HYGROSCOPICITY OF DECAYED WOOD: IMPLICATIONS FOR WEIGHT LOSS DETERMINATIONS

Susan E. Anagnost
Senior Research Scientist

and

William B. Smith
Associate Professor

Wood Products Engineering
SUNY College of Environmental Science and Forestry
One Forestry Drive
Syracuse, New York 13210

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ABSTRACT

Hygroscopicity changes were observed in red maple blocks subjected to brown rot, white rot, and soft rot. Brown rot reduced hygroscopicity, soft rot increased hygroscopicity, and white rot showed no change in hygroscopicity. The effect of these changes on weight loss tests when using moisture-conditioned block weights is a slight overestimation of weight loss for brown rot, a slight underestimation for soft rot, and no apparent change for white rot. When comparing changes in hygroscopicity prior to oven-drying with those observed after oven-drying, there were no differences for white rot and soft rot, while for brown rot, the reduction in hygroscopicity was enhanced by oven-drying.

Keywords: Hygroscopicity, wood decay, brown rot, white rot, soft rot, weight loss.

INTRODUCTION

The most common method for assessing wood decay is the weight loss test. Weight loss is used to measure natural durability (ASTM 1981), fungal decay capability and decay rates, preservative effectiveness, and as an index for related strength loss. The basic test [((weight before-weight after)/weight before)*100%] (Cartwright and Findlay 1946), is confounded by several variables: wood density (Butcher and Nilsson 1982) (Nilsson and Daniel 1992), weight of fungal hyphae (Jones and Worrall 1995), and hygroscopicity (Cowling 1961; Zabel and Morrell 1992). Either decay potential (% weight loss·original density) (Butcher and Nilsson 1982) or decay susceptibility ((weight before-weight after)/original volume) better compare woods of varying densities, such as for comparing wood species for natural durability. The weight of fungal hyphae was shown to cause an underestimate of the actual mass of wood substance lost (Jones and Worrall 1995). Hyphal mass accounted for varying amounts of the total weight loss depending on decay type and wood type.

The moisture-holding capacity of wood changes with decay (Cowling 1961). For weight loss methods using blocks conditioned to specified relative humidity (RH) conditions prior to and after decay (as opposed to oven-drying), such as ASTM D-2017, changes in hygroscopicity may cause different results than those obtained with blocks oven-dried prior to and after decay (Zabel and Morrell 1992). The magnitude of such differences has not been determined.

Different capacities to adsorb moisture are the result of unequal losses of, or changes in accessibility to, hygroscopic and hydrophobic cell-wall components during decay (Cowling

1961). Cell-wall components in order of decreasing hygroscopicity are hemicelluloses, cellulose, and lignin (Christensen and Kelsey 1959). Hygroscopicity of holocellulose in wood is influenced by its components; amorphous cellulose is responsible for much of the moisture adsorption while crystalline cellulose is much less hygroscopic (Cowling 1961). Cowling (1961) indicated that for sweetgum sapwood, brown rot decreased hygroscopicity beginning at low weight losses, while white rot caused an increased hygroscopicity only at high (>40%) weight loss. When weighing blocks in a conditioned state (as opposed to oven-dry), the amount of conditioned weight composed of the moisture lost or gained due to the relative loss or gain of a particular component may result in a higher or lower weight loss determination than the actual amount of cell-wall component lost. This effect is probably not critical for simultaneous white rot below about 40% weight loss, based on the results of Cowling (1961), but may be critical at higher weight losses. For brown rot the decrease in moisture-holding capacity could result in significant overestimation of weight loss. Changes in hygroscopicity for soft rot have not been studied.

Objectives of this study were to examine the effects of changes in hygroscopicity on weight loss determinations and to evaluate the magnitude of those effects. This study compared the hygroscopicity of brown-rotted, white-rotted, and soft-rotted wood both prior to and after oven-drying. The use of moisture-conditioned block weights to determine weight loss was evaluated in comparison to using oven-dry block weights.

