Integrated Efficacy Evaluations of New Preservatives in Alternative Wood Species

Rodney De Groot, Research Plant Pathologist
Douglas Crawford, Chemist
Bessie Woodward, Microbiologist
Forest Products Laboratory, USDA Forest Service

Abstract

Through an integrated laboratory and field testing program, the durability of a variety of wood species, when treated with emerging preservatives, is being evaluated. Results from this testing program will provide a broad database on the potential of alternative wood species to be treated with diffent preservatives. It is well recognized that inorganic waterborne preservatives do not protect hardwoods as well as they protect softwoods, but the degree of difference has not been quantified. The relationships between accelerated laboratory tests and actual field performance have also not been quantitatively defined. ‘Therefore, a series of linked, laboratory and field evaluations has been initiated that should provide the opportunity to judge the merits of diffrent experimental approaches to predict the ultimate field performance potential of new wood species by preservative combinations. This information will contribute to increasing the opportunities available for utilizing regional forest resources in U.S. transportation structures and strengthening the international trade of durable wood products. This paper presents an overview of the ongoing experimentation and the current status of this integrated research program

Introduction

One important component of any program that focuses on utilization of wood in U.S. transportation structures is the desire to stimulate local economies and enhance rural transportation systems through the use of locally available wood species. The emphasis on locally available species often requires consideration of wood species other than the primary commercially used wood species. Regionally distributed, underutilized hardwoods are of special interest in this program There is also a national need for a strong export trade. Preservative treatments, in concept, are being increasingly looked to as a technology that will generate additional opportunities for U.S. wood products in global markets. Both nationally (Wipf and others 1993) and internationally, development and testing of new wood preservatives that do not pose an environmental hazard are needed, Specific actions vary with individual political entities, but bans on one or more of the commonly used preservative systems are either appearing or being considered within several countries, including the United States.

The resolution of these needs presents a challenge. During the past two decades, waterborne preservatives have been used increasingly to treat softwoods. These preservatives enjoy a public perception of environmental preference over oilborne preservatives because of the lack of odor and the dry surface of the waterborne treated product. Indeed, waterborne preservatives are the preservative of choice when a high degree of human contact is involved. However, it is generally recognized that hardwoods are less protected from decay by waterborne preservatives than are softwoods. Furthermore, the commonly used waterborne preservative chromated copper arsenate (CCA) is now banned in Indonesia (Permadi 1995).

Hardwoods are commonly used for railroad ties, which are almost universally treated with creosote. However, many hardwoods that have a wide geographic distribution lack the density needed for ties, These hardwoods also lack the quality required for tine furniture and remain relatively underutilized in construction. Examples of such hardwoods in the United States are soft (red) maple that is omnipresent east of the Mississippi; silver maple which is common through the Midwest, Mid-Atlantic, and Northeastern regions; cottonwood which is prevalent along river bottoms throughout the West, North Central, and Southern regions; and yellow poplar which is abundant in the Mid-Atlantic states and Southeast region. Of these hardwoods, considerable engineering research is being directed towards development of designs and building components that will permit enhanced utilization of red maple and cottonwood, in particular. All these hardwoods lack natural durability and vary in treatability characteristics.

Another challenge in developing and testing new wood preservatives is that protocols for acceptance to standards are structured to provide comparison of the preservative chemical, not to characterize the variation within a wood species or between species of wood (AWPA 1994). Southern pine sapwood is the material that is usually utilized in these evaluations.

Through an integrated laboratory and field testing program, the durability of a variety of wood species, when treated with emerging preservatives, is being evaluated. The purpose of this paper is to present an overview of the ongoing experimentation and the current status of this integrated research program.

Materials And Experimental Methods

Linkage Through Experimental Design

This research is supported through several funding programs,[1] thus specific objectives of individual studies differ. However, all individual studies being done at various institutions and geographic locations are linked by the common objective to evaluate accelerated methods for predicting the performance life of preservative-treated wood. Either a component of the experimental design or the complete design of field trials conducted at all locations is repeated in field stake plots at the USDA Forest Service, Harrison Experimental Forest, in southern Mississippi. Furthermore, in either separate experiments or by means of subsampling, replicate stakes, which were treated at the Forest Products Laboratory (FPL) for field exposure in tropical and temperate locations, were also used to conduct parallel soil-block studies at FPL. This gives us a prime opportunity to explore whether results from laboratory soil-block studies and those from field plots in tropical locations fore cast relative performance of treated-wood products in temperate climates.

