WORKSHOP ON SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTING, COLUMBIA, MISSOURI, NOVEMBER 6-7, 1979 (ABSTRACTS)

Compiled by Paul S. Johnson and H. E. Garrett

Sponsored by

School of Forestry, Fisheries, and Wildlife

University of Missouri - Columbia

and

North Central Forest Experiment Station

USDA, Forest Service

St. Paul, Minnesota

PREFACE

On November 6-7, 1979, a group of foresters, forest scientists, tree physiologists, and horticulturists met in Columbia, Missouri to discuss recent research results on seedling physiology and growth problems in oak planting. This workshop was prompted by the recent increase in interest among North American foresters in planting oak. The purpose of the workshop was thus to provide a forum for exchange of ideas and research results in three subject areas: (1) physiology and genetics, (2) seedling propagation and production methods, and (3) field performance of planted oaks. The workshop was jointly sponsored by the School of Forestry, Fisheries, and Wildlife, University of Missouri, Columbia, and the North Central Forest Experiment Station, USDA Forest Service. H. E. Garrett and Paul S. Johnson were co-chairmen. Abstracts of the papers given at the workshop are presented here.

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PLANTING PROBLEMS IN SOUTHERN APPALACHIA

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Oak in southern Appalachia fail to regenerate naturally and to produce desirable species composition. Adequate stocking of northern red oak (*Quercus rubra* L.) is particularly hard to achieve. Foresters in the region note that they would plant oak if suitable techniques and material were available; at present little research is aimed at developing these.

The main planting problem is poor shoot growth of transplants under typical forest and old field conditions. Little attention has yet been given to planting advance regeneration, which avoids some problems inherent in this setting but introduces others. A wide array of planting techniques have been researched but none have solved the problems under operational conditions. Adequate growth can be obtained with combinations of intensive cultivation, nitrogen amendment, and large root stocks, but together these procedures are presently too expensive for forest culture.

Further progress in developing economical planting techniques will depend on a better understanding of the genetics and physiology of shoot elongation. Therefore, future research should be concentrated on those aspects of early root and shoot growth that have a direct relation to oaks' establishment phase. Further studies of nutrient relations and the genetics of early shoot growth should have especially high potential for improving oak performance.

OAK PHYSIOLOGY AND GENETICS

LEAF STRUCTURE OF SOUTHERN APPALACHIAN SPECIES

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and
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A linear displacement transducer was used to measure the leaf thickness of sun and shade leaves collected from eight oak species growing in the Mountain and Eastern Coalfield Region of Kentucky. Thickness of sun leaves varied from 155μ in *Quercus rubra* L. to 306μ in *Quercus stellata* Wang. Sun leaves were thicker than shade leaves for all species. Variation in thickness was greater among sun leaves. Sun leaves for the more shade-tolerant species were similar in morphology to shade leaves of the more shade-intolerant species.

WATER RELATIONS OF WHITE OAK

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and
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Analysis of white oak (*Quercus alba* L.) physiology during the past 8 years has shown that the degree of water deficit in a specific individual is a complex function of site microclimate, and drought-resistance characteristics. Water stress in white oak seedlings was often greater than in mature trees apparently because a large root system helps to avoid drought. Additional drought resistance characteristics included a leaf water potential for stomatal closure of -26.1 bars and the ability to maintain positive net photosynthesis at a leaf water potential of -29.7 bars.

A model was proposed that described the physiological and phenological functions of mature trees and seedlings. This model proved particularly useful in examining the patterns of growth periodicity. Seedlings exhibited the following general characteristics: (a) a short and simple transport pathway for water and photosynthate, (b) small carbohydrate reserves, which makes them dependent on current photosynthate for growth, (c) no root growth when the shoot was dormant, (d) distinct alternating periods of root and shoot growth, and (e) multiple shoot flushes. In contrast, mature trees had (a) a complex and lengthy transport pathway, (b) large carbohydrate reserves, (c) nearly continuous root growth, which was limited by environment (primarily temperature and moisture) rather than by the amount of carbohydrate available for growth, (d) some root growth reduction during leaf expansion, (e) only one flushing period per season, and (f) peaks in root growth in early spring before budburst, late spring after full leaf expansion, and early fall before leaf senescence.

HORMONAL CONTROL OF ROOT REGENERATION

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Early, vigorous root regeneration of planted tree seedlings is a critical factor in establishment and early growth of hardwood plantations. New lateral roots on taproots are initiated internally on the pericycle, or in older roots, on the cork cambium. The root initiation process appears to be triggered by a several-fold increase in root auxin concentrations that lasts about 24 hours.

