Field Performance of New Wood Preservative Systems in Secondary Timber Species

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Abstract

The objective of this ongoing study is to evaluate the performance of new, potential, and standard wood preservative systems in regionally important timber species. An important purpose of the work is to provide information on preservative/wood species combinations that could be used in transportation structures. Eleven preservative systems were evaluated in this study - ACQ Type B, Copper Citrate 2:1, CDDC, chlorothalonil/chlorpyrifos, copper-8-quinolinolate, tebuconazole/chlorpyrifos, RH287, propiconazole/chlorpyifos, copper naphthenate, CCA, and creosote. Field evaluations are being performed with ground contact field stakes and termite-specfic testing in Hawaii, and a laboratory soil bed test. The major wood species used with all the systems and evaluation methodologies were loblolly pine *(Pinus taeda,* softwood), northern red oak *(Quercus rubra,* dense hardwood), tulip poplar *(Liriodendron tulipifera*, medium density hardwood), and cottonwood *(Populus deltoides*, low density hardwood). More limited evaluations (field stakes only) are being conducted with eastern hemlock *(Tsugu canadensis),* red maple *(Acer rubrum),* and sweetgum *(Liquidambar styraciflua).* Information on the comparative treatability of these species correlated with formulation type is presented, as well as fungus cellar and termite test results. Results from the field stakes is not available yet.

Keywords: Wood preservative, timber bridge, ACQ, CDDC, copper citrate, chlorothalonil, chlorpyrifos, copper-8-quinolinolate, tebuconazole, RH287, propiconazole, copper naphthenate, CCA, creosote, red oak, tulip poplar, cottonwood, eastern hemlock, red maple, sweetgum.

Introduction

Despite improved timber products development and engineered timber bridge designs in the past century, there has been a decrease in the number of timber bridges built. New technology in steel and reinforced concrete in the early 20th century became desirable and economical alternatives to timber. As more steel and reinforced concrete bridges were constructed, development of better timber designs was slowed (7). At the same time advances were being made in wood preservation technology and the development of engineered wood products such as glulam beams and structural composite lumbers. Today's wood preservative and wood composite technology are capable of providing life spans of over 50 years and span up to 140 feet (7).

One economic consideration in the construction of timber bridges is material and shipping costs. Smith and Bush conducted a nationwide survey of timber bridge companies and found that the vast majority of bridges are constructed from southern pine *(Pinus spp.)* and Douglas-fir *(Pseudotsuga menziesii* (Mirb.)Franco) (11). Minor use species included red/white oak *(Quercus rubra* L. */Q. alba* L.), red maple *(Acer rubrum* L.), and red pine *(Pinus resinosa* Ait.). A survey of all Michigan road and drain commissions and 18 municipalities showed that 11% of the bridges they have worked with in the past five years have been constructed of timber products, and projects that 26% of bridges will be constructed of timber in the next five years (5). In order to save substantial money on shipping of southern or western species and to stimulate the local economies it would be advantageous to utilize one of the many species grown in the local region.

Anticipating an increase in the number of timber bridges to be constructed in coming years, and in order to promote their construction, the USDA Forest Service launched the Timber Bridge Initiative in 1988. Studies on mechanical and biological decay performance, in conjunction with traditional and new wood preservative systems, in under-utilized species is one major aspect of the Initiative. To date, 16 demonstration bridges have been built including the 42 ft eastern cottonwood Cooper Creek bridge in Appanoose County, Iowa. The two lane bridge, constructed in 1992 from creosote treated eastern cottonwood *(Populus deltoides* Bartr. ex Marsh), was built at a cost of approximately $34,200 for fabrication and construction of the bridge superstructure, railing and wearing surface. There has been no measurable creep, and no decay has been detected (6). Demonstration bridges such as this are quickly showing that hardwoods found locally in many parts of the country are an economical, structurally capable, and long lasting alternative building material.

Resistance of a weed species to biological decay is perhaps the most important factor in the service life of a timber bridge. Little is known about the decay performance and treatability of many under-utilized hardwood species with the new wood preservative systems of today. Some early treatability work investigated the permeabilities, and fluid and gas flow rates in various hardwoods. One such study evaluated unsteady-state gas flow in three hardwood species including yellow-poplar *(Liriodendron tulipifera* L.) (8). Choong and Fogg explored differences in gas permeability between the radial, tangential, and longitudinal directions in shortleaf pine *(Pinus echinata* Mill.) and yellow-poplar (2). Choong et al. also evaluated the permeability of various softwoods and hardwoods including red oak and yellow-poplar in the longitudinal direction with creosote, and found both to be more permeable than Douglas-fro and southern pine sapwood (3). Permeability coefficients can be determined for non polar liquids by measurements of air flow, due to the inertness of these fluids to the wood. In other words, for fluids which will not interact with the wood, differences in internal structure of various wood species are responsible for differing permeabilities and not differences between the fluids themselves (10). Given the anisotropic and variable nature of wood, it is clear how variation in permeability and therefore preservative retentions arise within a given species. Thomas discusses some of the anatomical features of three hardwood species that affect penetrability (12).

Other treatability studies have focused on variation of retentions between various species. Siau used a comparison of retentions of silicone, light hydrocarbon, and paraffin oils in loblolly pine *(Pinus taeda* L.), three western softwood species, and white oak to establish a linear relationship between permeability and retention (9). Weaver and Levi found different responses of species to various preservative systems, and that CCA and creosote penetrate similarly (13). This suggests that the differences between species are responsible for treatability differences, rather, or more so, than differences between preservative systems.

There is a lack of knowledge not only in decay resistance performance of many hardwood species with new preservative systems, but also in the treatability of these species with the preservatives. Gaining an understanding of which preservative systems are retained at the highest and lowest levels in which species, and which combinations are most variable in terms of retention may help partially explain results of field tests. It would also facilitate predictions of which species/preservative combinations will be most variable in terms of decay resistancconsistency an important consideration when deciding the proper materials for timber bridge construction.

Methods

Treating

Three hardwood species (red oak, yellow-poplar, and cottonwood) and one softwood species (southern pine) were cut into various test specimens, including the 19x19x450mm (AWPA 3/4-inch) field stakes (1) used for the treating analysis. Only sapwood was selected for southern pine and yellow-poplar to allow complete penetration of the treating solution. Red oak is primarily heartwood, so only heartwood was selected for this species to reduce the treating variability that would occur if stakes were composed of both heartwood and sapwood. No attempt was made to distinguish sapwood for cottonwood, because of the difficulty in identifying the heartwood in this species. To maximize consistency in southern pine wood density, only wood with between 6 and 10 annual rings per inch were cut into stakes.

