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# Eighth Workshop on Seedling Physiology and Growth Problems in Oak Plantings (Abstracts)

S. Sung, P.P. Kormanik, W.J. Ostrosina, and J.G. Isebrands

North Central Research Station
Forest Service—U.S. Department of Agriculture
1992 Folwell Avenue
St. Paul, Minnesota 55108

www.ncrs.fs.fed.us

# EIGHTH WORKSHOP ON
# SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTINGS
# HIAWASSEE, GEORGIA, SEPTEMBER 9-12, 2001

**Edited by**

S. Sung; P. P. Kormanik, W. J. Ostrosina, and J. G. Isebrands

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## Dedication and Preface

*Paul P. Kormanik*

This General Technical Report (GTR) is dedicated to Dr. Paul P. Kormanik, a principal silviculturist, with the Institute of Tree Root Biology, USDA Forest Service's Southern Research Station in Athens, Georgia. We honor Paul for his untiring research and development work promoting quality oak seedling production in forest nurseries and superior planting methods in the Southern Region of the Forest Service. His contributions are also valued nationwide. Paul is pictured above receiving an award from Fred Allen, director of the Georgia Forestry Commission, for his contributions to oak regeneration in the South. The presentation was made at the opening of the 8$^{th}$ Workshop on Seedling Physiology and Growth Problems in Oak Planting, held September 9-12, 2001, at the beautiful Lake Chatuga Lodge in the north Georgia Mountains near the Chattahoochee National Forest.

Organized by Paul and his colleagues from Athens, the workshop featured presentations on oak genetics and physiology, oak nursery practices, and oak silvicultural practices. Stephen Weaver of the Southern Region gave the keynote address on the importance of oak in the Region. Clayton Black of the University of Georgia, the featured banquet speaker and Paul's long-time biochemist friend, talked about his travels to Mongolia.

Little did the workshop participants know that during the field trip to nearby oak plantations on Tuesday, September 11, that their trip would be interrupted by the horrific terrorist attacks that morning in New York City and Washington, DC. The workshop went on, to the credit of the organizers, but none of us who attended will ever forget the 8$^{th}$ Oak Workshop.

Abstracts of the papers and posters from the workshop are presented here in alphabetical order of senior authors.

*J.G. Isebrands*
Rhinelander, WI

## ACKNOWLEDGMENTS

The authors wish to acknowledge the contributions of Linda Watson and Catharine Cook, who were in charge of registration. Thank you to Jim Cunningham, Jeff Magniez, and Michael Thompson who helped arrange the field trips and also to Jeff for his photography. We also thank the Southern Research Station and Region 8 of the USDA Forest Service and the Georgia Forestry Commission for sponsoring the workshop.

## REVIEW PROCEDURE

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

## DISCLAIMER

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

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# A TEST OF THE RELATIVE IMPORTANCE OF CANOPY AND ROOT SYSTEM GAPS IN A BOTTOMLAND HARDWOOD FOREST DOMINATED BY LAUREL OAK (*QUERCUS LAURIFOLIA*)

**Marianne K. Burke** and **Charles A. Harrison**
USDA Forest Service, Southern Research Station
Charleston, SC 29414

When gaps are formed in the canopy of forests, gaps also are created in living root systems, thereby enhancing the availability of soil moisture and nutrients in addition to light. The ability of advance regeneration to respond to the more available resources will influence their probability of becoming canopy trees. In the Lower Coastal Plain of South Carolina, laurel oak (*Quercus laurifolia*) is a dominant species in many bottomland hardwood forests, and it is the dominant tree species in both the canopy and advance regeneration at the Coosawhatchie Bottomland Ecosystem Study site along the Coosawhatchie River in South Carolina. This is a long-term ecosystem study site managed by the USDA Forest Service Southern Research Station on land owned by Westvaco Corporation. In 1997, 12 canopy gaps were identified in 70-year-old bottomland hardwood forest stands. Half of the gaps were in an area scheduled for regeneration the following year, and half were in an area not to be cut. In 1998, each gap was enlarged to a 15-m diameter by girdling the large trees and removing the smaller individuals. In each gap, four 1-m x 1-m plots were selected. Two of these plots were left intact and two were trenched to a 40-cm depth to kill roots within the plots in order to reduce nutrient and moisture uptake by canopy trees. A previous study had determined that almost no roots penetrated below 30-cm soil depths due to the high bulk density of the lower soil. Aluminum flashing was placed in the trenches before they were backfilled to eliminate regrowth of roots into trenched plots. Identical plots were also located in the closed canopy forest 50 m from each gap. One and two years after girdling and trenching, laurel oak seedlings in the gap plots were taller and had larger root crown diameter and greater root and stem biomass than saplings under the closed canopy. Biomass was predicted from allometric equations derived from laurel oak seedlings collected on the site. Other understory vegetation groups also thrived in the gap plots, which had greater cover and relative cover of herbaceous and especially grasslike (grass and sedge) understory vegetation than the non-gap plots. Generally, trenching did not have an effect on growth of the laurel oak seedlings, but it did increase the cover and relative cover of the other understory vegetation groups. Although laurel oak seedlings responded to the greater light availability, they were not as responsive as understory vegetation to the enhanced edaphic resources. Based on these observations, laurel oak seedlings in gaps should have an advantage in becoming canopy trees, but may initially experience more competition with other understory plant species.

## A CANKER DISEASE CAUSED BY *PHYTOPHTHORA RAMORUM* ASSOCIATED WITH EXTENSIVE MORTALITY OF *LITHOCARPUS* AND *QUERCUS* IN CALIFORNIA

**M. Garbelotto**
Department of Environmental Science, Policy, and Management,
University of California
Berkeley, CA 94720
and
**D. Rizzo**
Department of Plant Pathology
University of California
Davis, CA 95616

This paper describes a new canker disease of *Lithocarpus densiflorus, Quercus agrifolia, Q. kellogii,* and *Q. parvula* var. *shrevei* caused by *Phytophthora ramorum.* This pathogenic oomycete has never been isolated before in North America, and it is known to be present only in a small area of Europe, where it has just been described. The earliest and most consistent symptom of the disease on larger trees is brown or black discolored bark on the lower trunk followed by dark red sap seeping from the bark on the trunk. *Phytophthora ramorum* was isolated from cankers on mature trees at the root crown to 20 m above the ground. Although cankers are often initiated at the basal part of the tree, they did not enlarge below the soil line and were not found extending into the roots. Phloem and xylem cankers were delimited by thin black lines and ranged to over 2 m in length. The entire crown of affected trees often dies rapidly, and the foliage turns from an apparently healthy green to brown within a few weeks. The disease is currently known to be present from southern Oregon to the Big Sur region of California. Besides oaks and tanoaks, the pathogen also infects leaves and branches of at least six more hosts in four different plant families. The disease on these hosts appears as a foliar and twig die-back. Although *Phytophthora ramorum* is not as virulent on these further hosts, it appears that most inoculum infecting the oaks may come from them. The high susceptibility of several indigenous plant species to this pathogen suggests either a significant and new ecological predisposition in plants to infection by a native microbe, or the exotic nature of the pathogen itself.

