

Groundline decay prevention in southern yellow pine using time-released carbon source amendment

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ABSTRACT

Current technology for groundline decay prevention consists of the application of toxic materials to the wood surface to prevent the colonization of the wood by insects and fungi. We present a new, biotechnological approach to decay prevention. The amendment of the soil immediately adjacent to the wood with a time-released carbon source slows decay dramatically. The addition of a simple carbon source also alters the microbial community around the pole to one favoring bacteria over fungi. Bacteria are incapable of degrading lignin and are competing with fungi for mineral and organic nutrients in the soil. The establishment of a predominant bacterial community should slow wood decay, as will the shifts in soil microbial community caused by carbon amendment. Two mechanisms are proposed for this preservation: oxygen consumption and microbial community changes. Consumption of a readily degradable carbon source accelerates the depletion of oxygen from the soil during saturated conditions. This effect creates anaerobic conditions more rapidly than they would be achieved without amendment. Because decay occurs in anaerobic conditions at 1/5th to 1/10th the rate of aerobic conditions, increases in the length of time the soil around a pole is anaerobic decrease in the overall rate of degradation. Data on oxygen depletion in soil and water systems as well as microbial community changes in soil are presented to support these mechanisms. Also presented are laboratory and field data demonstrating the efficacy of time-released carbon amendment for preventing the decay of wood in contact with soil. In accelerated laboratory decay studies, carbon amendment allowed southern yellow pine test strips to have no loss of strength in the same time period that strips without amendment decayed completely (280 days). In the field, application of a time-released carbon source slowed the rate of decay for southern yellow pine stubs (as measured by Pilodyn?) to roughly 1/3 of their un-amended counterparts.

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INTRODUCTION

The biological degradation of wood in the environment is mediated by three major groups of organisms(1). Bacteria of many genera have the ability to utilize the cellulose and hemi-cellulose components of wood, generally using the material to support their growth and reproduction. Filamentous fungi use their hyphae and extra-cellular enzymes to penetrate and degrade wood structure. Finally, wood boring insects and insect larvae also participate in wood biodegradation.

The rigidity and structural integrity of wood is dependent on maintaining the lignin backbone and supporting cellulose materials. Wood consists of interlocked layers of cellulose and lignin. Bacteria are probably the most important in cellulose breakdown, while fungi, particularly the Basidiomycetes are the most important for lignin degradation. As each layer of lignin is compromised, more of the more readily degraded cellulose becomes available (2). As might be predicted in this scenario, it is the action of fungi in concert with bacteria which allows for the degradation of wood in nature. Almost all the organisms responsible for degrading the structure of wood are obligate aerobes, that is, they require oxygen for their metabolism. Groundline decay in utility poles is an example of the convergence of oxygen, fungi, and bacteria causing accelerated wood decay. A model of this process was given by the authors in an earlier publication(3).

For a very long time, man has looked for ways to treat wood that retard wood decay processes. Current technology has been based almost entirely on treating the wood with materials toxic to the bacteria, fungi, and insects. While this strategy has been quite effective, if done properly, it has led to potential environmental problems at the individual poles, and major hazardous waste problems at sites where wood is treated. In addition to inhibiting microorganisms and insects most of the chemicals also are toxins or carcinogens for humans and other animals. All of the major wood treating materials currently used, i.e. creosote, pentachlorophenol, and CCA, represent human and environmental health hazards. Currently EPA lists over 3,000 current and former wood treating operations as hazardous waste sites. The clean up of these sites represents a major liability for the wood treating industry and railroads, as well as society in general.

If we start with the premise that decay is inevitable, then our goal is to delay the onset or slow the progress of the decomposition process. One common requirement for wood decay is oxygen and another is water. In contrast to their cooperation in the degradation of wood, bacteria and fungi are in competition for oxygen and other resources (mineral and organic nutrients, water) in the area adjacent to the surface of the wood.

