Management of Fungal Diseases of Western Larch Seed and Seedlings

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Abstract—Several fungal diseases adversely affect production of western larch in container and bareroot forest nurseries. Grey mold caused by *Botrytis cinerea* may cause widespread problems; chemical pesticide use should be limited. Seedling protection from the pathogen *Meria laricis* can be sought with fungicides. *Fusarium* and *Cylindrocarponn*, among other pathogenic fungi, cause damping-off, cotyledon blight, and root disease. Reducing pathogen inoculum, enhancing host resistance, encouraging competing and antagonistic organisms, and minimizing chemical pesticide use are included in an integrated pest management system.

Production of western larch (*Larix occidentalis* Nutt.) seedlings in Pacific Northwest, U.S.A., nurseries has been steadily increasing for several years in response to greater demand for larch seedlings to reforest many sites, particularly those with severe root diseases (Byler 1982). Production of stock in sufficient numbers and quality is an important goal of many nurseries. However, production may be restricted by limited quantities of high-quality seed and by diseases that affect amounts and quality of seedlings produced.

Western larch seedlings are grown as bareroot or container stock. Bareroot stock takes one to two growing seasons, whereas container stock can be grown in 6 to 8 months. Both stock types are usually satisfactory for most reforestation requirements, and both may become diseased during nursery production.

Organisms normally incapable of causing problems on natural forest sites may cause extensive damage in nurseries because of inherent differences between these two environments. Production conditions that might incite organisms toward disease include large areas of monoculture, agricultural production practices, and greenhouse environments. Natural buffers that limit pathogen buildup in forest ecosystems are often absent in more artificial growing environments of nurseries. Also, many pathogens that affect nursery seedlings do not affect young trees in forest areas because the pathogens are unique to nurseries.

Although many pathogens are capable of infecting western larch seedlings in nurseries, relatively few cause severe enough damage to warrant concern or corrective action. This paper focuses on three major groups of diseases—two that cause foliar or top necrosis and one that affects root systems. Approaches to managing these diseases vary. Most nursery growers use an integrated approach to disease control, using cultural, biological, and chemical alternatives. Integrated pest management involves establishing threshold levels of disease, monitoring pest populations before and after treatments, using efficaceous treatments to keep disease levels within established thresholds, and keeping adequate records for all pest management activities.

BOTRYTIS BLIGHT

Grey mold caused by *Botrytis cinerea* (Fr.) Pers. is a major disease of western larch seedlings, particularly those grown within containers in greenhouses (James 1984). The fungus may cause some damage in bareroot beds, particularly when seedlings are overcrowded. Presence of free moisture on foliage for several hours and prolonged cool temperatures of about 13 to 14 °C determine the severity of the infection (Blakeman 1980). Wounded or necrotic tissues are initially infected. The fungus may spread to healthy tissues under conducive environmental conditions (Sutherland and Van Eerden 1980).

Larch's extensive production of necrotic foliage at the end of the growing season greatly contributes to its disease susceptibility. Many primary needles formed on young seedlings are lost as seedling growth ceases; these needles tend to accumulate at the base of seedlings and are easily infected by *Botrytis* spores, which are usually airborne (Jarvis 1980). Once colonization of necrotic needles occurs, the fungus spreads to adjacent seedling stems, causing infection and often killing individual seedlings. Over time, groups of seedlings become infected, and the fungus produces vast amounts of spores that spread to nearby seedlings, continuing the cycle (James 1984).

Management approaches to *Botrytis* blight stress prevention because of the difficulty in keeping disease in

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check once it becomes established (Maude 1980). The best control approach is to avoid environmental conditions suited for disease buildup (James 1984). This includes reducing seedling density to improve air circulation (Cooley 1981a) and limiting irrigation during periods of high host susceptibility. Adding drying agents to irrigation water may also help reduce infection (James 1984).

Control of fertilization will also influence level of disease; excess or improperly applied fertilizer may cause foliage to burn, providing infection courts for the pathogen; and too little fertilizer may stress seedlings, making them more susceptible to infection (Sutherland and Van Eerden 1980).

Another important cultural practice is sanitation, aimed primarily at reducing inoculum. Sanitation practices include periodic removal of dead or infected plants and plant debris and cleaning interior greenhouse spaces with a sterilant between seedling crops (Cooley 1981a). A recent innovative approach to sanitation that shows promise in reducing disease impact is removal of necrotic foliage from the tops of containers with a vacuum (Dumroese and others 1992). Although this approach is somewhat labor-intensive, it works well and is cost-effective when compared with chemical pesticide applications.

