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Application of chloropicrin to Douglas-fir stumps to control laminated root rot does not affect infection or growth of regeneration 16 growing seasons after treatment☆

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Abstract

Phellinus weirii (Murr.) Gilb. causes laminated root rot (LRR), a major disease affecting growth and survival of *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir) and other commercially important conifer species throughout the Pacific Northwest. This disease is known to spread to a replacement stand by root contact between replacement trees and residual infected stumps and roots from the harvested stand. One strategy to manage LRR is to reduce the residual inoculum on a site through application of a fungicidal chemical to infested stumps. The first two studies in this series established that chloropicrin (trichloronitromethane), applied to infested stumps, largely eliminates *P. weirii* from most of the belowground biomass and determined the effective dosage to apply. This third study approximated an operational application and based treatment success on reduction of LRR in the replacement stand. The study area was an 8-ha, 65-year-old naturally regenerated second-growth stand that was predominantly Douglas-fir. The stand was surveyed preharvest and postharvest (clearcut). Each *P. weirii*-infected entity (standing dead or down trees and stumps) was marked, and the location of its center was mapped. Circular plots (0.04 ha) were located so as to include concentrations of infested stumps. Plots were stratified based on their estimated biomass of inoculum into eight replicate blocks of four plots each. Three chloropicrin treatments and an untreated control were assigned randomly to four plots in each of the eight blocks: (a) 100% labeled dosage to all stumps, (b) 20% labeled dosage to all stumps, (c) 100% labeled dosage to only visibly *P. weirii*-infected (stump-top stain or advanced decay) stumps, and (d) control (nothing done to the stumps). Holes were drilled into stump tops, a dose of chloropicrin poured in, and the holes plugged. The labeled dosage was 3.3 ml of chloropicrin per kilogram of estimated stump and root biomass. Douglas-fir seedlings were planted in the winter following treatment application. When the stand was considered established, each plot was thinned to an inter-tree spacing of 2.4 m and the trees tagged. Diameter at breast height, total height, and mortality of trees were recorded every 2–5 years. A total of 1041 tagged trees were observed for 16 growing seasons following treatment. Application of chloropicrin to stumps in the harvested stand did not influence the rate of LRR-caused mortality or growth of Douglas-fir seedlings in the replacement stand.
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1. Introduction

Phellinus weirii (Murr.) Gilb., causes laminated root rot (LRR), a major disease affecting growth and survival of *Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir) and other commercially important conifer species throughout the Pacific Northwest, and is responsible for large annual losses in stand productivity (Nelson et al., 1981; Thies, 1983; Bloomberg and Reynolds, 1985). The disease influences stand composition (Holah et al., 1993; Ingersoll et al., 1996) and dynamics (Cook, 1982; Holah et al., 1997) by directly killing susceptible trees or by predisposing them to windthrow, insect attack, and other secondary agents. *P. weirii* spreads throughout a stand when uninfected roots contact roots of previously infected living or dead trees. *P. weirii* has been reported to survive saprophytically in the large roots of dead trees or stumps for several decades (Hansen, 1976, 1979) and for as long as 50 years (Childs, 1963). Such

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persistence and spread allow the fungus to remain on the site beyond the life of an individual host and to infect trees of the replacement stand (Tkacz and Hansen, 1982). The biology, distribution, and impact of the disease, relative susceptibility of host species, and options for management are summarized in Thies and Sturrock (1995) and Hansen and Goheen (2000).

Strategies to manage laminated root rot (Thies and Sturrock, 1995) have focused on changing species composition or reducing inoculum before a stand is regenerated with a susceptible species. Fumigation is one means of reducing inoculum of some root rotting fungi. Reports of fumigant application to soil as well as directly to wood to destroy particular fungi have been reviewed previously (Filip, 1976; Filip and Roth, 1977; Thies and Nelson, 1982). Examination of excavated stumps colonized by *P. weirii* has shown that extensive stain or decay of the stump top is contiguous with advanced decay and stained wood within the root collar and major roots (Thies and Sturrock, 1995). The presence of decay columns forming ‘‘ducts’’ from the stump top to infected portions of the root system suggested the possibility that placing a volatile liquid biocide, such as chloropicrin (trichloronitromethane), into an infected stump would allow the fumigant to volatilize and gasses to diffuse through the stump and roots and kill *P. weirii* (Thies and Nelson, 1982).

