AN OUTSIDE PERSPECTIVE ON GROWING LONGLEAF PINE—THOUGHTS FROM A NURSERY MANAGER IN THE PACIFIC NORTHWEST

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ABSTRACT—Nursery managers in the Pacific Northwest have decades of experience growing pine seedlings in containers. This wealth of information may benefit the South's newly emerging longleaf pine (*Pinus palustris* Mill.) container nursery industry. Container seedling root morphology, seedling nutrition, and integrated pest management (sanitation, chemical control, proper irrigation, disinfestation of seeds and containers) are pertinent to successful production of high-quality seedlings.

INTRODUCTION

For about 30 years in the Pacific Northwest growers have used containers to produce conifer seedlings for reforestation. During the evolution of the industry, growers have tried and modified many techniques to improve seedling quality; some they have discontinued. Three topics from the Pacific Northwest may benefit the South's developing container nursery industry: root morphology, seedling nutrition, and integrated pest management. Although currently a huge demand exists for longleaf pine (*Pinus palustris* Mill.) seedlings because of extensive planned planting projects (Outcalt 2000), progressive growers will strive for high-quality stock to ensure business despite future market fluctuations.

ROOT MORPHOLOGY

Whenever growers of container stock gather, discussions about root morphology of a good root system are abundant. Regardless of definitions, we must meet two criteria: (1) root systems must be sufficient to hold the medium together and withstand shipping, and (2) roots must be able to resume growth after outplanting in order for seedlings to survive and grow on the site. These goals form the business paradigm of root morphology. Poorly developed root systems look bad to our customers, and dead seedlings after planting look even worse. Using hard-sided containers, which are common in our industry, to meet this business paradigm may have risks. One risk that has received much attention is the potential for seedling toppling (Burdett 1978). In most containers, lateral roots contact the cavity wall, are deflected downward until they reach the cavity bottom, and are air-pruned at the drainage hole. After outplanting, these deflected lateral roots resume growth from the bottom of the root plug, often forming a "pivot-point" on which the root plug and seedling top can move, resulting in a toppled tree (Burdett and others 1986).

From this risk a biological paradigm has emerged root growth after outplanting should develop like that of a natural seedling. In forests, seedling lateral roots initiate and grow horizontally close to the soil surface (Baliskey and others 1995; Burdett 1978; Harrington and others 1989), which is typical for longleaf pine as well (Heyward 1933). Growing container seedlings so that lateral root initiation and growth occurs high on the root plug after outplanting provides several advantages. First, with improved mechanical stability seedlings are less prone to lean or blow over in wind (Burdett 1978; Burdett and others 1986). Second, seedlings have roots closer to the forest floor (organic matter) and subsequently nutrients, moisture (Jurgensen and others 1997), and soil-borne mycorrhizal inoculum (Harvey and others 1987a,b). Third, nursery-inoculated mycorrhizae (for example, *Pisolithus tinctorius* on southern pines) show better development and persist longer on seedlings with good lateral root development near the soil surface (Ruehle 1983, 1985).

To meet the objectives of the biological paradigm, containers modifications enhance root growth higher on the plug after planting. Hard plastic containers with slits running the length of the cavities allow air pruning higher on the plug (Ford 1995). Air-pruned lateral roots resume growth after outplanting. Similarly, Jiffypots® (essentially "wall-less" containers) also allow lateral root air-pruning the entire depth of the medium. Containers with copper-coated cavity interiors also prune developing lateral roots of many conifer species, yielding a "bushier," more fibrous root system, lacking long, downward-deflected laterals. Many research projects show the feasibility of enhancing root growth higher on the plug and modifying root systems in containers, particularly pines (Burdett 1978; Burdett and others 1986; Dumroese and Wenny 1997a; McDonald and others 1984; Wenny and Woollen 1989).

Copper-coated container treatments have other benefits in the nursery. Seedlings are generally easier to extract because of the absence of roots along the cavity wall and growing into the styrofoam container. Furthermore, the amount of disease inoculum found on inner walls of reused containers is usually about one-half that of containers without copper (Dumroese and others, in press). Copper products can be applied to containers; factory-coated

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containers are currently more expensive than nontreated containers. For example, in 1999 styrofoam containers (112 cavities and 105 ml (6 in^3 volume)) without copper (Superblock®) cost 0.036 cents per cavity while the same container with copper (Copperblock®) cost 0.048 cents per cavity.