The wood specimens were allowed to condition to ambient room conditions for a period of several months before treating. Additional field stakes were cut from two more hardwood species (red maple and sweetgum *(Liquidambar styraciflua* L.), and one more softwood (eastern hemlock *(Tsuga canadensis* (L.) Carr.), in fewer numbers. These additional specimens were not included in the statistical study due to differences in the number of replicates, which would have provided a poor comparison.

Twenty stakes of each species were treated with each of the preservative systems at four different retentions (as shown in Table 1), for a total of eighty stakes per preservative system/species combination. The large degree of replication should have provided an average free from affected by differences within species such as where the wood was cut from, grain orientation, etc. Treating began with weighing the conditioned stakes and preparing the treating solution. CDDC is the only system requiring more than one treatment. The first is treatment of the wood with a copper-amine water solution (cupric hydroxide). The stakes were allowed to dry to ambient conditions for several months before the second treatment, which was sodium dimethyldithiocarbamate (SDDC) in water. Active ingredient retentions are based on the retention of copper + retention SDDC in pounds per cubic foot. See Table 1 for a description of all preservative system formulations.

The stakes were placed in metal containers and weighted down using aluminum blocks, with plastic mesh between stake layers and between the stakes and the container or weights to ensure maximum contact with the treating solutions. Following submersion of the stakes in the treating solution, the vessel was placed in a treating cylinder, where a vacuum of 25 inches of mercury was drawn for a period of 30 minutes. After the vacuum period, the cylinder was pressurized to 100psi for one hour and then released. The stakes were then allowed to remain submerged in the treating solution for a 10 minute equalization period. Finally, the stakes were blotted dry, weighed, and placed in a second conditioning room to allow evaporation of the carriers and solvents. Retentions based on the amount of active ingredient retained by the stakes were calculated using the pre- and post-treated weights, stake volume, and active ingredient concentration in the treating solution. Since complete penetration was assumed no penetration measurements were made.

Termite field testing was done at a site in Hilo, Hawaii. The test blocks were randomized and placed horizontally on top of hollow concrete blocks 10 cm above the ground at a field site in Hilo, Hawaii. This site provides a severe termite challenge due to the very high *Coptotermes formosanus* population in the area. Untreated pine bait stakes (300 x 25 x 13 mm) were driven vertically into the ground through the holes in the concrete blocks to attract termites to the samples. To encourage the termites to feed around the test material, untreated pine "feeder" stakes (450 x 19 x 19 mm) were laid between the three rows of eight blocks and along the perimeter. The bait stakes were in direct contact with the feeder stakes, which were in contact with the test blocks. The assembled units were enclosed with a boxed lid (650 x 650 mm and 150 mm high) to maintain dark conditions and provide shelter from the weather. Termite-damaged bait and feeder stakes were replaced every six months when the test blocks were inspected. This maintains a constant high termite hazard for the blocks. The rating system was according to the 10, 9, 8, 7, 6, 4, 0 scheme, where 10 means sound and 0 is failure.

Soil bed (fungus cellar) testing is done using by placing stakes (13 x 25 x 1000 mm) into bins of soil such that three quarters of the length is buried. The soil beds are kept in an insulated room maintained at 80°F and 90% RH. Soil moisture content is mainted at a level appropriate for soft rot attack. Stakes are inspected at three month intervals and rated using the same numbering scheme as described above for the termite specimens. For both termite and soil bed testing, a single retention of each preservative was evaluated.

Statistical Analysis

Retentions of active ingredients ranged from 0.015pcf to 20pcf. In order to place each of the treatments in the same scale it was necessary to convert retentions to a volume of treating solution retained. In order to standardize the volumetric retentions, each was divided by the stake volume of 162.45 cm^3, thus making the retention a proportion of treating solution volume:wood volume. It was assumed that small differences in the concentration of active ingredients was not a significant factor in solution absorption, so all target active ingredient retentions were combined and considered a single treatment.

All statistical analyses were performed using the General Linear Model (GLM) procedure of SAS (SAS Institute Inc. 1988). The ANOVA model was designed to detect significant differences between the means for the species and preservative systems, and to test for a significant interaction term using the usual effects model. Another ANOVA using all combinations of species and preservative systems as the only treatment was also employed. This second ANOVA is called the "means" model by Milliken and Johnson (4). Tukey's "honestly significant difference" multiple range test was used to determine which treatment means were different.

The coefficients of variation (CV) were calculated for each species and preservative system, and ANOVA effects and means models and their associated Tukey tests were analyzed. The set of 80 replicates for each species/preservative system combination was broken into four subsets of 20, with each subset representing each of the active ingredient concentrations, before performing the ANOVA and Tukey tests. This was done to allow for replication in the CV analysis.

Results and Discussion

Mean Volumes Retained

The effects model from the ANOVA analysis show that the species, preservative system, and interactions of the two are all significant explainers of variation. Of these, the species effect has an F value (7673.53) more than 10 times the other effects, and therefore is most important in explaining differences in average volumes of treating solutions retained per unit volume of wood. This tits suggestions of previous work in the Introduction that suggest that the internal structure of wood is responsible for varying permeabilities and retentions.

Figures 1-A through 1-D show the average volume of preservative retained by each species and the results of Tukey's multiple range test, which identities significant differences between each species/preservative combination in the means model. The Tukey's results are the letters at the top of each bar in the histograms. Those treatment combinations with the same letter are not significantly different, nor are treatment combinations which share any letters significantly different. The Tukey's designations are also valid across species in figures 1-A through 1-D.

It is apparent that red oak stakes retained a much lower volume than the other species. Note that the only overlap in designations from red oak to other species were between the SDDC uptake in red oak and creosote uptake in southern pine. Conversely, the cottonwood stakes retained the highest volume of every preservative. Retentions of the water-borne preservatives were similar in the cottonwood and yellow-poplar field stakes. Overall, the southern pine and yellow-poplar stakes were largely intermediate in the average retentions of the preservatives. The yellow-poplar stakes exhibited the most distinct difference between the water-borne, and oil and organic solvent borne preseservative systems. Based on the average density of each species, these results were expected. It is now apparent, however, that while the medium and low densities of southern pine and cottonwood differ insignificantly, the high density wood of red oak consistently retains significantly lower volumes of all treating solutions but creosote compared to the other species studied.