METHODS

Blocks (25 mm (radial) × 10 mm (tangential) × 5 mm (longitudinal)) of red maple (*Acer rubrum* L.), either all heartwood or all sapwood, were previously decayed by two methods: agar-block with sapwood feeder strip supports or agar-block with plastic mesh supports (Anagnost and Smith 1997). The soft-rot fungus, *Chaetomium globosum* Kunze (P-591 C. J. K. Wang, SUNY-ESF), the brown-rot fungus, *Oligoporus placentus* (Fr.) Gilbn. & Ryvarden (ED-19 Wang, SUNY-ESF), and the white-rot fungus *Trametes versicolor* (L.:Fr.) Pilát (P-71, Wang, SUNY-ESF) were provided by C. J. K. Wang at the State University of New York College of Environmental Science and Forestry (SUNY-ESF), Syracuse, New York. The cultures were grown for two weeks on 2% malt extract agar before inoculum plugs were placed in chambers. Eight blocks were exposed per treatment. Blocks were decayed for 2, 4, 6, 8, 12, and 16 weeks.

Conditioned weight losses instead of oven-dry weight losses were utilized. Original block weights and post-decay block weights were obtained at 12% EMC (equilibrium moisture content) condition (35°C, 65% RH), in order to determine any changes in hygroscopicity prior to oven-drying. The blocks were then oven-dried (24 h; 105° C) and weighed. To determine the effects of the different decay types on hygroscopicity after oven-drying, blocks were conditioned stepwise to three relative humidity conditions, 40%, 68%, and 80% in conditioning cabinets and weighed upon equilibration (typically 10 to 14 days). Throughout the test, reference blocks were kept in the conditioning cabinets and weighed frequently to monitor RH conditions. Weights of reference blocks varied ±0.2%. Because pre-decay oven-dry weights were not available, and to compare weight losses of conditioned blocks to estimated oven-dry weight losses, estimated oven-dry weight losses were calculated by estimating original oven-dry weights with the following formula:

$$\text{weight loss (\%)} = \frac{\text{post-decay oven dry weight}}{\text{pre-decay 12\% EMC weight}/(1 + 0.1153)} \qquad (1)$$

where the original oven-dry weight was estimated as pre-decay 12% EMC weight / (1 + 0.1153), and the mean moisture content of the control blocks at 12% EMC was 11.53%. Weight losses of the test blocks were adjusted for the control block weight loss.

A means separation test, the small sample *t*-test, was applied, and 95% confidence intervals were determined to test significant differences in moisture-holding capacity.

RESULTS

Brown-rotted heartwood and sapwood showed significant decreases in hygroscopicity following oven-drying that were increasingly apparent at higher relative humidity conditions (Figs. 1 and 2).[1] White-rotted blocks showed no significant change in hygroscopicity after oven-drying (Figs. 1 and 2) regardless of wood type. Soft-rotted blocks showed a slight, significant increase in hygroscopicity (Figs. 1 and 2). Changes in hygroscopicity were similar for sapwood and heartwood, which corresponds to the similar low decay resistance observed for red maple by Anagnost and Smith (1997). All moisture-conditioned weight losses were significantly different from control (non-decayed) block weight losses (Anagnost and Smith 1997).

[1] For Figures 1 and 2, the letters above the bars indicate significant differences in the means of eight replicate test blocks using the small sample *t*-test. Ninety-five percent confidence intervals were calculated as $x \pm t_{.025}$ where $t_{.025} = 2.365$ (standard deviation)/$\sqrt{8}$.