ESTABLISHING BOTTOMLAND OAK PLANTATIONS IN THE LOWER MISSISSIPPI RIVER ALLUVIAL VALLEY

Emile S. Gardiner
USDA Forest Service, Southern Research Station
Center For Bottomland Hardwoods Research
Stoneville, MS 38776

In the 1960s, researchers at the USDA Forest Service, Southern Hardwoods Laboratory in Stoneville, MS, initiated a sustained research program to address artificial regeneration of bottomland oaks (*Quercus* spp.) in the Lower Mississippi River Alluvial Valley. Through this research effort, basic techniques for direct seeding and establishing seedlings of bottomland oaks were developed. These techniques were applied to establish the earliest oak plantations on public property for restoration of forest cover and production of hard mast for wildlife habitat. Concurrent to these early afforestation activities on public holdings, drainage programs and agricultural commodity prices provided incentive for private landowners to emphasize agricultural land uses. High commodity prices, especially for soybeans (*Glycine max* [L.] Merrill), supported additional deforestation in the region where the original bottomland forest was reduced from an estimated 21 million acres at the time of European settlement to about 5 million acres. Signing of the "Swampbuster" legislation in 1985 slowed bottomland hardwood deforestation and current governmental incentives are encouraging land use shifts back to forest cover. More than three decades after the first oak plantations were established, there is a strong demand for reliable techniques to establish bottomland hardwoods on economically marginal agricultural land. Afforestation efforts over the last decade resulted in the establishment of more than 300,000 acres of hardwood plantations on public and private land in the Lower Mississippi River Alluvial Valley. Bottomland oaks are the most common species established in these plantations, making up over 75% of the planting stock. A summary of techniques and associated problems of establishing bottomland oaks on economically marginal agricultural land in the Lower Mississippi River Alluvial Valley will be presented at the workshop.

# OAK REGENERATION IN THE MID-ATLANTIC REGION

**Peter J. Gould**
Pennsylvania State University
School of Forest Resources
University Park, PA 16802

The objectives of this presentation are to (1) describe recent trends in growing-stock composition in the region; (2) examine the species composition, abundance, height, and diameter of advanced regeneration; and (3) describe how oak and non-oak advanced regeneration develop after overstory manipulation. Permanent plot data collected under a number of treatments will be used to illustrate the development of advanced regeneration before and after overstory manipulation.

## GUIDE TO MICROLEPIDOPTERA FEEDING ON INDIGENOUS OAK OF CENTRAL AND EASTERN NORTH AMERICA NORTH OF MEXICO

**John R. Grehan** and **Claudia A. Violette**
Frost Entomological Museum, Department of Entomology
University of Pennsylvania
University Park, PA 16802
**John A. Stein** and **Denise Binion**
USDA Forest Service
Forest Health Technology Enterprise Team
Morgantown, WV 26505
**Robert E. Acciavatti**
USDA Forest Service
Forest Health Protection
Morgantown, WV 26505
**Michael Sabourin**
Grantsburg, WI 54840
and
**William E. Miller**
Department of Entomology
University of Minnesota
St. Paul, MN 55108

A guide to oak-feeding Microlepidoptera is currently being developed to focus attention on the smaller moth species that belong to the community of oak-feeding insects. These moths represent a collection of various families comprising many species that have small bodies and often cryptic larval stages that either burrow within the host or live within shelter constructed by the larva. Microlepidopterans are often less visible than the more well known Macrolepidoptera that have relatively large external leaf-feeding larvae.

The guide will present an overview of the biodiversity and taxonomic composition of the microlepidopteran fauna known to inhabit the indigenous oak species of eastern North America north of Mexico. The species are primarily drawn from the literature, and some additional records are drawn from museum collections. The guide will provide foresters and forest entomologists with an outline of current information on the diversity, identification, and biology of the oak-feeding Microlepidoptera community. We anticipate future studies will continue to develop a more detailed and precise characterization of the oak fauna with respect to host-plant preferences, species abundance and persistence, and the challenge of accurate identification.

The guide will include two main sections.

1) The microlepidopteran species with notes on the morphology of the adult and larva (the latter where known), the known hosts, larval biology, and species distribution. Adults and larvae will be illustrated in color plates where possible, and the distribution range will be mapped. A general summary of host-plant relationships will be presented.
2) An introductory guide to the identification of 50 indigenous oak species in eastern North America with illustrations and notes on habitat, growth form, bark, twigs, buds, leaves, and acorns. Also included with species description is the most current distribution information mapped to the county level. An electronic version of the oak key with species description will be published on the Forest Health Technology Enterprise Team Web site within the next year.

## OAK REGENERATION IN THE LAKE STATES: AN OVERVIEW OF 20 YEARS OF RESEARCH

**J.G. Isebrands** and **Ronald M. Teclaw**
USDA Forest Service, North Central Research Station
Rhinelander, WI 54501

In the early 1980s we established an interdisciplinary research program to address the lack of oak regeneration in Lake States forests. The program included fundamental and applied studies conducted in the laboratory, growth chamber, greenhouse, nursery, and field. Ten field studies were established on county, State, and Federal lands in cooperation with forest managers. These studies included overstory manipulation studies across a gradient of habitat types, underplanting studies in hardwood and pine stands, and exclosure studies. The funding for the program ended in 1991, but the field studies remain as a living legacy of the program. In addition, more than 82 publications resulted from the program. In this contribution we give an overview of the most significant applied results and lessons learned from the 20 years of research.

Our most significant findings were in eight categories.

1) *Herbivory*—herbivore browsing is the most important problem affecting oak regeneration in the Lake States. Tree shelters, fencing, use of large nursery stock, and repellents provide some protection.
2) *Frost*—frost in the establishment phase and during the early growing season seriously affects oak regeneration. Silvicultural treatments that provide canopy cover ameliorate the frost problem.
3) *Competition Control*—competing vegetation control with mechanical or chemical methods significantly improves oak artificial regeneration success.
4) *Nursery Stock Quality*—improvements in nursery stock quality are needed in Lake States. Improved seed sources, seed handling, and nursery cultural practices result in larger caliper, higher quality oak nursery stock. Containerized stock also shows promise.
5) *Oak Hybridization*—northern red oak, black oak, and northern pin oak routinely hybridize naturally throughout the Lake States. Hybrid oak seeds do not perform as well in the nursery and often exhibit poorer form after establishment.
6) *Light Intensity*—once established, oak seedlings perform better at higher light intensities provided by silvicultural treatment or natural disturbance gaps.
7) *Tree Shelters*—large tree shelters under a 50% crown cover show promise for providing herbivore protection and for improving early growth during establishment. However, results are variable and material and maintenance costs are high.
8) *Oak Under Pine*—we have had much success in establishing oak seedlings naturally and artificially under pine by emulating the natural ecological life history relationship of oak/pine in the Lake States. Pine overstories provide favorable overstory and understory conditions for natural as well as artificial oak regeneration.