A very clear trend in the retentions of the individual preservatives is apparent from the figures. In every species, the water-borne systems were retained at higher volumes than the organic solvent systems. This is no doubt due to the ability of polar water molecules to enter wood cell walls and swell the stakes. This fact may mean that significant differences between aqueous and organic systems are not valid, however differences within the two types are valid. In addition, within the water-borne systems, SDDC was always the highest volume retained followed by cupric hydroxide, propiconazole/pyethroid, copper citrate 2:1, ACQ type C, and finally CCA at the lowest. As a group, the oil and organic solvent-borne systems were absorbed in smaller volumes than water-bornes. The following trend is evident in each species. RH287 was always at the highest volume retained followed by copper-8-quinolinolate, chlorothalonil, tebuconazole, copper naphthenate, and creosote at the lowest retention.

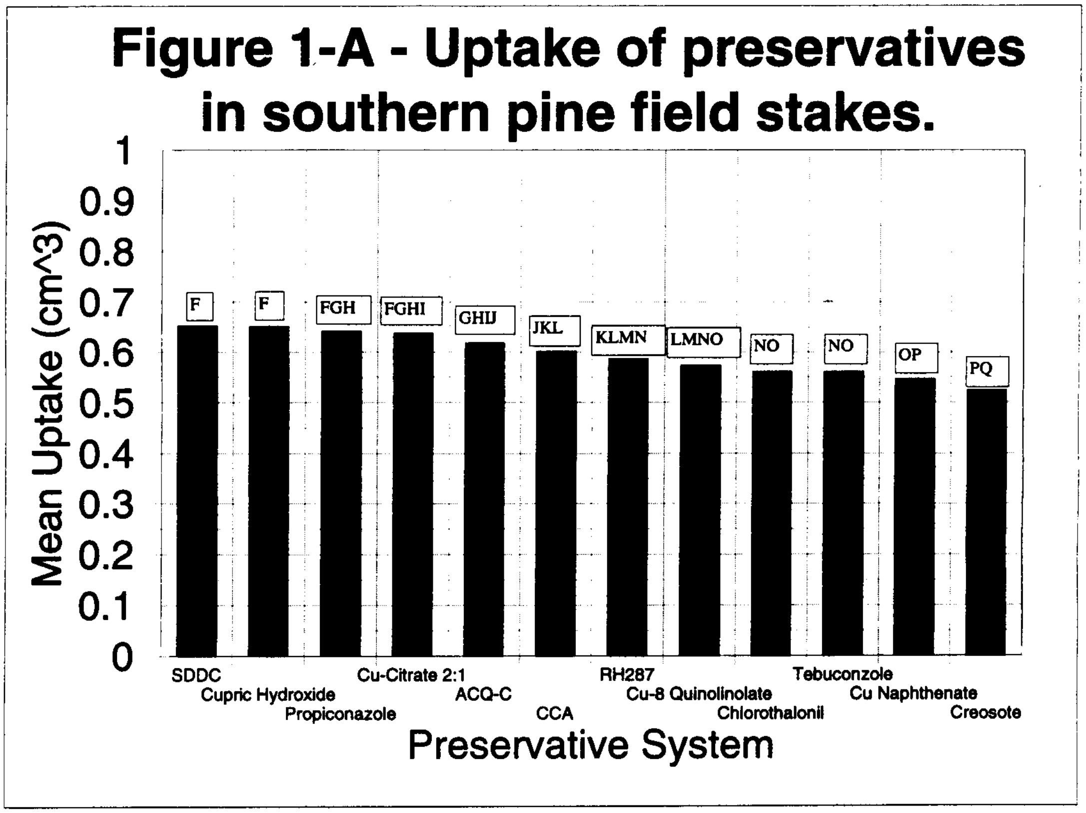
Mean Coefficients of Variation

The effects model from the ANOVA of coefficients of variation also show all three effects (species, preservative systems, and interactions) are significant in explaining differences in mean coefficients of variation. As for the volume/volume means, the species effect is most important with an F value of 64.02 compared to 4.15 and 2.79 for the preservative systems and interactions, respectively.

The fact that the species effect is many times greater than the others is of little surprise considering the inherently variable nature of wood, which seems to fit observations made by previous researchers. This is especially true compared to the relatively consistent nature of the treating solutions, which are composed of a large proportion of solvent and only small differences in the amounts of active ingredients.

Red oak had a significantly higher CV of 0.12, while the other three were not significantly different and ranged from 0.05 for southern pine to 0.065 for cottonwood. Among the preservatives, the only significant differences identified by the effects model was that copper-8-quinolinolate had a higher CV than chlorothalonil, creosote, RH287, tebuconazole, cupric hydroxide, SDDC, CCA, and copper citrate 2:1. From the means model analysis, four of the eleven preservative systems exhibited significant differences between species. These were cupric hydroxide and SDDC (both of the CDDC dual treatment system), copper citrate 2:1, propiconzole/pyrethroid, and copper naphthenate. In all four cases the significant differences were found between red oak and the other species.

The higher variability of some preservatives in red oak, and more variability in retentions within red oak, itself, maybe explained by varying proportions of latewood within each sample. A sample with a large proportion of high density latewood would not absorb nearly as much treating solution as one with a relatively small proportion of latewood. Another explanation would be varying extractives contents between specimens, which would result in varying permeabilities. For example, a specimen cut from near the center of the tree will have a lower extractives content than one cut from nearer the sapwood/heartwood interface end containing more extractives.



