forest Experiment Station; and the North Central Forest Experiment Station. Finally, the workshop participants are grateful to Burnell Fischer and Purdue University for accepting the responsibility of hosting the fifth workshop in the spring of 1992.

## REVIEW PROCEDURES

Each abstract published in this general technical report was critically reviewed by at least one of the two 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 and style of their papers.

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## OAK PHYSIOLOGY AND GENETICS

# GENETIC VARIATION PATTERNS IN NORTHERN RED OAK

Howard B. Kriebel, Professor, School of Natural Resources,
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Significant levels of genetic variation have been found in northern red oak (*Quercus rubra* L.) in all phenotypic characteristics that have been investigated. Drought resistance is higher in trees from provenances in the hot-summer, low-precipitation western and southwestern part of the species distribution (Iowa, Missouri, Kansas). Cold hardiness is strongly related to estimated average annual minimum temperature of the origin and to latitude and recent climatic regime. Both provenance and family have significant effects on growth rate. In a mid-latitude test where the two effects could be separated, they accounted, together, for about one third of the total variance in growth rate; two thirds of this was provenance effect and one third family. The trees were in their third decade of growth. At age 14, no geogrpahic pattern was evident in mid-latitude tests (latitudes 40° to 42° N), but by the third decade trees from farther north at latitudes 43° to 46° N from the Mississippi River to western Maine were consistently higher in growth rate than local trees or trees of other origins.

Time of flushing shows a geographic pattern. In the north central region of the U.S., it starts in trees of northwestern provenances and progresses "eastward" and "southward", ending in trees of mid-latitude origin from southern Michigan to Pennsylvania, rather than in "southern" trees. Data from plantings in Tennessee, however, suggest that the trend may be from south to north. Date of budbreak is later at high elevations than at low elevations. Time of leaf senescence is related to latitude, progressing clinally from north to south. Family differences have been detected in resistance to insect defoliation and in tree form.

# GENOTYPE AND RADICLE CLIPPING INFLUENCE NORTHERN RED OAK ROOT GROWTH CAPACITY

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The study evaluated the influence of pre-sowing radicle clipping on root growth capacity (RGC) and morphology of five open-pollinated northern red oak (*Quercus rubra* L.) families. All acorns were pre-germinated, and the emerging radicle tip was removed on half of the acorns immediately before spring sowing. RGC, the ability to grow new roots when transplanted into a favorable environment, was measured as the total number or total length of new roots grown in a 5-week period in a greenhouse. Caliper, height, height growth increment, and leaf area were also recorded.

There was a strong interaction among the five families and the radicle clipping treatment on RGC. Two families responded to the radicle clipping by doubling the mean number or length of new roots produced. The other three families showed no RGC responses to radicle clipping. Differences among families did not exist for first-year height or caliper. Differences among families did exist for height growth increment and leaf area developed in the greenhouse. Radicle clipping resulted in a 50 percent greater height growth increment and significantly increased leaf area. The family highest in RGC values was also highest in leaf area. These results indicate that there may be significant root growth response differences between families, even when no differences are apparent in caliper or height. These results also suggest that the radicle clipping treatment may be useful in improving northern red oak seedling field performance. Further studies are being conducted to compare the outplanting performance of these families and treatments.

# RELATING EARLY PERFORMANCE OF PLANTED RED OAK SEEDLINGS TO NURSERY ENVIRONMENT AND SEEDLOT ORIGIN

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A study was initiated in 1986 to investigate effects of undercutting and seedlot origin on growth of planted northern red oak (*Quercus rubra* L.) seedlings. Seedlots from 7 trees were sown in 2 replicated seedbeds and grown for 1 year. One seedbed was undercut in the summer of 1987 between flushes. The other seedbed served as a control. The following measurements were recorded for 840 seedlings before outplanting: total height, diameter, number of flushes, and number of lateral roots greater than or equal to 1 mm in diameter. Field survival and height growth increment data were collected at the end of the first growing season.

Undercutting had a greater effect on seedling growth than did seedlot origin in the nursery. Undercutting resulted in a 50 percent increase in number of lateral roots. First-year field survival was affected by both seedlot origin and undercutting treatment. Mean survival for undercut seedlings equaled 92.1 percent, while survival for control seedlings was 85.2 percent. First-year height growth increment was significantly influenced by seedlot origin but not by undercutting treatment.

Except when the number of lateral roots were used to describe survival in the control seedlings, use of nursery data on an individual seedling basis as an indicator of first-year field performance was unsuccessful. Coefficients of determination values for all of the simple regression models tested were less than 0.11.

# CHANGES IN CARBON FIXATION, PARTITIONING, AND ALLOCATION DURING EPISODIC GROWTH IN NORTHERN RED OAK SEEDLINGS

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Northern red oak (*Quercus rubra* L.) is an important component of the hardwood forests of the eastern half of the United States. The high value of red oak for timber, aesthetics, and wildlife is widely recognized. However, it is difficult to adequately regenerate harvestable stands or to increase the oak component in existing stands. We believe that information on the basic biological patterns of growth and development can be useful in nursery seedling production, artificial regneration, and natural regeneration techniques. Because of the lack of basic biological information, we have been studying shoot and root growth, photosynthesis, carbon fixation, carbon transport, and carbon and nitrogen interactions of northern red oak seedlings.

Northern red oak has a flushing growth habit characterized by cyclic patterns of stem, leaf, and root growth. During a growth flush the new stem elongates, then the leaves expand. In contrast to most other simple leaves (e.g. cottonwood) that mature from lamina tip to base, red oak leaf maturity progresses from lamina base to tip. After full expansion and initiation of export, new leaves continue to develop photosynthetically well into the next flush. Photosynthesis, $^{14}C$-fixation, and $^{14}C$-transport from first-flush source leaves increase and decrease in direct response to each subsequent flush of growth, indicating control of source leaf metabolism by sink demand. Allocation of $^{14}C$-photosynthate exported from a source leaf changes from 90 percent upwards to developing leaves and stem to 95 percent downwards to lower stem and roots during a flushing episode. The $^{14}C$ partitioning to various chemical fractions depends on time after fixation, the particular plant part analyzed (e.g. leaf, stem, or root), and phase of the flush cycle. Studying carbon allocation patterns in red oak grown in controlled environments could provide the background information necessary for predicting how these patterns might change with stress and could provide the knowledge necessary to develop physiologically based management strategies and genetic improvement programs.