Competition for available resources is a fundamental tenet of biology and is visible on all levels of life. To utilize this competition to control the activity of wood decay organisms, a readily bioavailable carbon source and sulfate source can be added adjacent to the pole's surface. The limiting factor in the degradation of the carbon source will, in fact, be another limited resource for which bacteria compete with fungi, namely oxygen. This competition creates conditions which are described as anaerobic (defined as extremely depleted oxygen) and leads to increases in the quantity of organisms which are adapted to life without oxygen. Anaerobic conditions cause a rapid dominance of bacteria and subsequent, slower rise of anaerobic bacteria (4). Bacteria are also favored over the fungi in this system because the bacteria are more readily adaptable, are able to consume the carbon source and grow at a faster rate than the fungi.

Microbial metabolism is most rapid under conditions where oxygen is available to serve as an electron acceptor. The amount of energy available to an aerobe is approximately 19 times that which can be extracted by anaerobes from the same food materials. It is well known that the rates of microbially mediated processes are many times slower in the absence of oxygen (1). This will be especially true of wood decay organisms because of the unique nature of wood and its constituents. Since it is a complex polymer, cellulose, like almost all polymers, is slowly degraded anaerobically(5). Further, there are no known pathways for the anaerobic biodegradation of lignin (6). A detailed review of anaerobic degradation of lignin suggests it may be biochemically possible, but is very rare in nature (2).

The anaerobic community induced by the addition of carbon should be either greatly slowed or completely prevented from degrading the wood. In the presence of mineral sulfates, the anaerobic community formed is likely to be one of sulfate reducers. The reduction of the sulfate should also produce hydrogen sulfide (H_2S). H_2S is known to inhibit insect activity and repel larger animals.

This work shows that carbon amendment accelerates the formation of anaerobic conditions in water saturated systems. It will also show that carbon amendment preserves the break strength of test stakes in accelerated laboratory studies and that time-released carbon amendment slows the softening of full-size, untreated, southern yellow pine stubs in field studies near Charlotte, North Carolina.

METHODS

Laboratory Tests: Oxygen Depletion

We determined the rates of oxygen depletion in an aqueous solution caused by the addition of soil alone and soil with carbon amendments. An aqueous system was used due to the limitations of the instrument used, a membrane based dissolved oxygen (DO) probe (YSI Biological Oxygen Monitor). Oxygen depletion caused by the addition of 1 g of soil with and without 0.1 g/carbon source to 10 ml de-ionized water was measured over time. This apparatus was interfaced with a PC and the data logged until the dissolved oxygen reached 0 mg/L.

Laboratory Tests: Test stakes

Laboratory testing was performed on model stakes (0.5 in. x 0.5 in. x 10 in, southern yellow pine). Model stakes chosen for the study were free from visible defect (knots, cracks etc.) as per the clear timber testing standards described by ASTM (1954). Evaluation of the wood decay process is based on visual observation of the poles after incubation (as recorded in photographs) and the ASTM procedure for testing the Static Bending Strength of wood (7). As per this method, all test-poles were weighed, dried in a 55° C oven for 12 hours and re-weighed. When constant weight was reached, the model poles were placed on the test apparatus, which was built as a scaled down version of the apparatus described by ASTM for the ‘static bending’ of small, clear, timber specimens (D143-52)(7).

The bearing block was scaled down and the distance between the bearing plates was reduced to 4 inches. Because of this width, each 10-inch test-pole could be sampled twice, once at the ground line and once well above the ground line (the clean end of the test-pole). The ASTM method, which uses 2 inch width sections of wood has been scaled down for the model

pole size used. The method was further modified in that rather than comparing sections of wood of equal distance from the pith, the modified method compares sections of wood to themselves by testing two sections along the same grain. These modifications serve to apply the method to our particular case rather than alter the parameter tested. In each test, the maximum pressure exerted by the bearing block was recorded as the breaking pressure.