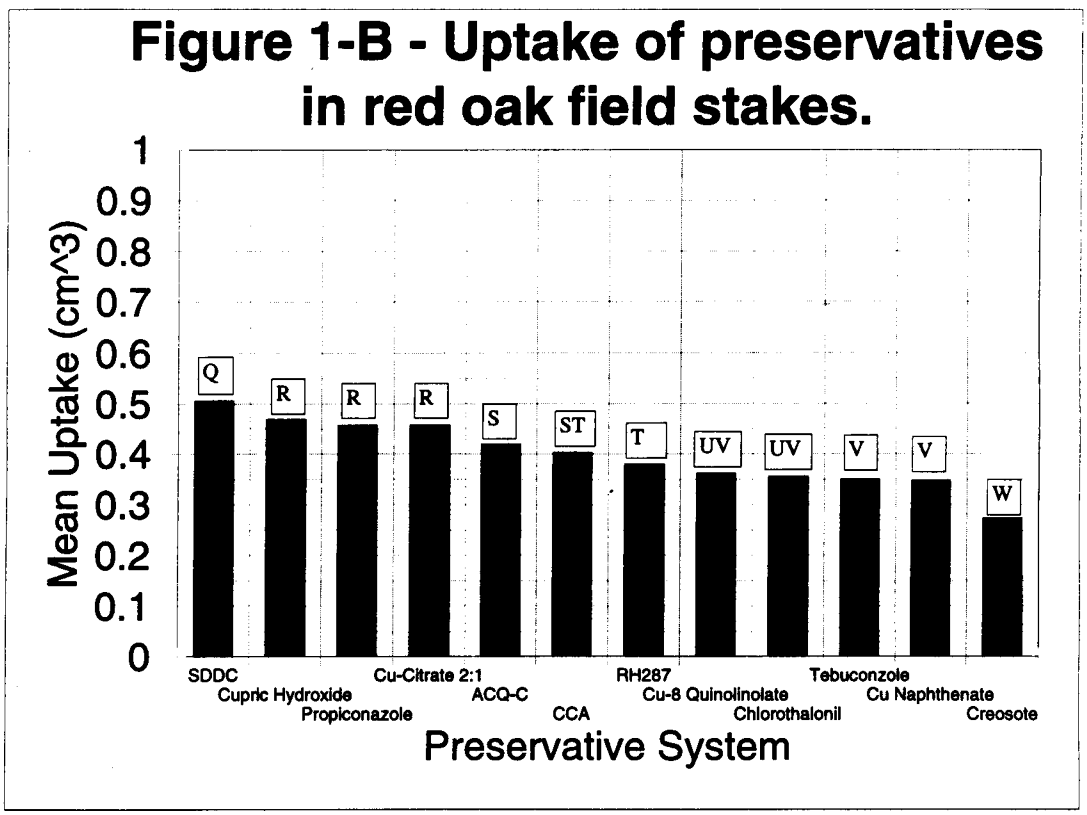


Figure 1- Mean uptake of preservative systems in southern pine, red oak, yellow-poplar, and cottonwood field stakes.

Figure 1-C - Uptake of preservatives in yellow-poplar field stakes.

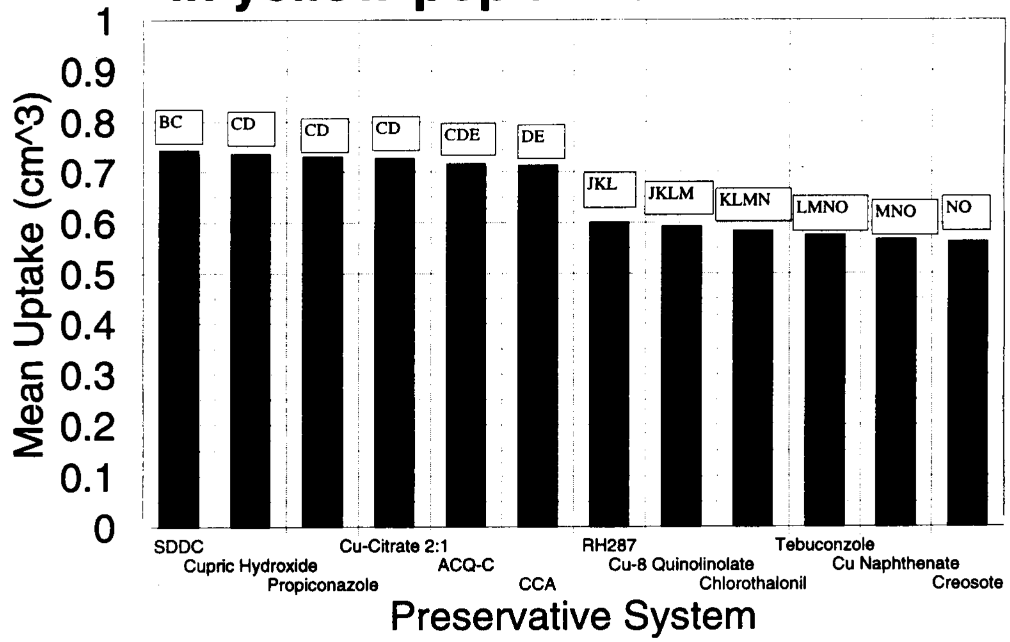
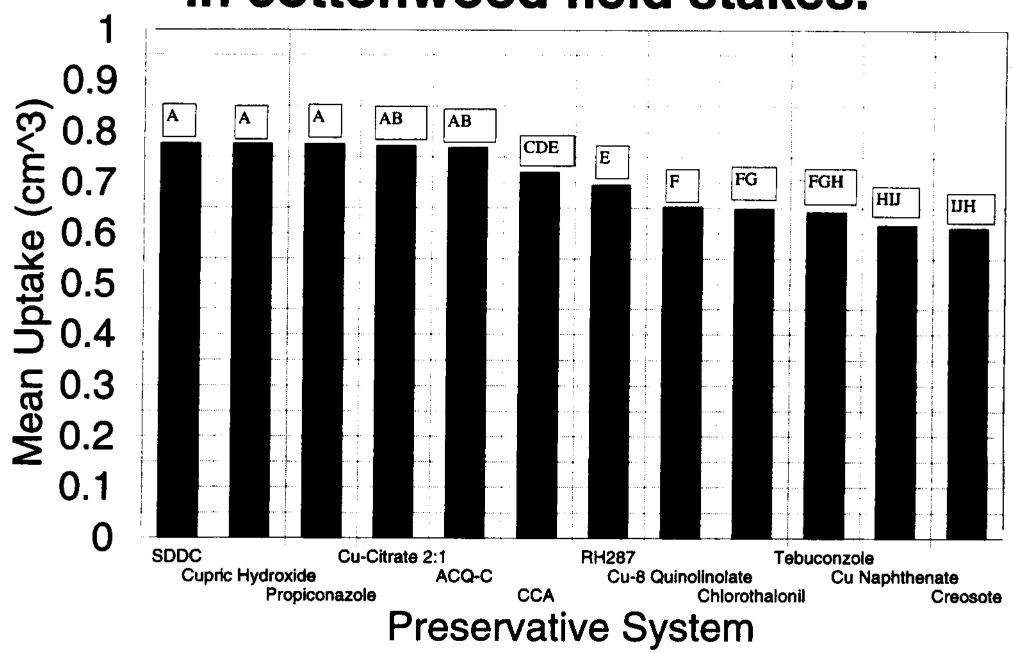


Figure 1-D - Uptake of preservatives in cottonwood field stakes.



