

EFFECT OF THINNING AND THINNING PLUS FERTILIZATION ON DOUGLAS-FIR: RESPONSE TO *ARMILLARIA OSTOYAE* INFECTION

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ABSTRACT

Second growth *Pseudotsuga menziesii* (Mirb.) Franco stands were thinned to a 5 x 5 m spacing (TT); an additional set of plots were thinned and fertilized once with 360 kg ha⁻¹ N as urea (TF). An unthinned stand (UT) served as a control. Trees were inoculated with two isolates of *Armillaria ostoyae* (Romagn.) Herink 10 years after silvicultural treatment. Two types of inoculation were compared: 1) a 10 cm diameter x 20 cm long cylindrical block of inoculum was placed in contact with a 0.5-3.0 cm diameter root and 2) a 1.75 cm diameter by 10.0 cm long cylindrical plug of *A. ostoyae* inoculum was inserted into a hole drilled into a primary root.

Trees receiving the TF and TT treatments produced greater stem diameter growth, leaf area, and wood produced/m² leaf area/year than the UT treatment. Infection rates were higher in trees receiving the TF treatment compared to the other treatments regardless of inoculation technique. The lowest infection rates were measured in trees that were thinned but not fertilized. They had the lowest concentrations of sugar, starch, and cellulose in root bark tissue and the highest concentrations of lignin, phenolic compounds and protein precipitable tannins than the other two treatments. Thinning combined with fertilization may predispose *P. menziesii* trees to *A. ostoyae* infection by lowering concentration of defense (phenolic) compounds and/or raising the amount of sugars in root bark tissue. Thinning a stand infested with a pathogenic species of *Armillaria* is undesirable. Thinning may produce *P. menziesii* trees more resistant to *A. ostoyae* but the effect may be negated by large amounts of potential inoculum in the form of dead root biomass left on the site.

Keywords: Thinning plus fertilization, thinning, *Armillaria ostoyae* Douglas-fir

INTRODUCTION

Armillaria root rot is a serious forest problem in large areas of the United States (Wargo and Shaw 1985). Many former pine stands have been converted to more disease-susceptible spruce and fir species as the results of an 85-year-old fire suppression policy and past cutting practices (Arno 1980; Filip and Goheen 1984). Approximately 1% of the total commercial forest land in northern Rocky Mountain forests are occupied by large active root disease centers, and 13% of these forests contain scat-

tered root disease mortality of at least 3 trees/ha (James *et al.* 1984). Trees of all ages and sizes are attacked, but because early mortality is scattered and the trees are small, the problem is not often recognized. The majority of root pathogen mortality in the northern Rocky Mountains and Canada has been attributed to *Armillaria* (Williams and Leaphart 1978). Recent surveys indicate that *Armillaria* infection may be concentrated on certain sites and forest types in the Pacific Northwest (McDonald *et al.* 1988; James *et al.* 1984).

Trees growing on nitrogen-limited sites may be particularly prone to *Armillaria* attack (Shields and Hobbs 1979). Thus, trees experiencing nitrogen deficiency, or low-light intensity, may change the susceptibility of trees to pathogen. Multiple stresses may ultimately reduce tree defense to the point where it can no longer repel attack by *Armillaria* (Redfern 1978).

The objective of this study was to determine if thinning, or thinning combined with nitrogen fertilization, would improve the physiological status of second-growth Douglas-fir and thereby increase resistance to *Armillaria ostoyae* infection.

MATERIALS AND METHODS

Site Descriptions

Gold Hill

Gold Hill, located in the Panhandle Forest near Sandpoint, Idaho, Lat. 48° 12' N, Long. 116° 30' W, T56N, R1W, Sec.6, NE¼, SE¼ Boise meridian, is at 954 m elevation with a 35% slope toward the NE. Annual precipitation is 533 mm with 22% occurring as snowfall; snowpack averages 1.0-2.2 m. Mean annual air temperature is 6.4°C with extremes of -26.6 to 35.6°C. The soil, a loamy skeletal mixed Entic Cryandep, in the Vay series (Weisel 1982) is derived from volcanic ash overlying a noncarbonate argillite of the Wallace formation of the Montana Beltrock Supergroup. The 2 cm thick litter layer (L) is comprised of undecomposed *P. menziesii* needles and *Alnus sinuata* Torr. leaves. The 0.2 cm thick F layer is composed of partially decomposed *P. menziesii* needles and twigs. The latter two layers overlie a 0.2 cm thick humus (H). The root zone is largely limited to a coarse gravelly loam 24 cm thick. A 1987 inspection of 78 *P. menziesii* stumps (5 -12 cm dia.) from trees cut during a 1977 thinning treatment did not reveal native species of *Armillaria*.