# EFFECT OF DEFOLIATION ON GROWTH AND PHOTOSYNTHESIS OF NORTHERN RED OAK SEEDLINGS GROWN UNDER DIFFERENT CONDITIONS OF LIGHT, NUTRIENTS, AND WATER

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The potential for defoliation of oak (Quercus spp.) seedlings by gypsy moth is quite high. We were interested in examining both interactions between various natural stresses and resulting gypsy moth feeding preferences and results of defoliation stresses on growth and photosynthetic responses of oak seedlings. A factorial experiment was carried out with northern red oak (Q. rubra L.) seedlings. The seedlings were grown in the greenhouse under one of eight conditions: watering with 10 or 50 percent Hoagland's nutrient solution daily or twice a week in a split-block design with and without shade cloth. After 2 months under these conditions, one-half of the seedlings within each treatment were manually defoliated. This foliage was fed to fourth instar gypsy moth larvae in a preference test with leaf discs from each of the eight treatments. At the end of 3 months, photosynthetic parameters were measured on a subsample of the seedlings. After 4 months, trees were harvested, separated into stems, roots, and leaves, leaf area measured, and dry weights obtained.

Photosynthetic quantum yields were similar for plants in all treatments. Light compensation point was higher and dark respiration rate greater for plants grown in high light than for plants grown in low light; however, there were no significant interactions with defoliation. There was a significant defoliation x soil moisture interaction for maximum net photosynthesis, such that defoliation increased photosynthetic rate when drought stress was present (compensatory photosynthesis), but not when soil mositure was adequate.

Defoliated seedlings had a 32.6 percent mortality rate; significantly higher than that of check seedlings (1.3 percent). Dry weights and leaf areas were significantly reduced by most stress factors. Two-way interactions of stresses with defoliation were significant and in most cases positive, in the sense that defoliation had a lesser effect in depressing growth in the presence of stress than when resources were abundant. Drought stressed foliage was significantly preferred over unstressed foliage by gypsy moth larvae in the leaf consumption/preference test.

# RESPONSES OF BLACK AND WHITE OAK SEEDLINGS TO ATMOSPHERIC DEPOSITION AND WATER STRESS

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In the spring of 1988, 100 uniform seedlings of black oak (*Quercus velutina* Lam.) and white oak (*Q. alba* L.) were potted in 15 cm pots in a mixture of 50 percent Berks silt loam soil and 50 percent washed sand. The seedlings were randomly assigned to an ozone treatment of 0, 70, or 150 ppb, a sulfate treatment of 1 or 5 $gm/m^2/yr$, and a water regime of well watered or intermittently stressed during the growing season. After 16 weeks of treatment the seedlings were measured for height, leaf midrib length, stomatal conductance, and photosynthetic rate. Leaf, stem, and root dry weight were also determined.

Sulfate had a significant effect on stem dry weight of black oak, while water stress had a significant effect on photosynthesis, stomatal conductance, and height of white oak. Ozone did not have an impact on seedling growth but did have a significant effect on photosynthesis and stomata conductance. These observations suggest that, within the first season of treatment, atmospheric deposition does not have a significant effect on the growth of oak seedlings. The growth habit of oak seedlings, which is to flush over a short time in the spring and then set bud with little additional summer growth, makes it difficult to detect growth differences. To more accurately assess the effects of atmospheric deposition on the growth of oak seedlings, experiments must be conducted over 2 or more years.

# ALLELOPATHIC INFLUENCES OF GOLDENROD ON OAK SEEDLINGS AND TRANSPLANTS

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Tall goldenrod (*Solidago altissima* L.) and several closely related species commonly invade and form dense, persistent stands in abandoned fields and cleared areas. Invasion of tree seedlings into these stands is very slow, even when the area is surrounded by mature, seed-bearing trees. Growth inhibition of tree seedlings by allelopathic compounds in goldenrod plants was investigated. Earlier results revealed that dried goldenrod foliage (litter) added to potting soil strongly inhibited growth of northern red oak (*Quercus rubra* L.) seedlings and transplants. Further studies showed that goldenrod leaves contained higher concentrations of inhibitors than goldenrod roots, stems, or flowers. Inhibitor concentrations were higher during late summer and early fall (August, September, and October) than in late spring or late fall (May or November).

Soil, collected monthly (July through November) from plots with goldenrod stands and from plots previously cleared of goldenrod, was used as potting media for oak seedlings in a greenhouse study. The soil leachate was continually recycled through the pots. Both northern red oak and white oak (*Q. alba* L.) grew well in all soil collections with two exceptions: (1) root elongation was reduced 14 percent in soil from goldenrod stands collected in November, and (2) addition of 6 g of goldenrod litter to soil in pots significantly reduced all aspects of seedling growth.

Rooting of mung bean (*Vigna radiata* L. Wilzek) cuttings in water extracts of goldenrod leaves confirmed the presence of inhibitors up to time of leaf senescence. The mung bean assay is sensitive to phenolic growth inhibitors such as pyrocatechol and coumarin at concentrations as low as $10^{-3}$ M.

We conclude that goldenrod inhibitors remain below toxic levels in soils through most of the growing season but rise to toxic levels when the amount of leaf litter present is high (i.e. under dense stands from late fall to spring). However, in excessively drained soils, inhibitors are readily leached through the root zone as was demonstrated in a nursery bed with sandy soils where oak seedlings were unaffected by addition of 300 $g/m^2$ of goldenrod litter to the soil surface.

# COMPETITIVE AND ALLELOPATHIC COMPONENTS OF GRASS SOD INTERFERENCE ON WHITE OAK SEEDLING GROWTH

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Without ground cover management, many old fields planted with white oak (*Quercus alba* L.) seedlings develop a grass (*Festuca arundinacea* Schreb.) sod. Grass sods, especially tall fescue sods, have been shown to interfere with hardwood seedling growth through both competition and allelopathy. Our previous studies examining effects of grass interference on white oak seedling growth were confounded by transplant shock. In the experiment described below, white oak seedlings were first established and then exposed to interference to simulate conditions found under natural regeneration.

Seedlings were established by overwintering 36 germinated acorns in each of thirty-two 60 x 60 x 60 cm boxes filled with a 1:1 sand:topsoil mixture. Acorns were collected from one open-pollinated tree in each of six natural stands in Jackson County, Illinois. Interference treatments were applied after seedlings completed the first flush of growth and averaged 8 cm tall. Treatments consisted of factorial combinations of two levels of soil moisture (-0.2 and -0.5 bars), with and without bluegrass (*Poa pratensis* L.) sod, and watering with either sand or tall fescue leachates. Boxes in which soil moisture was cycled between -0.1 and -0.2 bars required 15 more liters of leachate than boxes cycled between -0.4 and -0.5 bars. The latter required an average of 83 liters over a 180-day period. Boxes with a bluegrass sod required 25 percent more water or leachate to maintain the prescribed soil moisture levels than boxes without grass sod.