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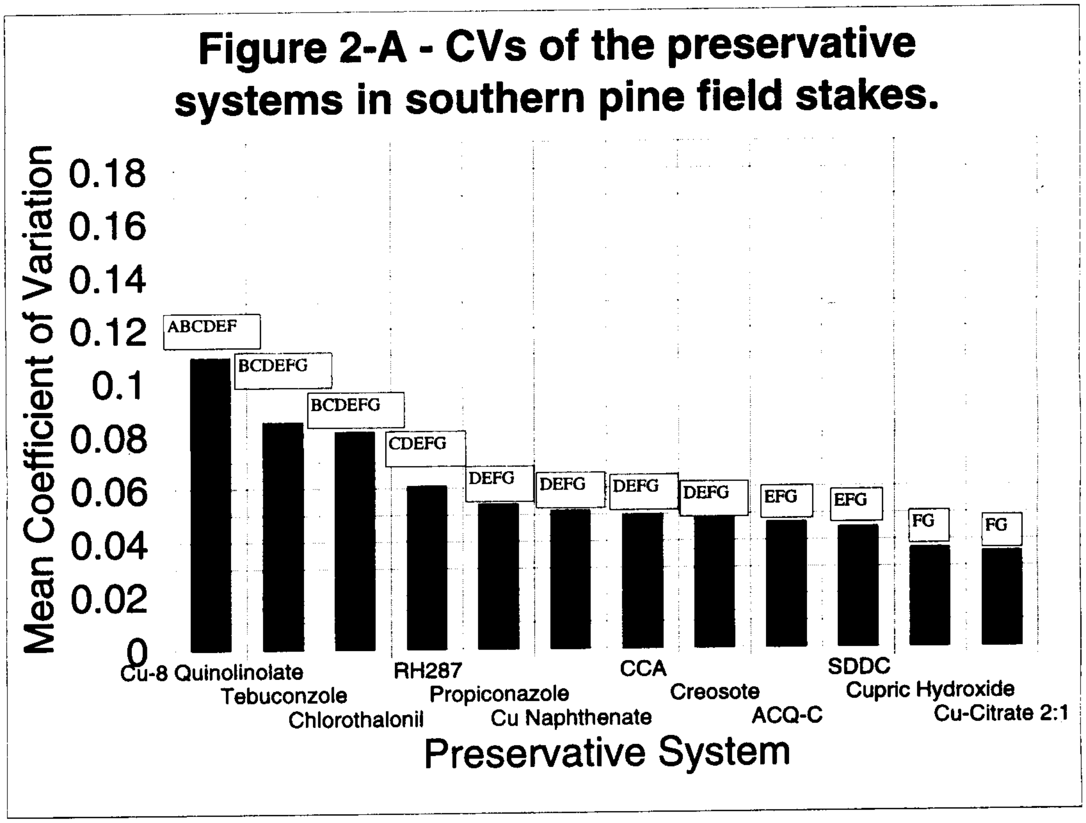


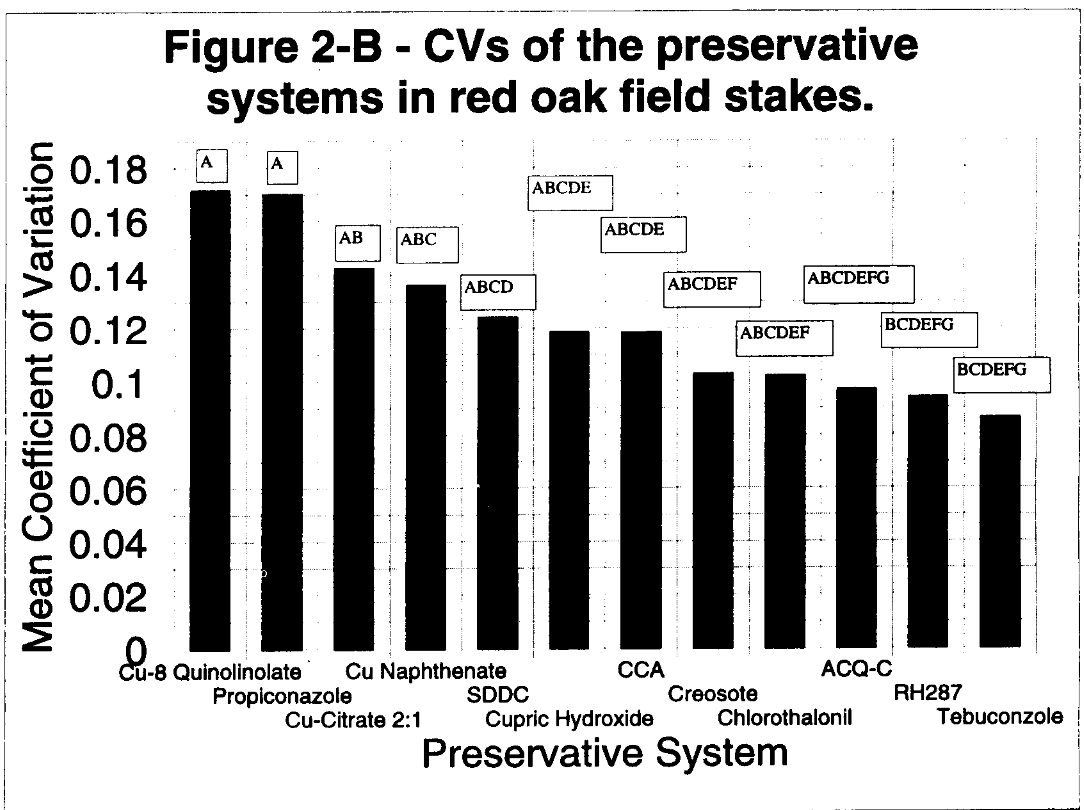
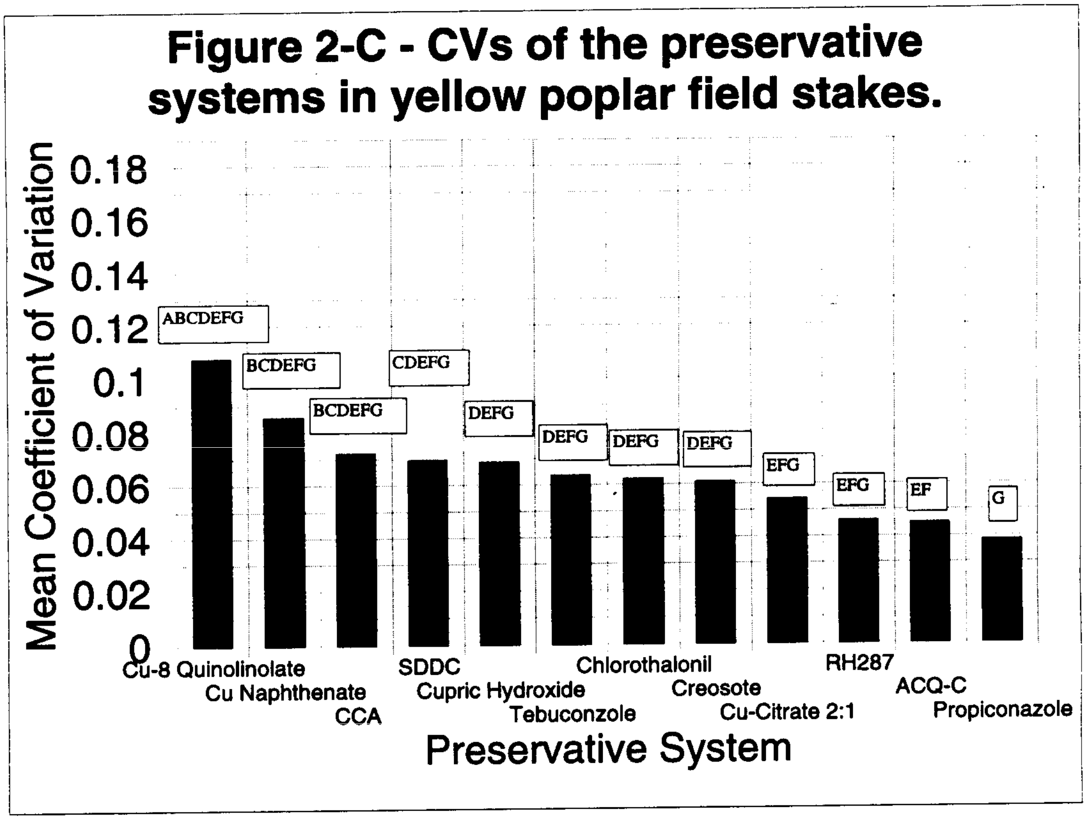


