Short- and long-term ground-contact decay efficacies of three copper-organic systems and possible implications for standardization criteria for copper-based systems

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Abstract

The major wood preservative systems for residential applications in North America are the second-generation copper-organic systems, which contain relatively high levels of copper and an organic cobiocide to control copper-tolerant fungi. The objective of this paper is to address concerns about the standardization criteria for new or modified systems including the relevance of laboratory efficacy data, field testing duration, whether the field test sites should incorporate one plot with the presence of copper-tolerant fungi for testing ground-contact systems, and to consider not only average ratings but also the number of stakes with ratings at or below a threshold efficacy value. In this study, three promising copper-based systems that had been selected from a large number of candidates based on standard laboratory tests were used to treat three sets of southern pine field stakes. Two of the sets were small research size stakes. One research set was installed at Dorman, Mississippi, where copper-tolerant fungi are present, and the other was installed at Saucier, Mississippi, which has little previous indication of copper-tolerant fungi. The third set consisted of nominal 2 by 4s that were installed at Dorman. All three sets were treated with the same formulations. Stakes were inspected after 39 months of exposure, and the 2 by 4 Dorman and the Saucier research sets were reinspected after about 17 years of exposure. The results showed that: 1) good laboratory efficacy employing standard tests and fungi does not ensure good field efficacy; 2) results from 39 months of field exposure with research size stakes do not correlate well with decay ratings of 2 by 4s at 39 or 210 months of exposure; 3) fungal deterioration occurs faster at the site with copper-tolerant fungi, with decay randomly attacking individual stakes within one copper treatment so that some stakes performed poorly and others remained in very good-to-excellent condition; 4) efficacy results from different tests sites are not necessarily comparable; and 5) both average efficacy ratings and the number of stakes with efficacy ratings at or below a threshold value should be considered. Implications of the results with the current criteria for standardizing new copper-based systems are also discussed.

Wood products are used extensively in applications where they can be biodegraded by various fungi, insects such as termites, and marine organisms. To prevent this biodegradation, most wood products for exterior use are treated with a biocidal preservative system. Wood preservation has undergone recent dramatic changes worldwide due to environmental and disposal concerns and governmental regulation (Preston 2003, Schultz et al. 2007). In North America the major residential preservatives are copper-rich systems, where copper(II) is combined with an organic cobiocide to control copper-tolerant fungi (Kamdem 2008, Freeman 2008). The two major commercial systems are copper quat and copper azole, with several formulations of each available.

The standardization or accreditation process for new or modified systems involves developing a comprehensive data packet with laboratory and field efficacy and depletion data, formulation, analytical procedures, environmental and health aspects, and proposed applications, that is submitted to the accrediting agency. This process is designed to ensure that

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the consumer receives a dependable and safe product. In the United States, most wood preservatives are standardized by the American Wood Protection Association (AWPA) or the International Code Council (ICC) (McIntyre 2008).

Some professionals are concerned about the adequacy of the process, with formal and informal discussions taking place. This includes the relevancy of laboratory efficacy tests to outdoor "real-world" field results, the field exposure duration necessary with small research stakes to ensure good performance during the long service life expected by consumers from commercial-size treated wood (Lebow et al. 2008), and if field trials for copper-organic ground-contact systems should be run at sites with copper-tolerant fungi. About 20 years ago, extensive laboratory studies were initiated on a number of copper-organic systems employing common laboratory efficacy tests (Nicholas and Sites 1995, Helmer 2008), and three promising candidates were identified. These three systems were subsequently employed to treat southern pine (SP) research size stakes which were installed at the Dorman, Mississippi, and Saucier, Mississippi, test sites, with copper-tolerant decay fungi known to be present at Dorman. Additionally, a set of larger SP 2 by 4 nominal stakes were treated and installed at Dorman. All of the stakes were treated with the same formulations for the three systems. This paper reports the average decay ratings for all three sets at 39 months and the long-term decay ratings for the 2 by 4s and the Saucier research sets after about 17 years of exposure.