Root regeneration (RR) of spring-lifted red oak (*Quercus rubra* L.) stock varies greatly from year to year for largely unknown reasons. Generally, RR of fall-lifted stock is much poorer than spring-lifted stock. Root regeneration was not related to root carbohydrate levels.

Red oak, white ash (*Fraxinus americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.) 1-0 nursery stock were root soaked in various hormone solutions (IAA, Kinetin, GA_3) for 20 hours and then grown for 4 weeks in a greenhouse. IAA at 100 to 200 mg/l significantly increased RR. Kinetin alone either had no effect or was inhibitory to seedling growth. GA_3 at 500 mg/l reduced RR of red oak, stimulated RR of white ash, and inhibited leaf development of yellow-poplar. Among red oaks planted in the field, growth was best for trees pretreated with 100 mg/l IAA plus 0.1 mg/l Kinetin. The use of hormones to enhance early growth of planted trees warrants further research.

INDOBUTYRIC ACID ENHANCES ROOT REGENERATION IN TRANSPLANTS

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Root regeneration of transplanted pin oak (*Quercus palustris* Muenchh.), scarlet oak (*Q. coccinea* Muench.), and white oak (*Q. alba* L.) was shown to be closely correlated with bud and shoot growth. Indobutyric acid-potassium salt (IBA) treatment to the roots accelerated root regeneration over that of untreated plants. Optimum preplant IBA treatment was a 5-minute aqueous root soak of 1,000 mg/liter.

New root regeneration was also stimulated by localized applications of IBA. New roots developed not only at the base of the tap root but also at the site of IBA application. Successful localized treatment was achieved with IBA impregnated toothpicks inserted through the roots or IBA impregnated string wrapped around the roots midway to the crown.

Napthalene acetic acid - K salt (1,000 mg/liter) was almost as effective as IBA in stimulating new root initiation but inhibited elongation and branching of these new roots. 2,4-D, 2,4,5-T and several other auxins did not stimulate root regeneration.

The use of IBA to treat roots of oak transplants may have application in improving survival and subsequent growth of new oak plantings.

Oak Physiology and Genetics

PATTERNS OF GEOGRAPHIC VARIATION IN NORTHERN RED OAK

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The flushing date of northern red oak (*Quercus rubra* L.) displays a geographic pattern. In the north-central region, the earliest-flushing trees are those of northwestern origin. The flushing trend is then "eastward" from trees of northern origin to trees of northeastern origin and "southward" to trees of central and southern provenance. The latest-flushing trees are those of mid-latitude origins from southern Michigan to Pennsylvania. The time of autumn leaf coloration is strongly correlated with seed source latitude. Early coloration is associated with high latitude and late coloration with low latitude. The capacity to survive summer heat and drought conditions also varies geographically. Trees native to regions that have hot, dry summers, e.g. Kansas, are most capable of survival. Growth rate varies with geographic region of origin, but the regional effect is small except for the slow growth of trees of extreme northern provenances planted in areas farther south. Growth rate also varies with stand or local population and with progeny and is apparently influenced most by these factors. The apparent importance of local variation in growth rate of red oak indicates that further improvement efforts in the north-central region should be concentrated on phenotypic selection without particular regard to geographic origin. For planting in the 38° to 43° latitudinal belt in the region, native trees for progeny testing may be selected anywhere west of the Appalachians, except in the extreme north as described and south of the southernmost of our provenances.

GROWTH MODELS AND THE EXPERIMENTAL ANALYSIS OF GROWTH PATTERNS IN TREES

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Most oak species growing in the Central United States display a characteristic shoot growth pattern: periods of growth separated by periods of rest. Seedlings and saplings may have as many as four growth flushes in a single growing season but mature trees have only one, or rarely two. Neither the alternation between shoot growth and rest nor the difference between the shoot growth patterns of juvenile and adult trees are directly related to the environment. To understand such phenomena, we should know how growth and development of a tree's organs depend on plant-environment interactions as well as the "correlative", functional relation between organs and organ systems. Without adequate analysis and integration of these major aspects of tree function and development, we will never understand how a tree works. Integration of our fragmented and scarce knowledge requires the construction of explanatory, hierarchical models constituting collective hypotheses of the complex system "tree". Although such models will at first have only modest predictive power, they should assist us in recognizing important gaps in our knowledge and in devising experimental tests to fill these gaps. Work on rhythmic shoot growth and the determination of shoot growth patterns by correlative changes illustrates that testable hypotheses can arise from such growth models of trees.