Our findings suggest that to successfully regenerate oak in the Lake States more intensive management is needed than is currently employed—including time, effort, and money.

# GRADING OAK SEEDLINGS FOR ASSESSING THEIR COMPETITIVE ABILITY PRIOR TO OUTPLANTING

**Paul P. Kormanik** and **Sung, Shi-Jean S.Sung**
Institute of Tree Root Biology, USDA Forest Service,
Southern Research Station
Athens, GA 30602
and
**Zarnoch, Stanley J.**
USDA Forest Service, Southern Research Station
Asheville, NC 28802

It is well known that artificial regeneration of many oak species has been less than satisfactory and there are no standard criteria by which seedlings are either grown or evaluated prior to outplanting. In the past, most nursery produced oak seedlings were of inferior planting stock as 1-0 material and various methods of using 1-1, 2-0, and even 2-1 were evaluated to improve planting stock quality. These attempts of extending the nursery production period were expensive and produced seedlings deemed too large for outplanting. Various combinations of root and top prunings were undertaken to reduce shipping and planting costs as well as to attempt to improve survival and growth after outplanting. Characteristically, while these clipping treatments were sometimes effective in improving survival, growth was not improved. Thus, it took 3-5 years for the seedlings to obtain the heights that existed prior to clipping. During this period, the seedlings became overtopped and were no longer competitive. Few successful plantings have been reported. It was generally conceded that large diameter seedlings were most competitive and that seedlings would become more competitive in the field as they became a meter or more in height. Unfortunately, most did not.

At the USDA Forest Service Institute of Tree Root Biology (ITRB) in Athens, Georgia, we developed a nursery protocol (described elsewhere in these proceedings) that has proven to be effective in producing high quality planting stock of most of the oaks native to the Eastern and Southeastern United States. We developed a seedling evaluation procedure that is very effective in identifying the future competitive seedlings based upon their nursery development as 1-0 stock. This protocol has the additional benefit of being a first step in screening that can identify poor families as well as poor performers within a family, as illustrated in table 1 for northern red oak (*Quercus rubra*) and table 2 for white oak (*Q. alba*). In addition, the protocol has produced comparable data in tests on five other southern oak species. Table 1 was taken from a particular year's experiment where 24 or more open pollinated half-sib progenies were evaluated before outplanting.

What our data clearly indicate is that if a seedling has more first-order-lateral-roots (FOLR) than the mean number for that family, when produced by our nursery management protocol, its root collar diameter (RCD) and height (HGT) will both be greater than their respective family means. These individuals would then meet our standards for outplanting stock. We use minimum FOLR number, RCD, and HGT of 4, 8.0 mm and 90 cm, respectively, as our criteria for northern red oak planting stock. In this example, mother tree 2-23-850 would probably be excluded from further testing since in reality only about 20% of its progeny exhibited desirable nursery competitiveness (table 1).

Table 1.—Morphological and growth characteristics of 1-0 *Quercus rubra* seedlings

| Family | FOLR# | | % of Seedlings with | RCD, mm | | HGT, cm | |
|---|---|---|---|---|---|---|---|
| | x | Range | FOLR ≤ x | x | Range | x | Range |
| 2-23-850 | 2.7 | 0-25 | 72 | 6.2 | 1.0-16.9 | 73 | 8-207 |
| 4-2-902 | 3.6 | 0-15 | 62 | 8.4 | 3.6-15.0 | 124 | 46-223 |
| 4-27-100 | 4.2 | 0-19 | 56 | 9.3 | 2.9-17.9 | 141 | 33-246 |
| 4-14-2459 | 5.9 | 0-20 | 52 | 10.5 | 3.4-18.9 | 125 | 22-253 |

Table 2 presents white oak data from the 2000 growing season. The mother trees have been followed for over 25 years at the Georgia Forestry Commission Arrowhead Seed Orchard. Records have been maintained and individuals that have not consistently produced acorns have been gradually eliminated. Progenies from the remaining individuals are consistently the most competitive seedlings in the nursery and have been developing very well in our outplanting trials. The performance of the progeny from the Arrowhead Seed Orchard, when compared to that of the wild collection, indicates significant potential for improving seedling quality through judicial selections in seed orchards. For example, most half-sib progeny groups (35 in this particular trial) had at least 45% plantable seedlings (table 2). In our normal wild collections, we characteristically obtain 25-30%.

Table 2.—Morphological and growth characteristics of 1-0 *Quercus alba* seedlings

| Family | FOLR# | | % of Seedlings with | RCD, mm | | HGT, cm | |
|---|---|---|---|---|---|---|---|
| | x | Range | FOLR ≤ x | x | Range | x | Range |
| ASO-5 | 6.7 | 0-28 | 53 | 9.3 | 2.7-18.6 | 86 | 14-198 |
| ASO-16 | 5.8 | 0-27 | 56 | 10.3 | 2.0-19.0 | 89 | 12-180 |
| ASO-18 | 4.8 | 0-28 | 56 | 9.8 | 2.3-19.8 | 98 | 22-183 |
| ASO-42 | 5.2 | 0-42 | 55 | 9.2 | 2.1-22.4 | 90 | 8-188 |

## GEORGIA FORESTRY COMMISSION'S NURSERY PROTOCOL – LESSONS TO BE LEARNED FROM GOLDILOCKS

**Taryn Kormanik**
Department of Agricultural and Environmental Science
University of Georgia
Athens, GA 30602

Nursery management raises many questions that scientists, both basic and applied, have yet to answer. High quality seedling production, with minimal or no deleterious impacts on the local environment, would be much easier if nursery managers knew everything about the soil and plant processes that constitute a crop of seedlings. The Institute of Tree Root Biology (ITRB) has only scratched the surface of these questions. However, even in the absence of complete knowledge, the Institute has developed nursery management guidelines that consistently yield high quality seedlings for reforestation. The guidelines wield a multi-pronged approach, covering everything from procurement of suitable seed stock to outplanting issues. One major emphasis is the manipulation of soil fertility levels. Through several years of testing and fine-tuning, the following levels of extractable micro and macro soil nutrients have proven optimal for seedling production in the Flint and Walker GFC nurseries:

| | |
|---|---|
| Phosphorous | 100 ppm |
| Potassium | 130 ppm |
| Calcium | 400 – 600 ppm |
| Magnesium | 75+ ppm |
| Copper | 0.3 – 3 ppm |
| Zinc | 5 – 15 ppm |
| Boron | 0.4 – 1.2 ppm |

Various aspects of these guidelines will be discussed.