The objectives were to:

1. determine field decay efficacy of the three systems that were selected based on promising laboratory tests,
2. compare the average 39 months' fungal ratings for the research size stakes at the two sites, one of which has copper-tolerant fungi, and
3. compare the ratings at about 3 years of exposure for the Dorman research size stakes to short- and long-term performance for commercial-sized material installed in an adjacent plot.

Methods

The three systems were initially selected following agar plate synergism (Schultz and Nicholas 1995) screening, soil block AWPA E10 tests which employed the supposedly copper-tolerant fungus *Postia* spp. and other decay fungi, and fungus cellar AWPA E14 tests for soft-rot efficacy (Nicholas and Sites 1995) which included depletion samples. The latter two laboratory screening tests are commonly employed in the initial laboratory screening of potential commercial systems (Helmer 2008). The three soluble copper(II) systems that showed promise were copper plus benzoic acid, copper plus naphthenic acid, and copper plus relatively small amounts of the azole (or triazole) propiconazole. The latter system is similar to current commercial copper azole (CA) systems except that ammoniacal copper sulfate was used in the experimental formulation and the azole employed commercially is either tebuconazole or a propiconazole/tebuconazole mixture. The copper plus naphthenic acid formulation was intended to result in the *in-situ* formation of copper naphthenate (not confirmed by chemical analysis), but generally employed much higher copper levels than the commercial waterborne copper naphthenate system. Even though there are similarities in the actives between the latter two research formulations and current commercial systems, results from these systems should not be directly compared to the commercial systems due to formulation differences. For example, all of the systems were formulated using copper sulfate and later studies showed increased copper depletion with copper sulfate than copper carbonate.

Field testing consisted of two sets of research size stakes 19 by 19 by 457 mm (0.75 by 0.75 by 18 in.) and one set of nominal 2 by 4 by 18 inch/457 mm stakes, all cut from defect-free SP sapwood. All of the samples were treated with the same formulations by a full-cell process, with the retentions based on weight gain and the copper retention based on copper as metal. The water-based formulation for the copper/benzoic acid and copper/azole treatments consisted of copper sulfate plus benzoic acid or propiconazole with ammonia and sufficient acetone to dissolve the organic biocide. The copper sulfate plus naphthenic acid waterborne formulation contained ammonia plus small amounts of propylene glycol.

Two sets of research size stakes were installed at the Dorman, Mississippi, and Saucier, Mississippi, test sites, with 10 replicate stakes per treatment at each location. One set of nominal 2 by 4 stakes were installed adjacent to the research size stakes at Dorman. The Dorman plot is located in northeast Mississippi, has an acidic heavy clay soil that is poorly drained, and is in a high (AWPA 4) deterioration zone. Copper-tolerant decay fungi are sporadically present (Schultz et al. 2000). The Saucier plot is located in the Harrison National Forest near the Gulf Coast, has an acidic sandy loam soil that is well drained, and is classified as a severe (AWPA Zone 5) deterioration zone. Copper-tolerant fungi are known to exist near this area but this specific plot has much lower prevalence than at Dorman (Schultz et al. 2000, Lebow et al. 2003). The stakes were annually inspected up to 3 years, based on an earlier AWPA E7 10, 9, 8, 7, 6, 4, and 0 rating system where 10 is no attack, 9 is a trace to 3 percent, etc.; the "6" rating was employed a few years prior to it being adapted by the AWPA. The 2 by 4 Dorman and Saucier research stakes were reinspected after about 17 years of exposure. Unfortunately, the Dorman research stakes were pulled at about 15 years to make room for another study but only about 200 of the initial approximately 700 stakes were saved. The area was scanned several times with a metal detector and an additional approximately 100 stakes that failed were identified. Due to the large number of missing stakes, however, the long-term data from this set were not used. Also, intermediate ratings were not conducted on the three sets. Only the decay ratings are given in this paper as minimal termite attack generally occurred.

