Approaches to Integrated Pest Management of Fusarium Root Disease in Container-Grown Conifer Seedlings[1]

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James, R.L.; Dumroese, R.K.; Wenny, D.L. 1990. Approaches to Integrated Pest Management of Fusarium Root Disease in Container-Grown Conifer Seedlings. In: Rose, R.; Campbell, S.J.; Landis, T. D., eds. Proceedings, Western Forest Nursery Association; 1990 August 13-17; Roseburg, OR. General Technical Report RM-200. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 240-246. Available at: http://www.fcanet.org/proceedings/1990/james.pdf

Abstract - An integrated approach to management of *Fusarium* root disease in container-grown conifer seedlings includes reducing levels of pathogen inoculum within the seedling growing environment, enhancing host resistance to infection and disease development, encouraging organisms competing with or antagonistic toward pathogenic *Fusarium* spp., and minimizing use of chemical fungicides whenever possible. Integrating these procedures into standard growing regimes should greatly reduce impact of *Fusarium* root disease.

INTRODUCTION

Diseases caused by *Fusarium* spp. are important limiting factors in the production of container-grown conifer seedlings in the western United States and Canada (James and Gilligan 1985 James and others 1987, 1989; Sutherland and others 1989). Several types of diseases associated with these pathogenic fungi have been identified, including pre- and post-emergence damping-off and cotyledon blight of young germinants, and root diseases of older seedlings (James 1986a, 1987b).

Root disease is especially difficult to control because once symptoms appear on seedlings, their root systems are usually extensively colonized with pathogenic fungi (James and others 1987). Chemical fungicide applications are largely ineffective in reducing further damage (James 1986b) and trying to save these seedlings is usually unsuccessful (James and others 1988c). A more reliable approach is to prevent infection when seedlings are young.

Several investigations (Bloomberg 1971, 1973; Hansen and Hamm 1988; James 1985c; James and others 1987) have shown that shortly after seeds germinate, germinants often become infected with *Fusarium.* Pathogen inoculum may reside on or within planted seed (James 1986a, 1987b), or on the inner walls of containers used to grow seedlings (James and Gilligan 1988b, 1988c;James and others 1988a;Sturrock and Dennis 1988). Once infected, seedlings may or may not display disease symptoms which result from decay of root systems, such as foliar chlorosis and necrosis or wilting (James and Gilligan 1988a; James and others 1987). Expression of disease symptoms in infected seedlings is enhanced by late season hardening and bud initiation stress (James and Gilligan 1985; James and others 1987).

Because of problems controlling *Fusarium* root disease with chemical fungicides (James and others 1988c), efforts have recently focused on an integrated approach to reduce disease damage using cultural, biological and chemical methods of control. This paper discusses techniques that have either proven effective or hold promise for reducing losses from *Fusarium* root disease in container-grown conifer seedlings. Four aspects of an integrated pest management program have been identified. Each will be discussed under its appropriate heading.

REDUCTION OF PATHOGEN INOCULUM

To reduce infection levels, it is important to limit pathogen inoculum within and adjacent to the seedling growing environment. Since seed is often an important inoculum source in container seedling operations (James 1986a, 1987b), steps to reduce amounts of seedborne *Fusarium* are necessary. Past evaluations have indicated that most *Fusarium* is carried externally on seedcoats (James 1984,1985b, 1986b). Rarely does this fungus actually penetrate the seedcoat to infect seed endosperm or embryo (Bloomberg 1966). Several types of chemicals have been tested to reduce seedborne *Fusarium.* Common surface sterilants like household bleach (active ingredient = sodium hypochlorite) and hydrogen peroxide are usually effective in reducing levels of *Fusarium* on seed (Advincula and others 1983; Barnett 1976; James and Genz 1981). However, some problems with seedling toxicity and reduced seed germination have occurred, especially with hydrogen peroxide (Edwards and Sutherland 1979; James and Genz 1981). Bleach treatments have been more successful and are often used operationally by some nurseries (Dumroese and others 1988; Wenny and Dumroese 1987). Common fungicides applied directly to seed have limited utility, partly because they may adversely affect seed germination (Dick and others 1958; Peterson 1970; Shea 1959) and young seedling growth (Cooley 1983; Lock and others 1975). Perhaps one of the most effective and least toxic treatments is standard water, either heated or applied over seed as a running water rinse (Dumroese and others 1988). Water heated with microwaves was effective in eliminating *Fusarium* on seedcoats (James and others 1988b); however, care must be taken not to exceed temperatures lethal to seeds. Running water rinses for at least 48 h have proven effective in reducing seedborne *Fusarium* without adversely affecting seed germination (Dumroese and others

[1]Paper presented at the 1990 Conference of the Western Forest Nursery Council, Roseburg, Oregon, August 13-17, 1990.