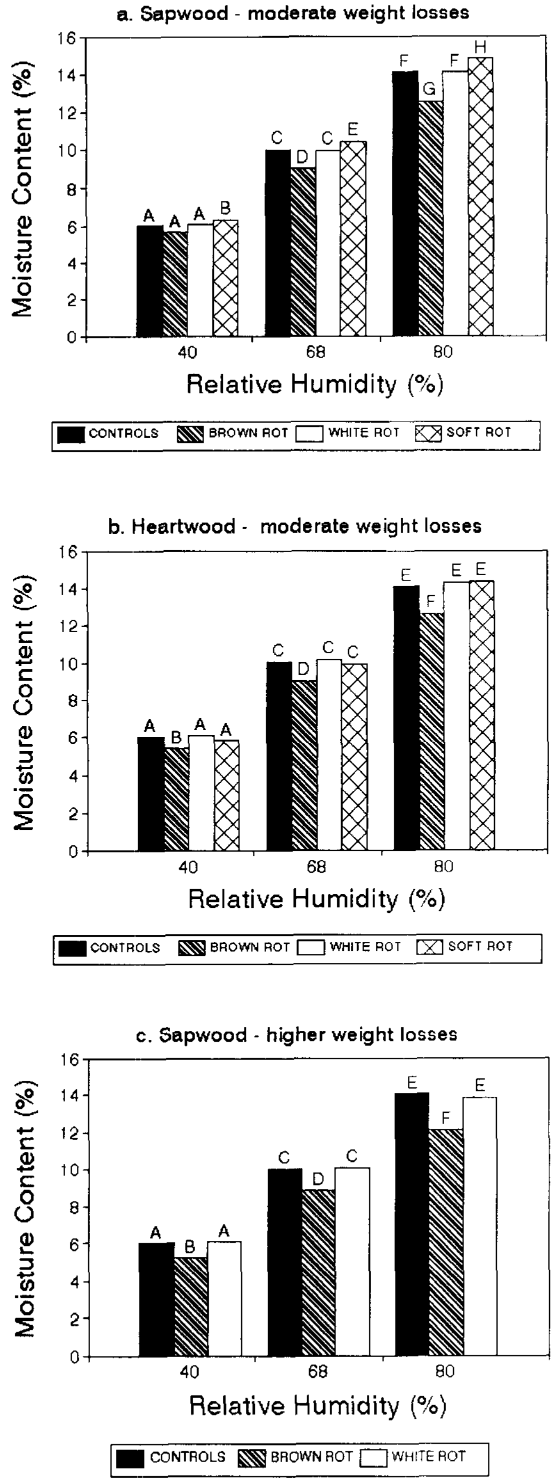

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FIG. 1. Hygroscopicity after oven-drying of brown rot, white rot, and soft rot of maple sapwood (a and c) and heartwood (b) in feeder strip cultures. a. At similar weight losses (brown rot, 12.5%; white rot, 12.8%; and soft rot, 10.5%) with exposure times of 8 weeks, 6 weeks, and 16 weeks, respectively, brown rot showed significant reductions in hygroscopicity. White rot showed no change in hygroscopicity, while soft rot showed a significant increase in hygroscopicity. b. Hygroscopicity of brown rot, white rot, and soft rot of maple heartwood at similar weight losses (5.2%, 5.8%, and 6.8%, respectively) at 12 weeks' exposure. Brown rot showed a significant reduction in hygroscopicity. c. Hygroscopicity of brown rot and white rot at higher, similar weight losses than in Fig. 1 (24.5% and 24.3%). Time of exposure was 16 weeks for brown rot and 8 weeks for white rot. Only brown rot showed any significant difference in hygroscopicity.

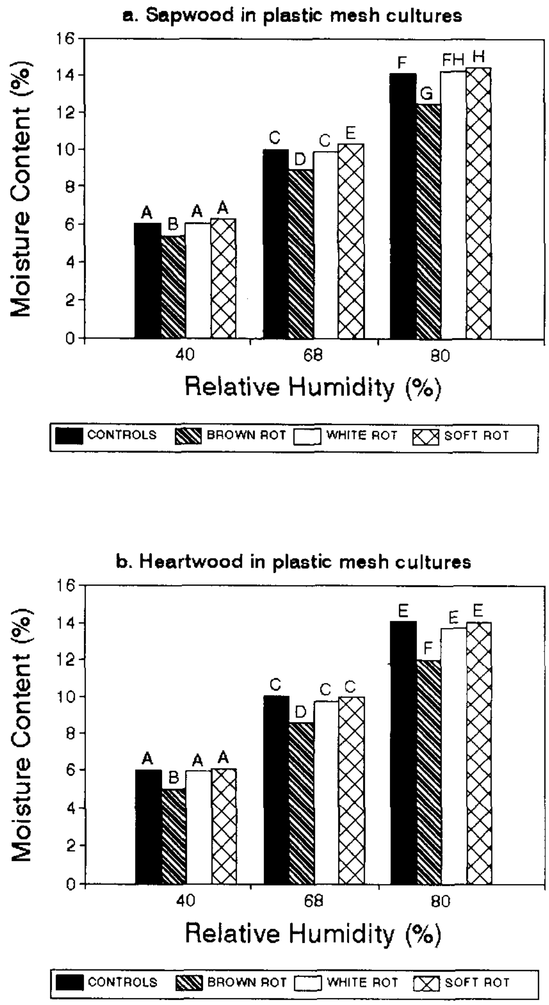

FIG. 2. Hygroscopicity differences for maple sapwood (a) and heartwood (b) decayed in plastic mesh cultures. a. Hygroscopicity of brown rot, white rot, and soft rot of maple sapwood at 16 weeks. At similar weight losses (brown rot, 10.8%; white rot, 8.7%; and soft rot, 8.8%) soft rot showed significant increases in hygroscopicity at 65% and 80% RH. Brown rot showed significant decreases in hygroscopicity at all RH's. White rot showed no change in hygroscopicity. b. Hygroscopicity of brown rot, white rot, and soft rot of maple heartwood at similar weight losses (8.1%, 7.1%, and 7.9%, respectively) at 6, 12, and 16 weeks, respectively. Soft rot and white rot showed no change, while brown rot showed a significant decrease in hygroscopicity.