After 4 months, height growth averaged 7.8 cm with no differences in response to treatments. Height differences among seedlings of different open-pollinated families were apparent, although data analyses are incomplete. Data on final height, basal stem diameter, root length, leaf area, and leaf, shoot, and root dry weights, taken 5 months after initiating treatments, still need to be analyzed. The latter data will also be used to examine carbon allocation patterns of white oak seedlings when exposed to various stresses.

# VEGETATIVE PROPAGATION OF NORTHERN RED OAK: AN UPDATE

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There has been some recent success in Europe in vegetative propagation of the European white oaks with grafting, softwood cuttings, cuttings from stump sprouts, and tissue culture. Vegetative propgation of northern red oak (Quercus rubra L.) and other members of the red oak group has been less successful. However, there are efforts underway in the U.S. and Europe to develop reliable techniques for propagating northern red oak (NRO). Most problems with grafting NRO have been solved, and members of the North Central Fine Hardwood Tree Improvement Cooperative are successfully grafting NRO. Vegetative propagation of NRO from cuttings and tissue culture has been researched less and with less success.

Recent studies suggest that new approaches show promise for both propagation of softwood cuttings and tissue culture of NRO. Juvenile NRO cuttings can be rooted easily with applied growth hormones. In addition, more mature cuttings can be rooted successfully using high hormone concentrations (i.e. 1.5% IBA) and light restriction methods (i.e. blanching and/or etiolation) at the proper stage of development under mist. Once rooted, cuttings can be acclimated and assume a normal shoot growth pattern. Rooting cuttings from mature trees is still difficult to achieve. There has been some success in rooting stump sprouts from older trees using the aforementioned methods; however, there is a strong genetic component in the rootability. For example, some NRO provenances root much easier than others. Efforts are also underway to combine serial grafting with softwood cutting methods to root scions from mature trees.

Tissue culture methods for NRO are being developed in the U.S. and France. Progress has been slow, but several protocols show promise on a research scale. One such approach is the work of Gingas at Ohio State on regeneration of plantlets from NRO embryos employing desiccation and rehydration treatments. Some success has also been demonstrated by Bennett at Texas A&M with Shumard oak (Q. shumardii Buckl.) stem sections, another member of the red oak group. Several other groups, including University of Wisconsin-Madison, University of Tennessee, and INRA-France have work underway on tissue culture of NRO. Given the present successes on vegetative propagation, continued research will likely soon lead to major improvements in our ability to clone NRO for research and commercial applications.

# CULTURAL PRACTICES AND OAK SEEDLING ROOT DEVELOPMENT

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The Hardwood Seedling Quality Cooperative consists of the state forest nurseries of Illinois, Indiana, Iowa, Missouri, and Ohio. Efforts are being made to improve the root characteristics of northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and black walnut (*Juglans nigra* L.). Interest has centered on the number of first-order lateral roots > 1 mm (lateral roots coming directly off the taproot). These roots normally persist through the lifting, grading, storing, shipping, and field planting processes, while many of the higher order roots die during the transplanting process. The first-order lateral roots provide a trellis system from which new roots develop.

A relatively high percentage of seedlings in any seedlot produce seedlings with less than 2-3 permanent first-order laterals. These seedlings are often, but not always, the smallest ones. An objective of the cooperative is to determine the critical minimum number of permanent first-order laterals that are needed for seedling survival and competitive growth in the field. Competitively growing seedlings will become a part of the dominant or codominant canopy. From limited field observations it appears that at least 6-8 permanent first-order lateral roots are needed.

Cultural practices such as seedling density and undercutting and genetic factors can influence the number of permanent first-order lateral roots. Decreasing density to 3-6 seedlings/ft$^2$ in nursery beds increased the number of permanent first-order lateral roots produced in the first season of seedling growth. Undercutting seedlings also increased the number of permanent first-order laterals due to thickening of existing lateral roots and by causing new roots to be produced from the wounded zone. If the undercutting is properly timed, these new roots become part of the permanent root system. Field excavation of undercut seedlings has shown that these wound-roots persist and provide sites for new root development. The timing of undercutting is critical because oak seedlings do not show synchronized growth flushes.

If seedlings were graded using the number of permanent first-order lateral roots as a criterion, field survival and growth would be improved. Precise counts are not necessary, but attention to the mass of large roots (not just root fibrosity) is needed. Mother trees should be selected which produce large numbers of progeny with more than 6-8 first-order lateral roots.

# EFFECTS OF NURSERY REGIME AND OTHER TREATMENTS ON FIELD PERFORMANCE OF NORTHERN RED OAK

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After one growing season, height growth performance of northern red oak (*Quercus rubra* L.) seedlings was compared as a function of: nursery cultural variables (stock age, container vs. bareroot, +/- root pruning, +/- transplanting); nursery location (Alabama and Pennsylvania); planting procedures (+/- top clipping, +/- hormonal root soak); and direct seeding (+/- protection from small mammals). In all, 33 completely randomized single-tree plots for each of 20 different treatments were represented at three recently harvested sites in northern, central, and southern Pennsylvania. Sixteen treatments utilized the same seedlot.

Over all sites, survival was very good averaging 93 percent. One year after outplanting, survival averaged 94 percent for seedlings soaked in 200 mg/l IAA and 0.1 mg/l kinetin for 24 hours compared to only 83 percent for those which were soaked in water only. Seedling height growth increment was significantly affected by stock age and top clipping before planting, but not by other treatments. Seedlings that had been top clipped to a height of 15 cm at the time of planting flushed 2 to 3 weeks later and grew an average of 23 cm, compared to 8 cm for unclipped seedlings. Also, 2-year-old seedlings grew significantly more than 1-year-old seedlings (19 vs. 10 cm). None of the other treatment comparisons showed significant differences in height increment. Direct-seeded acorns with small mammal protection germinated at 70 percent with a total height of 21 cm vs. unprotected seeds germinating at 62 percent and a height of 18 cm.

Expensive nursery related treatments of containerization, transplanting, root-pruning, and utilizing nurseries with longer growing seasons do not appear to add enough to seedling performance to justify the greater incurred costs. However, top clipping resulted in greater height increment and a more vigorous looking seedling with little to no added cost. Clipped seedlings were nearly as tall as unclipped seedling at the end of the first year. At this early stage in the study, 2-0 bareroot seedlings were the most promising nursery-grown seedlings. In addition, it seems that direct-seeding of acorns can be a successful low-cost method of establishing red oak, if predation by small mammals is controlled. More definite recommendations will be made as additional growth data are collected over the following years.