Whenever possible, a minimum of 20 replicate units/species by preservative by retention combination was used in laboratory-scale, simulated ecosystems and in field studies that permitted repeated measurement of the same unit. This was done to permit development of failure curves for small populations of the same wood by preservative by retention combination when evaluated by different methods or in different environmental settings. In a data analysis from prior FPL field plots with stakes that were nominally 50 by 100 mm in cross section, we estimated that 20 was the minimum number of replicate units needed to characterize population trends. This design protocol had some impact on limiting the number of field sites when exposures had to be made on a fixed budget, and the protocol did restrict the number of combinations that could be evaluated in soil beds that have a finite physical capacity. In the end, the experimental design will allow a detailed comparison of performance histories of treated-wood species in tropical and temperate plots. These comparisons will hopefully enable researchers to determine whether tropical environments yield the same relative performance among experimental combinations and whether tropical exposures yield any quantitative indication of potential durability of treated products.

Selection Of Wood Species

Several wood species have potential application in transportation structures. To gain information on possible interactive effects among wood species and preservatives, three species were considered as a core to be included in each evaluation, if possible. Other species were selected because of the regional abundance or anticipated unique performance profiles with waterborne systems (Table 1).

[1]This research is supported in part by the U.S. Federal Highway Administration, the USDA Foreign Agricultural Service, the Western Wood Products Association, and several chemical suppliers. The total program involves cooperative studies with CSIRO, Division of Forest Products, Clayton, Victoria; Department of Primary Industries, Forest Service, Indooroopilly, Queensland; Forest Products Research and Development Center, Bogor, Indonesia; State University of New York, College of Environmental Science and Forestry, Syracuse, NY; Michigan Technological University, Houghton, MI; Mississippi State University, Starkeville, MS; Oregon State University, Corvallis, Oregon; and University of West Virginia, Morgantown, WV.

Table I—Wood species utilized in efficacy evaluations of alternative preservatives.

Species	Characteristics
Core	
Southern Pine: wood from several sources (e.g., *Pinus, elliotii, palustris,* or *taeda).*	Commonly used preservatively treated, construction wood in eastern USA; also used as representative of pine construction in Indonesia
Red oak: *Quercus rubra* and related spp.	Representative of railroad ties
Douglas-fir: *Pseudotsuga menzezii*	Commonly used construction material in western USA, refractory heartwood; wood from second-growth Coastal Douglas-fir was used
Regionally Important	
Red maple: *Acer rubrum*	Important in eastern USA, subject of much engineering research on laminated structures
Hard (sugar) maple: *Acer saccharrum*	Common in Northcentral and Northeast USA; dense wood with potential of increased usage
Cottonwood: *Populus deltoides*	Common in central USA and along river bottoms in western USA
Yellow birch: *Betula alleghaniensis*	Prominent in Northeastern USA; interest in new opportunities of utilization of heartwood core
Sweetgum: *Liquidambar styraciflua*	Common in Southeastern USA
Tulip poplar: *Liriodendron tulipifera*	Common in Mid-Atlantic states and Southeast USA
White oak: *Quercus alba* and related spp.	Common in eastern USA; also used in railroad ties
Red (Norway) pine: *Pinus resinosa*	Common in Northcentral and Northeast USA
Eastern hemlock: *Tsuga canadensis*	Common in Northeastern and Northcentral USA
Western hemlock: *Tsuga heterophylla* Grand fir: *Abies grandis*	Common western softwoods; component of Hem-Fir grouping in lumber grading
Keruing: *Dipterocarpus* spp.	Used as representative Indonesian hardwood

Selection Of Preservatives

In this research program, we emphasize evaluating the efficacy of emerging preservatives in alternative wood species rather than conducting chemical research on new preservative compounds. We selected preservatives in which the active ingredient (biocidal component) was being considered within the United States, was approved by the Environmental Protection Agency (EPA), or was in use in another country. Thus far, we have worked principally with systems that contained only a single active ingredient. In future work and as our ability to design protection systems increases, we anticipate emphasis to be placed on blends or combinations of active ingredients.

Both waterborne and oilborne preservatives are considered in this research program. Although several anticipated uses for treated-wood products might entail a high level of human contact, therefore favoring inorganic systems, many transportation structures are not frequently exposed to humans. These structures also endure repeated vibration and are exposed to lengthy periods of weathering where organic systems function well. Not every preservative is used in all experimental combinations, but the program, as a whole, includes the preservatives listed in Table 2 in at least one experiment.

Preparation Of Wood Materials

Some experimental units were prepared and treated at the FPL, shipped to field locations, and installed by cooperators. Other units were prepared, treated, and installed by cooperators. All experimental materials used in FPL laboratory experiments and field plots were prepared and treated at FPL.

In soil-bed (fungus cellar) studies at FPL, stakes were 3 by 19 by 150 mm, with the longest dimension parallel to the grain. In most of our field trials, stakes were 19 by 19 by 450 mm, with the longest dimension parallel to the grain. With a few studies, however, we used stakes that were 25 by 50 by 500 mm. The Douglas-fir were incised prior to treatment. No other wood

Table 2—Preservatives Included in integrated research program.