Prior to oven-drying, the hygroscopicity of blocks subjected to brown rot decreased only slightly (Fig. 3a). After oven-drying, however, the reduction in hygroscopicity from brown rot was of greater magnitude beginning at about 5% weight loss (Fig. 3a). White-rotted blocks showed no significant changes in hygroscopicity before or after oven-drying at up to 44% weight loss (Fig 3b). Soft-rotted sapwood blocks from feeder strip cultures showed similar increases in hygroscopicity both prior to and after oven-drying for weight losses greater than 10% (Fig. 3c).

For brown rot at low weight losses, conditioned weight losses were greater than estimated oven-dry weight losses (Fig. 4a). These differences, however, were not great. For example, at 16% oven-dry weight loss, the conditioned weight loss is 4% greater or 16.6%. At 10% oven-dry weight loss, the conditioned weight loss is 8% greater or 10.8%.

For white rot, below 10% weight loss, conditioned weight losses were slightly lower than oven-dry weight losses (Fig. 4b). For instance, at 7% oven-dry weight loss, the conditioned weight loss was 10% less or 6.5%. At higher weight losses, differences were less. At 42% oven-dry weight, the conditioned weight was 1% less or 41.5%.

Soft rot showed a trend similar to white rot at lower (<10%) weight loss (Fig. 4c). At 10% oven-dry weight loss, the conditioned weight loss is 4% less or 9.6%, while at 7% oven-dry weight loss, the conditioned weight loss is 5% less or 6.6%.

DISCUSSION

Wood hygroscopicity is influenced by the moisture-holding capacity of its three major components: cellulose, hemicelluloses, and lignin. Reductions in hygroscopicity are most likely caused by greater removal of amorphous cellulose and hemicelluloses relative to lignin and crystalline cellulose. The trends observed here after oven-drying are similar to those observed by Cowling (1961) on ground wood meal after drying. The rapid reduction in hygroscopicity at early stages of brown rot reflects a rapid consumption of amorphous cellulose (Cowling 1961).

Weight loss determinations using moisture-conditioned weights instead of oven-dry weights are influenced by the changes in hygroscopicity caused by decay. The effects of decay on hygroscopicity prior to oven-drying are of concern when using weight loss methods that use conditioned weights (Zabel and Morrell 1992). Cowling (1961) studied the effects of decay on hygroscopicity after oven-drying. These effects prior to oven-drying have not been widely investigated.

Brown-rotted blocks showed only a slight reduction in hygroscopicity prior to oven-drying. This contradicts the greater reductions observed in brown-rotted blocks after oven-drying here and by Cowling (1961). This also contradicts the rapid removal of amorphous cellulose at early stages described by Cowling (1961) to explain reductions in hygroscopicity. It is unclear why similar decreases in hygroscopicity both prior to and after oven-drying were not observed. Winandy and Morrell (1993) noted a reduction in some hemicelluloses with little change in the glucan component at low weight losses from brown rot. However, if their results are corrected for total weight loss, a considerable amount of glucose was removed, the source of which was either cellulose, hemicellulose, or both. Cellulose crystallinity remains intact at early stages of decay by brown-rot fungi, based on X-ray diffraction analysis (Cowling 1961). However, at early stages, there is also a marked reduction in the degree of polymerization of cellulose with a 50% reduction at 4% weight loss