Oak Physiology and Genetics

ROOT STARCH CONTENT INDICATES EFFECTS OF DEFOLIATION

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Starch content in roots of oak trees can be used as an indicator of the effects of defoliation on the tree. Studies utilizing both natural (insect) and artificial defoliation showed that starch content in the roots declined in proportion to the severity and number of consecutive defoliations. Starch content can be determined by the simple histochemical iodine test, and the effects of defoliation on an individual tree or a group of trees can be judged by the intensity of the stained starch. Tissue taken from the buttress roots just below the soil line indicated the status of starch in the root system. Starch content in the roots not only shows the effects of defoliation but may also indicate the probability of the tree's surviving an additional defoliation. Oaks that had low starch before defoliation or no starch after defoliation were more likely to die than trees with moderate or high starch levels before defoliation or low or moderate starch levels after defoliation. Even seasonal differences in the effects of defoliation were related to starch content: defoliation in months when starch content was low resulted in greater crown damage and mortality than defoliation in months when starch content was high. Starch reserves seem to be a critical factor in the survival of oaks after defoliation.

OAK SEEDLING PROPAGATION AND PRODUCTION METHODS

SEED TECHNOLOGY PROBLEMS

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Extensive research suggests three critical periods in the collection and care of *Quercus* acorns: (1) collection, (2) extended storage, and (3) delayed germination. Only mature acorns should be collected, and acorn color is the best and easiest index of maturity. Acorns of the red oak group can be stored up to 3 years by keeping acorn moisture content high, by maintaining the temperature slightly above freezing, and by allowing gas exchange between container and cooler atmosphere. Attempts to store acorns of the white oak group have failed completely. Control of germination could help in storage and in nursery operations, but research in this area is just beginning.

Oak Seedling Propagation and Production Methods

COLLECTING, STORING, AND GERMINATING ACORNS OF SOUTHWESTERN OAKS

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Acorn loss to insects, birds, rodents, and other wildlife prompted seed collection of four oak species 2 months or more prior to normal acorn drop. *Quercus kelloggii* Newb. acorns begin to fall by late September and *Q. chrysolepis* Liebm., *Q. wislizenii* A. DC., and *Q. dumosa* Nutt. acorns fall from mid-October through November.

Viable acorns were picked as early as August 24 for *Q. kelloggii, Q. chrysolepis, Q. dumosa,* and a few *Q. wislizenii* were picked as early as August 10. Cold stratification was not required; however, *Q. kelloggii* acorns picked on July 27 and *Q. chrysolepis* acorns picked August 10 germinated after storage at 3 C for 1 month. Germination tests showed that the tip of the acorn shell must be removed to obtain good germination of prematurely picked acorns.

Long-term storage of prematurely picked acorns was generally poor due to loss of viability and to germination during storage. *Q. dumosa* acorns picked in August and dried to 40 percent of their initial fresh weight remained viable. Because acorn moisture content drops as they mature, acorns can only be dried to 60 to 80 percent of their fresh weight at maturity. *Q. dumosa* acorns picked in early September and dried to 60 percent of their fresh weight did not germinate in storage and remained viable for 12 to 15 months.

Oak Seedling Propagation and Production Methods

GERMINATION AND OCCURRENCE OF NORTHERN RED OAK IN THE LAKE STATES

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Constant temperature tests showed that northern red oak (*Quercus rubra* L.) germinate best at 34°F. Direct seeding trials and soil surface temperature measurements supported the low temperature concept. The time period of favorable temperatures was longer on soil scarified sites than on unscarified sites but it was still not long enough for maximum germination.

These findings partially explain not only the sporadic chronological and geographical occurrence of red oak regeneration but also its greater frequency on north slopes and in uncut stands and also its association with sugar maple, (*Acer saccharum* Marsh.). Among the desirable hardwoods, sugar maple has the lowest germination temperature requirement. Temperature seemingly accounts for the abundance of sugar maple to a far greater extent than tolerance. Northern white-cedar (*Thuja occidentalis* L.) and hemlock (*Tsuga canadensis* (L.) Carr.) for example, have equal or greater tolerance but seldom regenerate. However, both require high germination temperatures, which rarely coincide with favorable moisture conditions.

The best chance of obtaining more red oak may be to sow pregerminated acorns at or prior to snow melt to assure the most favorable temperature-moisture conditions and to reduce their exposure time to predators.