# UNDERCUTTING INFLUENCES ROOT MORPHOLOGY AND FIELD PERFORMANCE OF NORTHERN RED OAK

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Compared to northern red oak (*Quercus rubra* L.) seedlings that were not undercut in the nursery, undercut seedlings had significantly greater ($p < .05$): (1) lateral root dry weight at time of planting, (2) dry weight and surface area of taproots, fine (< 2 mm in diameter) lateral roots, and coarse (> 2 mm) lateral roots at the end of the first growing season in clearcuts, (3) survival at the end of 4 years after underplanting in a shelterwood, and (4) probabilities of "success" (i.e. attaining a given height) after 6 years in clearcuts. For seedlings planted in clearcuts, sixth-year success probabilities also increased as initial seedling diameter 2 cm above the root collar increased. For seedlings planted under shelterwoods, clipping shoots 20 cm above the root collar before outplanting increased 4-year survival of seedlings with and without undercutting. For seedlings with intact shoots, survival decreased with increasing initial shoot diameter for seedlings with and without undercutting.

# DRYING AFFECTS THE GROWTH OF NORTHERN RED OAK SEEDLINGS

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Bareroot northern red oak (Quercus rubra L.) seedlings usually experience some amount of drying during harvesting, grading, and transplanting. To determine the effects of drying on regrowth, seedlings were given factorial combinations of with and without 70 minutes drying on a sorting table, with and without preplanting water soak to rehydrate, and with and without auxin (IBA) soak treatments. Seedlings exposed to 70 minutes of drying lost 13 percent of their internal water (mostly from the roots) and recovered over 90 percent of the lost water with the 10-minute rehydration soak.

The study was done twice, in 1986 and in 1988. The 1986 results indicate that drying (with or without auxin or rehydration) increased plant dry weight at the end of one growing season as compared with seedlings given no drying (control). Seedlings that had the IBA soak with or without drying treatment had greatest plant dry weight increase.

In 1988 there were no significant differences between treatments after one growing season. However, after oak growth phase lag-1, seedlings exposed to drying conditions had significantly lower relative growth rate (RGR) than seedlings given dehydration-IBA treatment. Between lag-1 and the September harvest date, there were differences in net assimilation rate and leaf area ratio. Seedlings exposed to drying conditions had significantly higher RGR than did seedlings given the dehydration-IBA treatment. Leaf area ratio was greatest for IBA-treated seedlings, which also had the lowest net assimilation rate. Seedlings exposed to drying conditions had the highest net assimilation rate and lowest leaf area ratio. No trees of one treatment had both high net assimilation rate and leaf area ratio.

# NURSERY INOCULATION OF NORTHERN RED OAK SEEDLINGS WITH THE FUNGAL SYMBIONT *SUILLUS LUTEUS*

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Previous nursery studies with *Quercus* species reveal seedling nutrition, drought tolerance, and growth is improved by establishing an effective mycorrhizal association. The ectomycorrhizal symbiont, *Suillus luteus* (L. ex Fr.) Peck, a symbiont of *Quercus* adapted to the prevailing environmental conditions of the northern USA, is a promising candidate for routine inoculation of seedlings in northern nurseries. In this study, I introduced *S. luteus* into a northern Michigan nursery and evaluated the effects of inoculation on ectomycorrhizal development, growth, and nutrition of four families of northern red oak (*Q. rubra* L.) seedlings 1 and 2 years after sowing. Vegetative inoculum of *S. luteus* was thoroughly mixed into fumigated nursery soil.

At the end of year 1, the percentage of seedlings successfully inoculated with *S. luteus* varied significantly among families. Seedlings in the control plots developed relatively small amounts of ectomycorrhizae with indigenous fungal symbionts. Evaluation of seedlings 2 years after sowing revealed *S. luteus* persisted on lateral roots. Seedlings in two of four families inoculated with *S. luteus* were significantly larger in size and weight than control plants. Seedling foliage nitrogen and phosphorus content did not differ significantly among families or inoculation treatments. Within the control plots, fruiting bodies of *Hebeloma* and *Inocybe* species, *Laccaria laccata* (Scop.:Fr.) Berk & Br., and *Thelephora terrestris* Ehrh. ex Fr. were observed. These results suggest the fungal symbiont *S. luteus* can be successfully introduced into tree seedling nurseries of the northern USA. Moreover, early ectomycorrhizal development will improve the growth of northern red oak seedlings in the nursery.

# IMPACT OF WEEVIL FEEDING AND PATHOGENIC FUNGI ON OAK ACORN AND SEEDLING SURVIVAL

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In the United States, managed oak (*Quercus* spp.) forests comprise approximately 109 million acres of commercial timberlands, 42 percent of the hardwood volume, and almost 23 percent of all producing forest land. The problem of inadequate quantities of viable acorns and low survival concerns managers of oak plantings. Oak regeneration failures may result from (1) poor germination because of silvicultural practices and environmental stresses, (2) harmful effects of diseases and insects on acorns and seedlings, and (3) injury to acorns and seedlings by browsing animals and understory competition.

Studies were designed to evaluate the impact of the acorn weevil and two fungi on acorn germination, survival, seedling shoot growth, and leaf biomass of northern red oak (*Q. rubra* L.) and white oak (*Q. alba* L.). After adult acorn weevils (*Conotrachelus posticatus* Boheman) deposit their eggs on damaged, cracked or sprouting acorns, the developing larvae feed on and damage the sprouting seedlings. *Cylindrocladium scoparium* Morgen, a very virulent fungi, and *Fusarium solani* (Mart.) emend Snyder & Hansen, a weak pathogen, are usually found in association with acorn weevil damage.

Using paired male weevils, fungi, or weevil-fungus combinations, we found that (1) weevils alone had a detrimental effect on acorn survival, (2) the *Fusarium* fungus alone resulted in limited injury, (3) the weevil-*Fusarium* combination was more injurious than *Fusarium* fungus alone to germinating acorns and seedlings, and (4) the *Cylindrocladium* organism alone and in combination with male weevils caused more acorn and seedling mortality than any of the other treatments on both oak species. Subsequent studies with the various fungi combinations and paired male, paired female, and male-female combinations substantiated previous results. In addition, paired females alone resulted in more damage to germinating acorns than other weevil combinations on acorns and seedlings of both northern red and white oak.