The site, classified as a *Thuja plicata* Donn./*Clintonia uniflora* (Schult.) Kunth. habitat type (Cooper *et al.* 1987), is dominated by 38-year-old second-growth *P. menziesii*, 10.3 m tall with a basal area of 37 m²ha⁻¹. Shrub vegetation covers 50% of the site and consists of 30% *Alnus sinuata* (Regel) Rydb, 10% *Acer glabrum* Torr., 10% *Holodiscus discolor* (Pursh.) Maxim. and 50% *Pachistema myrsinites* (Pursh.) Raf.

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Tacoma Creek

Tacoma Creek is located on the Colville National Forest near Cusick, Washington, Lat. 49° 32' N, Long. 116° 43' W, T35N R43E, Sec. 31, SW ¼, NE ¼, Willamette meridian, at an elevation of 1015 m on a SW exposure with a slope of 15%. Mean annual air temperature is 6.0°C ranging from -22.7 to 32°C. Annual precipitation averages 635 mm with 27% occurring as snow during the winter months; snowpack ranges from 1.2-3.3 m. The soil is a sandy, frigid, Andic cryochrept derived from volcanic ash overlying glacial drift comprised of granite. The organic horizon consists of three layers; a 2-3 cm layer of undecomposed *P. menziesii* twigs and needles (L layer), a 2 cm thick layer of partially decomposed *P. menziesii* needles (F layer), and a 2 cm-thick humus (H layer). The root zone extends to a depth of 150 cm.

The site is classified as a *Tsuga heterophylla* (Raf.) Sarg./*Gymnocarpium dryopteris* (L.) Newm. habitat type (Cooper *et al.* 1987) and is dominated by 34-year-old, 10-12 m high *P. menziesii*. A few *Pinus ponderosa* Dougl. ex Laws, *Thuja plicata* Donn. and *Pinus contorta* var. *latifolia* (Engelm) are also present. The stand has a basal area of 32 m²ha⁻¹. Shrub vegetation covers 40% of the site and consists of 70% *Ceanothus velutinus* Dougl., and 30% *Alnus sinuata*. A 1987 inspection of 73 *P. menziesii* stumps from trees (3-11 cm dia.) cut during a 1977 thinning treatment did not reveal any colonization by native species of *Armillaria*.

Solomon Mountain

Solomon Mountain, located on the Panhandle National Forest near Moyie Springs, Idaho, Lat. 48° 48' N, Long. 116° 08' W, T63N, R3E, Sec. 29, SW ¼ NE ¼, Boise meridian, is at 1170 m elevation on a west exposure with a slope of 10%. Mean annual air temperature is 6.1°C with extremes from -23 to 32°C. Annual precipitation averages 635 mm with 40% occurring as snow during the winter months; snowpack ranges from 2.1-4.2 m. The soil is a loamy mixed frigid andic xerochrept of the Pend Oreille Series (Chugg and Fosberg 1980) derived from volcanic ash overlying glacial drift. The organic horizon is comprised of a 3-4 cm-thick undecomposed *P. menziesii* needles (L layer) atop a 3 cm-thick partially decomposed layer of *P. menziesii* twigs and needles (F layer); the latter overlie a 2 cm-thick humus (H layer). The root zone extends to a depth of 40 cm.

This site, classified as a *Pseudotsuga menziesii*/*Symphoricarpos albus* (L.) Blake habitat type (Cooper *et al.* 1987), is dominated by 34-year-old, 18 m tall *P. menziesii*. A few *Pinus ponderosa* are also present on the site. Stocking level of trees in this stand is 28 m²ha⁻¹ basal area. Shrub vegetation covers 30% of the site and consists of 70% *Symphocarpus albus* L. Blake, 10% *Amelanchier anifolia* Nutt., 10% *Holodiscus discolor*, and 10% *Acer glabrum*. A 1987 investigation of 126 *P. menziesii* stumps (2-9 cm dia.) from trees cut during a 1977 thinning treatment revealed no colonization by *Armillaria*.