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1988; James 1984, 1987a). Therefore, procedures are available for reducing seedborne *Fusarium* inoculum without adversely affecting germination or establishment of young germinants.

Seedling containers may accumulate *Fusarium* inoculum when reused several times without adequate cleaning (James and Gilligan 1988b, 1988c; James and others 1988a; Sturrock and Dennis 1988). Contaminated styroblock and Ray Leach ® pine cells have been implicated as important inoculum sources for new seedling crops. Most *Fusarium* inoculum resides near the bottom of containers (James 1989b; James and others 1988a), probably existing on remaining organic debris, such as pieces of soil mix, roots and algal growth which is inadequately removed during cleaning. Most growers have used high pressure steam for cleaning their containers, sometimes followed with immersion in a bleach solution. Although such operations reduce amounts of *Fusarium,* enough inoculum usually survives to cause problems to the next crop (James and others 1988a). Recent investigations (James and Woollen 1989; Sturrock and Dennis 1988) have shown effective elimination of *Fusarium* on containers immersed in hot water (68-80°C) for 3-10 minutes. A solubilized spreader such as R-11 or standard detergent is often added to water to ensure all container surfaces come into contact with hot water. Styroblock containers probably require exposure to higher temperatures for longer durations than pine cells (James and others I988a). Another promising treatment is immersion of containers in sodium metabisulfite, a chemical used to kill yeast organisms in brewing (Sturrock and Dennis 1988). This chemical is toxic to fungi when mixed in a water solution. Major disadvantages of this treatment are chemical toxicity to workers and problems of solution disposal after use. For these reasons, most growers are implementing some form of hot water immersion for cleaning their containers.

Another possible source of *Fusarium* inoculum in container operations is the growing media Most pre-mixed peat/ vermiculite growing media are usually pathogen free (James 1985a). This media may contain high populations of potentially antagonistic fungi, such as *Trichoderma* spp. (James 1985a, 1989a). However, if *Fusarium* spp. are introduced into growing media, they may quickly colonize it and cause severe disease problems (James 1985a; James and Gilligan 1984). Therefore, it is important to prevent pathogen introduction into the media. If contamination is suspected, steaming the media (82°C for 30 min) will usually eliminate pathogens, while allowing some beneficial microorganisms to survive (Baker and Olsen 1959; Hartmann and others 1990).

Keeping the growing environment clean is important in reducing problems from *Fusarium* and other pathogenic fungi. Greenhouse interiors, including floors, walls, ceilings, and benches should be thoroughly cleaned and sanitized between crops. Organic debris, which may harbor *Fusarium* inoculum, should be eliminated as much as possible (James and others 1987). Standard sterilants such as bleach or similar household products are usually effective in cleaning these surfaces. Unfortunately, some greenhouses have dirt or gravel floors, surfaces nearly impossible to sterilize. Higher disease losses are expected in greenhouses without concrete floors (James and others 1988c).

Another potential inoculum source in container operations is irrigation water. Pathogen propagules may readily colonize some nursery water supplies, especially those from, or exposed to ponds, streams, or ditches. Well water is usually much less contaminated (Landis and others 1989). Although *Fusarium* spp. are not important water contaminates (Burgess 1981), propagules of *Fusarium* may be carried in water and subsequently introduced into crops (Cook 1981).

Some *Fusarium* spp. pathogenic to conifer seedlings may also colonize other hosts. For example, greenhouse weeds may be infected with *Fusarium oxysporum* Schlecht., which is pathogenic to conifer seedlings (James and others 1987, 1989). Weeds just outside greenhouses may also serve as hosts to *Fusarium* spp. (Landis and others 1990). It is important that these other hosts which serve as inoculum reservoirs be eliminat-ed.