Field Testing

During the summer of 1996, we began a field test at Lake Wiley near Charlotte, NC. This plan involved the introduction of sixteen (16) 5 foot long, full (8-12") diameter, untreated southern yellow pine utility pole timbers into the earth. These tests used the prototype RS21 (U.S. Patent #5,770,265) treatment material. In 1998, a second round of testing was initiated. This time 24 timbers were used, improving the statistical significance of this test and also allowing sets of timbers under each treatment protocol to be left alone until the end of the study to determine the impact of sampling on the experimental results.

To avoid the cost of breaking full size utility pole sections and to allow for repeated testing of the same pole over time, the field test at Lake Wiley has relied on a Pilodyn 6J? penetrometer method for evaluating wood decay. The Pilodyn? penetrometer fires a pin into the pole surface with a uniform, constant force (6 joules) and then measures the depth of penetration. At the time of planting, baseline data for the penetrability of the timbers was obtained.

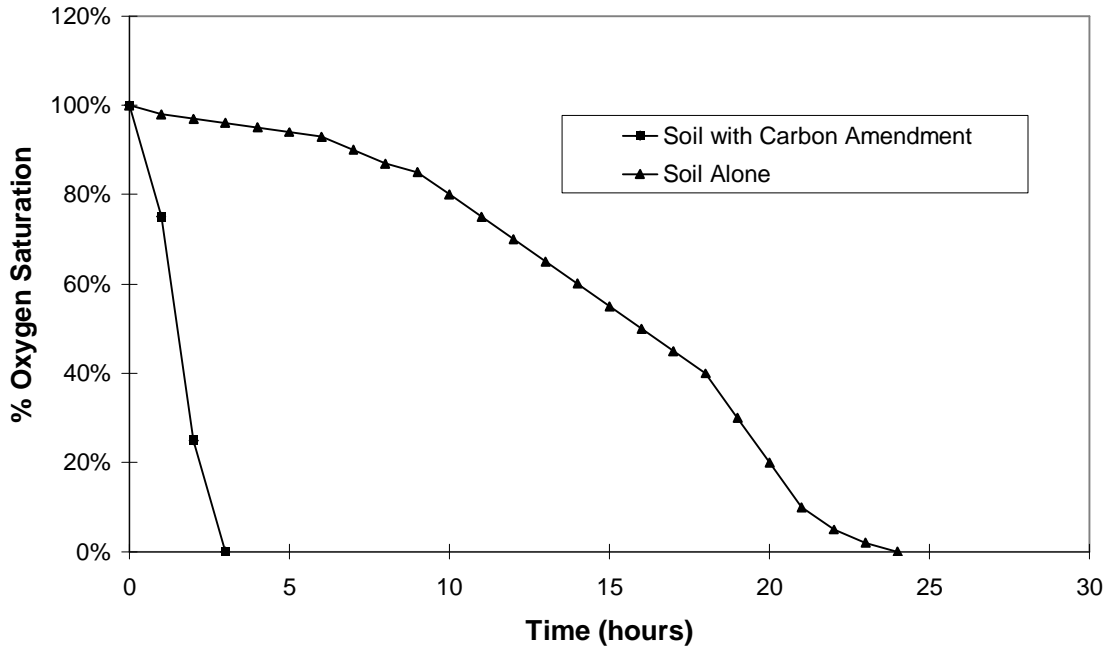
RESULTS

Laboratory results: Oxygen depletion studies

The accelerated depletion of oxygen caused by carbon amendment was as expected. In Figure 1, the addition of 0.1 grams of a simple carbon source caused the rate of oxygen consumption to increase nearly 8 fold. Amended samples were depleted of oxygen in an average of three hours while samples which were not amended took an average of 24 hours to deplete their oxygen. In nature it is difficult to deplete the soil at the base of pole of oxygen continually due to its contact with the atmosphere. However in conditions where the soil is moist or saturated with water, the presence of the simple carbon source causes the oxygen to be depleted much more rapidly, and

therefore extends the length of time the soil around the pole will be anaerobic. As was previously mentioned, anaerobic conditions mean slower degradation, bacterial domination of resources, and possibly the elimination of lignin degradation. The impact of these changes is observed in the laboratory and field efficacy tests.