Waterborne perservatives	Oilborne perservatives/creosotes
Acid copper chromate (ACC)	Chlorothalonil (CTL)
Ammoniacal copper zinc arsenate (ACZA)	Chlorothalonil/chlorpyrifos
Ammoniacal copper citrate (CC)	Copper naphthenate
Ammoniacal copper quat Type B (AC Q-B)	Creosote "P1"
Ammoniacal copper quat Type D (ACQ-D)	Creosote "A"
Chromated copper arsenate (CCA)	Creosote "B"
Copper dimethyldithiocarbamate (CDDC)	Creosote , pigment emulsified (PEC)
Copper naphthenate	Isothiazolone
Propiconazole	Oxine copper (copper-8-quinolinolate)
Propiconazole/pyrethroid	
Rh 287	
Sodium octaborate tetrahydrate	
Tebuconazole	
Tebuconazole/chlorpyrifos	

species was incised. Stakes were prepared from the kiln-dried wood furnish as supplied. Except for Douglas-fir, only wood that was free of knots was used for stakes. Douglas-fir stakes for field plots included wood with small-sized knots.

All wood stakes were cut from the finish to the de sired dimension, then equilibrated to a constant weight. The equilibrated stakes within each size group in each species were then weighed and arrayed by weight, The entire lot of weighed stakes was then divided into groups of 30, each with equivalent mean density and equivalent variation in density. This was accomplished by dividing the total population of stakes that were arrayed by weight into divisions of 30 replicate stakes, Each division was sequenced by density (weight/constant volume). To develop the set of 30 replicate stakes per treatment, we selected stakes from each of the divisions in a selection process that alternatively passed up and down the array from the least dense to most dense division.

Soil-Block Procedures

Standard and modified soil-block procedures were utilized within FPL. In a study that is evaluating alternative preservatives for use in softwood construction in Indonesia, blocks of Southern Pine sapwood were selected and treated with preservatives in accordance with A WPA E-10 (AWPA 1995c), except that the blocks were pressure treated by the fill-cell process in the same work tank and treating solution as were the field stakes to which the blocks are referenced. In other studies, an attempt was made to compare soil-block methodology with field test procedures. In these comparative evaluations, soil blocks were made from cross sections of 10 randomly selected stakes that were withdrawn from the set of 30 that were treated with each concentration of preservative in their respective tests. For each assay fungus used in the soil-block test, one 19-mm-long block was cut from midlength of each of the 19- by 19-by 450-mm stakes that were removed for analyses from each lot of 30 stakes per treatment. This created 10 replicate cubes per preservative treatment for each assay fungus.

Treating Procedures At FPL

Comparisons of wood preservative chemicals in wood products are usually made on a basis of equivalent loadings (retention levels) in a given wood species, Standard procedures for preparing soil blocks (AWPA 1995c) or field stakes (AWPA 1995b) define Southern Pine sapwood as the preferred wood and require selection of clear wood materials with a maximum allowable variation in density.

This research program encompasses a host of wood species. Each experiment entails treatment of a number of wood species to different retention levels with a group of preservatives (Table 3). To accomplish this array of treatments with a minimal amount of chemical, the retention series for all preservatives in all wood species is accomplished by treating all woods with the same gradient series of percentage active ingredient and allowing the resultant retention (weight/volume) to be distributed as determined by the variability in density of the wood materials being treated. As a result of the method of stake selection, a comparability in distribution of solution uptakes is anticipated for each wood by

Table 3—Concentration of active ingredients used at FPL when treating different wood species for evaluation of preservative efficacy.

Active ingredient (%)			Copper (%)	
Water-borne systems[a]	Creo-sotes	Chloro-thalonil (oil-borne)	Oxine copper (oil-borne)	Copper naph-thenate (oil)
0.08 a	7.5	0.37	0.04	0.04
0.15 a	15.0	0.74	0.08	0.08
0.30 abc	30.0	1.48	0.30	0.30
0.60 abc	65.0	2.96	0.60	1.20
1.20 abc			1.20	
2.40 abc			4.80	
4.80 c				

[a]Letter following concentration identifies type of experiment in which that concentration of active ingredient was used: a = soil-block studies; b = stake tests in U.S. field plots, c = stake tests in Indonesia. This partitioning of experiments was done only with the water-borne preservatives as indicated here.

treatment combination. However, visual identification of heartwood is not always possible, so some variability results. At each treatment, the preservative uptake of individual stakes is recorded on a computer. The identity of each stake is maintained in the field, and ultimately the performance of individual stakes will be related to the actual preservative uptake for that stake. Field results from each plot will ultimately be displayed in a computer-generated spreadsheet that relates performance to preservative retention on an individual stake basis. We anticipate that this will be an improvement from past practices of recording only the average retention and not accounting for the actual variation in retention that occurred in the population of stakes at time of treatment (Gutzmer and Crawford 1995).