A final way of reducing amounts of *Fusarium* inoculum within the growing environment is periodic removal of diseased seedlings. Several pathogenic *Fusarium* species produce spore-containing structures called sporodochia on above-ground portions of diseased seedlings (Nelson and others 1983). Spores released from these structures may be disseminated via irrigation splash and air currents to infect nearby seedlings (Burgess 1981; Cook 1981). Therefore, if diseased seedlings are removed before sporodochia form and release spores, threat to other seedlings is reduced. Dead seedlings left in greenhouses may also become colonized by other pathogens, such as *Botrytis* thereby enhancing potential of these pathogens to cause greater problems (Landis and others 1990). Diseased seedlings should be carefully removed, placed in bags and removed to disposal areas that will not threaten nursery seedlings.

ENHANCE HOST RESISTANCE

Most conifer species are susceptible to *Fusarium* root infection at some level, but disease expression by infected seedlings varies greatly among different species and among individuals of a single species. For example, although ponderosa pine seedlings are often infected with *Fusarium* spp., they rarely display disease symptoms (James and Gilligan 1988a). However, Douglas-fir (James and others 1987), Engelmann spruce (James and Gilligan 1985), and western larch (James 1985c) seedlings display disease symptoms much more commonly.

Several factors probably influence level of disease expression of infected seedlings. These might include seedling moisture stress (Bloomberg 1976), greenhouse temperatures (especially extremes) (Bloomberg 1976; Tint 1945b), and nutrient levels within seedlings and the growing media (Bloomberg 1985; Tint 1945a). Seedlings infected with *Fusarium* often display disease symptoms toward the end of the growth cycle when they are water and nutrient stressed to initiate bud set (James and others 1987, 1988c). From a disease expression standpoint, it is probably important to limit both water and nutrient stress to the least amount necessary to initiate bud set. Recent work (Montville and Wenny 1990) indicates nutrient stress may be unnecessary for bud initiation, and foliar applied fertilizers can be used to reduce nutrient stress during periods of reduced moisture applications. If infected seedlings are stressed for prolonged periods, they will probably become diseased, i.e. fungi colonizing their roots become active and "pathogenic," eliciting disease expression (Bloomberg 1971). Temperature may be very important in disease expression since most pathogenic *Fusarium* spp. are considered warm weather fungi. That is, they grow more rapidly (Booth 1971; Nelson and others 1983) and are more pathogenic (Bloomberg 1976; Tint 1945b) when temperatures are high. Bareroot stock often displays disease symptoms when ambient temperatures exceed certain thresholds (Bloomberg 1971, 1973, 1976), particularly in July and August. Fortunately, green-house temperatures can be regulated during most of the growing season. However, if seedlings are moved outdoors to shade

houses, temperature control is lost. Since this usually occurs in conjunction with moisture and nutrient stress to enhance bud set (Landis and others 1989), *Fusarium* root disease often becomes most apparent after seedlings are placed outside and temperatures become warm (James and others 1987, 1988c). Keeping seedlings cool with irrigation may help alleviate this problem.

Early literature dealing with damping-off of conifer seedlings (Rathbun 1922; Rathbun-Gravatt 1925; Spaulding 1914; Tint 1945a) emphasized the importance of regulating nutrient applications during periods when young germinants are susceptible to damping-off fungi. Adding nutrients (especially nitrogen) during seedling emergence but before stem lignification enhances damping-off losses by making seedlings more succulent. Added nutrients may also promote growth of pathogenic fungi (Landis and others 1989). Therefore, it is important to regulate fertilizer during the critical stage of seedling establishment and promote rapid lignification of germinant stems.

ENCOURAGE COMPETING AND ANTAGONISTIC ORGANISMS

Fusarium spp. compete with a wide range of microorganisms in natural soil. Several different types of organisms will commonly occupy the same niches as *Fusarium,* i.e. root cortical cells and rhizospheres. If nonpathogenic organisms occupy these sites first, pathogenic *Fusarium* spp. may be excluded and therefore unable to infect and elicit disease. In addition, many soil microorganisms produce antibiotics which give them competitive advantages (Baker and Cook 1974; Brian and McGowan 1945; Papavizas 1985; Weindling and Emerson 1936). Antagonism and competition are important in the balance of organisms colonizing organic substrates in soil. If specific microorganisms that display both competitive and antagonistic properties can be introduced into nursery systems, it is possible to exert biological control on pathogenic organisms such as *Fusarium* (Baker and Cook 1974).