Results and discussion

Table 1 shows the treatments, average retentions for the nominal 2 by 4 stakes, average decay ratings, and the number of stakes that had an efficacy rating of "7" or less at 39 months for all stakes (an AWPA rating or "7" or less is generally considered as cause for concern), and the decay ratings at 212 months for the Saucier research size stakes and at 210 months for the Dorman 2 by 4 stakes. Since all of the stakes were treated with the same formulation, only the retentions for the 2 by 4 stakes are shown.

Laboratory vs. outdoor ground-contact efficacy

As previously mentioned, all three systems were selected from a large list of candidates following extensive laboratory

Table 1. — Treatment, average retentions, and average decay efficacies, with the number of stakes with an AWPA rating of "7" or less after 39 months of exposure given in parentheses adjacent to the average ratings. Each average is based on 10 replicate stakes, and the retentions are for the 2 by 4 stakes.

	Retention (kgm^{-3})		19 mm by 19 mm stakes			2 by 4 stakes	
			Dorman	Saucier	Saucier	Dorman	Dorman
Treatment (%a.i.)[a]	Cu	Additive	39 months	39 months	212 months	39 months	210 months
0.25% Cu	1.6	0.0	7.6 (3)	9.2 (0)	0.7	8.6 (2)	0.8
0.50% Cu	3.0	0.0	8.0 (2)	9.9 (0)	5.1	8.9 (1)	2.3
1.0% Cu	5.9	0.0	10.0 (0)	10.0 (0)	9.3	10.0 (0)	4.3
1.5% Cu	9.6	0.0	9.0 (1)	10.0 (0)	8.8	10.0 (0)	5.3
0.5% BA	0.0	3.0	1.6 (8)	0.0 (10)	0	0.6 (10)	0
1% BA	0.0	6.4	0.0 (10)	0.0 (10)	0	2.2 (10)	0
2% BA	0.0	12.5	1.2 (9)	0.0 (10)	0	1.7 (10)	0
3% BA	0.0	17.3	1.8 (8)	0.0 (10)	0	2.4 (9)	0
0.25% Cu/0.25% BA	1.4	1.4	7.6 (2)	8.0 (2)	2.3	8.6 (2)	3.5
0.5% Cu/0.25% BA	2.9	1.4	9.9 (0)	9.3 (0)	8.6	9.4 (1)	7.0
1.0% Cu/0.25% BA	6.2	1.6	10.0 (0)	10.0 (0)	8.3	10.0 (0)	6.1
0.25% Cu/0.5% BA	1.6	3.0	8.7 (2)	8.8 (3)	3.0	9.4 (1)	1.7
0.5% Cu/0.5% BA	3.2	3.2	7.0 (3)	8.9 (1)	5.1	9.8 (0)	3.9
1.0% Cu/0.5% BA	6.6	3.4	8.4 (2)	10.0 (0)	9.7	10.0 (0)	6.2