In a study in which several preservatives were evaluated for their ability to protect Douglas-fir, we used a slightly different concentration of active ingredients (Table 4). All experimental materials were treated using the full-cell process. Calculations of chemical retention in each treated item were made on the basis of weight gain during treatment.

Creosote was diluted with toluene to simulate an empty-cell process. Copper naphthenate, chlorothalonil, and oxine copper were dissolved in No. 2 diesel oil, which met AWPA requirements for hydrocarbon Type A (AWPA 1995a), and then diluted with

Table 4-Concentration of active ingredients used at FPL in treatment of Douglas-fir for evaluation of preservative efficacy.

Active ingredient (%)			Copper (%)
Water-borne systems	Creo-sotes	Chloro-thalonil (oilborne)	Copper naph-thenate (oil)
0.37	7.5	0.37	0.31
0.75	15.0	0.74	0.62
1.50	30.0	1.48	1.25
3.00	60.0	2.96	2.50

toluene to achieve desired solution concentrations of diesel fuel and active ingredient. Treating solutions with oxine copper and copper naphthenate were mixed with toluene so that the amount of No. 2 diesel fuel was only 30% by weight of the total solution. Treating solutions with chlorothalonil were adjusted so that the diesel fuel comprised 22%, by weight, of the total solution.

For field testing, 30 replicate stakes were treated for each wood species by preservative by retention. At time of treatment, the retention of each treated stake was calculated on the basis of weight gain. Stakes treated with oilborne and waterborne preservatives other than ammoniacal systems were then allowed to air dry prior to shipment to a field site. Stakes treated with ammoniacal systems were wrapped in plastic and stored at least 2 weeks at ambient temperature before being unwrapped and allowed to air dry. Ten stakes were randomly withdrawn from each set of 30 replicate stakes for chemical analysis and to use in laboratory decay studies.

Evaluations

Evaluations of wood preservative efficacy in different wood species include the following:

- Laboratory decay studies in which treated-wood products are challenged with pure cultures of wood-destroying fungi
- Laboratory-scale, simulated ecosystems in which treated wood is exposed in soil beds that are maintained to selectively favor one or more grouping of deterioration organisms
- Field trials structured to expose treated wood to selective attack by termites
- Field trials designed to subject treated wood to naturally occurring microflora and fauna, either in ground contact or above-ground exposure

Pure Cultures

Laboratory experiments with pure cultures of wood-destroying fungi offer the opportunity to challenge the treated-wood product with organisms known to be tolerant of the preservative or the generic family of preservatives under evaluation. As such, pure cultures offer an opportunity to present a challenge for a specific wood by preservative combination that represents the worst possible exposure that could occur in the field. Laboratory decay studies with pure cultures also provide the opportunity to explore specific questions about the effect on wood species, veracity of fungi from different ecosystems against a specific wood product by treatment, effect of different physiologic groups of fungi, and even sequential effects of different, known organisms. A weakness of this approach is that pure cultures do not reproduce natural environmental settings and thereby do not simulate the interactive, competitive effects of natural microbial systems. Another limitation is that there is no universal agreement on the merits of these methods as predictors of actual field performance. The ASTM-type soil-block tests are generally more severe than the agar-block tests in that soil block usually gives greater threshold values (Cockroft 1974). Some researchers (Duncan 1953) consider results from soil-block studies with oilborne preservatives to be indicative of threshold values that occur in the field. Others (McNamara 1994) remain to be convinced. The severity of challenge posed by soil-block tests is greater than what occurs within 5 years of exposure above ground (De Groot 1994), but long-term relationships are not yet identified.

The appeal of agar-block methodology lies in its simplicity, relative ease of repeating the test with different fungi in any laboratory around the world, and reported speed, i.e., results within 3-6 weeks (Levi 1969). For these reasons, agar-block studies were included in our integrated evaluation protocol. In one study, a recent variation (Worrall and others 1991; Worrall and Wang 1991) of the agar-block procedure was used to evaluate the efficacy of waterborne and oilborne formulations of copper naphthenate in red maple (Smith and others 1996). In this procedure, miniature blocks measuring 5 mm (longitudinal dimension) by 10 mm (tangential) by 20 mm (radial) were treated according to experimental design and then supported on a plastic "needlepoint" mesh (2.5 perforations/cm) that rested on the mycelium of the assay fungus. This methodology proved useful in evaluating the preservative treatments against soft-rot and white-rot fungi, but did not promote aggressive decay by brown-rot fungi. Consequently, the agar-block method proved not to be of value as a way to evaluate efficacy against brown-rot fungi. This result with brown-rot fungi was surprising in light of Levi's (1969) prior success with veneers of wood that rested directly on mycelial mats. Smith (1996) believes that the reduced decay by the brown-rot fungus G. *trabeum* in this type of test is due to a requirement for a greater wood moisture content than occurs with this experimental procedure. Nonetheless, we confirmed this general performance profile in subsequent experimentation at FPL.