Several types of organisms have potential as biological control agents of pathogenic fungi. Bacteria in the genus *Pseudomonas* and actinomycetes in the genus *Streptomyces* are potentially important biocontrol agents (Baker and Cook 1974; Brown 1972). Perhaps the most widely studied group of potential biocontrol agents are fungi in the genera *Trichoderma* and *Gliocladium* (Papavizas 1985). Several of these fungi successfully compete with, are antagonistic toward, and parasitize plant pathogenic fungi. *Trichoderma* spp. are often very fast growing and rapidly colonize substrates, thus excluding pathogens such as *Fusarium* spp. Several of these fungi are also parasitic on other fungi including plant pathogens (Ayers and Adams 1981; Hubbard and others 1983; Papavizas 1985). Recently, special strains of *Trichoderma* have been genetically engineered to be more effective biocontrol agents (Stasz and others 1988). When introduced on seed or within the growing medium, these strains rapidly colonize the rhizosphere and may exclude host invasion by plant pathogens (Harman and Taylor 1988; Harman and others 1989). Unfortunately, these engineered biocontrol agents are yet to be tested for their efficacy to control *Fusarium* root disease in container-grown conifer seedlings. However, such evaluations are planned.

Another interesting possibility for biocontrol involves inoculating nursery seedlings with nonpathogenic strains of *Fusarium* (especially *F. ozysporum)* to exclude invasion of host roots by pathogenic strains. This "cross protection" has been effective in several agricultural systems (Damicone and Manning 1982; Davis 1967). The rationale behind this approach is that sites commonly colonized by pathogens can just as easily be colonized by nonpathogenic (saprophytic) strains of the fungus. Since many *Fusarium* spp. are rapid colonizers of root cortical tissues (Booth 1971; Nelson and others 1983), by introducing nonpathogenic strains, these sites can be occupied preferentially by desirable organisms. Of course, it is important that strains of *Fusarium* used for biocontrol are nonpathogenic under all potential conditions for host production. Pathogenicity tests with *Fusarium* spp. isolated from conifer seedlings have identified several nonpathogenic strains (James and others 1989), but these strains have yet to be tested for their ability to "cross protect" hosts from pathogenic strains.

Ectomycorrhizal fungi may display antagonism toward some plant pathogenic fungi (Marx 1972; Sinclair and others 1975; Stack and Sinclair 1975). Mycorrhizal symbionts usually colonize fine root tips and provide a physical barrier to pathogen colonization; these symbionts may also produce antibiotics which restrict development of some pathogens (Marx 1972; Stack and Sinclair 1975). Most young container-grown seedlings are nonmycorrhizal, but infection increases towards the end of the growth cycle, especially if seedlings are placed outside where mycorrhizal inoculum is more available. However, it is possible to inoculate seedlings with mycorrhizae a few weeks after germination (Castellano and others 1985; Sinclair 1974). Specific mycorrhizal symbionts have been developed for specific conifer species. These symbionts may improve seedling performance and be antagonistic toward potential plant pathogens. Since not all mycorrhizal fungi are equally beneficial to particular hosts, it is important to introduce those organisms best adapted to specific hosts (Castellano 1987). Although some inoculation of container-grown seedlings has been successful (Castellano and others 1985; Marx and others 1982), much more work is needed to evaluate specific responses of some conifer species and effects of mycorrhizal symbionts on plant pathogens.

MINIMIZE CHEMICAL FUNGICIDES

Previously, many growers have attempted to control *Fusarium* root disease by using chemical fungicides once disease symptoms are apparent. As mentioned earlier, such an approach has been largely unsuccessful because once disease symptoms are seen, seedling roots are often completely colonized with pathogenic fungi. In general, most fungicides are more effective in preventing infection than curing infected seedlings (Delp 1980). Although fungicides may be effective during the damping-off phase, they are usually ineffective later in the growth cycle when seedlings are several months old (James and others 1988c). For example, benomyl is commonly used against damping-off (Landis and others 1990), but is ineffective against *Fusarium* root disease later in the growing season (Shrimpton and Williams 1989). Further, most pathogen inoculum is concentrated near the bottom of plugs in container-grown seedlings (James 1989b) and it is unlikely that fungicides readily penetrate throughout the root zone in sufficient concentrations to be effective against pathogens.