OAK SEEDLING PROPAGATION AND PRODUCTION METHODS

MICROCULTURE OF *QUERCUS RUBRA:* POTENTIAL FOR MICROPROPAGATION OF OAK-WILT RESISTANT GENOTYPES

Brent H. McCown, *Associate Professor, Department of Horticulture, University of Wisconsin, Madison, Wisconsin*

Microculture (tissue culture) of woody plants is receiving increased attention by researchers. The emphasis of genetic improvement work through microculture has shifted from the research laboratory to practical application. Micropropagation is now being commercially utilized in the woody ornamental industry and the same techniques should be applicable for multiplying desirable genotypes of forest tree species. By utilizing simple media and laboratory procedures, *Betula* species can be rapidly multiplied in culture by use of shoot-tip cultures. Utilizing only 125 square feet of culture shelf space, ½ million birch can be clonally produced each year. The shoots produced in culture can be rooted within 2 weeks by conventional means and then can be treated as regular seedlings. The cultures show high genetic stability and the resultant plants are vigorous and highly uniform, which make them particularly useful for mass production, accelerated growth programs. When selections of *Quercus rubra* L. resistant to oak wilt, *Ceratocystis fagacearum*, were isolated, we conducted some preliminary work to see if the procedures used with birch would be applicable for multiplying oak. Rapidly multiplying shoot-tip cultures of *Quercus* have been produced. Interestingly, oak appears to retain its episodic growth pattern in culture. The use of micropropagation as a means of producing large numbers of desirable selections of dicot trees has been demonstrated; however, only a few species have been utilized. The successful application of these techniques for producing the difficult-to-propagate, episodically-growing species such as *Quercus* would be highly informative.

RAISING CONTAINER-GROWN BUR OAK SEEDLINGS IN GREENHOUSES

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A regime has been developed to grow 20-25 cm tall bur oak (*Quercus macrocarpa* Michx.) seedlings with 5-8 mm caliper in large containers for spring planting in the northern Great Plains. Limited experience indicates this regime is also suitable for northern red (*Quercus rubra* L.) and black oak (*Q. velutina* Lam.).

Plant germinating acorns in 300-500 ml containers 1 cm below the surface of 1:1 #1 sphagnum peat and vermiculite of 3-5 mm particle size, containing 3 percent forest duff to provide mycorrhizal fungi. If seeded March 15, the crop flushes three times and reaches 20-25 cm height by June 15. Move the seedlings to a shadehouse to complete their caliper and dry weight growth, and begin a second crop in the greenhouse. During germination, set furnace at 21 C day and night, begin full cooling at 27 C and maintain 70 $\pm$ 20 percent relative humidity. Keep rootball moist, allow surface to dry between waterings, and add no fertilizer until the first leaves are fully expanded.

During the multiple flushing stage set furnace at 24 C day and night, begin cooling at 32 C with full cooling at 37 C and maintain 70 $\pm$ 20 percent relative humidity. Add supplemental light at night and raise CO_2 level during the day. Do not shade. Keep rootball moist with high N nutrient solution, pH 6-7. Rinse foliage after watering. Spray as needed to control insects and foliage diseases. Bait the floor and entryways to control rodents.

Hardening will occur naturally in the shadehouse, and the seedlings need only be mulched to be overwintered. If the second crop is still too small by September 15, it must be hardened in the greenhouse. During hardening set furnace at 15 C day and night and begin cooling at 25 C. Turn off supplemental light and CO_2 generator. Water with low N, high PK nutrient solution. After 5 weeks reduce heat to 1 C, with maximum permissible day temperature 10 C. After 5 weeks at 1 C, seedlings can be moved to the shadehouse, mulched, and stored until spring.

Oak Seedling Propagation and Production Methods

POTENTIAL VALUE OF SPECIFIC ECTOMYCORRHIZA TO ARTIFICIAL REGENERATION

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Little is known of the significance of specific ectomycorrhizal fungi to growth and development of oak seedlings. Most work has been limited to field observations, field association of specific fungi, aseptic synthesis tests, use of oak soil as a source of inoculum, and inoculations with truffle fungi. Techniques have recently been developed to form specific ectomycorrhizae on pine seedlings in conventional tree nurseries. Field trials on adverse and routine sites show that pine seedlings benefit more from ectomycorrhizae formed by *Pisolithus tinctorius* than from naturally occurring ectomycorrhizae formed by *Thelephora terrestris* or other fungi. These results indicate that specific ectomycorrhizae formed in the nursery can be used to improve survival and growth of pine seedlings on various sites. Recently, the program was expanded to determine the significance of specific ectomycorrhizae in nursery production of oaks.