Sampling and Analysis

The study was set up as a randomized block design (Kirk 1982) with the three sites described above as blocks. Two

treatments were implemented in the fall of 1977 on 0.1 ha plots. One treatment was thinned to a 5 x 5 m spacing (TT), and the other thinned to a 5 x 5 m spacing and then fertilized at 364 kg ha⁻¹ N as urea (TF) (Scanlin *et al.* 1978). A strip approximately 4 m wide, fertilized at the same rate, served as a buffer for trees near the plot borders (Scanlin *et al.* 1978). Plots were located at least 20 m apart so fertilization would not affect the thinned or control plots. An unthinned and unfertilized plot served as a control (UT).

Ten years after fertilization, in the fall of 1987, 10 second-growth *P. menziesii* trees on each of these plots were measured for height, diameter at breast height (dbh), age, diameter growth at breast height since fertilization, diameter growth at bh per year, sapwood basal area, and vigor measured as g wood produced/m² leaf/year (Waring 1983).

Nutrient Analysis

The 10 trees in each plot were sampled in September of 1987 for foliar nutrient content using methods described by Comeford and Leaf (1984). Three composite samples of current needles from each tree were dried at 80°C, ground to <1 mm, and a 1.0 g subsample was ashed at 525°C. The ash was dissolved in 6.0 ml of 1 N HCl, brought to 50 ml volume with deionized water and analyzed for Al, B, Ca, Cu, Fe, Mg, Mn, K, P, S and Zn (Jackson 1958) on a Jarrell-Ash 9000 inductively coupled plasma spectrometer. Total N was analyzed by standard microkjeldahl techniques modified to include nitrate (Bremner and Mulvaney 1982).

Biochemical Measurements

Three randomly selected trees on each plot were sampled September 1987 for root bark tissue analysis. One-half to three-centimeter diameter roots, 7-10 cm long, were selected from each directional gradient of the tree (North 0-90° E 90-180°, S 180-270° and W 270-360°). Root bark was removed, dried at 80°C for 48 hours and ground to pass a <1 mm mesh screen. A 1.0 g sample of ground outer bark tissue from each directional gradient of the tree was pooled with the other three quadrants. A 0.2 g subsample was analyzed for total sugars and starch using the method developed by Hansen and Moller (1975). Cellulose and lignin in root bark tissue was analyzed by procedures developed by Van Soest (1963). Phenolic compounds were extracted from a 100 mg subsample with 10.0 ml of 80% aqueous acetone (V:V) for 24 hours (Julkunen-Tiito 1985). Five ml of extract was then diluted in 20 mls of 80% aqueous acetone (V:V). One ml of the solution was added to a 30 ml test tube, followed by 1.0 ml distilled H₂O, then 1.0 ml of Folin-Ciocalteu reagent. The solvents were mixed, followed immediately by 5 ml of 20% NaCO₃ (V:V) solution, and then thoroughly mixed again. After 20 minutes the absorptivity of the solution was read at 700 nm on a Bausch and Lomb 21 spectrophotometer (Julkunen-Tiito 1985). Phenol standards were dissolved in 80% aqueous acetone (V:V). Protein precipitable tannins were analyzed in 50 µl subsamples of the diluted 80% aqueous acetone extract using the radial diffusion assay developed by Hagerman (1987).

Inoculum Preparation

Two isolates of *A. ostoyae*, isolate JR 1953 and isolate DC1, were grown on 3% malt agar. Isolate JR 1953 was obtained from Dr. Jim Reaves of Alabama Agricultural and Mechanical University, Normal, Alabama (Reaves *et al.* 1984), and isolate DC1 was collected from a dying *Pinus monticola* Dougl. ex. Don. in the Deception Creek Experimental Forest in northern Idaho (Entry *et al.* 1986). These isolates have been challenged against known haploid isolates of *Armillaria* and determined to be *A. ostoyae* = North American Biological species I (NAB-SI). Cylindrical blocks ~10 cm diameter x 20 cm long, and cylindrical plugs ~1.75 cm diameter x 10 cm long of *Alnus rubra* Bong., were washed and placed in 10.0 L autoclave bags with 2 liters of malt extract media. These were autoclaved for 60 minutes at 136 atmospheres (20 psi), allowed to cool and inoculated with one of the two *A. ostoyae* isolates. They were incubated for nine months and well colonized by the fungus before inoculation.