0.25% Cu/1% BA	1.4	5.6	4.9 (5)	7.6 (4)	1.0	7.8 (3)	0.8
0.5% Cu/1% BA	2.7	5.4	9.0 (1)	9.7 (0)	6.3	10.0 (0)	7.9
1.0% Cu/1% BA	5.8	5.8	9.0 (1)	10.0 (0)	6.9	9.0 (1)	4.3
0.25% Cu/2% BA	1.4	11.1	7.9 (2)	7.4 (3)	0	7.6 (3)	0
0.5% Cu/2% BA	2.7	11.2	8.5 (2)	9.5 (1)	4.6	9.8 (0)	4.1
1.0% Cu/2% BA	5.3	10.7	9.9 (0)	9.9 (0)	8.4	10.0 (0)	3.8
0.5% NA	0.0	3.2	2.1 (8)	0.0 (10)	0	3.9 (9)	0
1.0% NA	0.0	6.2	2.8 (7)	0.8 (10)	0	4.5 (8)	0.4
2.0% NA	0.0	11.9	6.7 (4)	5.5 (6)	0	8.3 (1)	0
3.0% NA	0.0	17.8	8.3 (2)	5.7 (7)	0	8.4 (0)	0
4.0% NA	0.0	25.2	8.7 (1)	6.2 (5)	0	8.8 (0)	0
0.25% Cu/1% NA	1.6	6.6	7.2 (4)	10.0 (0)	4.9	9.4 (1)	2.0
0.5% Cu/1% NA	3.2	6.4	8.8 (1)	10.0 (0)	8.4	9.3 (0)	4.9
1% Cu/1% NA	6.2	6.2	10.0 (0)	10.0 (0)	9.7	10.0 (0)	7.0
0.25% Cu/2% NA	1.6	12.5	9.8 (0)	10.0 (0)	4.6	9.9 (0)	4.7
0.5% Cu/2% NA	3.2	12.5	9.8 (0)	10.0 (0)	8.6	10.0 (0)	6.7
1% Cu/2% NA	6.2	12.3	9.9 (0)	10.0 (0)	8.9	9.6 (0)	5.4
0.25% Cu/3% NA	1.6	19.2	9.9 (0)	10.0 (0)	6.5	9.8 (0)	3.4
0.5% Cu/3% NA	3.0	18.4	9.3 (0)	10.0 (0)	8.4	9.8 (0)	6.2
1% Cu/3% NA	6.4	19.2	10.0 (0)	10.0 (0)	8.6	10.0 (0)	6.9
0.25% Cu/4% NA	1.6	24.4	10.0 (0)	10.0 (0)	5.7	9.5 (1)	3.7
0.5% Cu/4% NA	3.2	25.3	9.7 (0)	10.0 (0)	9.7	10.0 (0)	3.5
1% Cu/4% NA	6.6	26.4	10.0 (0)	10.0 (0)	9.2	10.0 (0)	8.8
0.01% Prop	0.0	0.1	1.9 (8)	0.8 (9)	0	6.8 (3)	0
0.05% Prop	0.0	0.3	5.9 (5)	1.3 (9)	0	8.7 (0)	0.4
0.1% Prop	0.0	0.6	7.0 (3)	3.8 (5)	0	7.8 (1)	0
0.25% Cu/0.01% Prop	1.6	0.1	9.8 (0)	9.9 (0)	0	9.9 (0)	2.3
0.5% Cu/0.01% Prop	2.9	0.1	9.0 (1)	9.0 (1)	4.7	9.7 (0)	6.4
1% Cu/0.01% Prop	5.9	0.1	9.8 (0)	10.0 (0)	4.9	9.8 (0)	8.2
0.25% Cu/0.05% Prop	1.6	0.3	9.9 (0)	9.0 (1)	0	10.0 (0)	8.3
0.5% Cu/0.05% Prop	3.0	0.3	9.4 (1)	10.0 (0)	5.5	10.0 (0)	5.5
1% Cu/0.05% Prop	6.2	0.3	10.0 (0)	9.0 (1)	9.2	10.0 (0)	8.9
0.25% Cu/0.1% Prop	1.6	0.6	9.6 (1)	10.0 (0)	0	10.0 (0)	5.9
0.5% Cu/0.1% Prop	2.7	0.6	9.9 (0)	10.0 (0)	5.3	10.0 (0)	6.4
1% Cu/0.1% Prop	6.6	0.6	10.0 (0)	10.0 (0)	7.8	10.0 (0)	9.3

(*Continued*)

Table 1. — (*Continued*)