Techniques developed to infest fumigated nursery soil with *Pisolithus* ectomycorrhizae for pine seedlings worked well for white oak (*Quercus alba* L.) (fall sowing) and northern red oak (*Q. rubra* L.) (spring sowing). Genetic variation in white oak controlled the amount of ectomycorrhizae formed and the amount of stimulation derived by seedlings from *Pisolithus* ectomycorrhizae. Isolates of *P. tinctorius* from oak were not as effective as pine isolates in forming ectomycorrhizae and stimulating growth of red oak seedlings. These preliminary studies proved that techniques developed for inoculum production, soil infestation, and seedling root assessments of pine can be applied to oak seedlings. The next logical step is field testing.

NUTRIENT REGIME AND INOCULATION RATE INFLUENCE GROWTH OF CONTAINER-GROWN RED OAK SEEDLINGS

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Stratified *Quercus rubra* L. seed were sown in polyethylene-coated paper bands (4 x 4 x 10 1/2") filled with medium-fine silica sand inoculated with *Pisolithus tinctorius* (0, 100, 200, or 300 ml equivalents/ft^2). Modified Hoaglands solutions were added weekly after shoot emergence to provide nitrogen (N) levels of 0, 100, and 200 ppm and phosphorus (P) levels of 0, 50, and 100 ppm. The experimental design was a 4 x 3 x 3 randomized block factorial with 4 replications of each treatment combination. Seedlings were grown for 17 weeks in a greenhouse with supplemental fluorescent and incandescent light to give a 16-hour photoperiod. Seedling height; number of leaves; stem diameter; percent *P. tinctorius* colonization; and dry weight of leaves, stems, and roots were determined. Percent colonization was erratic and was not correlated with the rate of inoculation.

Seedling height, stem diameter, dry weight of the various tissue components, and foliar nitrogen concentration were significantly increased by increasing the amounts of either nitrogen, phosphorus, or the level of inoculum. Dry weight of lateral roots and the number of leaves per seedling were not influenced by *P. tinctorius* application. All variables showed significant interaction between nitrogen and rate of inoculation. No significant phosphorus-inoculum interaction was detected. Increasing nitrogen concentrations in the fertilizer solution significantly reduced the P concentration in the foliage. Foliar N/P ratio increased with increasing N/P ratio in the nutrient solution and overall nutrient concentration. Inoculation rate had no significant effect on foliar N/P ratio.

The greatest growth response and stem diameter were achieved with 300 ml/ft^2 of *P. tinctorius* and nitrogen and phosphorus levels of 100 and 50 ppm, respectively.

EFFECTS OF VARIOUS STORAGE REGIMES AND PACKAGING METHODS ON ROOT REGENERATION AND HARDWOOD SEEDLING QUALITY

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The dependence of survival and early shoot growth of out-planted hardwood seedlings on root regeneration indicate the need to adapt nursery cultural practices and storage techniques to maximize physiological quality of planting stock. Recent experiments in Ontario on overwinter storage (November-April) of sugar maple (*Acer saccharum* Marsh.), silver maple (*Acer saccharinum* L.), red oak (*Quercus rubra* L.), white ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), paper birch (*Betula papyrifera* Marsh.), and black walnut (*Juglans nigra* L.) nursery stock indicate that storage temperature and packaging method markedly affect physiological quality and out-planting performance. Storage at -5 and -10 C resulted in low root regeneration and poor shoot growth compared to survival and growth of spring-lifted control stock. Root regeneration and overall growth potential of cold-stored stock at 0.5 and 5 C were comparable to those of spring-lifted controls. Seedlings totally enclosed in plastic-lined Kraft bags with moist peat surrounding the roots showed highest root regeneration capacity and lowest shoot water stress. Root regeneration capacity of all species examined was significantly correlated with shoot xylem water potential at time of removal from storage. First- and second-year survival and growth of out-planted red oak seedlings were significantly correlated to both root regeneration capacity and shoot xylem water potential at time of removal from storage.

Integration of methods to produce planting stock of high physiological quality with improved silvicultural techniques of site preparation and weed control appears highly promising in increasing survival and initial shoot growth of newly planted seedlings.

FIELD PERFORMANCE OF PLANTED OAKS

RED OAK GROWTH AFFECTED BY AGE OF PLANTING STOCK, MULCHING, TOP PRUNING, AND FERTILIZATION

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Survival and growth of planted northern red oak (*Quercus rubra* L.) seedlings on cutover forested sites were studied in relation to top pruning, fertilizing, age and size of seedlings at planting time, and method of artificial regeneration. Top pruning at planting time and at 1 and 2 years suppressed annual height growth, produced smaller diameter seedlings, and significantly reduced survival of 1-0 seedlings. Mulching in combination with top pruning did not significantly affect height growth or survival. Fertilizing with combinations of N and P, with and without plastic mulching, did not significantly affect growth of 2-0 seedlings in 5 years after treatment. The use of calcium cyanamide as a fertilizer herbicide did not significantly affect red oak seedlings. Direct-seeded acorns and 5- to 6-week-old tubelings were almost completely destroyed by rodents. If oaks are to be artificially regenerated, planting bare-rooted seedlings offers the best hope of success. Overall, 30 to 50 percent of the planted seedlings, regardless of treatment, averaged more than 6 feet tall at 7 years from seed. It is expected that many of those that are presently dominant or codominant will reach maturity in the new stand.