Another potential problem from fungicide usage is development of resistance to specific chemicals by pathogenic fungi (Dekker 1976; Delp 1980). Resistance has been demonstrated for several plant pathogenic fungi, especially those subjected to consistently high doses of a specific fungicide. Although foliar pathogens most commonly develop resistance, some root pathogens have also become resistant to certain chemicals

(Dekker 1976; Georgopoulos and Zaracovitis 1967). By minimizing exposure of pathogenic fungi to chemical fungicides, selection pressures for fungi to develop resistance are reduced.

An integrated management program for *Fusarium* root disease should discourage indiscriminate use of fungicides for the reasons discussed above. When used, they should be for a specific purpose (such as to control damping-off if losses are relatively high). Experience has shown that much pesticide use is unnecessary and does not reduce disease (Dumroese and others 1990). Reducing fungicide use will also reduce costs of seedling production, problems with worker exposure to potentially toxic chemicals, and potential problems with contamination of nursery sites and nearby groundwater.

CONCLUSIONS

Fusarium root disease of container-grown conifer seedlings can be satisfactorily controlled by implementing an integrated approach to disease management. Such an approach should be designed to prevent initial infection by pathogenic fungi. This can be done most effectively by reducing levels of pathogen inoculum within and adjacent to the growing environment, providing growing conditions more beneficial to the growth of host plants than pathogenic fungi, encouraging proliferation and development of competing and antagonistic organisms, and minimizing use of chemical fungicides. Integrated disease management using these approaches should help growers reduce losses from *Fusarium* root disease while placing less emphasis on chemical control.

LITERATURE CITED

Advincula, B. A., J. Y. Woo and A. D. Partridge. 1983. A method for germination of western white pine seeds. Unpublished report. 4p. College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow.

Ayers, W. A. and P. B. Adams. 1981. Mycoparasitism and its application to biological control of plant diseases. p. 91-103. *In* Biological control in crop production. 46lp. Allaneheld-Osmun Publishers, Totowa, NJ.

Baker, K F. and R. J. Cook. 1974. Biological control of plant pathogens. 433p. W. H. Freeman and Co., San Francisco, CA.

Baker, K F. and S. M. Olson. 1959. Soil steaming. California State Florist Association Bulletin 8(9):1-10.

Barnett, J.P. 1976. Sterilizing southern pine seeds with hydrogen peroxide. Tree Planters' Notes 27(3): 17-19.

Bboomberg, W. J. 1966. The occurrence of endophytic fungi on Douglas-fir seedlings and seeds. Canadian Journal of Botany 44:413-420.

Bboomberg, W. J. 1971. Diseases of Douglas-fir seedlings caused by *Fusarium oxysporum.* Phytopathology 61:467-470.

Bloomberg, W. J. 1973. Fusarium root rot of Douglas-fir seedlings. Phytopathology 63:337-341.

Bloomberg, W. J. 1976. Simulation of Douglas-fir seedling root growth, damping-off, and root rot. Canadian Forestry Service. Rept. BC-X-127. 43p. Pacific Forest Research Centre, Victoria, B. C., Canada.

Bloomberg, W. J. 1985. The epidemiology of forest nursery diseases. Annual Review of Phytopathology 23:83-96.

Booth, C. 1971. The genus *Fusarium.* 237p. The Commonwealth Mycological Institute, Kew, Surrey, England.

Brian, P. W. and J. C. McGowan. 1945. Viridin: a highly fungistatic substance produced by *Trichoderma viride.* Nature 156:144-145.

Brown, M. E. 1972. Plant growth substances produced by microorganisms of soil and rhizosphere. Journal of Applied Bacteriology 35:443-451.

Burgess, L W. 1981. General ecology of the Fusaria. p. 223-235. *In Fusarium:* diseases, biology and taxonomy. 457p. The Pennsylvania State University Press, University Park, PA.

Castellano, M. A. 1987. Ectomycorrhizal inoculum production and utilization in the Pacific Northwestern U.S. - a glimpse at the past, a look to the future. p. 290-292. *In* Mycorrhizae in the next decade: Practical applications & research priorities. Proceedings 7th North American Conference on Mycorrhizae [Gainesville, FL, May 3-8, 1987]. University of Florida, Institute of Food and Agricultural Sciences, Gainesville, FL

Castellano, M. A., J. M. Trappe and R. Molina. 1985. Inoculation of container-grown Douglas-fir seedlings with basidiospores of *Rhizopogon vinicolor* and *R. colossus:* effects of fertility and spore application rate. Canadian Journal of Forest Research 15:10-13.