Figure 1: Oxygen Depletion in Aqueous System



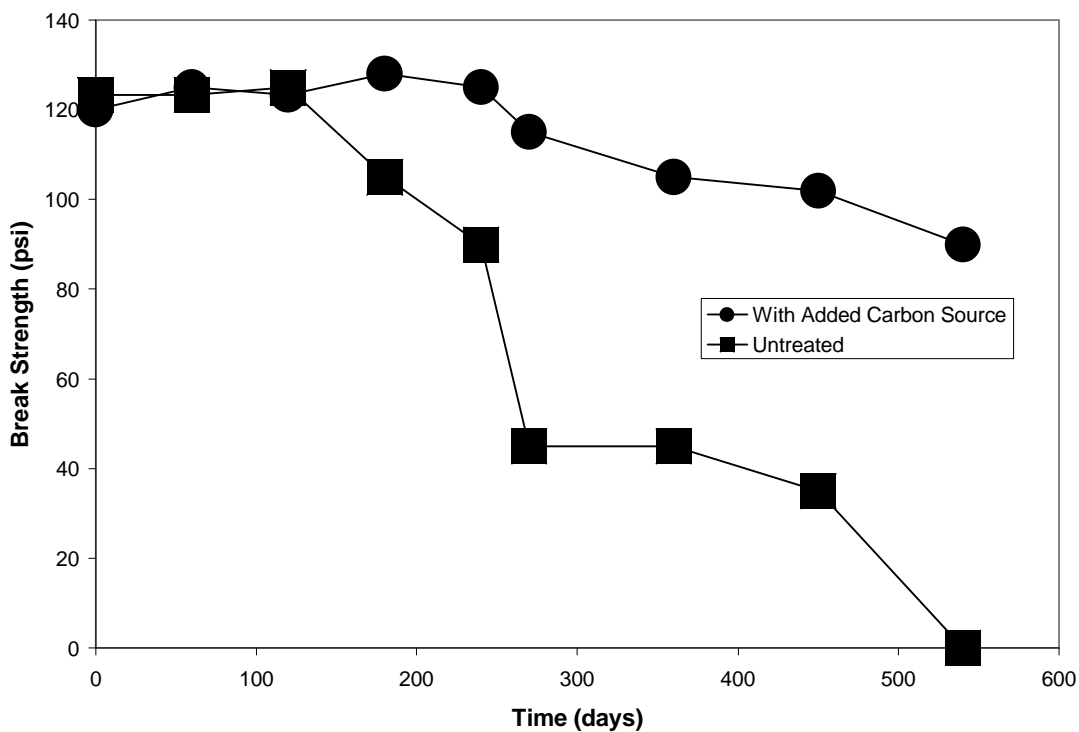
Laboratory Results: Test stakes

The results from the laboratory studies using model test stakes are given in Figure 2. As can be seen, the periodic addition of a simple carbon source to the stakes alters the rate at which they lose break strength. Without carbon amendment, the stakes began to lose their strength very rapidly (around 180 days) and had lost all of their strength after about a year and a half. Carbon amended stakes had no significant loss in strength for 270 days and retained an average of 75% of their initial break strength when the study was concluded after 18 months.

To determine if this effect could be replicated in the field, it was necessary to modify the method of carbon amendment. In the field, the direct addition of the carbon source would be ineffective due to carbon dilution in wet conditions. To overcome this limitation, a time-release

mechanism was devised by which the carbon is released whenever biological activity (and therefore the likelihood of decay) in the area is high. This technology, as well as the use of carbon amendment to preserve wood in contact with soil have been patented by Triangle Laboratories (Durham, NC) and the University of North Carolina at Chapel Hill (U.S. Patents #5,770,265 and #6,004,572).