This paper describes the third in a series of stump fumigation studies. In the first study (Thies and Nelson, 1982) fumigants were applied for the first time (1978) to stumps colonized by *P. weirii*. Stumps were treated by drilling holes in their tops, pouring a dose of fumigant into the holes and plugging the holes. One year later, the stumps were evaluated and it was found that *P. weirii* had been eliminated from the stumps and most roots. A second study (Thies and Nelson, 1987) tested application techniques with doses based on estimated stump and root biomass. After 20 months, the fumigants had eliminated the fungus from the stumps and reduced the volume of roots supporting *P. weirii* to 22% of the prefumigation volume). Similar results have been reported when using the fumigant Telone II-B (Fraser et al., 1995). These early studies demonstrated that fumigants could move through wood (stumps and roots) to eliminate *P. weirii* inoculum, and that an effective dose was related to the quantity of estimated below ground biomass. During these stump fumigation studies, stumps were excavated and the pathogen viability was tested. The presumption was that, had the fumigated stumps remained undisturbed in the soil, the fumigants and the various microbial antagonists recolonizing the roots might have eliminated the pathogen.

This paper reports the results of the third stump fumigation study, which simulated an operational application in which the treated stumps remained undisturbed in the soil after fumigation. To evaluate the success of stump fumigation as an intervention strategy for LRR, the replacement stand was observed for 16 growing seasons following treatment for mortality caused by LRR.

2. Materials and methods

2.1. Study site

The study area is an 8-ha clearcut with very low relief ($\leq$2% slope) on the Olympic Peninsula near Matlock, WA (47°13′N, 123°26′W). Mean elevation is 40 m, mean annual precipitation is 125 cm, and soil in the study area is a Hoodsport gravelly sandy loam (Haplorthod). The Hoodsport soil series formed in glacial deposits of 50–75 cm of loose ablation till overlaying very compact lodgment till. Surface soil consisted of a moss layer (probably in excess of 75% cover throughout), overlying poorly developed litter and fermentation layers, with a 1- to 5-cm deep humus soil horizon.

The site is class II (McArdle et al., 1961) and supported a 65-year-old naturally regenerated second-growth stand that was predominantly Douglas-fir (99% by harvest volume). Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) constituted the remainder of the overstory with occasional western red-cedar (*Thuja plicata* Donn ex D. Don) regeneration and frequent patches of vine maple (*Acer circinatum* Pursh). Understory shrubs were primarily sclerophyllous salal (*Gaultheria shallon* Pursh) with frequent sword fern (*Polystichum munitum* (Kaulf.) Presl) and big huckleberry (*Vaccinium membranaceum* Douglas) and a partial ground cover of twin flower (*Linnaea borealis* L.). In-depth analysis of the herbaceous flora of the study area was presented in Ingersoll et al. (1996). Before harvest, the site was part of a contiguous forest stand bordered by an access road and a recent clearcut to the west (Fig. 1).

The study area was clearcut during the summer of 1988. Because success of the fumigation required retention of a volatile chemical in each stump, care was taken to not crack or penetrate residual stumps or disrupt their roots. After conventional felling, whole trees were moved to the landings by shovel logging where they were limbed and bucked. Shovel logging was accomplished by using an excavator with a modified grapple so that trees were lifted over stumps and placed on piles. Next, the excavator was carefully relocated to avoid damage to stumps or roots, and trees were lifted and restacked in another pile. In this way the trees were moved from pile to pile advancing across the clearcut with a minimum of machine travel. This method of moving the trees resulted in little damage to the residual stumps and surface roots of the sort that might be experienced by dragging logs and making multiple trips with skidders. Further, this method of moving the trees significantly reduced the amount of slash on the study area to predominantly small pieces directly in contact with the soil surface. On this very rocky site, the logging activity disturbed much of the thin soil layer and exposed mineral soil.

2.2. Estimation of biomass

An estimate of belowground stump and root biomass for individual stumps was required twice during establishment of this study: (a) for blocking treatment plots according to the relative amount of inoculum present belowground, and (b) to

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