## LIGHT ACCLIMATION BY LAUREL OAK SEEDLINGS

**Kenneth W. McLeod**
Savannah River Ecology Laboratory
University of Georgia
Aiken, SC 29802
and
**Marianne K. Burke**
USDA Forest Service, Southern Research Station
Center for Forested Wetland Research,
Charleston, SC 29414

Forest gap dynamics predicts that species that can most fully use the new light environment of a gap will become the replacement individuals. When a gap is created, as when a tree falls, all seedlings in the existing regeneration layer theoretically have an equal opportunity to become the next canopy individual in the new gap environment. But the loss of a single canopy individual frequently begins a process whereby the gap slowly enlarges as the opening affects the canopy trees bordering the gap. When this happens, the light and rhizosphere environment slowly changes. If a species can acclimate to the new environment, then it will have a competitive advantage.

Along the Coosawhatchie River in South Carolina, 12 canopy gaps were identified in each of two sections of a bottomland hardwood forest, dominated in the canopy and advanced regeneration layer by laurel oak (*Quercus laurifolia*). Each gap was enlarged to a 15-m diameter by girdling large trees and removing the smaller ones. In each gap, four 1-m x 1-m plots were established. Two plots were trenched to kill roots within the plots to reduce nutrient and water uptake by canopy trees, and two were left intact. Aluminum flashing was placed in the trench to inhibit root regrowth before the trench was backfilled. Another set of four plots was located in the adjacent closed canopy forest near the enlarged canopy gap and treated like these four above. To determine the response of laurel oak seedlings, photosynthetic light response curves (from 75 to 1,200 $\mu$mole/m$^2$/s) were determined during the first two growing seasons after gap enlargement. Photosynthetic rates were significantly greater in the gaps than under closed canopy for all light levels greater than or equal to 150 $\mu$mole/m$^2$/s. Seedlings exposed previously to the higher light levels in the gaps were better able to use higher light levels. However, maximum photosynthetic rates of these seedlings were still only 50% of those observed in seedlings growing in full sunlight. Since the photosynthetic rate of gap and non-gap seedlings differed even when stomatal conductance was similar, seedlings in gaps or under closed canopy must differ in leaf structure. Trenching did not affect seedling photosynthesis. Based on these observations, laurel oak seedlings previously exposed to higher light levels in gaps should have an initial advantage of greater potential photosynthetic rates over seedlings that existed under full canopy.

## INSECTS THREATEN OAK SEEDLING REGENERATION

**Daniel R. Miller**
USDA Forest Service, Southern Research Station
Athens, GA 30602-2044

Paul Kormanik asked me to speak to you today and leave you with one message: forest managers dealing with oak regeneration need to "**fear the weevils**" because weevils feed on acorns and have no controls. Acorn insects, my focus in this paper, are one of four groups of insects that impact mast production and regeneration. Defoliating insects are by far the most recognized and diverse of these groups, causing highly visible damage at various times of the year. Major control efforts are geared to defoliators such as gypsy moths throughout the range of oaks. Impacts of defoliating insects are generally associated with several years of severe defoliation and include growth losses, branch dieback, and reduction in mast production. Under stress, extensive tree mortality can also occur, often due to activities of a third group of insects: woodborers. Woodborers are a diverse group and generally attack dead or dying trees, leading to direct loss of mast production. Regeneration pests are the last group of insects that impact seedlings directly by causing growth loss or mortality.

Acorn insects can be divided into primary or secondary insects. The primary insects, such as *Curculio* weevils, filbertworms, and gall wasps, damage the acorn directly to introduce a larva. Secondary insects, such as acorn moths, midges, and *Conotrachelus* weevils, take advantage of existing holes or damage. There are 23 species of *Curculio* weevils that feed on oak in North America and 11 of these species are in the East. Any forest stand or seed orchard generally has three to four species at the same time. Insect damage to acorns can result in average losses of 50% of mast crops with the *Curculio* weevil accounting for most of the insect damage. Adult weevils generally emerge in August/September, mate, and climb trees to lay eggs inside acorns. Larvae feed inside the acorn, often with numerous other larvae inside the same acorn, until the acorn falls and the larvae leave the acorns and burrow into the ground to depths approaching 12 inches. Larvae remain underground for about 2 years and then pupate and reemerge as adults.

An effective integrated control program is required to address three major concerns: (1) the lack of acorns of specific families; (2) cost of handling acorns to remove damaged ones; and (3) germination failures in nursery beds. Effective physical control tactics for weevils will likely involve sanitation procedures. The removal of all acorns in the fall will reduce population levels and impacts in 2 years. Removal of unwanted trees in seed orchards will also reduce population levels. Harvesting directed to trees with large crops late in the season may yield fewer damaged acorns in harvests. Prescribed fire is not likely to be effective against acorn weevils since the larvae are protected underground. Biological control tactics are not promising at this time but in the future may include host resistance, parasites, predators, diseases, and pheromones. No chemical controls are registered for oak acorn weevils. Various pyrethroids, organophosphates, and carbamates are registered for pecan and chestnut weevils, cone and seed pests in pine seed orchards, defoliators, and ornamental pests. Work is required to expand labels to include oak acorn insects as well as to determine effective spray programs. Timing and frequency of sprays, monitoring tools and models, spray coverage, and pre-harvest restrictions need to be addressed. Use of systemic insecticides is possible, but further research is needed on insecticides and doses, method and timing of application, entry paths, and effects on germination and tree health.

## MINOR PATHOGENS CAN HAVE MAJOR IMPACTS ON OAKS

**William J. Otrosina, Shi-Jean S. Sung,** and **Paul P. Kormanik**
USDA Forest Service, Southern Research Station
Institute of Tree Root Biology
Athens, GA 30602

Numerous fungal pathogens have been described that attack various oak species. The majority of these fungi are regarded by pathologists as minor curiosities that are either rare or have very little impact on oak survival and growth. Two examples of such diseases are *Botryosphaeria* canker and powdery mildew. Again, these diseases are not regarded as serious threats to oak regeneration; however, we had a catastrophic loss due to *Botryosphaeria* canker in a northern red oak experimental field study. The study contained over 12 genetically unrelated families totaling over 1,400 trees. By age three, occasional symptoms such as branch flagging and limited dieback began to appear. Within 3 years after the initial appearance of symptoms, all the trees in these plantings had died. Why would an essentially secondary pathogen, normally limited to attacking weakened trees, attack vigorously growing trees planted on a high quality site? We are uncertain of the mechanisms involved in this disease outbreak, but we theorize a large amount of available inoculum, coupled with high tree growth rates, may have played a role. The rapid growth rates may produce large amounts of more susceptible young tissue that can facilitate disease spread.