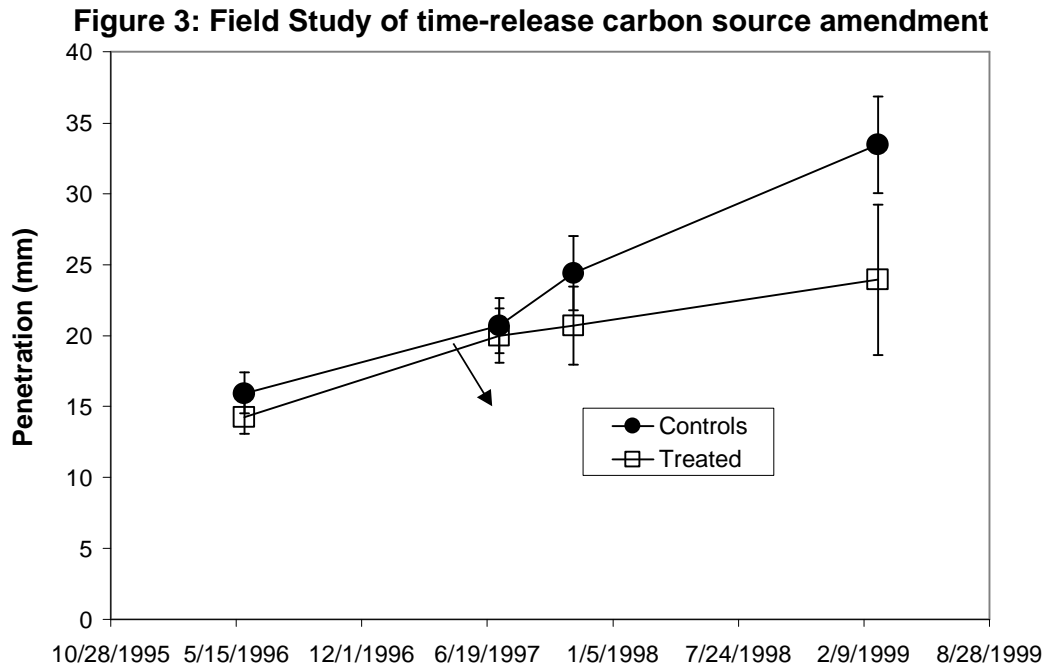
Figure 2 : Lab Study of 0.5" Test Strips



Field Results

The results of the field test of the time-release carbon source amendment are given in Figure 3. Pilodyn? penetration increases with increasing decay and was used as a surrogate measure for this study. Treatment material was added in after decay had begun in order to simulate likely re-treatment conditions. Prior to June of 1997, the rate of decay was nearly identical in all stubs. Following the addition of the time release carbon source, the rates of decay diverged significantly. Control samples (without carbon source amendment) showed a 65% increase in Pilodyn? penetration from July of 1997 to March of 1999. During the same time

period, stubs with time-release carbon sources added to the soil around them had an increase of penetration of only 20%. Extrapolated, this indicates a three-fold life extension caused by the addition of the time-release carbon source. If the full length of the study is considered, the life extension is still more than two-fold.



Discussion

The information in this paper indicates that carbon amendment will accelerate the depletion of oxygen under water saturated soil conditions. The depletion of oxygen is believed to cause three distinctive effects which lead to the preservation of wood: 1.) formation of anaerobic conditions under which all biodegradative processes occur more slowly. 2.) alteration of the soil microbial community to one which is predominated by bacteria (which cannot degrade lignin). And 3.) reduction of added sulfate to sulfide (which is known to inhibit insects). Carbon amendment is demonstrated to preserve the break strength of wood test stakes in laboratory studies, and the addition of a time-released carbon source slows the softening of untreated southern yellow pine stubs in a field study. Time-released carbon amendment represents an alternative to using toxic methods of groundline decay prevention.

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