Inoculation Techniques

In the fall of 1987, 10 trees from each plot were inoculated with both isolates of *A. ostoyae*. Each tree was inoculated a total of four times; twice using a plug method and twice by a block method. The plug method involved drilling a 2.00 cm diameter hole 10 cm deep into a main root of each tree. A 1.75 cm diameter x 10 cm long plug of *A. rubra* colonized by *A. ostoyae*, was inserted into the hole. All plugs fitted snugly and made contact with the cambium and sapwood of each root. One-half to 3.0 cm diameter roots were inoculated with *A. ostoyae* using the block method by securely fastening a 10.0 cm diameter x 20 cm long block, colonized by *A. ostoyae*, to the root. Blocks and roots were wrapped in plastic to prevent desiccation of the inoculum and then covered with soil and left for one year.

Verification of Infection

After one year, inoculated sections of roots were removed and carefully washed with tap water, followed by distilled water.

Six subsections approximately 0.25 cm in length and including cambium were cut from each root, surface sterilized with 1% NaClO solution for 7 minutes, flamed for 3-5 seconds and then placed on 3% malt agar in 60 ml test tubes and capped. *Armillaria* recovered in test tubes was identified as *A. ostoyae* by diploid-diploid culture challenged with a culture of DC1 and JR 1953 to insure the identity of the isolate. The percentage of inoculations infected was calculated from the culture results. Tree infection was rated for the block and plug methods as follows: no inoculation recovered 0, one inoculation recovered 1, both inoculations recovered 2. Total infection rate combined the plug and block methods; all four successfully recovered infections would be rated as 4.

Statistical Analysis

The data were found to be normally distributed using univariate procedures and analyzed with ANOVA (SAS Institute 1982) for a randomized block design. The residuals were normally distributed with constant variance. Individual treatment means were computed with Fisher's protected least significant difference (LSD) test at $p \geq 0.05$.

RESULTS

Growth Measurements

In 1987, 10 years after thinning, tree height was not significantly different among the three treatments (Table 1). Diameter at breast height, leaf area, sapwood area, and g wood produced/m² leaf/year were significantly greater in trees from the TF and TT treatments than those from the UT control. The ratio of sapwood:heartwood diameter growth since fertilization, sapwood basal area, and leaf area of TF trees were significantly greater than from trees in the TT treatment; these parameters were also greater for trees in the TT treatment compared to the UT treatment (Table 1).

Table 1. — 1987 growth measurements on second-growth *Pseudotsuga menziesii* 10 years after treatment and prior to inoculation with *A. ostoyae*.¹

Treatment	Height (m)	Dia ² (cm)	CSF ³ (cm)	SBA ⁴ (cm ²)	Vigor (g wood produced/m ² leaf/yr)	Leaf area (m ² /m ²)	Sapwood heartwood ratio (cm ² /cm ²)
Thinned and fertilized	15.8 A ⁵	9.23 B	3.94 C	232 C	102 B	79 C	2.92 C
Thinned	15.3 A	8.24 B	3.05 B	186 B	93 B	63 B	1.91 B
Unthinned control	13.6 A	5.46 A	1.10 A	66 A	49 A	22 A	1.13 A

¹An average of 30 replications per treatment, (10 trees/site x 3 sites).

²Stem diameter measured as breast height.

³Radial growth of stem since fertilization measured at breast height.

⁴Sapwood basal area measured at breast height.

⁵In each column values followed by the same letter are not significantly different at $p \geq 0.05$ as determined by Fisher's Protected Least Significant Difference (LSD) test.

Nutrients

Concentrations of foliar N, P, K, Ca, Mg, Cu, and S were not different among trees in the three silvicultural treatments (Table 2). Concentrations of total Mn, Fe, B, and Zn were lower in foliage of trees from the TF treatment than the UT control. Zinc was the only nutrient more concentrated in foliage of trees from the TT treatment than those from the TF or UT treatments. Foliar concentrations of Al, Fe and B were lower in trees that received the TT treatment than trees that received the UT treatments (Table 2).

Physiological Responses

Concentrations of sugar and starch were higher in the root bark tissue of trees in stands receiving the TF treatment than the trees in stands receiving the TT, but not the UT treatment (Table 3). Concentrations of cellulose were higher in root bark tissue of trees growing in stands that received the TF and UT treatments than the TT treatment. Concentrations of phenolic compounds and protein precipitable tannins were significantly higher in root bark tissue of trees growing in stands that received the TT treatments; they did not differ between trees growing in stands that received the TF and UT treatments (Table 3). Lignin concentration and the phenolic:sugar ratio were higher in root bark tissue of trees growing in stands that received the TT treatment than trees growing in stands that received the TF treatment, but not the UT treatment (Table 3).