NUTRITION

How much fertilizer is required to grow acceptable longleaf pine seedlings? Growers of longleaf pine should work to find answers to the following five questions:

1. What is the optimum foliar nitrogen (N) concentration for best outplanting performance?
2. What is the optimum N fertilization rate to limit needle production in the nursery and thereby avoid the expense of shearing?
3. Are the answers to questions 1 and 2 compatible?
4. Can increased fertilization with phosphorus (P), potassium (K), and calcium (Ca) enhance root collar diameter growth?
5. Does the grower maintain adequate crop history records to develop an optimum fertilization program for the nursery?

It is well proven that seedling foliar N concentration is related to outplanting survival (Duryea and McClain 1984; van den Driessche 1988). Unfortunately, the optimum N concentration appears to be conditional on what aspect of seedling viability (height, shoot biomass, root biomass, root collar diameter, root growth potential, cold hardiness, survival, or growth) is most important (Bigg and Schalau 1990; Landis and others 1989). For a given species, the fertilizer regime necessary to yield quality seedlings also varies tremendously by nursery because of variables like climate, seed source, water quality, nursery structure, and expertise of the grower (Dumroese and Wenny 1997b). Although obtaining proper foliar N concentration varies at individual nurseries, some aspects of N fertilization appear constant. High N fertilization rates generally decrease the amount of root weight in relation to total seedling biomass in ponderosa pine (*Pinus ponderosa* L.) (Cornett 1982, cited in Landis and others 1989), red pine (*Pinus resinosa* Ait.) (Timmer and Armstrong 1987) and loblolly pine (*Pinus taeda* L.) (Torbert and others 1986). More root weight in relation to total longleaf pine seedling biomass may be the reason needle-clipped seedlings showed higher survival after outplanting over non-clipped seedlings (South 1998). However, evidence exists that nutrient loading (luxury consumption of high N fertilizer in the nursery) enhances pine seedling field performance, especially against aggressive weeds and drought (Timmer and Aidelbaum 1996).

For longleaf pine, a good nutrition program has several concerns. First is controlling N fertilization to reduce problems with needle lodging, clipping, and the potential for growth reductions due to excessive clipping (Barnett and McGilvray 1997; Barnett and McGilvray 2000). Controlling N fertilizer can also increase root weight in relation to total longleaf pine seedling biomass. Another focus is stimulating root collar diameter growth, which is a critical morphological characteristic for seedling growth and survival after outplanting. Large diameter seedlings survive better and grow more vigorously in the field (South and others 1993). Generally, increasing P, K, and Ca in fertilizer solutions discourages shoot growth while encouraging root growth and stem lignification (Landis and others 1989), which should result in larger diameter seedlings.

It is important to maintain good nursery records, especially for cultural practices. Detailed records allow growers to duplicate successful crops, adjust fertilizer applications to current crops in order to achieve desired growth, and make plans to avoid problems in future crops (Nelson 1991). Landis and others (1994) present a fine review on data collection and its benefits to growers. Their treatise should be required reading for anyone growing forest seedlings.

INTEGRATED PEST MANAGEMENT

At the University of Idaho Forest Research Nursery we have spent considerable time focusing on disease control and integrated pest management (IPM). Pest management really boils down to proper irrigation and good sanitation.

Proper Irrigation

Watering too often encourages development of nearly all root rot diseases in the Pacific Northwest caused by fungi in the genera *Fusarium*, *Pythium*, *Phytophthora*, and *Cylindrocarpon*. Excessive irrigation also fosters spread of shoot diseases by fungi in the genera *Botrytis*, *Rhizoctonia*, and *Sirococcus* either because foliage remains wet too long or because spores are spread by splashing irrigation water. Similarly, water management for disease control is paramount in longleaf pine container nurseries (McRae and Starkey 1996).

Three methods help determine when irrigation is needed: visual-tactile, container or block weight, and pressure chamber. Generally nurseries only use the first two methods (Landis and others 1989). The easiest, least-expensive method is visual-tactile. Essentially, growers look at and feel the medium to see if irrigation is necessary. Some advantages of this method include: (1) by monitoring root development growers notice diseases; (2) they need no special equipment; and (3) they develop “a feel” for their crop. With regular, close inspection, they enhance the art of growing seedlings. A few disadvantages exist because it is difficult to: (1) check medium around roots until there is sufficient root development to extract a plug; (2) define to employees when irrigation is necessary; and (3) maintain objectivity concerning optimum times to irrigate.