# EARLY GROWTH PATTERNS OF CHERRYBARK OAK: ENVIRONMENTAL AND PHYSIOLOGICAL INFLUENCES

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Research on natural regeneration of cherrybark (*Quercus falcata* var. *pagodifolia* Ell.) and other red oaks has emphasized techniques for increasing the amount (numbers) of advance regeneration, maintaining it in the understory, and increasing its growth rate. Results from several studies indicate that these objectives can be accomplished by use of a modified shelterwood system coupled with control of midstory and understory competition. Severing of existing cherrybark oak seedlings near the ground line at the time of understory control results in faster height growth and larger, more desirable seedlings than does release from understory competition alone. Stocking of cherrybark oak seedlings can be increased by underplanting beneath a heavy shelterwood where midstory and understory species are removed. Best survival and height growth were obtained from seedlings which were clipped just above the root collar at time of planting.

Shade studies performed over the last 4 years indicate that best growth of cherrybark oak seedlings is made at a light intensity of about 50 percent of full sunlight. Intensities of 100, 53, 24, and 8 percent of full sunlight were compared. Shade cloth used in these studies altered light intensity but not light quality. Best growth (total height, root collar diameter, total weight, top weight, root weight) occurred at 53 percent sunlight. Light treatments also influenced nutrient allocation patterns within the seedlings. Highest root/shoot ratios occurred at full sunlight and lowest at 24 percent sunlight. Recently initiated studies are examining morphological development, photosynthetic efficiency, and carbon allocation patterns in cherrybark oak seedlings and seedling sprouts under both natural and controlled conditions.

# RED OAK WHIP PRODUCTION IN CONTAINERS

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A method for producing 2 m tall northern red oak (*Quercus rubra* L.) seedlings in one growing season is described. Acorns are germinated (about March 1) and grown under greenhouse conditions until May 15 (the last frost date for our area). Seedlings are moved outdoors, placed under 70 percent shade for 2 weeks to acclimate, transplanted from #1 containers (3.5 l pots) to #3 containers (11" diameter, 9" deep fiber pots), and grown under full sun for the rest of the growing season. The rapid growth is attributed to extending the growing season (about 10 weeks) and avoiding transplant shock by not root pruning. Root growth is controlled by applying 100 gm $CuCO_3$/l exterior latex paint to the interior container surfaces. The application of copper-containing salts stops girdling root development within the pot. The 2 m tall whips continue vigorous growth when field planted. This technique can also be used for English (*Q. robur* L.), shingle (*Q. imbricaria* Michx.), scarlet (*Q. coccinea* Muenchh.), and Shumard (*Q. shumardii* Buckl.) oaks and for red maple (*Acer rubrum* L.).

# EFFECTS OF TUBULAR TREE SHELTERS ON NORTHERN RED OAK SEEDLINGS PLANTED IN HARVESTED FOREST OPENINGS

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The use of tree shelters was studied to determine seedling microenvironmental conditions and initial growth responses for sheltered northern red oak (Quercus rubra L.) seedlings planted in harvested upland hardwood forest openings. For these studies, three recently-harvested forest openings (2-3 acres) were planted with 1-0 northern red oak nursery stock in the spring of 1987. Fourteen-seedling treatment units, replicated three times per study site, were randomly assigned to treatments consisting of a British-made, 120-cm-tall plastic tubular tree shelter with an early-summer spot herbicide application, a tree shelter consisting of a 120-cm-tall plastic tubular tree shelter with an early-summer spot herbicide application, three different weed control treatments, and an untreated control. Three additional harvested forest openings were broadcast sprayed with glyphosate. They were planted with 1-0 northern red oak seedlings in the spring of 1988. Fourteen-seedling treatment units, replicated 3-4 times per study site, served as controls or were assigned one of the two shelter treatments.

Shelter microenvironmental conditions were periodically measured during the 1987 and 1988 growing seasons. Significantly higher levels of relative humidity and carbon-dioxide concentrations were found inside the shelters. Differences among daytime temperatures were not significant. Interior light intensities varied with the shelter type and location within the tree shelter. Light quality transmission levels along the visible spectrum varied among the two types of shelter materials.

The use of poor quality seedlings, poor planting practices, frost heaving, rodent and 17-year cicada damage appeared to confound the 1987 results. Seedlings in both types of tree shelter treatments, however, exhibited significantly greater mean 2-year height growth increments but had significantly less mean 2-year caliper growth increments. There were no significant differences among tree shelter treatments for 2-year stem volume growth, suggesting that a reallocation of stem biomass may be occurring among sheltered seedlings. For seedlings planted in 1988, first-year number of flushes and height and stem volume growth were significantly greater for both shelter treatments as compared to the control. There was no significant difference in caliper growth.

# RESULTS OF PLANTING OAKS ON COAL SURFACE-MINED LANDS

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Oaks (*Quercus* spp.) have been used in reclamation plantings on coal surface-mined lands since the 1930s. Until 10 to 15 years ago, many of these plantings were on ungraded or partially leveled spoils. Spoils were not topsoiled or seeded to herbaceous cover species. Oaks planted on these mine-spoils often compared favorably with or exceeded growth of planted oaks on adjacent unmined soils. Bur oak (*Quercus macrocarpa* Michx.) did well especially on spoils that were planted and direct-seeded in the 1940s in Missouri, Kansas, Oklahoma, and Ohio. Similarly, successful stands of planted northern red oak (*Q. rubra* L.) developed on spoils in Illinois, Indiana, Ohio, Pennsylvania, and Kentucky. Outstanding growth of planted northern red, Shumard (*Q. shumardii* Buckl.), chestnut (*Q. prinus* L.), and white (*Q. alba* L.) oaks was recorded on cast overburden in Illinois and Indiana. Site indices for 20-year-old northern red, white, and black (*Q. velutina* Lam.) oaks on spoils in eastern Kentucky were similar to indices on nearby unmined sites. Sawtooth oak (*Q. acutissima* Carruthers), an introduced species, has been successful in wildlife habitat plantings on Appalachian coal spoils.

Recent plantings of oaks made on surface-mined lands reclaimed under present Federal and State laws have been less successful. Studies show that excessive soil compaction caused by spoil handling, grading, and topsoiling practices combined with competition from dense herbaceous covers greatly reduce survival and growth of planted oaks and other tree species. Many acres of mined land in naturally forested regions are not being returned to forest production because existing reclamation laws and regulations directly or indirectly discourage planting or prevent successful establishment of trees. Thus, mined lands that may have potential for producing and increasing the supply of oak are instead being developed primarily into grasslands.