Other pathogens, such as powdery mildew of white oaks, do not kill their host but affect photosynthetic rates. They affect foliage by invading and impairing cells that are involved in photosynthesis, causing affected foliage to be distorted and smaller in size. We conducted a study in which we measured photosynthetic activity of white oak foliage in relation to amount of powdery mildew infection. Our data indicate photosynthetic activity is reduced significantly as powdery mildew infection increases ($r^2 = 0.89$). While not directly causing mortality, powdery mildew infection in young trees outplanted in the field can adversely impact growth and, thus, competitiveness. Diseases such as these underscore the need for awareness of potential disease threats affecting oak regeneration. Research that addresses the impact of this and other diseases in the nursery and field will provide critical information necessary to ensure successful artificial regeneration of oaks.

# HARVESTING INTENSITY, SITE DISTURBANCE, AND UNDERSTORY CONTROL AFFECT SURVIVAL AND GROWTH OF HARDWOODS 5 YEARS AFTER PLANTING

**Felix Ponder, Jr.**
USDA Forest Service, North Central Research Station
Jefferson City, MO 65102.

Five years after planting, survival and growth of northern red oak (*Quercus rubra* L.) and white oak (*Q. alba* L.) were examined for differences between treatment combinations that included three levels each of harvesting intensity (organic matter removal) and site disturbance (soil compaction), and two levels of understory vegetation control (weed control). This research is part of the USDA Forest Service initiative to study the long-term soil productivity (LTSP) of forested lands in the United States. The study consists of three levels of organic matter removal and soil compaction as main effect treatments in a factorial design and weed control as a secondary treatment applied in a split arrangement. The levels of organic matter removal included bole only (BO), whole tree (WT), and whole tree plus forest floor (WT+FF), and the levels of compaction included none, moderate, and severe. The understory was present ($U_+$) or absent ($U_-$). Organic matter removal treatments had little effect on survival for either tree species. But both soil compaction and understory control did. Percent survival was better for the moderate and severe treatments than for the uncompacted treatment for both species, but differences were significant ($\alpha$=0.05) only for northern red oak. Survival was significantly higher for the $U_-$ treatment than for the $U_+$ treatment for both tree species. Organic matter removal significantly affected 5-year height and diameter of both oak species. Both height and diameter were greater for BO and WT than for WT+FF. Soil compaction treatments affected the height of northern red oak and the height and diameter of white oak. Also, both northern red oak and white oak were significantly taller and larger in diameter in the $U_-$ treatment than in the $U_+$ treatment. Some two-way interactions and the three-way interaction were significant for some measurements for both species. These results indicate that the effects of soil compaction, organic matter removal, and understory control on survival and growth were apparent at age 5. But perhaps because of weeds' depressing effect on soil moisture and nutrient availability, understory vegetation survival and growth were affected more by differences in levels of understory control than by organic matter removal or soil compaction on this site.

## USE OF OAK IN RIPARIAN FOREST BUFFER RESTORATION IN THE MIDWESTERN U.S.

**Richard C. Schultz, Thomas M. Isenhart, William Simpkins, James Raich, Joe P. Colletti, Thomas L. Schultz, Jennifer Nelson** and **Emily Stauffer**
Agroecology Issue Team, Leopold Center for Sustainable Agriculture
Iowa State University
Ames, IA 50011

Intensive row crop agriculture and grazing have modified the hydrology of much of the Midwestern U.S. Corn Belt. Most of the natural prairie, wetland, and forest ecosystems have been replaced by annual row crops and introduced cool-season grass pastures. Soil organic matter has been reduced and surface soil has been compacted, reducing infiltration and increasing surface runoff. As a result, streams have had to carry higher storm flows and lower base flows. Many meandering stream channels have been straightened resulting in faster flows and more incision. The incision has produced vertical stream banks in danger of collapse. Water tables have been lowered, producing aerated rooting zones that are deeper than they were 150 years ago. Because the riparian zone (flood plain) often contains some of the most fertile soil in the landscape, farmers also have removed most of this native plant community and replaced it with annual crop plants or cool-season grasses. As a result of these changes, sediment, fertilizers, and other agricultural chemicals have easy access to stream channels, producing sediment and chemical laden streams that are responsible for major siltation of streams and reservoirs and the hypoxia problems of the Gulf of Mexico.

The USDA Conservation Reserve Program under the 1996 Farm Bill created an opportunity for farmers to improve stream water quality and to provide wildlife and aquatic habitat and potential alternative products by restoring perennial riparian plant communities. The program has two major options: 1) grass filters and 2) riparian forest buffers. The latter consist of one or more woody plant zones adjacent to the stream and a native or cool-season grass filter strip between the woody zones and the crop field. The woody zone(s) must make up at least one-third of the width of the buffer where restoration takes place on previous crop ground and all but 7 m of the width on restored pastures.

Members of the Agroecology Issue Team of the Leopold Center for Sustainable Agriculture have played a key role in developing riparian buffer designs for intensive agricultural landscapes. Their basic model was one of several used to develop the Riparian Forest Buffer Conservation Standard of the USDA Natural Resources Conservation Service. Their model consists of a wide variety of trees and shrubs planted parallel to the channel. They also use a mixed native grass and forb community as the grass filter between the tree/shrub zone and the crop field. For the most part, fast growing bottomland tree species are planted right along the banks of the channel. However, because of the modified hydrology of many of the streams in the region, the rooting zone often is deep enough to support high quality upland species such as oaks (*Quercus* spp.) and black walnut (*Juglans nigra*). Red, white, bur, and swamp white oak are used extensively in these plantings. These trees can provide high quality timber as well as hard mast for species such as turkey that use the restored corridors to move from one island habitat to the next.

Oaks are planted in mixtures with other species, but they are planted on micro-sites that are suitable for them. Since the goal of buffers is to provide a plant community with a rough surface throughout, cool-season grasses such as timothy and rye are planted with the trees on restored crop field sites. If the site was a pasture, glyphosate kill-strips are used for planting sites. While these understory plants provide some competition, they are necessary to provide the frictional surface necessary to slow surface runoff and trap sediment and associated chemicals. As a result, growth rates of the oaks and other trees may not be as rapid as expected in timber plantations.