We also determined that variation among replicates can be controlled with soft-rot and white-rot fungi. In prior research with brown-rot fungi in which blocks were supported on glass rods over an agar substrate, variability recognized it as being too severe to permit statistical analysis (Cowling 1957). Through this integrated laboratory and field testing program, we will have the opportunity to relate results on copper naphthenate in red maple to subsequent field performance. However, it appears that more can be gained from the agar-block procedure, especially in light of its reported quick response time.

The use of wood blocks of small volume in laboratory, soil-contact decay studies (Bravery 1979) holds promise as a technique for rapid evaluation of new preservatives (miniblock procedure). This technique has been used previously to evaluate efficacy of wood preservatives on western red cedar sapwood (Scheffer and others 1987, 1988). For these reasons, the miniblock procedure was investigated for its utility as a tool for initial evaluations of relative performance of alternative preservatives on a variety of wood species. A cooperative evaluation of this test procedure was executed with Oregon State University. Laboratory activities were conducted at the university; data analysis was done at FPL. We found that this method lacked sensitivity in detecting significant differences among experimental varieties. This was probably due to the heterogeneity of variance in the experiment. We also observed that only a few fungi caused relatively more decay in a variety of wood species than did other fungi. These results suggest that the efficiency of this type of procedure could be increased by minimizing the number of assay fungi and maximizing the number of independent replications. The miniblock procedure seemingly has potential as an accelerated method for evaluating new preservatives. However, before this procedure can be accepted as a standard protocol, the source of procedural variability, reproducibility, and sensitivity needs to be defined.

At the FPL, we are conducting soil-block studies (AWPA 1995c) that utilize blocks prepared from subsets of the lot of stakes that were treated for either field exposure or analysis, as previously described, and we are conducting soil-block tests of parallel design using pine sapwood blocks. This should give us an opportunity to determine whether relative performance profiles in the laboratory are equivalent to those that we observe in the field. We are using representative, standard brown-, white-, and soft-rot fungi in the decay tests. It is anticipated that we will be able to define separate performance profiles for treated woods against each of the three major groups of wood-decomposing fungi.

We then will be able to compare those separate profiles with field performance in different ecosystems and with performance of comparable treatments by wood combinations in soil-bed (fungus cellar) exposure. In our investigation of alternatives to CCA for treatment of pine in Indonesia, we are complementing an extensive field trial that is replicated in West Java, southern Mississippi, and Wisconsin, with a soil-block study of alternative preservatives in pine sapwood blocks. In that soil-block study, we utilize only leached blocks because the pine in Indonesia is used mostly for cooling towers. Wood-decaying fungi that are important in both countries are used in this study.

Simulated Ecosystem

Beds of nonsterilized soil can be used as a medium for accelerated evaluation of treated-wood materials in a laboratory setting that more closely simulates a natural ecosystem than do pure culture studies. Small, elongated members of treated and untreated wood are immersed vertically into a bed of soil and incubated at a temperature and soil moisture content that allows naturally occurring microorganisms to flourish. The size of the wood members can be several millimeters to centimeters in dimension. Since the inception of soil-bed methodology almost 30 years ago (Gersonde and Becker 1958), there has been a growing recognition that the predominant microflora in the soil (i. e., soft-, brown-, or white-rot fungi) can be somewhat selected through control of soil moisture content in these beds. Even termites can be introduced to more completely simulate field exposure (Johnson and others 1988). There has been a growing interest in quantifying the measurements of decomposition (Baines 1984) and characterizing the performance profiles of populations of replicates in soil beds (Thorton and others 1995)—an approach that will allow meaningful comparison of results from these systems with results from field trials.

In our current research program, the performance of several species of hardwoods treated with both oilborne and waterborne systems is being evaluated in the soil-bed facility at Michigan Technological University. Stakes treated with the corresponding retention levels of the same preservatives are also being field tested in Hawaii and southern Mississippi. In the Michigan facility, the soil-bed stakes are 10 mm thick.

Three formulations of creosote that are not currently accepted within AWPA standards are also being evaluated in soil-bed tests at FPL. One formulation is also being evaluated in several wood species in a field simulator at CSIRO, Clayton, Victoria. In addition, the experimental design for the FPL soil-bed study is replicated with two sizes of stakes in an FPL field plot in southern Mississippi and, in part, in the CSIRO field sites near Walpeup, Victoria. A soil-block study using these formulations was previously completed at FPL. In the FPL beds, the soil is kept at a high moisture content to promote attack by soft-rot fungi, Stakes are 3 by 19 by 150 mm (radial, tangential, and longitudinal, respectively), Stakes in the CSIRO accelerated field simulator (AFS) are 25 by 50 by ~250 mm (approximately half lengths of the 15 by 50 by 500 mm stakes that were cross sectioned for chemical analysis), Soil in the AFS is maintained at a moisture content that promotes attack by brown- and white-rot fungi.