## GROWTH OF OAKS ON TOPSOILED MINED LANDS

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Seedlings or seed of nine oak (*Quercus* spp.) species along with thirteen other species were planted on topsoiled minesoils in fall 1980, spring and fall 1981, and spring and fall 1982. Minespoils consisted of graded cast overburden covered with approximately 40 cm of eroded old-field surface soil. Oak species planted included white (*Q. alba* L.), swamp white (*Q. bicolor* Willd.), shingle (*Q. imbricaria* Michx.), bur (*Q. macrocarpa* Michx.), pin (*Q. palustris* Muenchh.), chestnut (*Q. prinus* L.), northern red (*Q. rubra* L.), Shumard (*Q. shumardii* Buckl.), and black (*Q. velutina* Lam.). Seedlings or seed of each species that were available were planted in replicated rows of 50 trees. Only seedlings of pin and northern red oak and seed of Shumard and northern red oak were available for all five plantings. First-year survival, third-year height, third-year basal caliper, and 1988 height were determined. The 1988 basal caliper was not determined because of repeated dieback and resprouting that had occurred.

White, bur, pin, and Shumard oak had the highest survival on the graded/topsoiled minesoil. Bur oak planted as seedlings did better than when planted as seed. Seedlings of bur, swamp white, and pin oak usually had the greatest third-year height. When planted as seed, seedlings of shingle, northern red, Shumard, and swamp white oak had the poorest growth in one or more of the plantings. The early superior growth of chestnut oak found in some plantings was not found after seven growing seasons. Northern red oak, black walnut (*Juglans nigra* L.), and yellow-poplar (*Liquidambar styraciflua* L.), species traditionally successful in southern Illinois and Indiana on pre-law reclamation plantings, did not do well on these graded/topsoiled minesoils. Sycamore (*Platanus occidentalis* L.), river birch (*Betula nigra* L.), yellow-poplar, and to a lesser extent, white ash (*Fraxinus americana* L.), outgrew the oaks in one or more plantings.

Recommended trees for planting on graded/topsoiled minesoils currently required in southern Illinois under Public Law 95-87 Surface Mining Control and Reclamation Act of 1977 include bur, swamp white, pin, and white oak. Moderate changes in the laws and regulations are greatly needed to produce the superior tree growth found on pre-law midwestern mined lands.

# FIELD PERFORMANCE OF VALLEY OAK SEEDLINGS UNDER DIFFERENT IRRIGATION REGIMES

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Valley oak (Q. lobata Nee) was once abundant in the central basin of California, which has a Mediterranean-like environment where there is little or no rainfall between April and October. Efforts are underway to reestablish this species; however, there is little information available on successful artificial regeneration procedures. A study was initiated to evaluate the effects of alternative irrigation regimes on seedling establishment using direct seeded acorns and transplanted container stock.

In late March 1988, 120 valley oak seedlings, produced from acorns sown the previous December in 2- x 2- x 5-inch plastic pots, were planted in a weed-free field. Seedlings were planted on a 5-foot spacing in holes augered to a depth of 3 feet using a tractor-mounted 8-inch drill. A 21-gm fertilizer tablet (22-10-5) was placed 8 inches deep in each planting spot. For a month after planting, seedlings were hand watered once or twice a week. In late April, seedlings were given one of the following four treatments for 5 months using gallon-per-hour drip emitters: (1) 1 gallon of water every week; (2) 1 gallon of water every 2 weeks, (3) 1 gallon of water every 4 weeks, and (4) no water (control). At 12 of the 30 planting spots from each treatment, a pre-germinated acorn was planted in late April next to the seedlings. The height of each seedling was measured every other week from mid-July through November.

All seedlings survived and grew vigorously. Container seedlings from the most frequently irrigated treatment were the tallest (64 cm) with significant differences among the remaining three treatments which ranged from 46 to 52 cm tall. Seedlings from directly seeded acorns grew significantly taller and continued to grow for 10 weeks longer than the transplanted seedlings. By November, average height of the seedlings from directly seeded acorns was 63 cm, compared to an average of 45 cm for adjacent transplants. This study indicates that valley oak seedlings can be successfully established by planting either container stock or acorns. Excellent growth and survival can be obtained if the planting area is kept free of weeds, planting spots are pre-augered, and fertilizer tablets are placed below the roots. Frequent irrigation does little to improve field performance. Direct seeding of valley oak acorns is recommended because it is cheaper and easier than establishing container stock and because seedlings from directly seeded acorns grew faster than container stock during the first year.

# ARTIFICIAL REGENERATION OF OAKS: PROBLEMS AND POTENTIAL

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Many of the maturing even-aged, mixed oak (*Quercus* spp.) stands in Pennsylvania are currently being harvested. High stumpage prices for oak and the need to salvage mortality associated with gypsy moth defoliations have accelerated harvesting in recent years. Shelterwood and clearcutting are the most frequent regeneration methods for reestablishing these oak stands. As in the past, natural regeneration is being counted on to provide the next generation of trees. Observations and inventories of stands harvested in the past 20 years, however, indicate that natural regeneration has resulted in inadequate stocking and lack of desirable species, particularly oaks.

While generally dismissed as expensive, artificial regeneration of hardwoods may be a management option worth reconsidering under today's conditions and in light of some recent research results. Clearly the need for artificial regeneration of oaks and other hardwoods currently exists throughout the range of the oak-hickory forest type. Artificial regeneration may be the only choice for reestablishing productive forest stands on the thousands of acres of previous shelterwood cuts which have failed to successfully regenerate. Artificial regeneration could also be used effectively to augment natural regeneration in recently harvested or soon to be harvested stands with desired species and genotypes.

Our studies conducted over the past 5 years show that artificial regeneration of selected hardwood species is both technically and biologically feasible. Technology has provided means to protect seedlings from herbivores and herbicides to release seedlings from competing herbaceous vegetation. The studies show that, when given protection from competing herbaceous vegetation and herbivores, growth of planted hardwood seedlings on forest sites is comparable to that of seedlings of natural origin. Average height growth after 4 years for planted seedlings of yellow-poplar (*Liriodendron tulipifera* L.), white ash (*Fraxinus americana* L.), and northern red oak (*Q. rubra* L.) in weed-free areas was approximately 11.5, 10, and 5 feet, respectively. The question that remains is the ability or willingness of the forest owner to make the necessary investments in time and money.

# POST-HARVESTING SILVICLUTURAL TECHNIQUES TO ENHANCE THE RED OAK COMPONENT OF SHALLOW-SITE FORESTS IN CENTRAL ONTARIO

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

Harvesting to remove about 40 percent of the overstory left a residual basal area of approximately 13.8 $m^2$/ha (60 $ft^2$/acre). The experimental design tested all possible combinations of stock type (1+0, 1+1) and treatment (prescribed burn, herbicide, control). Sixty-four northern red oak seedlings 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 in 1986 and 1987, and then again in the summer of 1987. The prescribed burn was executed in the spring of 1987 and effectively killed a high proportion of the maple competition. The planted oak in the burned area resprouted vigorously. In the spring of 1988, one half of the seedlings were clipped for biomass determination and allowed to resprout.