Infection

Infected segments of roots had 0.2-1.0 cm long strands of white mycelium emerging from the point of contact with the inoculum block and advancing into the root bark tissue parallel to the root axis. The white mycelial strands did not advance beyond the inoculum block-root contact interface. Infected root segments had 0.5-3.0 cm areas of resinosis surrounding the point of root contact. *Armillaria ostoyae* isolates recovered from seedlings were challenged against the original *A. ostoyae* isolate used to inoculate the *A. rubra* block at the start of the experiment by diploid-diploid crossings on 3% malt agar (Anderson and Ulrich 1982). Isolations from infected roots were found to be the same *A. ostoyae* isolate used to inoculate the *A. rubra* block.

Infection Rates

Trees growing in stands receiving the TF treatments had significantly higher percentage infection and infection rates, regardless of the inoculation method, than trees growing in stands receiving the TT or UT treatment (Table 4). Percentage infection did not differ between the trees receiving the UT and TT treatments, for both inoculation procedures, but plug inoculation infection rates were significantly higher for UT trees compared to trees growing in stands receiving the TT treatment (Table 4).

Table 2. — Concentration of elements in *Pseudotsuga menziesii* needles in 1987, 10 years after treatment, and prior to inoculation with *A. ostoyae*.

Treatments	Elements ($\mu\text{g}\cdot\text{g}^{-1}$ dry needle biomass)											
	Total N	P	K	Ca	Mg	Mn	Fe	Cu	B	S	Zn	Al
Thinning and fertilization	10,000 A ^{1,2}	1,632 A	5,540 A	8,209 A	1,226 A2	256 A	90 A	2.31 A	18.87 A	892 A	17.87 A	157 A
Thinning	10,267 A	1,634 A	5,450 A	8,501 A	1,165 A	285 AB	89 A	2.17 A	23.30 B	948 A	23.21 C	18 B
Unthinned control	10,399 A	1,621 A	5,459 A	8,876 A	1,157 A	297	110 B	2.10 A	25.89 C	879 A	20.10 B	175 A

¹Values represent the mean $n = 90/\text{treatment}$ (3 composite foliage samples/tree \times 10 trees \times 3 sites).

²Within each column, values followed by the same letter are not significantly different $p \geq 0.05$ as determined by Fisher's Protected Least Significant Difference (LSD) Test.

Table 3. — 1987 biochemical measurements of bark from 0.5-3.0 cm diameter roots of second-growth *Pseudotsuga menziesii* 10 years after treatment, and prior to inoculation with *A. ostoyae*.

Treatment	Sugar (mg g^{-1})	Starch (mg g^{-1})	Cellulose (%)	Lignin (%)	Phenolics (mg g^{-1})	Protein precipitable tannins (mg g^{-1})	Phenolic:Sugar ratio
Thinning and fertilization	40.97 A ^{1,2}	45.26 A	51 A	40 A	203 A	127 A	5.73 A
Thinning	23.61 B	34.52 B	35 B	60 B	254 B	164 B	17.19 B
Unthinned control	25.47 AB	37.92 AB	44 A	47 AB	144 A	104 A	10.32 AB

¹Average of 27 replications (3 roots/tree \times 3 trees \times 3 sites).

²In each column values followed by the same letter are not significantly different at $p \geq 0.05$ as determined by Fisher's Protected Least Significant Difference (LSD) Test.

Table 4.—Infection rates of *A. ostoyae* isolates JR 1953 and DC1 one year after inoculation on second-growth *Pseudotsuga menziesii* 10 years after silvicultural treatment.

Treatment	Block infection		Plug Infection		Total infection	
	% ¹	Rating ^{2,3}	% ¹	Rating ^{2,3}	% ¹	Rating ^{4,5}
Thinned and fertilized	30 B ⁶	0.78 A	27 B	0.58 C	28 B	1.36 C
Thinned	20 A	0.42 B	18 A	0.37 A	18 A	0.79 A
Unthinned control	18 A	0.59 B	16 A	0.42 B	17 A	1.01 B

¹Refers to percentage of roots with successful inoculations.

²Values are means of 60 replications (2 inoculations/tree x 10 trees x 3 sites).