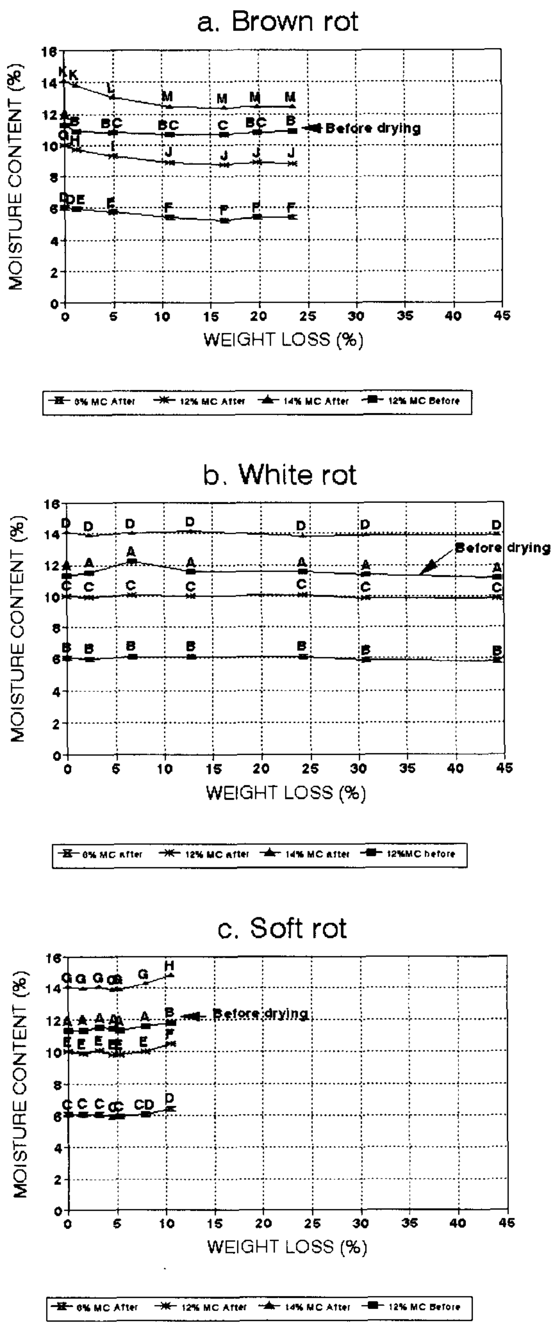

FIG. 3. Hygroscopicity both before (moisture-conditioned) and after oven-drying for brown rot (a), white rot (b) and soft rot (c). The letters next to each point indicate significant differences in the means of eight replicate test blocks using the small sample t-test. Ninety-five percent confidence intervals were calculated as x ± $t_{.025}$ where $t_{.025}$ = 2.365 (standard deviation)/$\sqrt{8}$. a. Brown rot caused reductions in hygroscopicity that were more ap- ← parent at higher relative humidity conditions. Note that the hygroscopicity of the moisture-conditioned blocks changed only slightly with increasing weight loss. b. For white rot, no significant changes in hygroscopicity were observed either before or after oven-drying. c. For soft rot, increases in hygroscopicity were observed at 16 weeks; 10% weight loss. These changes were similar both before and after oven-drying.

(Cowling 1961). This, along with the loss of hemicelluloses (Winandy and Morrell 1993), is believed to be the cause of the rapid strength losses observed at early stages of brown rot. Brown rot is thought to involve very small degrading agents, which are smaller than enzymes and are capable of infiltrating the cell wall and causing rapid depolymerization of cellulose (Flournoy et al. 1991; Srebotnik and Messner 1991). The relatively small change in hygroscopicity prior to oven-drying in brown-rotted wood may be the result of the formation of minute pores in amorphous and crystalline cellulose, which results in an increase of sorption sites. This phenomenon, balanced by loss of amorphous cellulose and hemicelluloses, may cause a net hygroscopicity change of near zero. Upon oven-drying, however, bonding occurs in these sites of early decay, with the remaining intact carbohydrates forming hydrogen bonds. When moisture is reintroduced, these sites that previously adsorbed water are unavailable.

For soft rot, the observed increase in hygroscopicity was probably due to the increase in surface area as a result of cavity formation. Many of these sites would be available both prior to and after oven-drying. Chemical analysis of blocks exposed to soft rot fungi have shown removal of all cell-wall components to varying degrees (Eslyn et al. 1975; Worrall et al. 1997), but the greatest reductions generally occur in cellulose. This would indicate that soft rot is localized at the sites of cavity formation and the remaining wall remains relatively unattacked.