Cook, R. J. 1981. Water relations in the biology of *Fusarium.* p.236-244. *In Fusarium:* diseases, biology, and taxonomy. 457p. The Pennsylvania State University Press, University Park, PA.

Cooley, S. J. 1983. Fungicide trials on sugar pine at a southern Oregon nursery. Tree Planters' Notes 34(3):1 5-18.

Damicone, J. P. and W. J. Manning. 1982. Avirulent strains of *Fusarium oxysporum* protect asparagus seedlings from crown rot. Canadian Journal of Plant Pathology 4:143-146.

Davis, D. 1967. Cross-protection in *Fusarium* wilt diseases. Phytopathology 57:311-314.

Dekker, J. 1976. Acquired resistance to fungicides. Annual Review of Phytopathology 14:405-428.

Delp, C. J. 1980. Coping with resistance to plant disease control agents. Plant Disease 64(7):652-657.

Dick, J., M. J. Finnis, L 0. Hunt and N. B. Kuerno. 1958. Treatment of Douglas-fir seed to reduce loss to rodents. Journal of Forestry 56:660-661.

Dumroese, R. K., R. L James, D. L Wenny and C. J. Gilligan. 1988. Douglas-fir seed treatments: effects on seed germination and seedborne organisms. p. 155-160. *In* Combined Meeting of the Western Forest Nursery Associations [Vernon, British Columbia, August 8-11, 1988]. USDA Forest Service, General Technical Report RM-167. 227p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Dumroese, R. K, D. L Wenny and K. E. Quick. 1990. Reducing pesticide use without reducing yield. Tree Planters' Notes (In press).

Edwards, D. G. W. and J. R. Sutherland. 1979. Hydrogen peroxide treatment of *Abies* seeds. Canadian Forestry Service, Bi-Monthly Research Notes 35:3-4.

Georgopoulos, S. G. and C. Zaracovitis. 1967. Tolerance of fungi to organic fungicides. Annual Review of Phytopathology 5:109-130.

Hansen, E. M. and P. B. Hamm. 1988. Canker diseases of Douglas-fir seedlings in Oregon and Washington bareroot nurseries. Canadian Journal of Forest Research 18:1053-1058.

Harman, G. E. and A. G. Taylor. 1988. Improved seedling performance by integration of biological control agents at favorable pH levels with solid matrix priming. Phytopathology 78:520-525.

Harman, G. E., A. G. Taylor and T. E. Stasz. 1989. Combining effective strains of *Trichoderma harzianuin* and solid matrix priming to improve biological seed treatments. Plant Disease 73:631-637.

Hartrnann, H. T., D. E. Kester and F. T. Davies. 1990. Plant propagation.Fifth edition. 647 p. Prentice-Hall Co., Engelwood Hills, NJ.

Hubbard, J. P., G. E. Harman and Y. Hadar. 1983. Effect of soilborne *Pseudomonas* spp. on the biological control agent, *Trichoderma hamatum,* on pea seeds. Phytopathology 73:655-659.

James, R. L 1984. Fungi colonizing Douglas-fir seed at the Champion Timberlands Nursery, Plains, Montana. USDA Forest Service Report 84-13. 3p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L. 1985a Diseases associated with containerized seedling soil mixes. Tree Planters' Notes 36(2):3-5.

James, R. L 1985b. Pathogenic *Fusarium* on spruce seed from the Towner Nursery, North Dakota USDA Forest Service Report 85-23. 9p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L 1985c. Studies of *Fusarium* associated with containerized conifer seedling diseases: (2). Diseases of western larch, Douglas-fir, grand fir, subalpine fir, and ponderosa pine seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service Report 85-12. 7p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L1986a Diseases of conifer seedlings caused by seed-borne *Fusarium* species. p. 267-271. *In* Conifer tree seed in the Inland Mountain West: Proceedings of the symposium. [Missoula, MT, August 5-6, 1985]. USDA Forest Service, General Technical Report INT-203. 289p. Inter-mountain Forest and Range Experiment Station, Ogden, UT.