Container weight change can be a useful method to determine irrigation need (Landis and others 1989). The process is straightforward and has advantages and disadvantages (table 1). After the medium is saturated, containers are weighed on an accurate scale to determine saturated container weight. Thereafter, most of the change of container weight is due to loss of water through seedling transpiration. At the Research Nursery, we irrigate when containers weigh 85 percent of their saturated container weight during the seedling initiation phase, 80 percent during the rapid growth phase, and 70 percent during the hardening phase (table 2).

Table 1—Advantages and disadvantages to using container weights to determine irrigation need

Advantages	Disadvantages
Easily done.	An accurate scale is required.
Easily repeated week to week, year to year.	Growers may stop looking at their crop (as is the case with visual-tactile).
Allows grower to objectively manipulate moisture available to seedlings, particularly important during hardening.	
Allows employees unfamiliar with practices to apply water when seedlings require it.	

Table 2—An example record of container weights assuming a saturated container weight of 11.8 kg[a], and that seedlings will be watered when container weight reaches 85% of the saturated container weight (11.8 kg x 0.85 = 10kg)[b]

Container weights	July 21	July 22	July 23	July 24	July 25	July 26
Saturated weight (kg)	11.8	11.8	11.8	11.8	11.8	11.8
Actual weight (kg)	10.0	11.3	10.6	10.0	11.1	9.8
Percentages	85%	96%	90%	85%	94%	83%
Need to water?	Yes	No	No	Yes	No	Yes

[a] kg = 2.2 lb
[b] Source: Dumroese and others (1998)

Growers can determine how long to irrigate by reweighing containers—stopping irrigation once they achieve saturated container weight. Saturated container weights change with crop age, so growers should determine a new saturated weight about once every 6 weeks (Dumroese and others 1998). Over time, growers can model the amount of irrigation water necessary to saturate containers at different crop stages.

Good Sanitation

Good sanitation, key to any nursery pest-management program, begins at cone collection. Harvesting high-quality cones and treating them correctly is the best start (Barnett and Pesacreta 1993). Because longleaf pine seedling diseases can reside on some seedlots and not others (Fraedrich 1996), growers should avoid having seedlots come in contact with each other (Neumann and others 1997b). One important seedborne pathogen is *Fusarium subglutinans* (Wollenweb. & Reinking) Nelson, Toussoun & Marasas f. sp. pini, which can cause significant mortality of longleaf pine seedlings in both bareroot and container nurseries (Carey and Kelley 1994; Fraedrich and Dwinell 1997).

Growers can reduce seedborne disease inoculum by soaking seeds in bleach, hydrogen peroxide, benomyl, or running water. At the Forest Research Nursery, a bleach treatment has worked well for pines, consisting of soaking seeds 10 min in a solution of 2 parts bleach (5.25 percent sodium hypochlorite) to 3 parts water, followed by a thorough rinse with clean water. (Dumroese and others 1988; Wenny and Dumroese 1987). In the South and particularly on longleaf pine, soaking seeds in hydrogen peroxide has yielded excellent germination results. Hydrogen peroxide is commercially available in two forms: 3 percent and 30 percent. The 3-percent hydrogen peroxide is less caustic and available in many stores, whereas the 30-percent grade must be ordered from chemical companies. Although a 4-h soak in 3-percent hydrogen peroxide effectively removed *Fusarium* inoculum from coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* [Mirb.] Franco) seeds without reducing germination (Neumann and others 1997a), longleaf pine seeds appear to perform better after a longer soak in a more concentrated solution. A 55-min soak in 30-percent hydrogen peroxide at 24 °C (75 °F) followed by a triple-rinse in clean water (Barnett 1976; Barnett and McGilvray 1997) is very effective in removing seedborne *F. subglutinans* (Fraedrich 1996). As a bonus, hydrogen peroxide treatments can also improve germination of low viability seedlots (Barnett 1976). Barnett and others (1999) found that a 10-min benomyl 50 WP drench (0.5 percent solution; 227 g per 45 L) was effective in improving germination of low- and medium-quality longleaf seedlots. When compared to the 55-min soak in 30-percent hydrogen peroxide, the benomyl treatment was as effective, less expensive, and safer (Barnett and others 1999). Soaking seeds in a container through which water flows reduces fungal inoculum (James 1987; James and Genz 1981). The simplest way to accomplish the running water soak is to place a hose in the bottom of the container used to soak seeds and allow water to run up and over the container top. To avoid cross contamination, growers should treat seedlots separately and thoroughly clean the soaking container with hot water and soap following treatment (Neumann and others 1997b).