Field Trials

Field trials (graveyard tests), in which the durability of experimentally treated woods is ascertained by monitoring the duration that those wood members resist attack of naturally occurring microflora and fauna, have the greatest international recognition as the method for evaluating wood preservatives. Wood members (i.e., stakes) are usually vertically inserted to a depth of half their length into the soil and monitored during years of exposure. Stakes of various dimensions are used, but there is a general perception that comparative results will be obtained more quickly with stakes of smaller dimension than with those of larger dimension. Except for some procedural concerns about the relative potential for chemicals to leach from thin stakes with large surface area/cross-sectional area ratios, graveyard tests or field trials are generally regarded as providing the most direct evidence of preservative efficacy for actual products used in field conditions.

However, a major limitation of field trials is the time required needed for comparative results, particularly in temperate environments, Sometimes, decades of exposure are required to obtain results. For this reason, there is a growing interest in exposing treated materials in tropical settings. However, this practice has raised questions as to whether performance data generated in a tropical ecosystem will predict relative performance in temperate environments (Freitag and others 1995). Trends in performance of nonpressure-treated wood packaging that was exposed above ground in an open field in Panama forecast trends for similarly exposed materials in temperate environment, but results from packaging exposed above ground in the jungle did not (De Groot and Stroukoff 1986). We have also determined that comparative evaluations with field trials can be slightly accelerated by increasing the number of replicates per treatment and referencing comparisons to population medians or quartiles rather than means (Link and De Groot 1990).

In the research program reported here, field trials of treated-wood materials are being conducted in temperate and tropical climates (Table 5). Three separate studies permit us to address whether results for field

Table 5—Location of field plots included in the integrated evaluation program.

Location	Environmental description
USDA Harrison Experiment Forest: Southern Mississippi, 2 km from Gulf of Mexico, USA	Mean annual precipitation, 1580 mm Average annual temperature, 19.6°C Soil type at plots: poarch sandy loam Mean annual precipitation, 780 mm
Madison, Wisconsin USA	Average annual temperature, 7.4°C Soil type: clay loam soil
Hawaii USA	Mean annual precipitation, 3290 mm Mean annual temperature, 23°C Soil type: hilo silty clay loam
Morgantown, West Virginia USA	Mean annual precipitation, 995 mm Average annual temperature, 11.4°C Soil type: Clarksburg silt loam
Innisfall Field Station North Queensland Australia	Mean annual precipitation, 3556 mm Mean annual temperature, 22.7°C Soil type: clay-loam of basaltic origin
Mallee Research Station Walpeup, Victoria Australia	Mean annual precipitation, 340 mm Mean annual temperature, 16.2°C Soil type: light and sandy overlaying a calcareous clay-pan
Cikampek, West Java Indonesia	Mean annual precipitation, 1,891 mm Average annual temperature, 32°C-34°C Soil type: association of red latosol, brown latosol, reddish laterit; parent material: intermedier tufvolcan

trials with stakes in tropical environments forecast performance of treated-wood products in temperate climates. These comparisons are (1) Hawaii versus southern Mississippi, (2) Indonesia versus southern Mississippi and central Wisconsin, and (3) northern Queensland versus southern Mississippi. Two of these studies are established with complete replication of experimental design and a minimum of 20 replicate stakes per variable. This should provide an opportunity to compare the performance profile of individual wood species by preservative combinations in terms of relative performance, i.e. rank, population parameters of average, median, percentile, variability, and rates of decomposition after a defined starting point.

The objective of one experiment is to determine the durability of Douglas-fir obtained from second-growth forests, which are likely to be the source of most lumber in the future. Field trials with treated stakes exposed in ground contact are being conducted in southern Mississippi and northern Queensland, The same experimental design is used at both locations but size of stakes and number of replicates per treatment differ. The stakes in Queensland are nominally 50 mm square; stakes exposed in Mississippi are 19 mm square. Only 10 replicates per treatment are exposed in Queensland; 20 replicates per treatment are exposed in Mississippi. In northern Queensland, treated materials are exposed above ground and in ground contact. The above-ground evaluations will be made on several different configurations designed to simulate construction components in Australia. Ten replicate, treated Douglas-fir members with nominal cross-section dimensions of 50 by 100 mm were used per treatment by retention combination. Four different simulated construction components were fabricated from each replicate member.

A mixture of hardwoods and softwoods is included in two other studies that pair field plots of comparable design in tropical and temperate ecosystems. Southern Pine sapwood is used as a reference wood species in field trials that are replicated in Indonesia, southern Mississippi, and central Wisconsin. Several hardwoods from the northeastern United States are included in this study, which also addresses performance of tropical hardwoods that are treated with emerging preservatives. Twenty replicate stakes per combination are exposed in each plot. These field plots are matched with a laboratory, soil-block evaluation of the same preservatives used in the field. This laboratory study is restricted to Southern Pine sapwood only.