³If all inoculations were positive infection rate = 2; if no inoculations were positive infection rate = 0.

⁴If all inoculations were positive infection rate = 4; if no inoculations were positive infection rate = 0.

⁵Values are means of 120 replications (4 inoculations/tree x 10 trees x 3 sites).

⁶In each column values followed by the same letter are not significantly different at $p \geq 0.05$ as determined by Fisher's Protected Least Significant Difference Test.

DISCUSSION

Pseudotsuga menziesii trees growing in stands thinned and fertilized 10 years earlier were characterized by higher sugar, starch and cellulose concentrations, but lower concentrations of lignin, phenolics and protein precipitable tannins, in root bark tissue of 0.5-3.0 cm diameter roots, than trees growing in stands that were thinned. *Armillaria ostoyae* block, plug and total infection rates were higher in trees growing in stands thinned and fertilized, than trees growing in stands that were thinned or left untreated. We found no difference in tree vigor as measured by g wood produced/m²/leaf area m/year between trees in stands that were thinned plus fertilized and trees in stands that were only thinned. Our data indicate there may be a relationship between the amount of phenolics and sugars produced in root bark tissue of *P. menziesii* trees and *A. ostoyae* infection rates.

Light, water and nutrients are critical resources for photosynthesis and plant growth. The relative amounts of these substances available to a tree plays an important role in how it allocates its resources internally. Biosynthetic processes can be influenced by these three environmental parameters. Lignin, tannins and phenolics are synthesized via the shikimic acid pathway (Goodwin and Mercer 1985) and often increase in concentration when growth is reduced and photosynthate is available (Waterman and Mole 1989). High amounts of nitrogen may shift carbon allocation away from the shikimic acid pathway, reducing the biosynthesis and concentrations of phenolic compounds and lignin in root tissues. Trees experiencing fast growth rates, or limited carbon production, may preferentially allocate carbon to primary cell wall development producing compounds such as hemicellulose and cellulose. Our experimental trees in the untreated stands experienced some light competition due to crown closure; however, they were not suppressed.

Results of our study are similar to those of others who analyzed phenolic concentrations in leaf tissues. Bryant *et al.* (1987) reported that N fertilization of *Betula resinifera* Marsh. increased tree growth, but decreased the concentration of leaf phenolics. Palo *et al.* (1985) found that as rapid growth of *Betula pendula* Roth. increased, the concentration of phenols in leaf tissue decreased and then rose again in the period of slower fall

growth. Davidson and Rishbeth (1988) reported that suppressed *Pinus sylvestris* L. and *Quercus robur* L. were preferentially infected by *A. ostoyae* and *Armillaria mellea* (Vahl ex. Fr) Qual.

Fungi can only degrade phenolic compounds and lignin when an additional carbon source is present and the rate is directly proportional to the amount of additional carbon (Kirk *et al.* 1976). The low sugar concentrations in the roots of trees growing in stands that have been thinned may provide less energy for *A. ostoyae* to degrade phenolic compounds and lignin. Thinning plus fertilization of *P. menziesii* may increase the growth rates to the point where more carbon is allocated to sugars and cellulose and less to phenolic compounds and lignin. Our data suggests that thinning *P. menziesii* stands may be an important silvicultural tool to keep trees in a physiological condition resistant to *A. ostoyae* attack.

Management Implications

Inoculum potential should be the major consideration when reforesting an *Armillaria* infested area (Rishbeth 1988). Before deciding to thin an *Armillaria* infested stand, managers must take into account the amount of potential *Armillaria* inoculum that may remain on site after treatment. Thinning a stand may produce *P. menziesii* trees more resistant to *A. ostoyae*, but the effect may be negated by a large amount of potential inoculum in the form of dead root biomass left on site. Previous studies indicate that commercial thinning provides an ample amount of root biomass which acts as an energy source for the fungus and can increase the incidence of the disease (Morrison *et al.* 1988; Filip 1979). If *P. menziesii* stands are thinned to the desired spacing when trees are small, residual root biomass is low compared to commercial thinnings. This helps to ensure a low source of potential inoculum and can be an effective tool to control the disease (Roth *et al.* 1977; Johnson and Thompson 1975). Precommercial thinning plus fertilization, while improving tree growth, may create a stand more susceptible to *A. ostoyae* infection. One should be sure that there is no pathogenic species of *Armillaria* on the site before using this treatment.

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