Figure 2- Mean coefficients of variation for southern pine, red oak, yellow-poplar, and cottonwood field stakes treated with selected preservative systems.



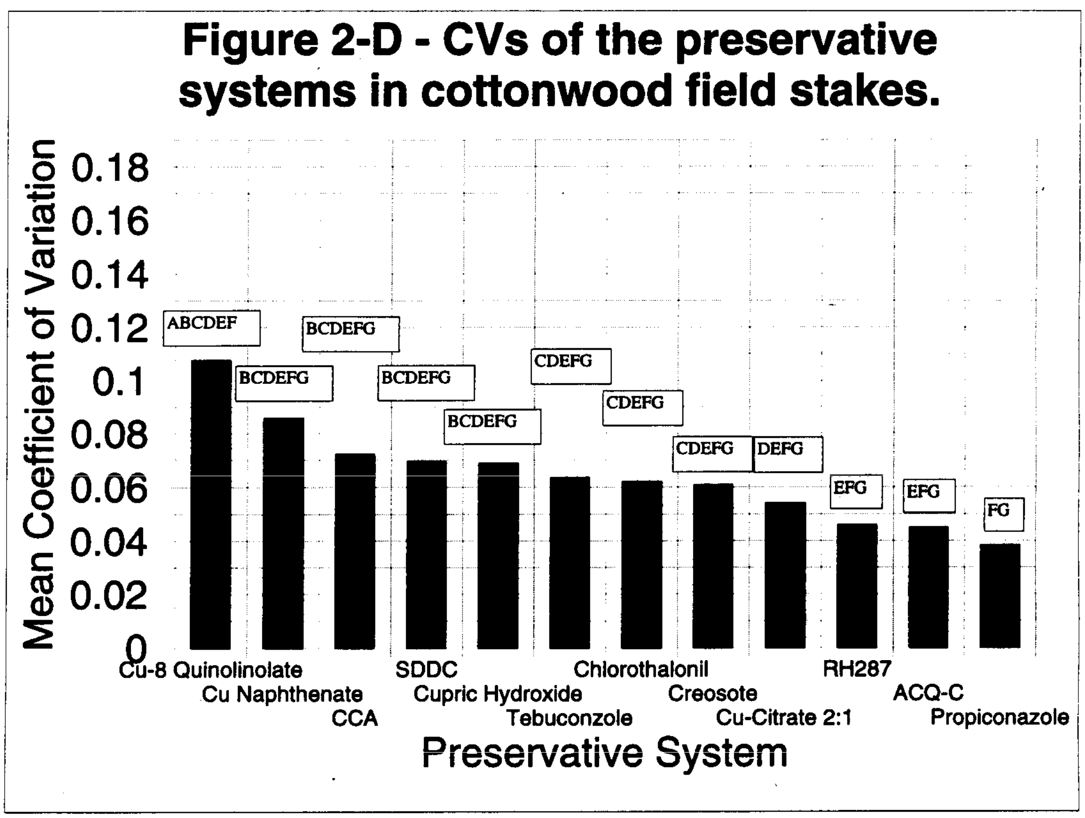


Figure 2- continued.

Soil Bed Results

Results from the soil bed testing are given in Table 1. Different sections of this project were installed in the soil beds as the stakes were treated and conditioned, so there are differences in total time exposures for various preservative systems. Substantial degradation has occured in the untreated controls - essentially all the yellow poplar and cottonwood stakes have failed after 18 months exposure. The southern pine and red oak controls have intermediate ratings of about 6 after this time.

Some of the systems are performing well with little or no wood species effect, generally having average ratings in the 9's - ACQ, copper citrate 2:1, and creosote. These treatments appear to have broad use in a number of wood species at the specified retention. Other treatments have lower average ratings (around 8.5 to 9.0) but are still with consistent performance across the wood species - copper-8-quinolinolate, tebuconazole/chlorpyrifos, chlorothalonil/chlorpyrifos, and copper napthenate. The latter three treatments are formulated in a P9 Type A oil, which probably helps their efficacy. If these treatments had been evaluated at a higher retention, results comparable to the first group would probably have been observed. The remaining treatments - CDDC, RH287, propiconazole/pyrethroid, and CCA show better performance in the southern pine, lower ratings in the two lower density hardwoods, and intermediate performance in red oak. This is especially striking with CCA, where the pine samples are rating a perfect 10, while the lower density hardwoods have average ratings in the 5's after 24 months. These treatments are more selective in activity and adaptation to hardwood species needs to be done with caution.

Termite Field Evaluations

Current results from the field testing for termite resistance are given in Table 2. The ratings of the untreated controls show that termites are attacking the tested wood species roughly in the order of density with the lower density species undergoing more attack. Lower ratings for the untreated controls would have been expected by this time. The relatively slow attack rate is probably due to the untreated controls being dispersed amongst the treated blocks. In other work, we have found that some wood treatments can have a general protective effect over the specimens in an entire box. This is particularly true for preservatives with P9 oil carriers. Nevertheless, the substantial attack on the untreated controls show that termite activity is present.