Treatment (%a.i.)[a]	Retention (kgm^{-3})		19 mm by 19 mm stakes			2 by 4 stakes	
	Cu	Additive	Dorman 39 months	Saucier 39 months	Saucier 212 months	Dorman 39 months	Dorman 210 months
0.25% Cu/0.01% Prop	1.3	0.1	10.0 (0)	6.2 (4)	2.8	9.7 (0)	1.1
0.5% Cu/0.01% Prop	2.6	0.1	7.9 (2)	9.2 (1)	4.7	9.3 (1)	2.3
1% Cu/0.01% Prop	4.6	0.1	10.0 (0)	10.0 (0)	8.8	10.0 (0)	4.5
0.25% Cu/0.05% Prop	1.3	0.3	9.5 (1)	9.9 (0)	4.4	9.7 (1)	2.8
0.5% Cu/0.05% Prop	2.6	0.3	8.9 (1)	10.0 (0)	7.6	10.0 (0)	5.8
1% Cu/0.05% Prop	4.5	0.3	9.3 (1)	10.0 (0)	8.3	10.0 (0)	8.0
0.25% Cu/0.1% Prop	1.3	0.6	10.0 (0)	9.8 (0)	7.7	9.8 (0)	1.8
0.5% Cu/0.1% Prop	3.0	0.6	9.8 (0)	10.0 (0)	9.1	10.0 (0)	9.2
1% Cu/0.1% Prop	5.4	0.6	10.0 (0)	10.0 (0)	9.3	10.0 (0)	6.9

[a] BA = benzoic acid; NA = naphthenic acid; and Prop = Propiconazole.

efficacy studies employing agar plate, soil block, and fungus cellar tests. Despite the extensive initial screening employing standard tests and fungi to select promising systems, the copper/benzoic acid system performed very poorly at both field test locations (**Table 1**). Specifically, a number of failures were noted after only 39 months at Dorman and a few failures also occurred at Saucier. The other two systems, copper/naphthenatic acid and copper/propiconazole which have similarities to current commercial systems, performed better.

The poor prediction of the laboratory efficacies to field trials for the one system, especially in the plot with copper-tolerant fungi, may be partially caused by many strains of the copper-tolerant *Postia placenta* fungus typically employed in laboratory tests having relatively poor copper tolerance. *P. placenta* (Fries) M. Larsen et Lombard is listed as one of two standard brown-rot fungi in laboratory soil block (AWPA E10 and E22) tests. Alternatively, the standard laboratory soil-block test employs sterilized soil and, therefore, does not have the microorganisms, such as bacteria and mold fungi, which are in a field site and can slowly detoxify an organic cobiocide.

Decay rates at Dorman Lake vs. Saucier in research stakes

More rapid or equivalent decay and a greater number of stakes with efficacy ratings of "7" or lower generally occurred at Dorman than Saucier. This is likely due to the presence of copper-tolerant fungi at Dorman. By contrast, for treatments which only employed the organics naphthenic acid or propiconazole, more decay occurred at Saucier, which is in a higher AWPA deterioration zone than Dorman. Prior work has shown that when matched stakes treated with one of several different systems were installed at five different sites, the relative efficacy of the systems varied. For example, a sodium pentachlorophenate formulation was the most effective preservative in the harsh climate of Panama but was least effective in the relatively mild climate at Madison, Wisconsin (Lebow and Highley 2008). Thus, it is apparent that ground-contact results obtained from one site are not necessarily comparable to results from another site.

The distribution of individual stakes' decay ratings within one treatment for many copper systems at Dorman were bimodal, with some stakes showing extensive decay while others performed very well-to-excellent. For example, with the 0.25 percent copper and 1 percent benzoic acid treatment after 39 months of exposure, the average decay rating at Dorman was 7.9 with two failures, one "9" and the rest "10s." Since the consumer is concerned as much or more about the percent of premature failures than the average service life, both average decay ratings and the number of stakes at or below a threshold efficacy ratings should be considered during standardization.

Decay rates of research vs. 2 by 4 stakes at Dorman Lake at 39 months of exposure

In comparing the ratings of the small research-sized vs. 2 by 4 stakes at Dorman, installed in adjacent plots, it was obvious that the smaller stakes generally decayed faster. But, when the results were plotted separately for each of the three systems with copper, little correlation was visually observed. Further, a linear regression of the 39 months' average decay ratings of the small vs. larger stakes for each of the three systems always gave a poor correlation that explained less than 50 percent of the variation. Much of this "weak" correlation for each system was due to the poorest-performing treatment with the lowest biocide retention. When this one aspect of the poorest performing treatment was removed, as there would be little commercial interest in further studying the worse system to develop a new preservative, the correlations for all three systems became even worse due to the one point away from the other "shotgun scatter points" being removed.