James, R. L 1986b. Occurrence of *Fusarium* on Douglas-fir seed and containerized seedlings at the Plum Creek Nursery, Pablo, Montana USDA Forest Service Report 86-4. 10p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L 1987a Effects of water rinse treatments on occurrence of fungi on spruce seed from the Towner Nursery, North Dakota USDA Forest Service Report 87-5. 4p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L 1987b. Occurrence of *Fusarium* on conifer tree seed from northern Rocky Mountain nurseries. p. 109-114. *In* Combined Western Forest Nursery Council and Intermountain Nursery Association: Proceedings of the meeting. [Tumwater, WA, August 12-15, 1986]. USDA Forest Service, General Technical Report RM-137. 164p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

James, R. L 1989a Fungi colonizing tree improvement peat-vermiculite media, USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service Nursery Disease Notes #85. 4p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L 1989b. Spatial distribution of fungi colonizing Leach pine cell containers - USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service Report 90-3. 7p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L, R. K Dumroese, C. J. Gilligan and D. L Wenny. 1989. Pathogenicity of *Fusarium* isolates from Douglas-fir seed and container-grown seedlings. Idaho Forest, Wildlife and Range Experiment Station Bulletin No. 52. 10p. University of Idaho, Moscow.

James, R. L, R. K. Dumroese and D. L Wenny. 1988a. Occurrence and persistance of *Fusarium* within styroblock and Ray Leach containers. p. 145-148. *In* Combined meeting of the Western Forest Nursery Associations: Proceedings of the meeting. [Vernon, British Columbia, August 8-11, 1988]. USDA Forest Service, General Technical Report RM-167. 227p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

James, R. L, R. K. Dumroese, D. L Wenny, J. F. Myers and C. J. Gilligan. 1987. Epidemiology of *Fusarium* on containerized Douglas-fir seedlings. 1. Seed and seedling infection, symptom production, and disease progression. USDA Forest Service Report 87-13. 22p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L and D. Genz. 1981. Ponderosa pine seed treatments: effects on seed germination and disease incidence. USDA Forest Service Report 81-16. 13p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L and C. J. Gilligan. 1984. Studies of *Fusarium* associated with containerized conifer seedling diseases: pathogenicity tests of isolates from the Alpine Nursery, Kalispell, Montana. USDA Forest Service Report 84-14. 29p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L and C. J. Gilligan. 1985. Containerized Engelmann spruce seedling diseases at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service Report 85-17. 15p. Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L. and C. J. Gilligan. 1988a. Association of *Fusarium* with non-diseased containerized ponderosa pine seedlings at the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service Report 88-5. 10p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L. and C. J. Gilligan. 1988b. Fungal colonization of styroblock containers - Plum Creek Nursery, Pablo, Montana. USDA Forest Service Report 88-10. 9p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L and C. J. Gilligan. 1988c. Occurrence of *Fusarium* on Leach pine cells from the USDA Forest Service Nursery, Coeur d'Alene, Idaho. USDA Forest Service Report 88-8. 10p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L., C. J. Gilligan, R. K Dumroese and D. L Wenny. 1988b. Microwave treatments to eradicate seed-borne fungi on Douglas-fir seed. USDA Forest Service Report 88-7. 8p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L., C. J. Gilligan and V. Reedy. 1988c. Evaluation of root diseases of containerized conifer seedlings at the Champion Timberlands Nursery, Plains, Montana USDA Forest Service Report 88-11. 21p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

James, R. L and R. L. Woollen. 1989. An evaluation of the efficacy of hot water-chemical treatments to clean styroblock containers - Champion Timberlands Nursery, Plains, Montana USDA Forest Service Report 89-5. 8p. Timber, Cooperative Forestry and Pest Management, Northern Region, Missoula, MT.

Landis, T. D., R. W. Tinus, S. E. McDonald and J. P. Barrett. 1989. The container nursery manual. Volume four: Seedling nutrition and irrigation. 119p. USDA Forest Service. Agriculture Handbook 674. Washington, D.C.

Landis, T. D., R. W. Tinus, S. E. McDonald and J. P. Barrett. 1990. The container nursery manual. Volume five: The biological component: Nursery pests and mycorrhizae. 171p. USDA Forest Service. Agriculture Handbook 674. Washington, D.C.

Lock, W., J. R. Sutherland and L J. Sluggett. 1975. Fungicide treatment of seeds for damping-off control in British Columbia forest nurseries. Tree Planters' Notes 26(3):16-18.