In order to evaluate all the combinations of preservative and wood species, only one retention could be tested due to space constraints. The retention tested is the expected field stake threshold if the preservative was tested in southern pine sapwood. In this above-ground termite testing, the specimens should perform well in the pine substrate over the relatively short timescale reported here (18 months). The only significant attack on treated material is with the RH287/cottonwood combination. After 18 months, these replicates are averaging 7.6. As this work progresses, we expcet to see attack on other treatments in the lower density hardwoods as well. This further illustrates the need for caution when using wood preservatives developed for use in softwoods, in a hardwood species.

Conclusions

Effects and Means Models

The effects model for the mean volumes of solutions retained by the wood species clearly show that there are sigificant differences among the species, preservative systems, and interactions. Of these, the effects due to differences between species was the largest, followed by the differences between preservative systems, and finally the interaction of the two. The corresponding means model identities the specific differences between each species and preservative combination.

The effects model for the mean coefficients of variation identified significant differences in variance between species, preservative systems, and interactions similar to those in volumes of treating solutions retained. Again the species effect is clearly most important, the interaction is least significant, and the preservative system effect is intermediate, though much closer to the interaction effect. The means model for mean coefficients of variation of treating solutions retained also shows significant differences between each species/preservative system combination.

Multiple Range Test Results

The high density heartwood of red oak retains the lowest volumes of treating solutions, while low density cottonwood sapwood retains the highest. Yellow poplar and southern pine, being intermediate in densities, are also intermediate in volumes of treating solutions retained. In all species, there is a clear trend from highest volume of solution retained to lowest as follows: SDDC, cupric hydroxide, propiconazole, copper citrate 2:1, ACQ-C, CCA, RH287, copper-8 quinolinolate, chlorothalonil, tebuconazole, copper naphthenate, and creosote. In all but the red oak stakes, there is a fair to very well defined drop in volumes retained going from aqueous to organic solutions.

Red oak is certainly the most variable in the volume of treating solutions retained, which is no doubt the result of varying proportions of early and latewood and varying extractives contents between specimens. The other three

Table 1. Results from Evaluation of Various Wood Preservatives in Selected Wood Species Using a Soil Bed (Fungus Cellar)

Treatment	Wood Species	Target Ret'n	Actual Ave. Ret'n	Ave. Ratings (Months) 3	6	9	12	15	18	21	24
ACQ	Southern Pine	0.40	0.39	10.0	10.0	10.0	10.0	10.0	10.0		
	Red Oak	0.40	0.36	10.0	10.0	9.9	9.9	9.4	9.3		
	Yellow Poplar	0.40	0.43	10.0	10.0	10.0	10.0	9.7	9.9		
	Cottonwood	0.40	0.39	10.0	9.9	9.9	9.9	9.6	9.9		
Copper Citrate 2:1	Southern Pine	0.40	0.38	10.0	10.0	10.0	10.0	10.0	9.6	10.0	9.9
	Red Oak	0.40	0.38	10.0	10.0	10.0	9.9	9.9	9.1	9.5	9.2
	Yellow Poplar	0.40	0.4	10.0	10.0	9.9	9.8	9.6	8.9	9.7	9.5
	Cottonwood	0.40	0.4	10.0	10.0	10.0	9.8	9.8	8.7	9.3	9.1
CDDC - Cupric Hydroxide/ Na Dimethyldithiocarbamate	Southern Pine	0.20 / 0.96	0.16 / 0.90	10.0	10.0	10.0	10.0	9.8	9.6		
	Red Oak		0.2 / 0.98	10.0	9.8	9.7	9.7	8.4	6.8		
	Yellow Poplar		0.21 / 0.99	10.0	9.5	9.1	9.0	7.9	6.5		
	Cottonwood		0.19 / 0.93	10.0	9.6	9.5	9.5	8.6	7.2		
Copper-8-Quinolinolate	Southern Pine	0.30	0.29	10.0	10.0	10.0	10.0	9.9	9.0		
	Red Oak		0.19	10.0	10.0	10.0	10.0	9.8	8.4		
	Yellow Poplar		0.32	10.0	10.0	10.0	10.0	10.0	9.0		
	Cottonwood		0.28	10.0	10.0	10.0	10.0	10.0	8.5		
Tebuconazole / CPF / P9 Oil	Southern Pine	0.06 / 0.0175 / 7.0	0.061 / 0.0204 / 8.2	10.0	10.0	10.0	10.0	9.1	8.9		
	Red Oak		0.070 / 0.0212 / 8.0	10.0	10.0	10.0	10.0	9.1	8.8		
	Yellow Poplar		0.064 / 0.0172 / 6.9	10.0	9.9	9.9	9.9	8.9	8.2		
	Cottonwood		0.072 / 0.0208 / 8.4	10.0	9.8	9.5	9.7	8.8	8.4		
RH287	Southern Pine	0.06	0.058	10.0	10.0	9.5	9.1	8.7	9.1	8.0	
	Red Oak		0.064	10.0	10.0	9.2	8.7	8.3	8.3	7.0	
	Yellow Poplar		0.064	10.0	8.1	5.9	4.0	1.2	0.9	0.7	
	Cottonwood		0.063	10.0	9.2	7.8	6.2	3.7	3.4	2.2	
Propiconazole / Pyrethroid	Southern Pine	0.06 / 0.03	0.054 / 0.027	10.0	9.6	9.0	8.8	8.7	9.2	8.6	
	Red Oak.		0.046 / 0.022	10.0	9.8	8.7	8.3	8.4	8.0	7.7	
	Yellow Poplar		0.071 / 0.030	10.0	8.9	8.0	7.4	6.5	5.6	3.6	
	Cottonwood		0.057 / 0.028	10.0	8.9	7.9	6.7	5.3	5.1	3.8	
CTL / CPF / P9 Oil	Southern Pine	0.30 / 0.0175 / 7.0	0.32 / 0.0118 / 7.4	10.0	10.0	10.0	10.0	9.5	9.2		
	Red Oak		0.34 / 0.0202 / 7.9	10.0	10.0	10.0	10.0	9.2	9.2		
	Yellow Poplar		0.33 / 0.0124 / 7.8	10.0	10.0	9.4	9.4	9.0	9.0		
	Cottonwood		0.33 / 0.0179 / 7.6	10.0	10.0	9.4	9.4	9.1	8.6		
Copper Naphthenate / P9 Oil	Southern Pine	0.06 / 7.0	0.053 / 6.0	10.0	10.0	10.0	10.0			9.2	
	Red Oak		0.053 / 6.2	10.0	10.0	10.0	10.0			9.3	
	Yellow Poplar		0.066 / 6.8	10.0	10.0	10.0	9.9			9.1	
	Cottonwood		0.056 / 6.6	10.0	10.0	10.0	10.0			9.1	
CCA	Southern Pine	0.40	0.37	10.0	10.0	10.0	10.0	10.0	9.7	10.0	10.0
	Red Oak		0.37	10.0	10.0	10.0	9.6	9.4	8.6	8.5	8.2
	Yellow Poplar		0.39	10.0	10.0	9.8	9.0	8.1	6.8	5.8	5.3
	Cottonwood		0.39	10.0	10.0	9.6	9.2	8.5	7.6	6.7	5.9
Creosote	Southern Pine	10.0	8.1	10.0	10.0	10.0	10.0			9.7	
	Red Oak		11.5	10.0	10.0	10.0	10.0			9.9	
	Yellow Poplar		9.2	10.0	10.0	10.0	10.0			9.2	
	Cottonwood		10.7	10.0	10.0	10.0	10.0			9.6	
Untreated	Southern Pine	-----	-----	10.0	9.4	8.4	7.6	6.4	7.1	6.4	
	Red Oak		-----	10.0	9.5	8.6	7.5	6.3	6.1	5.5	
	Yellow Poplar		-----	8.7	6.8	3.8	1.1	0.8	0.2	0.0	
	Cottonwood		-----	9.0	6.8	4.0	2.1	0.8	1.5	0.7	