The oak and other upland species help diversify the riparian buffer plantings in a landscape that is often devoid of diversity.  These narrow restored riparian ecosystems can trap over 90% of the surface sediment and 80% of the chemicals associated with that sediment before they get to the stream.  Infiltration rates in these undisturbed soils are five times greater than in adjacent crop fields.  They also can remove as much as 90% of the nitrate in the shallow groundwater.  These buffer plantings shade the channel, cooling the water and elevating oxygen levels.  In addition, they provide habitat for eight times more bird species than cool-season grass filters as well as deer, beaver, and other large mammals.  After seeing the potential of these buffers, most farmers become ardent supporters even though they have lost some productive crop ground.  Riparian forest buffers with oak and other species work.  For more information, visit our riparian buffer homepage at: http://www.buffer.forestry.iastate.edu/

## GROWTH AND DEVELOPMENT OF FIRST-YEAR, NURSERY-GROWN, OPEN POLLINATED HALF-SIB PROGENY OF WHITE AND SOUTHERN RED OAK

**Shi-Jean S. Sung** and **Paul P. Kormanik**
USDA Forest Service, Southern Research Station
Institute of Tree Root Biology
Athens, GA 30602
and
**Stanley J. Zarnoch**
USDA Forest Service, Southern Research Station
Asheville, NC 28802

White oak (*Quercus alba* L., WO) acorns from individual mother trees from the Arrowhead Seed Orchard (ASO, Milledgeville, GA), Beech Creek Seed Orchard (BSO, Murphy, NC), and Savannah River Station (SRS, New Ellenton, SC) were sown in December 1999 at the Whitehall Experiment Forest Nursery (Athens, GA). All six mother trees from BSO were grafted. By early April, germination exceeded 80% for all but six families. Five of these six families were from BSO. Seedlings that emerged after mid-April generally were much smaller than those that emerged earlier. Ten percent of the progeny of one SRS family were albino, i.e., their leaves contained very low levels of chlorophyll. Furthermore, the rest of the surviving seedlings from this family were much smaller than seedlings from other families. Buds for the first flushes started swelling near the end of April for most WO seedlings. Time from current flush bud swelling to next flush bud swelling in most seedlings was approximately 33 days for all flushes. Regardless of seed sources, elongation of the third, fourth, and fifth flushes occurred mainly between 4 and 12 days post bud break (dpbb), and the most active elongation occurred approximately 10 dpbb. About 89, 55, and 9% of ASO and SRS seedlings had three, four, and five flushes, respectively. Only 60, 15, and 2% of BSO seedlings had three, four, and five flushes, respectively. More than 60% of WO seedlings from each seed source group had fewer than the mean number of first-order lateral roots (FOLR). White oak seedlings with first flush length shorter than 5 cm generally had lower values in growth parameters including height, root collar diameter, flush number, and number. Based on germination time and percent and first flush length, it may be possible to assess progeny quality of given WO mother trees as early as mid-May. Except for root collar diameter, progeny from grafted WO mother trees performed poorly in several growth parameters in nursery as compared to progeny from other groups.

In mid-March 2001, southern red oak (*Q. falcata* Michaux, SRO) acorns from 12 mother trees from SRS were sown at the Whitehall Experiment Forest Nursery. By mid-May, germination for 10 SRO families ranged from 62 to 90%. The other two families had 52 and 14% germination. Similar to late germinated WO, the SRO seedlings that emerged after mid-May remained small. First flush bud of SRO seedlings began swelling 3 weeks later than WO first flush buds. However, similar to WO, time from current flush bud swelling to next flush bud swelling in most SRO seedlings was approximately 31 days. Based on data collected so far, elongation patterns of the second, third, and fourth flushes in SRO seedlings were similar to each other and to WO flushes. About 98, 85, and 15% of randomly selected SRO seedlings had three, four, and five flushes, respectively. Final assessment of progeny quality for individual SRO mother trees will be made at lifting. Feasibility of using germination percent and time and first flush length as early (e.g., early June) assessment criteria for SRO progeny quality will be determined at lifting when other growth parameter data are available.

**REGENERATING NORTHERN RED OAK ON A RICH MESIC SITE IN NORTHERN WISCONSIN**

**Ronald M. Teclaw**
USDA Forest Service, North Central Research Station
Rhinelander, WI 54501

A regeneration study was established in 1989 to evaluate the effects of overstory reduction and understory vegetation control on the establishment and growth of northern red oak. The study is located on the Park Falls District of the Chequamegon-Nicolet National Forest in northern Wisconsin, (45ºN, 90ºW) and is referred to as the Willow Springs Ecosystem Processes Study Site. The site is located within a northern hardwood stand with a northern red oak site index of 65 feet (base 50 years). The habitat classification is Acer/Viloa-Osmorhiza (AViO), a nutrient rich mesic site. Bareroot (1-0) and containerized northern red oak seedlings were planted in a clearcut, in two shelterwood stands (one thinned to 50% crown cover and one to 75% crown cover), and under a fully closed canopy that served as a control. Understory vegetation was controlled in the clearcut and two shelterwood stands according to a factorial design of spraying Roundup™ herbicide (glyphosate) and disking in 180-foot-wide strips. The bareroot seedlings were root-graded by the number of first-order lateral roots greater than 1 mm in diameter at the point of attachment to the tap root. Four-foot-tall tree shelters of two diameters (4 inch and 8 inch) were installed on a subset of both the bareroot and containerized seedlings.

Survival and growth trends started to develop as early as 2 years after planting; the best survival and growth were in the 50% crown cover shelterwood stand followed by the 75% crown cover shelterwood and the clearcut. The greatest mortality and poorest growth were under the closed canopy stand (100% crown cover). These trends continued to where in 2000 there were significant differences in seedling height relative to overstory cover; the largest seedlings were under the 50% canopy (avg. ht.=2.5 m), followed by seedlings under the 75% canopy (avg. ht.=1.8 m). Clearcut data have yet be to summarized. Furthermore, there was significant difference in seedling height relative to understory vegetation control under the 50% shelterwood canopy. Seedlings were largest in the spray and disk plots (avg. ht.=3.9 m) and smallest in the control plots (avg. ht.=1.4 m). Seedling height under the 75% shelterwood canopy was relatively unaffected by understory vegetation control. During the study, the seedlings planted under the fully closed canopy steadily declined until they were essentially nonexistent at the time of the last survey.

A complete analysis of seedling growth relative to overstory density, understory vegetation control, root grade, and tree shelter size will be presented at the workshop meeting.

# GENETIC RESOURCE MANAGEMENT FOR UPLAND OAKS FOR THE USDA FOREST SERVICE'S, SOUTHERN REGION

**Tom Tibbs**
USDA Forest Service, Southern Region
Atlanta, GA 30367

The USDA Forest Service has implemented a management program for two species of upland oaks, northern red oak and white oak. The objectives of this program are genetic conservation and development of sources of acorns for regeneration, gene conservation, and research. The program is based on genetic selection of families and seedlings in the nursery and on the establishment of seedling seed orchards and demonstration areas.