Using research stake efficacies at 39 months to predict long-term results with 2 by 4s

The 2008 AWPA Book of Standards, Standard E7 section 11.4, states that "The data generated by 3/4 inch (19 mm) stake [research] tests may be used to predict the service life of [commercial] wood treated with the subject preservative." To test this, the average decay ratings at 39 months for the research stakes at Dorman were compared to the long-term (210 months) ratings of the 2 by 4 stakes (**Fig. 1**). When the results were plotted little linear correlation was observed, with an r^2 always less than 50 percent. Further, as the system became better the correlation became worse, with a correlation of only 5.1 percent obtained with the copper/propiconazole system and 29.5 percent with the copper/naphthenic acid system. It is likely that fungal attack of wood treated with organic/copper systems may involve some initial biodegradation of the organic cobiocide followed by fungal

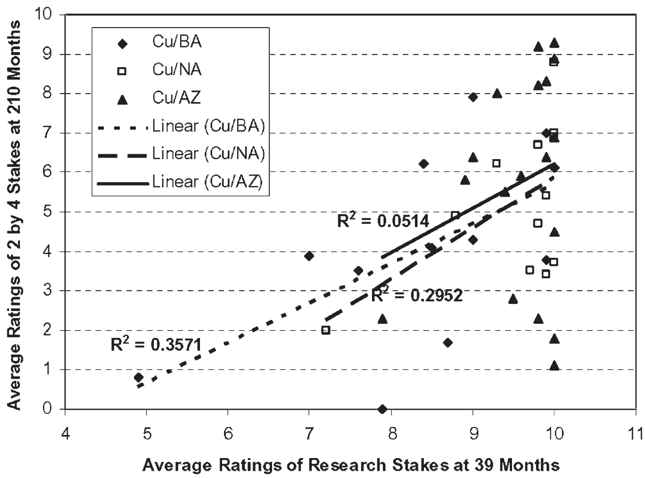

Figure 1. — Regression of the average ratings of the 19 mm research stakes at 39 months of exposure vs. the average ratings of the 2 by 4 stakes after 210 months of exposure, with both sets located adjacent to each other at Dorman.

attack and, thus, a correlation between short- and long-term efficacies, and/or actual service life in commercial applications, may not be linear. Prior research has also reached this conclusion (Morris and Cook 1995, Gobakken et al. 2008). Consequently, the AWPA membership recently voted to remove the service life prediction, section 11.4 in Standard E7.

As a second comparison, all of the treatments that gave excellent average decay ratings of 9.7 or above at both sites for the research stakes were noted. The decay ratings for 2 by 4s treated with these treatments after 210 months of exposure were then examined, with an average rating of 7.0 or above for these commercial-sized stakes considered a positive prediction. Conversely, if the 2 by 4 average ratings was 6.9 or less, the prediction was considered a failure. Based on this, only two copper/benzoic acid treatments were above 9.7 at 39 months for the research size stakes, and both of these treatments gave poor decay results (average ratings of 6.1 and 3.8) in long-term exposure with the 2 by 4 stakes. Results from research-sized stakes treated with copper/naphthenic acid and copper/propiconazole systems proved to be only slightly better at predicting the long-term performance of 2 by 4s by this criteria, with two of nine systems for the former and three of eight systems for the latter. Thus, in all cases excellent field decay efficacy results with small research size stakes at two locations after 39 months of exposure correctly predicted less than half of "successful" treatments (long-term average decay ratings of 7 or greater) for the commercial size 2 by 4 stakes with all three copper-based systems.