Prescribed burning increased oak seedling height growth over that of the control and herbicide treatments, although the increased height growth appears to be temporary. Herbicide application diminished total height growth relative to the control treatment after the first year. Loss of vegetation may have caused soil desiccation around the base of seedlings leading to reduced height growth. In the herbicide treatment, the 1+0 stock outperformed the 1+1 stock in annual shoot growth for all 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. Clipping resulted in rapid height growth from sprouts across all treatments with sprouts often exceeded 70 cm in height. For 1+0 stock, clipped seedlings from the herbicide treatment had the highest shoot growth and seedlings in the burned treatment had the least, possibly because they had already resprouted in response to burning.

These preliminary results indicate that a light prescribed burning can initially stimulate height growth of planted oak seedlings, but if not repeated may be of little use in the longer term. Larger stock (1+1) responds better to burning than smaller (1+0) stock, but the converse is true if competition is controlled by herbicides.

# PRESCRIBED BURNING TO ENHANCE GROWTH OF UNDERPLANTED NORTHERN RED OAK SEEDLINGS AFTER SHELTERWOOD CUTTING: EFFECT OF BURN INTENSITY

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In central Ontario, survival and growth of outplanted northern red oak (*Quercus rubra* L.) in low quality sugar maple (*Acer saccharum* Marsh.) stands subjected to shelterwood cutting may be enhanced by competition control measures such as fire and herbicides. This study investigated the effects of a prescribed burn at one of three intensities (light, medium and heavy), a broadcast glyphosate treatment, and no competition control measures on the height growth of 1+0 red oak stock. A shelterwood system cut initially reduced the maple overstory from 23.0 $m^2$/ha (100 $ft^2$/ac) to 13.8 $m^2$/ha (60 $ft^2$/ac). Nine oak seedlings were planted on a 2 m by 2 m spacing in each of the five replicated treatments.

Height growth was evaluated for the first and second growing seasons. Seedlings planted in the lightly-burned treatment had the greatest height growth in both years. In the first year, growth (13.9 cm) was significantly greater than for all other treatments; in the second year, growth (8.1 cm) was significantly higher than all other treatments except the herbicide application. Seedlings from the medium burn treatment had the next best height growth during the first year (9.6 cm) but had the lowest height growth the second year. After 2 years, total height growth (incorporating dieback) was ranked by treatment as follows: light burn (8.0 cm) = herbicide (4.6 cm) > heavy burn (3.0 cm) = control (1.8 cm) = medium burn (1.6 cm). It would appear that light burning stimulates height growth and adequately controls initial competition. Results indicate that a second light burn might be advisable, especially if competition potential is high.

# NORTHERN RED OAK REGENERATION PROGRAM IN ONTARIO: AN OVERVIEW

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Northern red oak (*Quercus rubra* L.) is one of the major species in the Algonquin Highlands and Huron-Ontario sections of the Great Lakes - St. Lawrence Forest Region. Presently there are four methods under investigation for regenerating northern red oak: (1) planting bare-root nursery stock, (2) planting germinated acorns in kraft tubes, (3) direct seeding of acorns, and (4) controlling competition with prescribed burning and herbicides.

Underplanting of 1+0, 2+0, and 1+2 bare-root nursery stock is being evaluated in red pine plantations following row-thinning or selective thinning and in shelterwood cuts of mixed hardwood-white pine stands. The survival of spring-planted stock averaged 90 percent compared to only 50 percent for fall-planted northern red oak seedlings. The latter stock may have winter killed in response to a late fall fertilization at the nursery that stimulated new growth just before lifting.

Planting of germinated acorns in 3.8- x 20-cm kraft tubes is being tried on sites with shallow soils or rocky terrain where it is difficult to plant bare-root nursery stock. Seedling emergence ranges from 0 to 92 percent. The reasons for failure are premature drying out of the tube's medium or inability of the germinant's roots to make early contact with the surrounding soil. Direct seeding of acorns is the fastest and cheapest method of artificial regeneration. Seedling production from spot-sown acorns under shelterwood cuts has ranged from 24 to 97 percent. The major limiting factor was the dense grass competition that developed in areas with insufficient shelter.

Trials in clear-cut red pine plantations using slash burning to encourage vigorous resprouting of previously planted northern red oak are being evaluated. Resprouting is usually more vigorous from cut stumps or broken stems than from spring-burned stems or stems repeatedly browsed by deer.

Competing vegetation and animal damage must be controlled to assure establishment of red oak. Chemicals will effectively control vegetative competition; however, establishment will not be secured unless northern red oak is protected from animal damage. Shelters to protect and train a much smaller number of oak than conventionally planted per unit area and use of deer-deterring tablets are being tested.

# OAK REGENERATION - WHAT WE KNOW

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Growth and development of saplings of four oak (*Quercus* spp.) species planted at five spacings in a minor stream bottom in southeast Arkansas showed significant differences among species and spacings. Spacing affected all tree size and biomass variables except survival. Water oak (*Q. nigra* L.) developed most rapidly; swamp chestnut oak (*Q. michauxii* Nutt.) most slowly. Diameters and heights, averaged over all spacings, ranged from 4.0 inches d.b.h. and 26.7 feet height for water oak to 2.0 inches and 13.9 feet in swamp chestnut oak. Above ground biomass ranged from 26.1 tons per acre for water oak to 7.4 tons in swamp chestnut oak. If only potential crop trees are considered, there was a 20-25 percent increase in growth over average of all trees.

Measurements made on a 27-year-old water oak plantation near Winnsboro, LA, and a 20-year-old cherrybark oak (*Q. falcata* var. *pagodifolia* Ell.) plantation near Vicksburg, MS, showed that oaks can be successfully grown in plantations. Average stand parameters in the water oak plantation were: 356 trees per acre, 6.6 inches d.b.h., 61 feet height, and 86 square feet basal area. The cherrybark plantation averaged 346 trees per acre. Diameters of the dominant/codominant trees ranged from 6.2 to 9.5 inches and heights from 55-65 feet.