Field Performance of Planted Oaks

THREE-YEAR FIELD PERFORMANCE OF ENGLISH OAK PLANTED IN AN OZARK CLEARCUT

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Shoot growth of container-grown and 1-0 bare-root English oak (*Quercus robur* L.) was measured in an oak clearcut (black oak (*Q. velutina* Lam.) site index 70) in southern Missouri. Containerized trees were grown in 294 cc (30 in^3) Spencer-Lemaire Rootrainers during an 8-month extended growing season. Half of the fall-planted trees were mulched with 4-mil black plastic sheets 91 cm square. Initial size of seedlings by treatment and stock class averaged 52 to 57 cm in height and 5 to 8 mm in caliper 2 cm above the root collar.

During the first year in the field, shoot dieback exceeded shoot elongation for all treatments. However, significantly less (0.05 level) net shoot dieback occurred on unmulched container-grown seedlings (1.3 cm) than on unmulched bare-root seedlings (6.5 cm); mulching further increased dieback on both stock classes by an average of 10.2 cm. By the end of the third growing season, mean net 3-year shoot elongation ranged from 24 cm for mulched container-grown seedlings to 39 cm for unmulched bare-root seedlings. When treatment effects were adjusted for initial seedling caliper, positive effects of mulching were significantly associated with large caliper and negative effects with small shoot caliper. This effect was most prominent for containerized trees during the third growing season. Mean shoot growth of English oak was 2 to 2½ times that of planted black oak, white oak (*Q. alba* L.), and northern red oak (*Q. rubra* L.) in previous studies in the same area under similar environmental conditions.

ROOT DEVELOPMENT AND EARLY GROWTH OF RED OAK SEEDLINGS

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Root development and top development of containerized and bare-root stock of northern red oak (*Quercus rubra* L.) seedlings were studied under field conditions. A very strong correlation was found between first year top growth and root development (tap root was most important) of direct-seeded plants; a weaker correlation was found between first year top growth and root development (lateral roots were most important) of bare-root seedlings; and a very weak correlation was found between first year top growth and root development of container grown seedlings. Growth media in the containers markedly affected root growth and thus top growth after outplanting. This was apparently related to reduced moisture movement from fine-textured soil to the coarse-textured growth media. Two years after outplanting in a silty loam soil, seedlings produced in containers with a 50/50 mixture of Pro-Mix BX and a sandy loam soil had a significantly larger root system and larger tops than seedlings produced in Pro-Mix BX alone.

Field Performance of Planted Oaks

CONTAINER SIZE AND GROWTH MEDIA INFLUENCE EARLY GROWTH AND SURVIVAL OF SOUTHERN OAKS IN MISSISSIPPI

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Morphological characteristics of 12-week-old *Quercus pagoda* Raf., *Q. nuttallii* Palmer, *Q. shumardii* Buckl., and *Q. nigra* L. seedlings grown in combinations of various container sizes (0.5, 0.9, and 1.9 liter) and growth media (peat-perlite, and 1:1 peat-perlite and sandy loam soil) were measured to evaluate the effects of container size and media on their growth and development. Stem length increased with increasing container size with few significant differences in root-collar diameter. Seedlings in the peat-perlite media had greater leaf surface areas than those in the combination media. Significantly greater root/shoot ratios were found in the 0.5 liter containers with the combination media as compared to the other treatments due to significantly smaller stem lengths and leaf surface areas of seedlings in this treatment. Root weights differed little between treatments. The 0.9 liter containers with the peat-perlite media produced seedlings comparable to those in the 1.9 liter containers and was selected as the best container-media combination of the six treatments tested. The 12-week-old seedlings were outplanted on an Upper Coastal Plain site in east-central Mississippi in July, 1977 and survival and growth were measured after the first field season and 1 year after outplanting. Nursery-produced 1-0 bareroot stock of the same age and seed source as the containerized seedlings were outplanted in March, 1978 for field performance comparison. Containerized seedling survival was 98 percent 1 year after outplanting. However, severe deer browse negated growth in the first field season. Root-collar diameters attained during the first field season by seedlings in the 0.9 liter containers with the peat-perlite media were comparable to those of the 1-0 bareroot stock at outplanting.