During sowing, growers should wash hands between different seed sources. If diseased seedlings appear in the crop, growers should remove them and either burn, bury, or discard them off-site to reduce inoculum (James and others 1990). Rolling or moving bench systems can greatly facilitate this operation. In greenhouses, weeds, soil or gravel underneath seedling crops contribute to disease expression; greenhouses with concrete floors have less disease problems (James and others 1988b). Weeds under tables may harbor pathogens similar to those that attack conifer seedlings (James and others 1987). When checking a crop to see if irrigation is necessary or if pests are present, growers can carry a bucket to collect and discard diseased seedlings. Reducing the inoculum load within a crop by vigorous culling of diseased seedlings will reduce the risk of that pathogen spreading, as well as reduce available substrate for secondary fungi, some of which also elicit disease (Landis and others 1990).

Many growers are often lulled into complacent sanitation and sloppy irrigation practices believing that they can cure or prevent problems with pesticides. But why hassle with chemical applications and the EPA Worker Protection Standard if you don't have to? Reducing pesticide applications reduces production costs, which in turn increases profits. Some chemical applications are prudent and unavoidable. A good chemical program involves rotating pesticides, especially fungicides, to avoid having diseases develop resistance to chemicals (Dekker 1976; Delp 1980). At least three fungicides should be in rotation, and fungicides should be from different chemical families, not just different chemicals or trade names. For example, if *Rhizoctonia* is the problem disease, a rotation of Cleary's 3336® (thiophanate-methyl), Bayleton® (triademefon), and Bravo® (chlorothalonil) would work well because all three products are in different families (benzimidazole, triazoles, and aromatic, respectively). A rotation of Cleary's, Bayleton, and Benlate® (benomyl) is less desirable because both Cleary's and Benlate are benzimidazoles.

After harvesting the crop, a thorough cleaning of the growing area between crops is an important step in any IPM program (James and others 1990). Proper container cleaning is also a prudent sanitation step. In one of our studies, we found that using pressurized hot water to wash containers, alone or in combination with bleach, allowed inoculum of potential pathogens to carry-over from crop to crop on both hard plastic and Styrofoam containers (James and others 1988a). This carry-over of disease inoculum can increase disease incidence (and seedling mortality) or decrease overall seedling growth overtime (fig. 1). Although figure 1 only shows a comparison of height growth, the same trend was evident for other morphological characteristics (root collar diameter, root weight, shoot weight, root volume) and merchantable seedlings produced per container (Dumroese and others, in press). Despite the testing of a wide-variety of chemicals (Peterson 1990, 1991), we have found a quick soak in hot water to be the most efficacious in removing disease inoculum from reused containers. In the interior Pacific Northwest, growers use a variety of large soak tanks (stock tanks, custom-built tanks) and methods for heating water (heaters on power washers, boilers) to accomplish the task. The key is water temperature and soak duration. For hard-sided plastic containers, a 15-sec soak in 82 °C (180 °F) water is very effective. Although some recommend a 10-sec (Peterson 1991) or 3-min soak (Sturrock and Dennis 1988) for Styrofoam containers, we have found a 1-min soak in 82 °C (180 °F) works well, but at 71 °C (160 °F) the duration must be increased to at least 3 min. We do not soak containers when temperatures fall below 70 °C (160 °F) because inoculum is not destroyed, or when temperatures are above 85 °C (185 °F) because Styrofoam containers begin to distort. A mechanized system where containers are on a conveyor and pass through hot water would be ideal for very large nurseries. However, several Pacific Northwest nurseries, including one growing 12 million seedlings, find that a system where containers are hand loaded into cages for submersion is cost effective.

It is only natural for new growers to err on the side of caution when dealing with diseases. I challenge longleaf growers, as they develop their art and science of growing seedlings, to reduce both the volume and frequency of pesticide applications. At the Research Nursery our focus on an IPM plan, stressing sanitation, proper irrigation, and container cleaning, drastically reduces the amount of pesticides (fig. 2). Reducing pesticides saves money, eases compliance with the EPA's Worker Protection Standard, lowers neighbors' concerns about inadvertent pesticide drift or groundwater contamination, and provides a market tool (healthy seedlings).