The poor correlations are undoubtedly caused by the inherent variation in decay efficacy at Dorman among individual stakes within one treatment. This is likely due to a variety of factors including biocide retention variation among individual stakes within one treatment (Schultz et al. 2004), natural durability variation among different SP sapwood samples (Nicholas et al. 2005), and the effect of the micro site and climate affecting the soil microorganisms that are present. This variation is further compounded due to the sporadic attack on copper-treated stakes mentioned above and by others (Lebow et al. 2003). The authors are doubtful if a "good" correlation is achievable between 3-year results with small research size stakes vs. 10+ years with commercial-sized lumber with copper-treated wood in soil contact where copper-tolerant fungi are present. The authors believe that the best that can be attained with a 3-year exposure period is distinguishing relatively poor performing from good-to-excellent copper-based systems.

Finally, the long-term efficacies of the Saucier research size stakes vs. the Dorman commercial size 2 by 4 stakes were separately compared for each of the three systems. A moderately good correlation (r^2 = 68.4%) was obtained with the poorest system, copper/benzoic acid (**Fig. 1**). The other two systems, however, gave correlations below 50 percent, perhaps due to the different test sites and/or stake sizes. Additionally, significantly different decay ratings were often obtained with the duplicate copper/propiconazole treatments after 17+ years of exposure at Saucier. For example, the two 0.5 percent copper and 0.1 percent propiconazole treatments gave average decay ratings of 5.3 vs. 9.1 after 212 months.

Discussion of results with current standardization criteria

The purpose of the standardization process, to quote the AWPA Technical Committee Regulations, Section 7.2, is "Standards should seek to assure at least that minimum product performance which would reasonably be expected by those considering the product use envisioned by the Standard" (AWPA 2008). To determine fungal efficacy, the AWPA (Appendix A: Data Requirement Guidelines for Listing Wood Preservatives) (AWPA 2008) requires soil-block (E10 or E22) and soft rot (E14) laboratory decay tests. The supposedly copper-tolerant fungus *P. placenta* is listed as one of two standard brown-rot fungi for the soil-block test for softwoods. Further, the AWPA E7 outdoor stake test is to be run at two geographically separated test plots in high decay hazard areas for a minimum of 3 years for a system intended for ground-contact (UC4). ICC criteria (ICC Evaluation Service, Inc., Acceptance Criteria for Proprietary Wood Preservative Systems – Common Requirements for Treatment Process, Test Methods and Performance, AC326, 2008) requires the same laboratory soil-block and soft rot tests and also one or two field tests (with two sites, one site must be an AWPA Decay Hazard Zone 4 or 5) for a minimum of 3 years. Thus, in both cases the initial laboratory and later research field stake tests in this study meet the minimal fungal efficacy requirements for both AWPA and ICC ground-contact standardization.

Based on the results of this study, the authors recommend that standard-setting organizations consider:

1. verifying that the standard copper-tolerant brown-rot fungus, *P. placenta*, employed in the soil block test is a sufficiently rigorous test of copper tolerance;
2. addressing whether copper-tolerant fungi are a significant problem with residential ground-contact applications and, if they are, consider if field tests should be conducted in at least one plot that has copper-tolerant fungi;
3. reporting both the average decay ratings and the number of stakes that are at or below a threshold efficacy value;
4. requiring at least two sites and not emphasizing data from one particular site over another;

5. lengthening the minimal field test duration required; and
6. putting more emphasis on reaffirmation data packages and modifying retention levels based upon this additional data and actual commercial service results.

Conclusions

Based on this ground-contact field study with three copper-based systems, the conclusions from this study are that:

1. good laboratory decay efficacies do not ensure good field efficacy;
2. results after 3 years of exposure on small research size stakes do not accurately predict long-term performance of commercial-sized material and, consequently, it may be worthwhile to require longer duration field trials;
3. decay in small research stakes treated with a copper-organic system and exposed in an area with copper-tolerant fungi may give a bimodal rating distribution; consequently, the average decay ratings and the number of stakes that performed below a threshold efficacy value should be reported; and
4. decay in small research stakes appears to be at least partially a random attack and, thus, results need to be viewed skeptically and not employed to predict service life of commercial lumber.

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