Another study that places great emphasis on hardwoods from a large geographic distribution within the eastern United States pairs field plots of comparable design in Hawaii and southern Mississippi. Selected combinations of woods and preservative treatment are also exposed, above ground, in Hawaii in a procedure that is selective for attack by Formosan termites. The core of this experimental design is also duplicated in a soil-bed study at Michigan Technological University. Twenty replicate stakes were used in the field and soil-bed methods.

Formulations of creosote that are not included within AWPA standards are being evaluated in soil-bed studies at FPL and CSIRO, as previously described. These evaluations are also being related to matched field plot designs in Victoria and southern Mississippi. Southern Pine, red oak, red maple, and Douglas-fir were used in field plots. Only stakes that were 25 by 50 by 500 mm in dimension were used in Australia. Two plots were installed in southern Mississippi: one with stakes of the same size as used in Australia; the other with stakes that were 19 by 19 mm in cross section. The latter experiment contained 20 replicates of treatment by wood combinations. The FPL plot in southern Mississippi that was conducted with 25- by 50-mm stakes contained only two formulations of creosote.

Concluding Remarks

In this integrated laboratory and field testing program, emphasis is placed on evaluating alternative wood species that are treated with emerging preservatives rather than on a fundamental research that focuses on the development of new active ingredients. It is perceived that this approach will enable rapid deployment of new technology to the protection of additional wood species. The development of a new preservative requires a considerable investment of time and resource to bring an idea into the marketplace. Not only must the efficacy of the active ingredient be demonstrated, but a host of environmental performance criteria must be addressed before the EPA will permit its use, i.e., grant a label permitting its use on wood. Therefore, all new preservatives have to meet criteria of standard-setting bodies, such as AWPA and EPA. As noted previously, efficacy evaluations are being conducted principally with Southern Pine sapwood, which yields little information relative to the performance of hardwoods. By working with active ingredients that have either completed EPA review or are in the process of being reviewed, we selected those compounds and systems that had immediate potential for use in the wood-treating industry if their technical performance shows promise.

Success in developing composite structures for engineering applications increases the further prospects for utilization of alternative wood species, hence the interest in durable species goes far beyond transportation structures and cooling towers. You might anticipate that greater emphasis will also be placed upon designing treatments that address unique challenges presented by the alternative species. Towards that anticipated trend, this integrated program still needs to identify an accelerated, reliable, sensitive method to evaluate preservatives that will yield results quickly enough to permit feedback into a design program for new systems.

None of the field experiments that we are conducting has progressed far enough to allow definitive conclusions. However, we have gained an impression that relative trends observed among creosote formulations in the soil-bed trials reflect relative trends observed in the field exposures. We sense that when stakes of only a few millimeters thick are used in soil-bed studies, the performance of creosote, relative to that of CCA, is much less than actually occurs in large products in the field. We have not seen this indication with the larger soil-bed stakes, but that study is not complete. Soil-bed studies involving alternative waterborne and oil-borne treatments are showing some separation of treatment efficacy. There is some indication of differences among species in performance of individual preservatives. The soil-bed studies have not run sufficiently long enough to allow definitive evaluations of relative performance or provide a pattern of results for comparison with field results.

Populations of untreated 19- by 19-mm Douglas-fir stakes exposed in southern Mississippi were degraded at the same rate as was observed in populations of larger, untreated Douglas-fir stakes exposed in Queensland. Results from soil-block studies completed at FPL have demonstrated some significant differences among preservatives in threshold (minimum retention) levels required to prevent attack by different fungi. These results indicate that we should see some marked differences in field performance.

References

AWPA. 1994. Technical committee regulations. In: Proceedings, American Wood Preserver's Association Vol. 90. Woodstock, MD: American Wood Preservers' Association: 462-478.

AWPA. 1995a. Standards for solvents and formulations for organic preservative systems. P9–92. In: Book of Standards. Woodstock, MD: American Wood Preservers' Association: 14–1 6.

A WPA. 1995b. Standard method of evaluating wood preservatives by field tests with stakes. E7-93. In: Book of Standards. Woodstock, MD: American Wood Preservers' Association: 270-281.

AWPA. 1995c. Standard method of testing wood preservatives by laboratory soil-block cultures. E 10–91. In: Book of Standards. Woodstock, MD: American Wood Preservers' Association: 288–298.

Baines, E.F. 1984. Preservative evaluation using a soil bed and static bending strength to measure performance. In: Proceedings, American Wood Preservers' Association. Woodstock, MD: American Wood Preservers' Association: 80: 67–79.