FIELD PERFORMANCE OF CONTAINERIZED AND BAREROOT BLACK OAK

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Black oak (*Quercus velutina* Lam.) seedlings inoculated with *Pisolithus tinctorius* (Pers.) Coker and Couch were grown for one season in 750 cc Spencer-Lemaire containers in the greenhouse and in a nursery (noninoculated seedlings were also grown in containers and in the nursery for comparison). Examination before planting revealed that 38 and 45 percent, respectively, of the roots of the containerized and 1-0 barerooted seedlings were infected with *Pisolithus*. Barerooted seedlings were significantly larger than containerized seedlings. However, total root system length of the containerized seedlings was significantly greater.

One year following outplanting on two clearcut sites, 94 percent of the container-grown seedlings inoculated with *Pisolithus* had survived. Survival of the inoculated and noninoculated 1-0 barerooted stock was 63 and 70 percent, respectively. Root weight, shoot length and weight, and leaf area of inoculated containerized seedlings increased significantly during the first year. The inoculated and noninoculated barerooted stock suffered severe shoot dieback and a decline in leaf area. Percent infection with *Pisolithus tinctorius* declined on roots of all inoculated seedlings during the first field growing season. The length of both suberized and unsuberized (i.e., white) roots of the container-grown seedlings, especially those inoculated with *Pisolithus*, increased significantly. Few of the inoculated and noninoculated barerooted seedlings developed new roots and many of the lateral roots were dead.

Diurnal measurements of xylem pressure potential and leaf conductance indicated that container-grown seedlings inoculated with *Pisolithus* better avoided water stress during a moderate mid-summer drought than noninoculated seedlings.

FIELD PERFORMANCE OF PLANTED OAKS

GROWTH AND NUTRITION OF PLANTED ALLEGHENY HARDWOODS

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Research conducted in northwestern Pennsylvania during the past 5 years has shown that intensive browsing by deer as well as severe nitrogen and phosphorus deficiencies in the soil are inimical to the success of planted Allegheny hardwoods. Planted seedlings must be protected against browsing and must be fertilized if they are to survive and grow at acceptable rates.

Species/fertilizer experiments conducted with planted black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), sugar maple (*Acer saccharum* Marsh.), and yellow-poplar (*Liriodendron tulipifera* L.) show that black cherry outperforms these other species in survival and rate of growth. This is in part due to the exceptional juvenile growth potential of black cherry and also to the fact that black cherry is tolerant of late-spring freezes, which often kill back the tops of white ash and yellow-poplar seedlings to the root collar.

Field performance of fertilized and unfertilized bare-root, containerized, and natural black cherry seedlings located on clearcut forest sites shows that: (1) 18 grams of nitrogen and 2 grams of phosphorus broadcast over a 3-foot-diameter plot will satisfy requirements for these nutrients, (2) bare-root stock should be 60 to 90 cm tall to grow rapidly after outplanting, (3) containerization offers no advantage, and (4) it is far better to protect and fertilize natural seedlings than to plant.

OVERSTORY DENSITY, STOCK SIZE, AND DEER BROWSING AFFECT SURVIVAL AND GROWTH OF PLANTED RED OAK

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and
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Lack of adequate oak advance regeneration in Pennsylvania is due mainly to loss of viable acorns to insects, rodents, and deer and of seedlings to deer. Poor survival and growth of planted seedlings in clearcuts and uncut stands led to this test of planting northern red oak (*Quercus rubra* L.) under three levels of overstory density (100 percent, 60 percent, and 30 percent stocked), using two sizes of nursery stock, with and without deer protection. After 3 years, the residual overstory trees were removed.

Survival did not differ between the large and small nursery stock, but the small stock had better height and diameter growth and appeared to respond better to release. Fenced seedlings had a significantly higher survival than unfenced seedlings. The effect of deer browsing was also shown by a decrease in the height of unfenced seedlings and a slower increase in diameter. Both fenced and unfenced seedlings responded to release, but the response was better for fenced seedlings. Survival, height, and diameter growth did not differ significantly between the 60 percent and 30 percent stocked plots, but all three variables decreased significantly for the 100 percent stocked plots. All plots responded to overstory release, but the 60 percent and 30 percent stocked plots respond more.

Protection from deer browsing is required for adequate survival and growth of planted red oak in Pennsylvania. Some type of shelterwood cutting with underplanting and protection of seedlings may be successful for regenerating stands that lack adequate advance regeneration.