## RESPONSE OF FOUR OAK SPECIES TO HERBACEOUS PERENNIAL LEGUMES IN AN UPLAND OAK SAVANNA RESTORATION PROJECT

**J. W. Van Sambeek**
USDA Forest Service, North Central Research Station
Columbia, MO 65211-7260
**R. L. McGraw** and **N. E. Navarrete-Tindall**
Department of Agronomy
University of Missouri
Columbia, MO 65211-6130
and
**P. R. Beuselinck**
USDA Agriculture Research Service
Columbia, MO 65211-6130

One of the new practices included in the Conservation Reserve Program is oak savanna restoration with widely spaced oak trees established with a ground cover of perennial legumes and warm-season grasses. Growth of hardwood seedlings is reduced by competing vegetation. Forage legumes have been shown to improve growth of black walnut seedlings and saplings by reducing grass competition and adding nitrogen to the soil. Less is known about the response of oaks to legumes or the potential benefits of using native legumes as a ground cover in hardwood plantings.

In spring 1999, an upland 1.5-ha area was plowed, cultivated, and seeded using a randomized block design with 3 replications of 12 treatments with and without warm-season grasses in combination with 6 legume treatments. Legume treatments included seeding with Illinois bundle flower (*Desmanthus illinoensis* (Michaux) MacMillian), panicled tick trefoil (*Desmodium paniculatum* (L.) DC), slender bush clover (*Lespedeza virginica* (L.) Britton), roundhead bush clover (*Lespedeza capitata* Michaux), a mixture of all four native Missouri legumes, or natural succession of resident vegetation. In spring 2000, six rows of trees were planted approximately 13 m apart across each ground cover plot to create six four-tree plots each planted with one seedling each of bur oak (*Quercus macrocarpa* Michx.), white oak (*Q. alba* L.), northern red oak (*Q. rubra* L.), and Shumard oak (*Q. shumardii* Buckl.) or black walnut (*Juglans nigra* L.). Extensive rodent and deer damage precluded meaningful measurements of stem height or basal diameter; however, we were able to evaluate survival and seedling vigor.

Overall first-year seedling survival was 85% for bur oak, 74% for black walnut, 70% for white oak, 55% for northern red oak, and less than 10% for severely dehydrated planting stock of Shumard oak. Bur and northern red oak had higher percentages of seedlings girdled by mice than white oak and black walnut (27% vs. 18%). Although no differences were found among species or legume treatments, deer browse was higher in plots without warm-season grasses than with warm-season grasses (68% vs. 58%). On a scale of 0 (dead) to 5 (multiple flushes with large healthy leaves), bur oak had the most vigorous seedlings (3.3) followed by black walnut (2.9), white oak (2.2), and northern red oak (1.9). Legume treatments with panicled tick trefoil reduced tree seedling vigor compared to a ground cover of resident vegetation. After two growing seasons, only panicled tick trefoil had produced dense stands that excluded most other vegetation.

## BLUEJACK, BLACKJACK, SOUTHERN RED, AND WATER OAKS AFTER 25 YEARS OF GROWTH IN SOUTHERN MISSISSIPPI


**Charles H. Walkinshaw**
USDA Forest Service, Southern Region
Tree Root Biology Team
Athens, GA 30602


In the early 1970s the need for ground-truth measurements using remote sensing tools was defined by W.G. Cibula and others at the National Space Technology Laboratories. I responded to this by planting six oak species on a site approximately 20 miles north of Gulfport, MS. These trees are now 25 years old and satisfactory for aerial photography, video and satellite scanning. This report explores the genetic variation encountered in the water oak population at the site.

Acorns were collected in 1974 at the Biloxi and Red Creek wildlife management areas in southern Mississippi. Six species were included: blackjack oak (*Quercus marilandica*), bluejack oak (*Q.* ***incana***), post oak (*Q. stellata*), southern red oak (*Q. falcata*), turkey oak (*Q. laevis*), and water oak (*Q. nigra*). Caps were removed and the acorns were heated to 45-50°C for 45 minutes, dried, and stored at 3-5°C for 6 months. The acorns were germinated in sand:vermiculite (1:1 v/v), planted in quart milk cartons of sandy soil, and transplanted in the field (cleared tree site). A thinning was made after 5 and 10 growing seasons.

More than 90% of the turkey oak and post oak seedlings died 5 years after planting. Bluejack oak had high mortality after 10 years, but the remaining living trees averaged 4.2 inches in d.b.h. Blackjack, southern red, and water oaks had d.b.h. values from 1.0 to 7.2 inches after 25 years. Mean diameters were 3.6 ± 0.24, 3.6 ± 0.29, and 4.1± 0.31 inches, respectively. The largest trees for the three species had diameters of 5.7, 7.2, and 6.8 inches. When all d.b.h. values for the three oak species were plotted as a histogram, they followed a normal distribution pattern. Bluejack oak appeared superior after planting, and it produced many acorns. By 25 years, it showed a mortality of approximately 60%. The diameters of bluejack oak, ranging from 1.4 to 7.6 inches, also followed a normal distribution curve. Differences among the diameters of bluejack, southern red, water, and blackjack oaks were not significant.

A parallel group of water oak seedlings were inoculated with spores from single fusiform rust galls in six experiments. As a result, 28.3 to 69.6% of the seedlings had dense telia on their lower surface. Many oak families failed to form telia with a number of field isolates of the fusiform fungus. However, susceptibility of oak families did not parallel that of slash pine families.

Results of this study indicate that growing blackjack, southern red, and water oaks in southern Mississippi is easy. The dense vegetation in the plots did not deter these oaks. I was surprised that some of the water oaks inoculated with fusiform rust were totally resistant. Thus the role of oaks in natural infections may be significant in creating new races of the fungus.

# THE UPLAND OAK RESOURCE AND THE NEED FOR AN ARTIFICIAL REGENERATION OPTION IN THE USDA FOREST SERVICE'S SOUTHERN REGION

**Stephen P. Weaver**
USDA Forest Service, Southern Region
Forest Management Unit
Atlanta, GA 30309

This paper examines the upland oak resource managed by the USDA Forest Service in the Southeastern U.S. Current management plans identify an increased need for additional acres in oak type at the same time that the oak type is decreasing and being converted to other forest types due to oak regeneration failures and major catastrophic events. The factors influencing the change of oak types are discussed. Seedling quality standards and acorn availability are identified as being important in the development of a successful oak-planting program.