A number of successful plantings from direct-seeding Nuttall (*Q. nuttallii* Palmer), water, cherrybark, and Shumard (*Q. shumardii* Buckl.) oaks have been established. Acorns can be sown by hand or machine at depths from 1 to 6 inches. After 18 years, trees averaged 3 to 3.5 inches d.b.h. and 20 to 25 feet tall with approxiamtely 300 trees per acre in a free-to-grow position. A Nuttall oak stand that averaged 138,000 seedlings/ac after establishment was reduced to 708 trees per acre after 28 years where tree release consisted of a one-time selection cut. The forest openings ranged from 0.02 to 0.84 acre in size. At age 28 years, none of the plots had oaks in a dominant or codominant position and only 20 percent had oak in the intermediate crown class. The stand apparently will regenerate with ash (*Fraxinus* spp.) and sugarberry (*Celtis laepigata* Willd.) replacing the original stand that was two-thirds oak. Openings 300 feet or more in diameter may be necessary to allow naturally regenerated Nuttall oak.

The seedtree method for regenerating oaks was attempted on two sites in Arkansas. Although the initial stand composition was quite different from the parent stands, the two sites are progressing toward the composition of the parent stands. At age 29, there were 35-40 oaks per acre in a dominant or codominant crown position.

# A STUDY TO DETERMINE THE FACTORS LIMITING NATURAL ESTABLISHMENT AND DEVELOPMENT OF RED OAK SEEDLINGS

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Conversion of maturing oak forests to thrifty young northern red oak (*Quercus rubra* L.) stands on good-quality sites is difficult throughout the range of oak. Large advanced regeneration of northern red oak seedlings is essential before the harvest cut to maintain red oak in developing new stands. On the better quality sites few seedlings become established, and even fewer gain dominance in the forthcoming stand. The processes that govern oak seedling establishment and their subsequent development in maturing oak forests are too poorly understood to manipulate stand conditions to favor northern red oak and discourage competing species.

The Northeastern Forest Experiment Station is aggressively addressing this problem with a regional study to identify those factors that inhibit red oak seedling establishment and growth on a broad spectrum of sites from northern Pennsylvania south through Kentucky. There are seven study installations planned, each as an independent experiment, with provisions for an overall geographic analysis. Different ecological land types throughout the region will be evaluated to determine the factors that limit the oak regeneration process. These factors may include lack of viable seed; light and environmental conditions; acorn and seedling predation from deer, small mammals, birds, and insects; understory interference and competition; and limitations from the intact forest floor. The study is designed so that each factor can be manipulated and made unlimiting.

# INFLUENCE OF SITE ON REGENERATION DEVELOPMENT AFTER PARTIAL CUTTING OF UPLAND OAK FORESTS.

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Successful natural regeneration of mature upland oak (*Quercus* spp.) forests requires large advance oak seedlings in the understory before the final harvest. Often, oak regeneration is lacking, or it is too small or not vigorous enough to form a significant component in the forthcoming stand. Species composition and development of regeneration is largely a function of site. Our study evaluated the impact of site and three levels of cutting on height growth of five species of oaks, yellow-poplar (*Liriodendron tulipifera* L.), and red maple (*Acer rubrum* L.) reproduction in southeastern Ohio.

Results showed that height growth of oak seedlings increased with decreasing overstory density (increased light) and with increasing initial seedling height at the time of overstory cutting. Because few if any differences existed among oak species, results from northern red (*Q. rubra* L.), black (*Q. velutina* Lam.), scarlet (*Q. coccinea* Muenchh.), white (*Q. alba* L.), and chestnut (*Q. prinus* L.) oak were pooled. Soil moisture and temperature regimes (indicated by aspect and slope steepness) affected the growth rate of yellow-poplar and red maple seedlings and but not that of the oaks. No other site variables were important. Stand density, aspect modified by slope steepness, and initial seedling height explained 63 percent of the variation in yellow-poplar growth and 45 percent in red maple growth. Residual stand density and initial seedling height explained 46 percent of the variation in height growth of oaks.

# DEGREE OF COMPETITION AND INTEGRATION IN ONE- TO EIGHT-YEAR-OLD SCARLET AND CHESTNUT OAK SPROUT CLUMPS

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Forest managers have recognized the suitability of stump sprouts for crop trees; however, few management guidelines have been developed for this regenerant type. One exception is thinning of sprout clumps which has consistently led to increased diameter growth for the residual stem(s) for five different species of upland oaks (*Quercus* spp.) in numerous regions of the country. Although competition within oak sprout clumps has been demonstrated, it is not clear which resource is most limiting or if competition within and among sprout clumps varies among species.

A study of 1- to 8-year-old sprouts clumps in the Appalachian region of western Virginia was conducted to elucidate some of the basic biology and demography of scarlet (*Q. coccinea* Muench.) and chestnut oak (*Q. prinus* L.). Light was the most limiting factor to sprout growth at age 2. By age 5 differences in the degree of competition between individual stems existed within these two species. In chestnut oak, competition for the first 7 or 8 years is dominated by interactions among sprout clumps. In scarlet oak, stem-to-stem competition within clumps is more important between ages 4 and 8. The relative importance of above-ground competition (light) decreased between ages 2 and 8 in both species.

It is hypothesized that competition differences between scarlet and chestnut oak sprout clumps reflects a difference in physiology or variation in selective pressures. Scarlet oak is dominant on the driest sites in our region. Selection for faster segregation within sprout clumps would minimize stem-to-stem competition and facilitate exploitation of the maximum soil volume by the remaining stems.

# STATUS OF REPRODUCTION TEN YEARS FOLLOWING CLEARCUTTING IN CENTRAL HARDWOODS

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Natural reproduction in upland hardwoods 8 to 13 years following clearcutting was assessed for 48 stands in southern Illinois. Clearcuts ranged in size from 5 to 250 acres. Dry sites in this study occurred predominantly along ridgetops and south- and west-facing slopes. The mesic sites occurred in coves and along north- and east-facing slopes.

Abundant reproduction for management of valuable hardwoods was present on all sites. There were more valuable hardwood stems per acre on the dry sites, with smaller average dbh, than on the mesic sites. Better oak (*Quercus* spp.) reproduction was found on the dry sites. There was an average of 202 dominant or codominant oak stems per acre on the dry sites compared to only 42 stems on the mesic sites. Reproduction can provide adequate high-value crop trees and trainers; however, timber stand improvement will generally be required on both mesic and dry sites.

U.S. Department of Agriculture, Forest Service.
1990. Van Sambeek, J.W.; Larson, Merlyn M., eds. Fourth workshop on seedling physiology and growth problems in oak plantings (abstracts); 1989 March 1-2; Columbus, OH. Gen. Tech. Rep. NC-139. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 30 p.

Research results and ongoing research activities in oak plantings and related physiology and genetics studies are described in 30 abstracts.

KEY WORDS: Plantations, propagation, regeneration.

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.

NORTH CENTRAL FOREST EXPERIMENT STATION