Table 2. **Results from evaluation of various wood preservatives in selected wood species by exposure to *Coptotermes formosanus* in a field site near Hilo, Hawaii.**

Treatment	Target Retn (pcf)	Wood Species	Calc Retn (pcf)	6 Months* Decay	6 Months* Termite	12 Months* Decay	12 Months* Termite	18 Months* Decay	18 Months* Termite
ACQ	0.40	Pine	0.43	10	10	10	10	10	10
		Oak	0.39	10	10	10	9.9	10	9.9
		Yellow Poplar	0.53	10	10	10	10	10	10
		Cottonwood	0.40	10	10	10	10	10	10
Cu-Citrate	0.40	Pine	0.40	10	10	10	10	10	10
		Oak	0.38	10	9.9	10	9.8	10	9.8
		Yellow Poplar	0.47	10	10	10	10	10	10
		Cottonwood	0.42	10	10	10	10	10	10
CDDC - Cupric Hydroxide/ Na Dimethyldithiocarbamate	0.20/0.96	Pine	0.17/0.95	10	10	10	10	10	10
		Oak	0.18/0.73	10	10	10	10	10	10
		Yellow Poplar	0.23/1.11	10	10	10	10	10	10
		Cottonwood	0.21/1.00	10	10	10	10	10	10
Cu-8	0.30	Pine	0.24	10	10	10	10	10	10
		Oak	0.22	10	10	10	10	10	10
		Yellow Poplar	0.30	10	10	10	10	10	10
		Cottonwood	0.27	10	10	10	10	10	10
Tebuconazole/CPF**	0.06/0.0175	Pine	0.047/0.0133	10	10	10	10	10	10
		Oak	0.064/0.0187	10	10	10	10	10	10
		Yellow Poplar	0.061/0.0170	10	10	10	10	10	10
		Cottonwood	0.079/0.0228	10	10	10	9	10	10
RH287	0.06	Pine	0.051	10	10	10	10	10	10
		Oak	0.064	10	10	10	9.9	10	10
		Yellow Poplar	0.062	10	10	10	10	10	10
		Cottonwood	0.064	10	10	10	7.6	9.0	7.6
Propiconazole/ Pyrethroid	0.06/0.03	Pine	0.060/0/028	10	10	10	10	10	10
		Oak	0.052/0.026	10	10	10	10	10	10
		Yellow Poplar	0.073/0.031	10	10	10	10	10	10
		Cottonwood	0.061/0/030	10	10	10	10	10	10
CTL/ CPF**	0.30/0.0175	Pine	0.26/0.0095	10	10	10	10	10	10
		Oak	0.34/0.0123	10	10	10	10	10	10
		Yellow Poplar	0.30/0.0112	10	10	10	10	10	10
		Cottonwood	0.35/0.0125	10	10	10	10	10	10
CuNaphthenate**	0.06***	Pine	0.055	10	10	10	10	10	10
		Oak	0.054	10	10	10	10	10	10
		Yellow Poplar	0.065	10	10	10	10	10	10
		Cottonwood	0.056	10	10	10	10	10	10
CCA	0.40	Pine	0.358	10	10	10	10	10	10
		Oak	0.362	10	10	10	10	10	10
		Yellow Poplar	0.427	10	10	10	10	10	10
		Cottonwood	0.395	10	10	10	10	10	10
Creosote	10.0	Pine	8.19	10	10	10	10	10	10
		Oak	11.30	10	10	10	10	10	10
		Yellow Poplar	9.67	10	10	10	10	10	10
		Cottonwood	11.5 0	10	10	10	10	10	10
Untreated	-----	Pine	-----	10	7.9	10	6.0	10	6.4
		Oak	-----	10	8.8	10	7.9	10	8.2
		Yellow Poplar	-----	10	7.9	9.0	6.2	8.9	6.0
		Cottonwood	-----	10	7.7	8.9	2.9	5.6	3.6

* Average ratings of 10 blocks; 10 indicates sound, 0 indicates failure.
** P9 oil retention = 7 pcf.
*** Retention of Copper only.

species are similar in the range of coefficients of variation, however there is no clear distinction between aqueous and organic solutions, though yellow poplar and cottonwood both follow the same trend.

Preservative Efficacy

Field termite testing is still in its early stages and few conclusions can be drawn yet. From soil bed testing, some of the preservative systems are performing well at the test retention in all the wood species tested. These are ACQ, creosote, and copper citrate 2:1 at target retentions of 0.40, 10.0, and 0.40 pcf, respectively.

Overall Conclusions

A long service life and biological decay resistance throughout the entire structure of a timber bridge are very important considerations. While field and laboratory decay tests will show which species and preservative systems are most appropriate for this application, this study has provided some information which will be useful in predicting consistency of decay performance within an individual bridge structure or between several bridges constructed of the same species and preservative.

In terms of the volumes of treating solutions required to treat a given volume of a species, it is clear that density is an important factor. As expected red oak retained significantly lower volumes of treating solutions than yellow-poplar or cottonwood. Southern pine, yellow-poplar and cottonwood had varying amounts of overlap, and fewer significant differences. Therefore, if lower amounts of treating solutions would be advantageous in the manufacture of the treated timber, red oak would be the best choice. However, this study showed that red oak is significantly more variable in retaining several preservative systems than cottonwood. All other comparisons between species are insignificant. Considering that treatments are most variable in red oak would make a less appealing choice in terms of consistency of decay performance.

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