## SURVIVAL OF UNDERPLANTED WHITE OAK AND COMPETITORS FOLLOWING A PRESCRIBED BURN

**Dale R. Weigel**
USDA Forest Service, North Central Research Station
Bedford, IN 47421
and
**Paul S. Johnson** and **Daniel C. Dey**
USDA Forest Service, North Central Research Station
Columbia, MO 65211

Based on our 15 years or more of research on underplanting oaks beneath shelterwoods in the Central Hardwood Region, we have developed prescriptions for regenerating northern red oak (*Quercus rubra* L.) in Missouri and Indiana and for regenerating white oak (*Quercus alba* L.) in Missouri. Our research suggests that there is little need for controlling competing vegetation after final removal of the shelterwood overstory and release of the underplanted oaks in upland forests in Missouri. In contrast, survival of northern red oak underplanted in an Indiana shelterwood can be as low as 13 to 26% after 13 years if competing vegetation is not controlled. Oak has low regeneration potential after overstory removal when competing with aggressive and fast growing species such as yellow-poplar (*Liriodendron tulipifera* L.) in Indiana. Therefore, we recommend that competing vegetation be controlled sometime during the first 6 years following removal of the shelterwood overstory to increase the competitiveness of oak reproduction.

We are interested in how fire can be used to control oak's competitors and to increase the developmental potential of oak reproduction. In Indiana, we are testing the use of prescribed burning to control competing vegetation after complete removal of the overstory by adding fire as a treatment to an ongoing research study that was designed to regenerate white oak by underplanting in a shelterwood. The study was established on the Martin State Forest (MSF) and the Paoli Experimental Forest (PEF) in southern Indiana in 1991. The prescription used in the original study included: 1) a reduction in overstory stocking to 60%, 2) treatment of competing woody vegetation with an herbicide at the time of harvesting, 3) underplanting white oak bareroot seedlings after the initial shelterwood harvest, and 4) removal of the shelterwood overstory after 3 years.

At both of the study sites, we conducted a spring surface prescribed burn to control competing vegetation after final overstory removal. Due to weather factors the sites were not burned the same year. The MSF site was burned 5 years after shelterwood removal, and the PEF site was burned 6 years after shelterwood removal. Although we did not make detailed observations on fire behavior, the fire at the MSF site burned hotter and more completely than the fire at the PEF site did.

To quantify the response of the planted white oak seedlings and their competitors to fire, we measured basal diameter and height of the planted oak reproduction and the tallest woody competitor within 1 m of the oak seedling. The reproduction was inventoried in the winter before burning and after the first growing season following the fire. Before burning, white oak reproduction, on average, was taller (286 cm vs. 217 cm) and had larger basal diameters (28 mm vs. 27 mm) at the PEF site than at the MSF site. Similarly, competitors, on average, were taller (326 cm vs. 293 cm) and had larger basal diameters (38 mm vs. 29 mm) at the PEF site than at the MSF site. Slightly more than 20% of the white oak seedlings at PEF suffered shoot dieback compared to more than half (58%) of the oaks at MSF. Complete mortality of white oak seedlings was similar at both sites where 7% (PEF) and 8.8% (MSF) of the seedlings died the first year after burning. The basal diameter and height of the planted white oak reproduction were significantly related to the probability that a stem experienced either shoot dieback or complete mortality.

Smaller diameter and shorter white oaks tended to be more susceptible to topkill by the fire than the larger diameter and taller stems. A similar number of competitors were present at PEF (18) and MSF (19). However, yellow-poplar, white ash (*Fraxinus americana* L.), and sassafras (*Sassafras albidum* (Nutt.) Nees) comprised 67% of the competitors at PEF, while only American beech (*Fagus grandifolia* Ehrh.) (13%) comprised more than 10% of the competition at MSF. Initial size of competing reproduction was less strongly related to post-fire shoot dieback or mortality than the initial size of white oak reproduction was smaller diameter and shorter trees to be more susceptible to fire damage or mortality. Shoot dieback in the oak competitors averaged 16.1% at PEF and 67.1% at MSF. Mortality of competitors was significantly lower at PEF (9.3%) than at MSF (30.4%).

## ABUNDANCE AND LOCALIZATION OF ALUMINUM IN THE FINE MYCORRHIZAL ROOTS OF OAK (*QUERCUS PETRAEA)*


**Christine Wilson**
Institut für Allgemeine Botanik
Johannes Gutenberg-Universität
Mainz, Germany 55099
and
**Dr. Joachim Block**
Abeitlung C, Waldschutz
Forstliche Versuchsanstalt Rheinland-Pfalz
Trippstadt, Germany 67705


This study focused on the seasonal abundance and diversity of ectosymbiotic mycorrhizae, associated with *Quercus petraea* (Matt) LIEBL, at different depths in the soil of limed and unlimed forest plots at Merzalben research station in the high elevation Palatinate Forest of Rheinland-Pfalz, Germany. The ultimate goal was to determine the localization and abundance of potentially toxic aluminum within fine roots and their associated mycorrhizae.

In Rheinland-Pfalz, oak trees are under increasingly severe stress. In 1984, only 8% of the oaks were in damage classes 2 to 4, but by 1999, 45% of the oaks were in damage class 2 and 5% were in classes 3 and 4 (Kronauer 1999). Many trees are living only to 125-150 years, or less than half of their expected life-span (Block, pers. comm.). The leading cause of forest decline in the region is generally thought to be atmospheric pollutants and acid rain. As the soil pH drops below 4.5, continued deposition of atmospheric acids from the mountain mists into the ground water may cause argilaceous minerals such as aluminum to be solubilized into potentially toxic forms ($Al^{3+}$) (Cunningham and Saigo 1995). Aluminum toxicity symptoms may include damage to root caps and meristems and similar restricted growth in plant shoots with mottling and necrosis of leaves (Bollard 1993). Aluminum may bind to meristem DNA, thus interfering with cellular division (Horst *et al*. 1983), and it may also precipitate essential phosphate, preventing translocation and leading to phosphate deficiency (Bollard 1993).

Using Morin™, a fluorescent chemical marker, according to fluorescent microscopic techniques described by Vogelei and Rothe (1993), the extracellular and intracellular locations of aluminum can be determined. Total cytoplasmic and bound aluminum concentrations in roots can be determined by standardized low and high pressure extraction procedures.

Freed acidic aluminum may enter the ectomycorrhizal tips, be deposited outside the walls or incorporated into the mycorrhizal sheath, or may go directly into the rootlet cells where damage can occur. Certain mycorrhizal species seem to act as a defensive barrier to the translocation of aluminum into the absorptive zone, while other species seem to allow free passage.


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## Mission Statement

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For further information contact:

North Central Research Station
USDA Forest Service
1992 Folwell Ave.
St. Paul, MN 55108

Or visit our web site:

www.ncrs.fs.fed.us

U.S. Department of Agriculture, Forest Service.
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Research results and ongoing research activities in field performance of planted trees, seedling propagation, physiology, genetics, acorn germination, and natural regeneration for oaks are described in 21 abstract.

KEY WORDS: Plantations, propagation, regeneration.

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