CONCLUSIONS

Growers of longleaf pine face an exciting and challenging future. Progressive growers that develop their "art of growing seedlings" along with proper attention to record keeping of cultural practices will be successful despite changing markets. Developing some criteria for "optimum" longleaf pine seedlings for root morphology, foliar N concentration, root collar diameter, and production costs should be a priority. All desirable seedling characteristics should be based on field results after outplanting rather than the aesthetic quality of the nursery crop. Proper irrigation and good sanitation will help reduce production costs and ensure production of high quality seedlings.

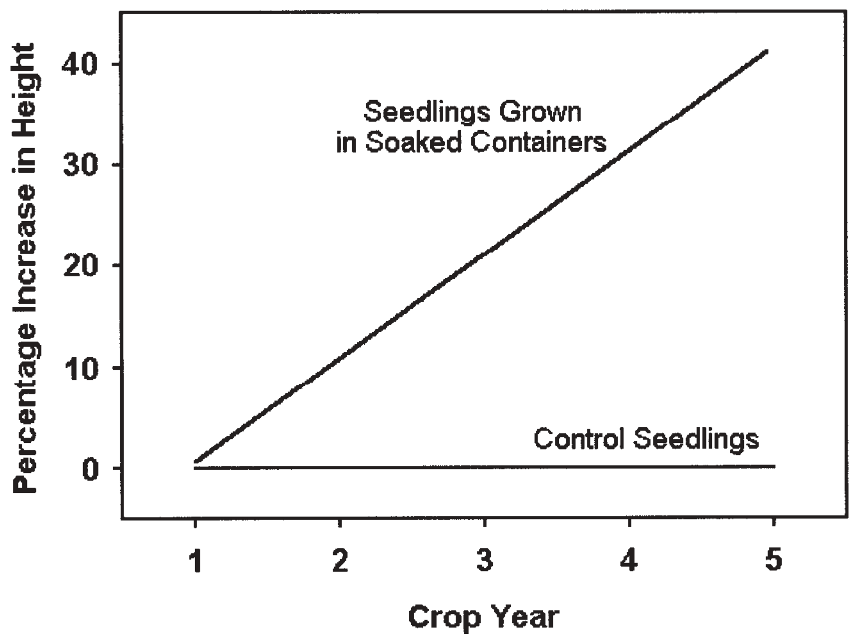

Figure 1—Relative heights of Douglas-fir seedlings grown in reused Styrofoam containers. At the end of the second growing season, seedlings grown in control containers (not dipped in hot water before the second growing season) were 10 percent shorter (heights normalized to 100 percent) than those grown in reused containers dipped in hot water (82 °C [180 °F] for 1 min). After three growing seasons, seedlings grown in reused, treated containers were nearly 25 percent taller than those grown in nondipped containers.