Many nursery growers traditionally control *Botrytis* blight with preventive applications of chemical fungicides during periods when seedlings are susceptible to infection. This often results in many applications of several different chemicals. In some cases, fungicide applications have been effective; in others, the level of effectiveness decreases with continued application (James 1984). Investigations have shown *Botrytis* can readily develop resistance to chemical fungicides, especially if one particular chemical is reused several times (Cooley 1981a; Gillman and James 1980; Miller and Fletcher 1974; Webster and others 1970).

Most growers have reduced chances of developing resistance by alternating several chemicals during pesticide application (Powell 1982). This makes the fungus less likely to develop resistance. For example, some growers alternate chlorothalonil with captan, dicloran, and systemic fungicides such as vinclozolin and iprodione to adequately control disease (James 1984).

Benomyl, a systemic fungicide with wide-ranging efficacy, was initially effective against *Botrytis* blight. However, after use for only a couple of crop cycles, this fungicide often became much less effective (Bollen and Scholten 1971). The chemical was ineffective against most strains of the pathogen (Cooley 1981a; Gillman and James 1980). Fungal strains that developed benomyl resistance retained this resistance indefinitely, even in the absence of the chemical (Maude 1980). Such experiences have resulted in less reliance by many growers on chemical fungicides to control *Botrytis* blight.

Management has become more focused on prevention, sanitation, and possible introduction of biological control agents. This latter approach is only in the formative stage with regard to *Botrytis* blight. However, recent successes with other crops (Tronsmo 1991) have encouraged this approach on conifer seedlings. Environmental contamination as well as concerns over human exposure to pesticides will reduce the future use of chemicals in nurseries. Fortunately, effective alternatives to chemicals are available. Many growers are determined to replace chemicals with other, more environmentally benign alternatives.

MERIA NEEDLECAST

Needlecast caused by *Meria laricis* Vuill. is a common disease that occurs in many natural stands of western larch (Dubreuil 1982). This disease can also occur in forest nurseries and is most often detected on bareroot seedlings during their second growing season (Cooley 1981b, 1984; James 1985b). *Meria* has been detected much less frequently on container-grown stock and on bareroot seedlings in their first growing season (James 1985b). The pathogen infects young, succulent needles early in spring. Spores are disseminated throughout periods of cool, wet weather, and several cycles may occur during the growing season (Dubreuil 1982). When environmental conditions are favorable, pathogen buildup may be rapid. Although needles are initially attacked, stems may be colonized and, under extreme conditions, entire seedlings killed (James 1985b). However, once warm, dry weather occurs, disease severity diminishes. If wet weather persists, the disease may cause extensive damage in bareroot beds despite control efforts (James 1985b).

Meria needlecast is most effectively managed by application of protective fungicides during periods of high seedling susceptibility (Cooley 1981b, 1984). Most growers have traditionally applied chlorothalonil (or similar foliar protectant fungicides), commencing in early spring when needles are forming (James 1991). Fungicide applications are geared toward preventing infection; therefore, several applications are usually required while young foliage is susceptible to infection and cool, wet weather persists (Cooley 1981b). Fungicide applications may be terminated once warm, dry weather occurs.

Unfortunately, fungicides may be only marginally effective if favorable environmental conditions for disease development persist throughout much of the growing season (James 1985b). Other, nonchemical approaches to control are currently unavailable. Because pathogen spores are airborne and can be disseminated long distances (Dubreuil 1982), preventing inoculum introductions into the nursery is usually impossible. Once the disease occurs within a particular nursery, it seems to persist indefinitely (James 1991). The disease has less impact in greenhouses because environmental conditions can be more easily controlled. However, in bareroot nurseries, growers are at the mercy of ambient conditions. When conducive conditions persist for extended periods during spring, some level of disease usually occurs in second-year bareroot seedlings. The management goal is to keep losses within tolerable limits until weather conditions no longer favor disease.

ROOT DISEASES

Root diseases affect both bareroot and container-grown seedlings. Probably the most important group of root pathogens are in the genus *Fusarium* (James and others 1991). These fungi damage a wide range of host plants including many agriculturally important crops. Conifer seedlings, including western larch, are susceptible to several different *Fusarium* species, the most common being *F. oxysporum* Schlecht., *F. proliferatum* (Matsushima) Nirenberg, *F. acuminatum* Ell. & Ev., *F. sporotrichioides* Sherb., and *F. solani* (Mart.) Appel & Wollenw. (James and others 1991). These fungi attack young seedlings, causing preemergence and postemergence damping-off (James 1986a, 1987). They also cause root disease of older seedlings throughout the growth cycle (James and others 1991). Damage may be especially severe on older container-grown seedlings stressed to induce hardening and bud set (James and Gilligan 1985; James and others 1987).