FIELD PERFORMANCE OF PLANTED OAKS

PLANTING RESULTS ON THE CUMBERLAND PLATEAU

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Results of 18 years of research on artificial regeneration of oak at Sewanee have been largely negative. In several studies using *Quercus alba* L., *Q. velutina* Lam., *Q. coccinea* Muenchh., and *Q. rubra* L., survival has been acceptable but growth and development have been poor. Thus, traditional planting methods do not appear to be the answer to regenerating oak. The oak planting outlook will continue to be bleak until breakthroughs are made that will allow planted oaks to compete with rapidly growing competition.

PROPAGATING TANOAK AND CALIFORNIA BLACK OAK ON A GOOD SITE IN NORTHERN CALIFORNIA

Philip M. McDonald, *Principal Silviculturist, USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Redding, California*

A laboratory trial of California black oak (*Quercus kelloggii* Newb.) acorns showed much faster and more complete germination of acorns positioned point-up rather than point-down (34 vs. 47 days and 24 vs. 21 percent). Acorns positioned on their sides germinated even slower and less completely than those positioned point-down. A field trial (808 seedspots) of tanoak (*Lithocarpus densiflorus* (Hook- and Arn.) Rehd.) acorns also showed much faster and more complete germination of acorns positioned point-up rather than point-down (12 vs. 41 days and 53 vs. 21 percent).

Fertilization with ¼ pound of 16-20-0 and irrigation with about ½ gallon of water per seedling every 2 weeks during summer significantly increased height of young tanoaks. Water alone and fertilizer alone also significantly increased seedling height over the untreated control. Foliar analysis confirmed that nitrogen and phosphorus were significantly greater in treated seedling leaves. At the time of maximum nutrient stress (June 20), four of five macronutrients tested were near poverty values in untreated seedlings. Fertilized black oak seedlings were three times taller than unfertilized counterparts at age 5.

Average predawn moisture stress at time of maximum stress (September 4) was lower for tanoak seedlings receiving water alone or water and fertilizer combined. For California black oak, moisture stress was lower for fertilized seedlings. In another test, differences in diurnal fluctuation between a large (10-foot tall) and small (1-foot tall) 6-year-old tanoak seedling were minor. In a third test between tanoak and black oak seedling-sprouts in full sun or deep shade, duration of high stress was much longer for plants in full sun.

Outplanting tanoak and black oak seedlings in large containers and shading tanoak seedlings did not increase survival.

Ten-year seedling survival in field trials was 30 percent for tanoak and 41 percent for black oak. Height growth of all but fertilized black oak seedlings was poor.

Establishment of tanoak in conventional plantations appears difficult; California black oak shows some promise.

INSECTS AFFECTING SEED PRODUCTION AND THE GROWTH AND FORM OF SEEDLINGS AND SAPLINGS

William H. Kearby, *Formerly Professor, Department of Entomology, University of Missouri, Columbia, Missouri*

Data on insect damage were collected on 1,536 northern red oak (*Quercus rubra* L.) seedlings planted in an upland oak forest in southern Missouri. Seasonal activity and impact of insects were determined in relation to (1) growth and developmental characteristics of containerized versus bare-root nursery stock, (2) top pruning of seedlings versus no pruning prior to planting, and (3) planting after clearcutting versus underplanting. Bud loss and defoliation in 1978 and 1979 were attributed to nine microleps, several undetermined May beetles (*Phyllophaga* sp.), and click beetles (*Limoneus* sp.). In addition, the leaf cutting weevil (*Attelebus bipustulatus* F.) caused 75 percent defoliation in one clearcut plot and 20 to 50 percent in three other clearcut plots. The twig pruner (*Elaphidionoides villosus* (F.)) caused 6 to 20 percent seedling mortality in unclipped seedlings in clearcut plots in 1979. The Asiatic oak weevil (*Cyrtepistomus castaneus* (Roelofs)) caused from 25 to 100 percent defoliation among the clearcut plots in 1978. In contrast, 1979 defoliation from Asiatic oak weevils was sparse in clearcuts (<25) but ranged from 25 to 50 percent in the overstory plots. Laboratory studies further showed that Asiatic oak weevil larvae feed on oak roots and can severely reduce numbers of fine roots. The role of insects that cause bud, leaf, and root losses is a potentially important problem associated with oak planting.

☆ U.S. Government Printing Office: 1981—766-657/157 Region No. 6

PESTICIDE PRECAUTIONARY STATEMENT

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key — out of the reach of children and animals — and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S. Department of Agriculture, consult your county agricultural agent or State Extension specialist to be sure the intended use is still registered.

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