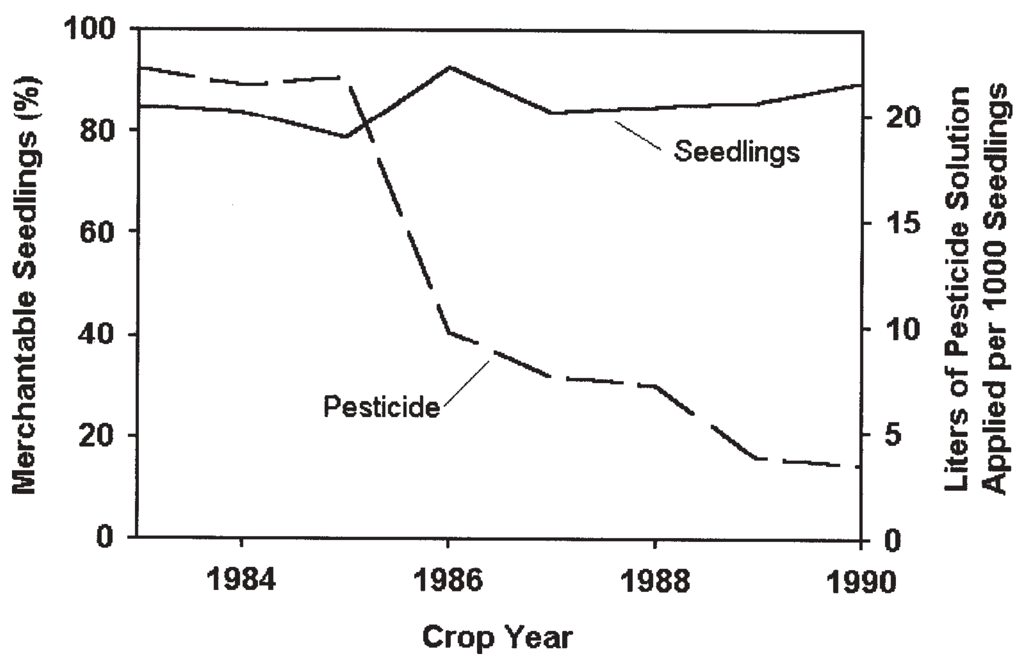

Figure 2—In 1986, the University of Idaho implemented an integrated pest management (IPM) plan that focused on sanitation, proper irrigation timing and amounts, and fewer preventative fungicide applications. The result was a significant drop in the amount of applied pesticide solution while the percentage of deliverable seedlings remained constant (1 L = 0.26 gal). Source: Dumroese and others (1990).

REFERENCES

Balisky, A.C.; Salonius, P.; Walli, C.; Brinkman, D. 1995. Seedling roots and forest floor: misplaced and neglected aspects of British Columbia's reforestation effort? Forestry Chronicle 71: 59–65.

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

Barnett, J.P.; McGilvray, J. 1997. Practical guidelines for producing longleaf pine seedlings in containers. Gen. Tech. Rep. SRS-14. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 28 p.

Barnett, J.P.; McGilvray, J. 2000. Growing longleaf pine seedlings in containers. Native Plants Journal 1: 54–58.

Barnett, J.P.; Pesacreta, T.C. 1993. Handling longleaf pine seeds for optimal nursery performance. Southern Journal of Applied Forestry 17: 180–187.

Barnett, J.P.; Pickens, B.; Karrfalt, R. 1999. Longleaf pine seed presowing treatments: effects on germination and nursery establishment. In: Landis, T.D.; Barnett, J.P., tech. cords. National proceedings: forest and conservation nursery associations—1998. Gen. Tech. Rep. SRS-25. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 43–46.

Bigg, W.L.; Schalau J.W. 1990. Mineral nutrition and the target seedling. In: Rose, R.; Campbell, S.J.; Landis, T.D., eds. Target seedling symposium: proceedings, combined meeting of the western forest nursery associations; 1990 August 13–17; Roseburg, OR. Gen. Tech. Rep. RM-200. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 139–160.

Burdett, A.N. 1978. Control of root morphogenesis for improved mechanical stability in container-grown lodgepole pine. Canadian Journal of Forest Research 8: 483–486.

Burdett, A.N.; Coates, H.; Eremko, R.; Martin, P.A.F. 1986. Toppling in British Columbia's lodgepole pine plantations: significance, cause and prevention. Forestry Chronicle 62: 433–439.

Carey, W.A.; Kelley, W.D. 1994. First report of *Fusarium subglutinans* as a cause of late-season mortality in longleaf pine nurseries. Plant Disease 78: 754.

Cornett, Z.J. 1982. Nutrient and mycorrhizal effects on the root-shoot ratio of containerized ponderosa pine seedlings. Tucson, AZ: University of Arizona. Ph.D. dissertation. 90 p.

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: 652–657.

Dumroese, R.K.; James, R.L.; Wenny D.L. Hot water and copper coatings in reused containers decrease inoculum of *Fusarium* and *Cylindrocarpon* and increase Douglas-fir seedling growth. HortScience (in press).

Dumroese, R.K.; James, R.L.; Wenny, D.L.; Gilligan, C.J. 1988. Douglas-fir seed treatments: effects on seedborne organisms and germination. In: Landis, T.D., tech. coord. Proceedings: combined meeting of the western forest nursery associations; 1988 August 8–11; Vernon, BC. Gen. Tech. Rep. RM-167. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 155–160.

Dumroese, R.K.; Landis, T.D.; Wenny, D.L. 1998. Raising forest tree seedlings at home: simple methods for growing conifers of the Pacific Northwest from seeds. Contribution 860. Moscow, ID: Idaho Forest, Wildlife and Range Experiment Station. 56 p.

Dumroese, R.K.; Wenny, D.L. 1997a. An assessment of ponderosa pine seedlings grown in copper-coated polybags. Tree Planters' Notes 48: 60–64.