Other major root pathogens of western larch seedlings include species of *Cylindrocarpon* and *Pythium*. *Cylindrocarpon* spp. are common rhizosphere inhabitants that often colonize cortical tissues on seedling roots (Booth 1966). They may become pathogenic under certain conditions, although they are not usually aggressive pathogens. *Pythium* spp. are especially damaging under conditions of poor soil drainage and may initiate disease by decaying fine roots (Hendrix and Campbell 1973). Normally, *Pythium* damage is limited to bareroot beds with poor drainage where water accumulates. Damage to container-grown seedlings is rare and may be associated with overwatering and using poorly aerated growing media (James 1992).

Root diseases are especially difficult to control because once seedling symptoms appear, their roots are usually extensively colonized with pathogenic fungi (James and others 1987). Chemical fungicide applications may be effective in controlling damping-off but ineffective in limiting root disease of older seedlings (James 1986b). Recent approaches to controlling root diseases have focused on prevention and using integrated pest management to reduce losses (James and others 1990).

Integrated pest management of western larch root diseases aims to reduce pathogen inoculum, enhance host resistance, encourage competing and anagonistic microorganisms, and minimize chemical fungicides.

Reduction of Pathogen Inoculum

To reduce root pathogen infection levels, it is important to limit pathogen inoculum within and adjacent to seedling growing environments. Seed is often an important inoculum source of root pathogens, particularly *Fusarium* spp. (James 1986a; 1987). Steps taken to reduce pathogen inoculum introduced into nurseries on seed are important. Soaking seed in common surface sterilants such as household bleach (active ingredient = sodium hypochlorite) and hydrogen peroxide are usually effective in reducing levels of pathogenic fungi (Advincula and others 1983; Barnett 1976; James and Genz 1981). Application of common fungicides to seed has limited utility because they may retard seed germination and young seedling growth (Dick and others 1958; Lock and others 1975; Peterson 1970). One of the most effective and least toxic treatments is tap water, either heated or applied over seed as a running water rinse (Dumroese and others 1988).

Seedling containers accumulate inoculum of root pathogenic fungi when repeatedly reused without adequate cleaning (James and Gilligan 1988a,b; Sturrock and Dennis 1988). Contaminated styroblock and Ray Leach® pine cells are important inoculum sources for new seedling crops (James and Gilligan 1988a,b). Most fungal inoculum resides near the container bottoms, probably existing on remaining organic debris such as pieces of growing media, roots, and algal growth inadequately removed during cleaning (James and others 1988). Recent investigations (James and Woollen 1989; Sturrock and Dennis 1988) have shown effective elimination of most pathogen inoculum on containers immersed in hot water (68 to 80 °C) for 3 to10 min. A soluble spreader such as R-11® or household detergent is often added to water to ensure that all container surfaces come into contact with hot water. Chemical sterilants such as sodium metabisulfite may also be used, although they have the disadvantage of being extremely caustic and somewhat dangerous (Sturrock and Dennis 1988). Hot water immersion of containers before reuse is the most satisfactory method.

Root pathogenic fungi may reside in nursery soil or growing media used to produce container seedlings. Nursery soil is often treated with broad-scale fumigants that kill all resident microorganisms, including pathogens (James 1989). Although expensive and dangerous to apply, these fumigants are effective in eliminating pathogens. However, the "biological vacuum" produced after fumigation may be invaded by the first introduced organisms. Care must be taken to ensure that pathogens are discouraged from introduction into newly fumigated soil. Soilless growing media used in container operations are pathogen-free, with some exceptions (James 1985a). The highly acidic nature of most growing media also discourages establishment by many pathogens. Media can be steam treated to eliminate potential pathogens while preserving desirable competing organisms (Baker and Olson 1959).

Keeping the growing environment clean is important in reducing problems from root pathogenic fungi. Many such fungi produce resting structures capable of surviving for long periods in the absence of suitable hosts (James and others 1987). Greenhouse interiors and the surface of implements used in bareroot seedling production may harbor these structures. Thoroughly cleaning these materials should reduce amounts of this inoculum introduced into new seedling crops.

Irrigation water may be an inoculum source for some root pathogens, particularly water molds such as *Pythium*. Nursery water from ponds, ditches, or streams may become contaminated with pathogens; deep wells are usually not contaminated (Landis and others 1989). Adequate filters or chemical treatment may be necessary to remove contaminants from water supplies.

Periodic inspections and sanitation procedures will go a long way in reducing pathogen inoculum in nurseries (James and others 1990). This is especially important in greenhouses where disease can spread and develop rapidly. Removal of diseased seedlings to prevent spread to surrounding, healthy seedlings is encouraged (Landis and others 1990). Sanitation coupled with the other

... are produced, often from a limited range of seed sources, little resistance occurs in nurseries. Many seedlings become infected with fungi capable of inducing disease. However, not all infected seedlings manifest disease symptoms (James and others 1990). Several factors probably influence the level of disease expression by infected seedlings. These might include seedling moisture stress, ambient and greenhouse temperatures, and nutrient levels within soil or growing media (Bloomberg 1985; Tint 1945a,b).