Marx, D. H. 1972. Ectomycorrhize as biological deterrants to pathogenic root infection. Annual Review of Phytopathology 10:429-454.

Marx, D. H., J. L Ruehle, D. S. Kenney, C. E. Cordell, J. W. Riffle, R. J. Molina, W. H. Pawuk, S. Navratil, R. W. Tinus and O. C. Goodwin. 1982. Commercial vegetative inoculum of *Pisolithus tinctorius* and inoculation techniques for development of ectomycorrhizae on container-grown tree seedlings. Forest Science 28:373-400.

Montville, M. E. and D. L. Wenny. 1990. Foliar fertilization of container-grown ponderosa pine and Douglas-fir seedlings. In these Proceedings.

Nelson, P. E., T. A. Toussoun and W. F. O. Marasas. 1983. *Fusarium* species: an illustrated manual for identification. 193p. The Pennsylvania State University Press, University Park, PA.

Papavizas, G. C. 1985. *Trichoderma* and *Gliocladium:* biology, ecology, and potential for biocontrol. Annual Review of Phytopathology 23:23-54.

Peterson, G. W. 1970. Seed-protectant chemicals affect germination of ponderosa pine seed. Tree Planters' Notes 21(4) :25-29.

Rathbun, A. E. 1922. Root rot of pine seedlings. Phytopathology 12:213-220. Rathbun-Gravatt, A. E. 1925. Direct inoculation of coniferous stems with damping-off fungi. Journal of Agricultural Research 30(4):327-339.

Shea, K R. 1959. Phytotoxicity of thiram to Douglas-fir seed. Forest Research Note 21. 5p. Weyerhaeuser Timber Company, Centralia, WA.

Shrimpton, G. and F. Williams. 1989. Benomyl drenches: no control for *Fusarium* and *Cylindrocarpon* caused root rot of container-grown conifer seedlings. Forestry Canada! British Columbia Ministry of Forests. FRDA Research Memo #128.

Sinclair, W. A. 1974. Development of ectomycorrhizae in a Douglas-fir nursery. I. Seasonal characteristics. Forest Science 20:51-56.

Sinclair, W. A., D. P. Cowles and S. M. Hee. 1975. Fusarium root rot of Douglas-fir seedlings: suppression by soil fumigation, fertility management, and inoculation with spores of the fungal symbiont *Laccaria laccata.* Forest Science 21:390-399.

Spaulding, P. 1914. The damping-off of coniferous seedlings. Phytopathology 4:73-88.

Stack, R. W. and W. A. Sinclair. 1975. Protection of Douglas-fir seedlings against *Fusarium* root rot by a mycorrhizal fungus in the absence of mycorrhiza formation. Phytopathology 65:468-472.

Stasz, T. E., G. E. Harman and N. F. Welden. 1988. Protoplast preparation and fusion in two biocontrol strains of *Trichoderma harzianum.* Mycologia 80:141 -150.

Sturrock, R. N. and J. J. Dennis. 1988. Styroblock sanitatization: results of laboratory assays from trials at several British Columbia forest nurseries. p. 149-154. *In* Combined meeting of the Western Forest Nursery Associations. Proceedings of the meeting. [Vernon, British Columbia, August 8-11, 1988]. USDA Forest Service, General Technical Report RM-167. 227p. Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Sutherland, J. R., G. M. Shrimpton and R. N. Sturrock. 1989. Diseases and insects in British Columbia forest seedling nurseries. Canada - British Columbia Forest Resource Development Agreement Report 065. 85p. Pacific Forest Research Centre, Victoria, B. C., Canada

Tint. H. 1945a. Studies in the *Fusarium* damping-off of conifers. II. Relation of age of host, pH, and some nutritional factors to the pathogenicity of *Fusarium.* Phytopathology 35:440-457.

Tint, H. 1945b. Studies in the *Fusarium* damping-off of conifers. III. Relation of temperature and sunlight to the pathogenicity of Fusarium Phytopathology 35:498-51 0.

Weindling, R. and 0. H. Emerson. 1936. The isolation of a toxic substance from the culture filtrate of *Trichoderma.* Phytopathology 26:1068-1070.

Wenny, D. L and R. K Dumroese. 1987. Germination of conifer seeds surface sterilized with bleach. Tree Planters' Notes 38(3):1 8-21.