Dumroese, R.K.; Wenny, D.L. 1997b. Fertilizer regimes for container-grown conifers of the Intermountain West. In: Haase, D.L.; Rose, R., coords. and eds. Symposium proceedings, forest seedling nutrition from the nursery to the field; 1997 October 28–29; Corvallis, OR. Corvallis, OR: Oregon State University Nursery Technology Cooperative: 17–26.

Dumroese, R.K.; Wenny, D.L.; Quick, K.E. 1990. Reducing pesticide use without reducing yield. Tree Planters' Notes 41(4): 28–32.

Duryea, M.L.; McClain, K.M. 1984. Altering seedling physiology to improve reforestation success. In: Duryea, M.L.; Brown, G.N., eds. Seedling physiology and reforestation success. Boston, MA: Martinus Nijhoff/Dr W Junk Publishers: 77–114.

Ford, A. 1995. Side-slit cell trays: the Ford report. Combined Proceedings of the International Plant Propagators' Society 45: 360–361.

Fraedrich, S. 1996. Seedborne disease of southern pines and developing strategies for their control. In: Landis, T.D.; South, D.B. tech. coords. National proceedings, forest and conservation nursery associations. Gen. Tech. Rep. PNW-GTR-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 75–81.

Fraedrich, S.W.; Dwinell, L.D. 1997. Mortality of longleaf pine seedlings caused by *Fusarium subglutinans* and an evaluation of potential inoculum sources. In: James, R.L., ed. Proceedings of the 3rd meeting of IUFRO Working Party S7.03.04, Diseases & Insects in Forest Nurseries; 1996 May 19–24; Orlando-Gainesville, FL. Northern Region Report 97-4. Missoula, MT: U.S. Department of Agriculture, Forest Service, Forest Health Protection: 48–54.

Harrington, C.A.; Brissette, J.C.; Carlson, W.C. 1989. Root system structure in planted and seeded loblolly and shortleaf pine. Forest Science 35: 469–480.

Harvey, A.E.; Jurgensen, M.F.; Larsen, M.J.; Graham, R.T. 1987a. Relationships among soil microsite, ectomycorrhizae, and natural conifer regeneration of old-growth forests in western Montana. Forest Ecology and Management 12: 233–251.

Harvey, A.E.; Jurgensen, M.F.; Larsen, M.J.; Graham, R.T. 1987b. Decaying organic materials and soil quality in the Inland Northwest: a management opportunity. Research Paper INT-RP-225. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 15 p.

Heyward, F. 1933. The root system of longleaf pine on the deep sands of western Florida. Ecology 14: 136–148.

James, R.L. 1987. Effects of water rinse treatments on occurrence of fungi on spruce seed from the Towner Nursery, North Dakota. Northern Region Report 86-4. Missoula, MT: U.S. Department of Agriculture, Forest Service, Timber, Cooperative Forestry and Pest Management. 4 p.

James, R.L.; Dumroese, R.K.; Wenny, D.L. 1988a. Occurrence and persistence of Fusarium within styroblock and Ray Leach containers. In: Landis, T.D., tech. coord. Proceedings: combined meeting of the western forest nursery associations; 1988 August 8–11; Vernon, British Columbia. Gen. Tech. Rep. RM-167. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 145–148.

James, R.L.; Dumroese, R.K.; Wenny, D.L. 1990. Approaches to integrated pest management of Fusarium root disease in container-grown seedlings. In: Rose, R.; Campbell, S.J.; Landis, T.D., eds. Target seedling symposium: proceedings, combined meeting of the western forest nursery associations; 1990 August 13–17; Roseburg, OR. Gen. Tech. Rep. RM200. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 240–246.

James, R.L.; Dumroese, R.K.; Wenny, D.L [and others]. 1987. Epidemiology of Fusarium on containerized Douglas-fir seedlings. (1) Seed and seedling infection, symptom production, and disease progression. Northern Region Report 87-13. Missoula, MT: U.S. Department of Agriculture, Forest Service Timber, Cooperative Forestry and Pest Management. 22 p.

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

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

Jurgensen, M.F.; Harvey, A.E.; Graham, R.T. [and others]. 1997. Impacts of timber harvesting on soil organic matter, nitrogen, productivity, and health of Inland Northwest forests. Forest Science 43: 234–251.

Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1989. Seedling nutrition and irrigation. Vol. 4. The container nursery manual. Agricultural Handbook 674. Washington, DC: U.S. Department of Agriculture. 119 p.

Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1990. The biological component: nursery pests and mycorrhizae. Vol. 5. Agricultural Handbook 674. Washington, DC: U.S. Department of Agriculture. 171 p.

Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. 1994. Nursery planning, development, and management. Vol. 1. Agricultural Handbook 674. Washington, DC: U.S. Department of Agriculture. Chapter 5: 161–168.

McDonald, S.E.; Tinus, R.W.; Reid, C.P.P. 1984. Modification of ponderosa pine root systems in containers. Journal of Environmental Horticulture 2: 1–5.

McRae, J.; Starkey, T. 1996. Containerized seedling longleaf production. In: Landis, T.D.; South, D.B. tech. coords. National proceedings, forest and conservation nursery associations. Gen. Tech. Rep. PNWGTR-389. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 8288.

Nelson, P.V. 1991. Greenhouse operation and management. Englewood Cliffs, NJ: Prentice-Hall, Inc. 612 p.

Neumann, M.; Trotter, D.; Kolotelo, D. 1997a. Seed stratification method to reduce seedborne Fusarium levels on conifer seed. Surrey, BC: British Columbia Ministry of Forests. Seed and Seedling Extension Topics 10(1&2):18–23.

Neumann, M.; Trotter, D.; Kolotelo, D. 1997b. Seed soaking tank sanitation method to reduce risk of contamination of seedlots by Fusarium. Surrey, BC: British Columbia Ministry of Forests. Seed and Seedling Extension topics 10(1&2): 17.

Outcalt, K.W. 2000. The longleaf pine ecosystem of the South. Native Plants Journal 1: 42–44, 47–53.

Peterson, M. 1990. Sanitation of styroblocks to control algae and seedling root rot fungi. Forest Resource Development Agreement (FRDA) Report 140. Victoria, BC: Forestry Canada and British Columbia Ministry of Forests. 19 p.

Peterson, M. 1991. Guidelines for the sanitation of nursery seedling containers. Supplement to Forest Resource Development Agreement (FRDA) Report 140. Victoria, BC: British Columbia Ministry of Forests. 16 p.

Ruehle, J.L. 1983. The relationship between lateral-root development and spread of Pisolithus tinctorius ectomycorrhizae after planting of container-grown loblolly pine seedlings. Forest Science 29: 519–526.

Ruehle, J.L. 1985. Lateral-root development and spread of *Pisolithus tinctorius* ectomycorrhizae on bare-root and container-grown loblolly pine seedlings after outplanting. Forest Science 31: 220–225.

South, D.B. 1998. Needle-clipping longleaf pine and toppruning loblolly pine in bareroot nurseries. Southern Journal of Applied Forestry 22: 235–240.

South, D.B.; Mitchell, R.J.; Zutter, B.R. [and others]. 1993. Integration of nursery practices and vegetation management: economic and biological potential for improving regeneration. Canadian Journal of Forest Research 23: 2083–2092.

Sturrock, R.N.; Dennis, J.J. 1988. Styroblock sanitization: results of laboratory assays from trials at several British Columbia forest nurseries. In: Landis, T.D., tech. coord. Proceedings: combined meeting of the western forest nursery associations; 1988 August 8–11; Vernon, B.C. Gen. Tech. Rep. RM-167. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 149–154.

Timmer, V.R.; Aidelbaum, A.S. 1996. Manual for exponential nutrient loading of seedlings to improve outplanting performance on competitive forest sites. NODA/NFP Technical Report TR-25. Sault Ste. Marie, ON: Natural Resources Canada, Canadian Forest Service. 21 p.

Timmer, V.R.; Armstrong, G. 1987. Growth and nutrition of containerized Pinus resinosa at exponentially increasing nutrient additions. Canadian Journal of Forest Research 17: 644–647.

Torbert, J.L.; Burger, J.A.; Kreh, R.E. 1986. Nutrient concentration effects on *Pisolithus tinctorius* development on containerized loblolly pine (*Pines taeda* L.) seedlings. Tree Planters' Notes 37(3): 17–22.

Van den Driessche, R. 1988. Nursery growth of conifer seedlings using fertilizers of different solubilities, and application time, and their forest growth. Canadian Journal of Forest Research 18: 172–180.

Wenny, D.L.; Dumroese, R.K. 1987. Germination of conifer seeds surface sterilized with bleach. Tree Planters' Notes 38(3): 18–21.

Wenny, D.L.; Woollen, R.L. 1989. Chemical root pruning improves the root system morphology of containerized seedlings. Western Journal of Applied Forestry 4: 15–17.