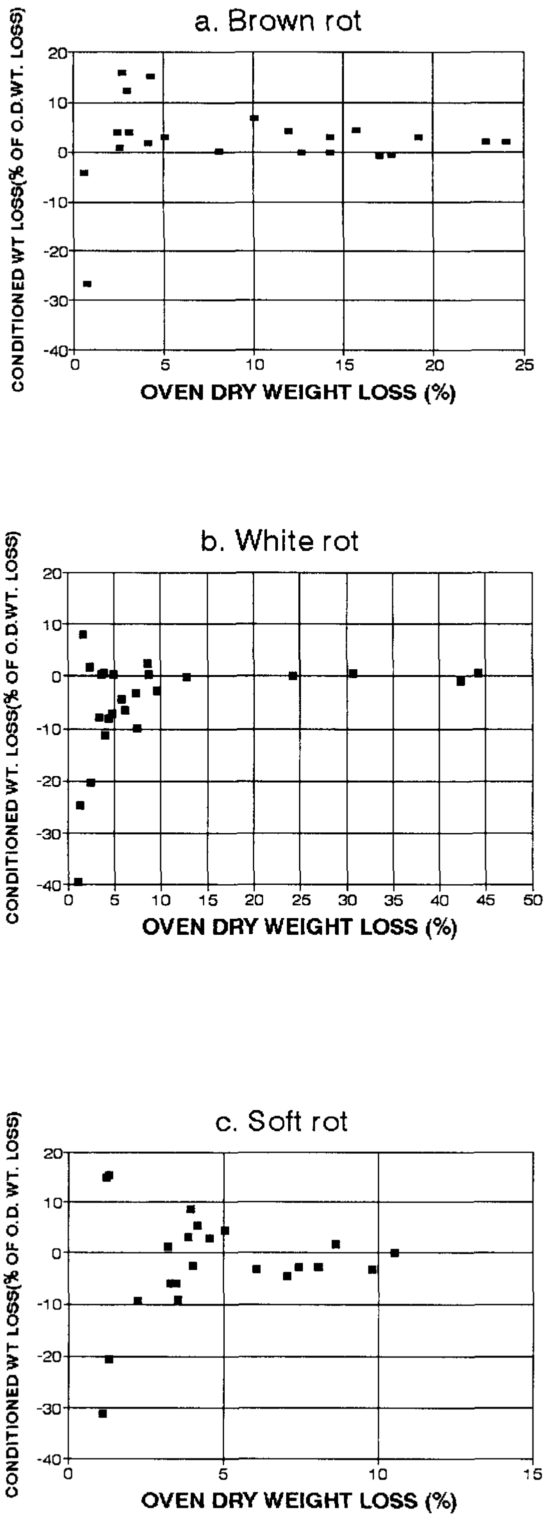

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FIG. 4. Comparison of weight loss determinations. The conditioned weight loss is expressed as a percentage of oven-dry weight loss. Note that the x axis varies. a. Brown rot above 5% weight loss shows a 0 to 7% difference between conditioned and oven-dry weight loss determinations, with conditioned weight losses greater than oven-dry. b. White rot from 5 to 10% weight loss shows a 0 to 10% difference. c. Soft rot from 5 to 10.8% weight loss shows 0 to 5% difference, with conditioned weight losses being less than oven-dry.

Trametes versicolor, a simultaneous white-rot fungus, has been shown to remove all cell-wall components at a somewhat equal rate compared to brown rot (Kirk and Highley 1973). The net change of zero in hygroscopicity indicates equal removal of wood components, at least at the weight losses observed in this study (maximum 44%).

Certain weight loss decay determination methods, such as ASTM D-2017, use conditioned weights rather than oven-dry weights. This study indicates that unbalanced removal of cell-wall components results in lower or higher than actual weight losses when using conditioned weights. For brown rot, higher weight losses were obtained using conditioned weight loss rather than oven-dry weight loss because post-decay weights were slightly lower relative to pre-decay weights due to a decrease in hygroscopicity; however, the magnitudes of these differences are small. If the reductions in hygroscopicity evident following oven-drying had been apparent prior to oven-drying, the magnitudes of the differences in weight loss would have been much greater.

CONCLUSIONS

Weight loss methods using moisture-conditioned blocks instead of oven-dry blocks are influenced by changes in hygroscopicity. Though these changes are slight, they should be taken into account when performing critical measurements such as chemical analysis. For brown rot, weight loss was slightly overestimated, for white rot no difference was observed, while for soft rot, weight losses were slightly underestimated using the moisture-conditioned method. Brown-rot hygroscopicity prior to oven-drying changes only slightly, while it is reduced significantly after oven-drying. This may reflect a change in the porosity of crystalline cellulose at low weight losses.

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