Bravery, A.F. 1979. A miniaturized wood-block test for the rapid evaluation of wood preservative fungicides. In: Screening techniques for potential wood preservative chemicals. Proceedings, special seminar, Peebles. Rep, 136. Stockholm, Sweden: Swedish Wood Preservation Institute: 55–65.

Cockroft, R. 1974. Evaluating the performance of wood preservatives against fungi. Journal of the Institute of Wood Science. 6(6): 2–8.

Cowling, E.B. 1957. The relative preservative tolerances of 18 wood-destroying fungi. Forest Products Journal. 7:355-359.

De Groot, R.C. 1994. Comparison of laboratory and field methods to evaluate durability of preservative-treated shakes. Wood and Fiber Science. 26(3): 306–314.

De Groot, R. C.; Stroukoff, M. 1986. Efficacy of alternative preservatives used in dip treatments for wood boxes. FPL–RP–481. Madison, WI: U.S. Department of Agriculture, Forest Service. Forest Products Laboratory. 21 p.

Duncan, C.G. 1953. Soil-block and agar-block techniques for evaluation of oil-type wood preservatives: creosote, copper naphthenate and pentachlorophenol. Special Release 37. Beltsville, MD: U.S. Department of Agriculture, Agricultural Research Service,. Bureau of Plant industry, Soils, and Agricultural Engineering, Division of Forest Pathology. 39 p.

Freitag, C. M.; Morrell; J. J.; Archer, K.J. 1995. Colonization of treated and untreated ponderosa pine exposed in Hilo, Hawaii. IRG/WP 95–20068. Stockholm, Sweden: The International Research Group on Wood Preservation. 11 p.

Gersonde, M; Becker, G. 1958. Prufung von Holzschutzmitteln fur den Hochbau auf Wirksamkeit gegen Pilze parxisgemassen Holzproben (Schwammkeller–Versuche) Holz als Rob-u Werkstoff. 16:3 46–57.

Gutzmer, D. I.; Crawford, D. M.. 1995. Comparison of wood preservatives in stake tests. 1995 Progress Report. FPL-RN-02. Madison, WI: U.S. Department of Agriculture, Forest Service. Forest Products Laboratory. 124 p.

Johnson, G. C.; Thornton, J. C.; Crefield, J. W.; Howick, C.D. 1988. Assessing timber durability using an accelerated field simulator 1. Initiation of decay and termite studies. Material und Organismen. 23(2): 97-114.

Levi, M.P. 1969. A rapid test for evaluating the fungicidal activity of potential wood preservatives. Journal of the Institute of Wood Science. Number 23. 4(5): 45-50

Link, C. L.; De Groot, R.C. 1990. Predicting effectiveness of wood preservatives from small sample field trials. Wood and Fiber Science. 22(l): 92-108.

McNamara, W.S. 1994. Soil block versus field test for evaluating and standardizing wood preservatives: a commercial view. IRG/WP 94–20024. Stockholm, Sweden: International Research Group On Wood Preservation. 5 p.

Permadi, Pipin. 1995. Personal communication. Bogor, Indonesia: FRRDC.

Scheffer, T. C.; Morrell, J. J.; Newbill, M. A.. 1987. Shellrot control in western redcedar: potential replacements for pentachlorophenol spray. Forest Products Journal. 37(7/8): 5 1–54.

Scheffer, T. C.; Newbill, M. A.; Morrell, J.J. 1988. Laboratory evaluation of potential replacements for pentachlorophenol in sprays to control sapwood decay in western redcedar poles. Holzforschung. 42: 185–1 89.

Smith, W.B. 1996. Personal communication. April 26. Syracuse, NY: State University of New York, College of Environmental Science and Forestry.

Smith, W. B.; Abdullah, N.; Herdman, D.; De Groot, R.C. 1996. Preservative treatment of red maple. Forest Products Journal. 46(3): 35–41.

Thornton, J. D.; Johnson, G. C.; Crefield, J. W.; Nguyen, N–K. 1995. Assessing timber durability using an accelerated field simulator. II. Specimen life statistics from decay and subterranean termite studies. Material und Organismen. 29/4: 273-288.

Wipf, Terry J.; Ritter, Michael A.; Duwaki, Sheila Rimal; Moody, Russell C. 1993. Development of a six-year research needs assessment for timber transportation structures. FPL–GTR–74. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 44 p.

Worrall, J. J.; Wang, C.J.K. 1991. Importance and mobilization of nutrients in soft rot of wood. Canadian Journal of Microbiology. 37:864-868.

Worrall, J. J.; Angnost, S. E.; Wang, C. J. K.. 1991. Conditions for soft rot in wood. Canadian Journal of Microbiology. 37: 869–874.

In: Ritter, M.A.; Duwadi, S.R.; Lee, P.D.H., ed(s). National conference on wood transportation structures; 1996 October 23-25; Madison, WI. Gen. Tech. Rep. FPL- GTR-94. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.