If infected seedlings are stressed for prolonged periods, they will probably become diseased. Temperature may be important in disease expression because most pathogenic *Fusarium* spp. are considered "warm weather" fungi, that is, they grow more rapidly and are more pathogenic when temperatures are high (Bloomberg 1976; Tint 1945b). Root disease in bareroot stock often occurs when ambient temperatures exceed certain thresholds in midsummer (Bloomberg 1976). In greenhouses, temperatures can be regulated during the growing season so that excessively high temperatures may be avoided.

Research on conifer root diseases has emphasized the importance of regulating nutrient applications during periods when young germinants are susceptible to damping-off fungi (Bloomberg 1976; Rathbun-Gravatt 1925; Tint 1945a). 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

To colonize, soil microorganisms usually compete with one another for nutrients, water, space, and organic matter. *Fusarium* spp. often occupy similar colonization niches of some other organisms (James and others 1990). If these niches are colonized by nonpathogens, exclusion of pathogenic *Fusarium* spp. may occur. Many soil microorganisms also produce antibiotics that may give them competitive advantages (Baker and Cook 1974; Papavizas 1985). Antagonism and competition are important in the balance of organisms colonizing organic substrates in soil (James and others 1990). 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* spp. (Baker and Cook 1974).

Organisms having potential as biological control agents include bacteria in the genus *Pseudomonas*, actinomycetes ... logical control agents (Stasz and others 1988). When introduced on seed or within the growing medium, these strains rapidly colonize the rhizosphere and may preclude host invasion by plant pathogens (Harman and Taylor 1988; Harman and others 1989). These biocontrol agents are yet to be tested on western larch seedlings to control *Fusarium* spp.

Inoculation of nursery seedlings with nonpathogenic strains of *F. oxysporum* offers another possibility for control (James and others 1990). These nonpathogens would occupy substrates to exclude pathogenic strains of the fungus. Saprophytic strains are well adapted to seedling root colonization and could exclude pathogen invasion. Such "cross protection" has been effective in several agricultural systems (Davis 1967). Pathogenicity tests of *Fusarium* spp. isolated from larch seedlings have yielded several nonpathogenic strains. However, these strains have yet to be tested for their ability to protect seedlings from pathogenic strains.

Ectomycorrhizal fungi may be antagonistic toward some plant pathogenic fungi (Marx 1972; Sinclair and others 1975). Ectomycorrhizal symbionts usually colonize fine root tips and provide a physical barrier to pathogen colonization (Marx 1972). These symbionts may also produce antibiotics that restrict development of some pathogens (Marx 1972; Stack and Sinclair 1975). Encouraging natural infection of nursery seedlings or introducing mycorrhizal inoculation into growing regimes may lessen the impact of root diseases (James and others 1990).

Minimize Chemical Fungicides

Many growers have attempted to control root diseases by using chemical fungicides once disease symptoms are apparent. Such an approach has been largely unsuccessful because once disease symptoms appear, seedling roots are usually compeletely colonized with pathogenic fungi (James and others 1987, 1990). Most fungicides are more effective in preventing infection rather than curing infected seedlings (Delp 1980). Therefore, it is easy to see why they have limited efficacy when applied after disease appears.

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 (James and others 1990). By minimizing exposure of pathogenic fungi to chemical fungicides, selection pressures for fungi to develop resistance are reduced.

Because experience has shown that much pesticide use is unnecessary and does not really reduce disease (Dumroese and others 1990), an integrated pest management program for root disease of western larch seedlings should discourage indiscriminate fungicide use. Fungicides should be used only for specific purposes, such as reducing levels of damping-off early in the crop cycle. Limiting fungicide use reduces cost of seedling production and problems with worker exposure to potentially toxic chemicals as well as potential environmental contamination.

CONCLUSIONS

Diseases affecting western larch seedlings in forest nurseries are best controlled by using principles of integrated pest management that minimize use of chemical pesticides. However, in some instances chemicals will be necessary to maintain disease losses within acceptable limits. This is especially true for *Meria* needle cast and sometimes for *Botrytis* blight.

Future emphasis on pest management in nurseries should focus on alternatives to chemicals whenever possible. This will result in greater emphasis on biological control. We have limited technology for biological control in forest tree nurseries. Few organisms are available for testing, and those that have thus far been tested have yielded disappointing results (James and others 1992).

We need development of more specific biological control agents for conifer seedlings that may be efficacious at particular sites. Satisfactory progress in this field will require increased commitment of resources for research of diseases and their control in forest tree nurseries. If such a commitment is made, the future should be bright for integrated pest management in nurseries.

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