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. In particular, I discuss container seedling root morphology, seedling nutrition, and integrated pest management (sanitation, chemical control, proper irrigation, disinfestation of seeds and containers) and how these 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, many techniques to improve seedling quality have been tried and modified, and some have been discontinued. Three topics came to mind where experience from the Pacific Northwest may be of help to 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 and definitions of a good root system are abundant. Irregardless of how we define it, we have 2 root system criteria that must be met: (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. This is 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 (Burgett 1978). In most containers, lateral roots contact the cavity wall and 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 and result in a toppled tree (Burgett 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 and air pruning higher on the plug (Ford 1995). Air-pruned lateral roots resume growth after outplanting. Similarly, Jiffy-pots® (essentially “wall-less” containers) also allow lateral root air-pruning the entire depth of the medium. Containers with cavity interiors coated with copper also prune developing lateral roots of many conifer species, yielding a “bushier,” more fibrous root system, lacking long, downward-deflected laterals (Figure 1). 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).

To meet objectives of the biological paradigm, containers can be modified in several ways to 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, Jiffy-pots® (essentially “wall-less” containers) also allow lateral root air-pruning the entire depth of the medium.

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Copper coated container treatments have other benefits in the nursery. Seedlings are generally easier to extract from
copper-coated containers 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 James, in press). Copper products can be applied to containers or some types of containers can be purchased with a factory-applied copper coating. Factory-coated containers are currently more expensive than nontreated containers. For example in 1999, styrofoam containers (112 cavities and 105 ml [6 in³] 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? To form a proper recommendation, I think growers of longleaf pine should work to find answers to the following 5 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. As a grower, are you maintaining adequate crop history records so an optimum fertilization program can be developed for your 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 the issue of proper foliar N concentration and how to obtain it at individual nurseries seems to be a gray area, 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 was suggested as the reason needle-clipped seedlings showed higher survival after outplanting over non-clipped seedlings (South 1998). However, some 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 should probably focus on: (1) 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) and for increasing root weight in relation to total longleaf pine seedling biomass and (2) stimulating root collar diameter growth. Root collar diameter growth 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). A fine review on data collection and its benefits to growers is found in Landis and others (1994). Their treatise on the subject 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). I think pest management really boils down to this: practice proper irrigation and good sanitation.

**Proper Irrigation**

Poor water management (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 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 ways can be used to determine when irrigation is needed: visual–tactile, container or block weight, and pressure chamber. Generally only the first 2 methods find much use in nurseries (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) growers are regularly looking closely at their seedlings (monitoring root development), which makes it less likely disease may start unnoticed; (2) no special equipment is needed; and (3) growers develop “a feel” for their crop (the art of growing seedlings is enhanced). 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% of their saturated container weight during the seedling initiation phase, 80% during the rapid growth phase, and 70% during the hardening phase (Table 1). Advantages and disadvantages to using container weights to determine irrigation need.

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

<table>
<thead>
<tr>
<th>Container Weights</th>
<th>July 21</th>
<th>July 22</th>
<th>July 23</th>
<th>July 24</th>
<th>July 25</th>
<th>July 26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated weight (kg)</td>
<td>11.8</td>
<td>11.8</td>
<td>11.8</td>
<td>11.8</td>
<td>11.8</td>
<td>11.8</td>
</tr>
<tr>
<td>Actual weight (kg)</td>
<td>10.0</td>
<td>11.3</td>
<td>10.6</td>
<td>10.0</td>
<td>11.1</td>
<td>9.8</td>
</tr>
<tr>
<td>Percentage</td>
<td>85%</td>
<td>96%</td>
<td>90%</td>
<td>85%</td>
<td>94%</td>
<td>83%</td>
</tr>
<tr>
<td>Need to water?</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*1 kg = 2.2 lb
+Source: Dumroese and others (1998).

Good Sanitation

Good sanitation is key to any nursery pest-management program and it 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), 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).

Reduce seedborne disease inoculum by soaking seeds in bleach, hydrogen peroxide, benomyl, or running water. At the Forest Research Nursery, a bleach treatment consisting of soaking seeds 10 min in a solution of 2 parts bleach (5.25% sodium hypochlorite) to 3 parts water, followed by a thorough rinse with clean water has worked well for pines (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 2 forms: 3% and 30%. The 3% hydrogen peroxide is less caustic and available in many stores, whereas the 30% grade must be ordered from chemical companies. Although a 4-h soak in 3% 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

2). Growers can determine how long to irrigate by reweighing containers—stopping irrigation once saturated container weight is achieved. Saturated container weights change with crop age so a new saturated weight should be determined about once every 6 weeks (Dumroese and others 1998). Over time, the amount of irrigation water necessary to saturate containers at different crop stages can be modeled.
concentrated solution. A 55 min soak in 30% hydrogen peroxide at 24 °C (75 °F) followed by a triple-rinsed 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% 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% 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.

Remember to treat seedlots separately and thoroughly clean the soaking container with hot water and soap following treatment to avoid cross contamination (Neumann and others 1997b).

During sowing, wash hands between different seed sources. As diseased seedlings are observed in the crop, 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 your crop to see if irrigation is necessary or if pests are present, carry a bucket to collect and discard diseased seedlings. Reducing the inoculum load within your crop by vigorous culling of diseased seedlings will reduce the risk of that pathogen spreading to the rest of your crop, 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 problems can be cured or prevented 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. Keep in mind that a good chemical program involves rotating pesticides, especially fungicides, to avoid having diseases develop resistance to chemicals (Dekker 1976; Delp 1980). At least 3 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

![Figure 1.—Longleaf pine seedlings grown in a styrofoam (left) and copper-coated styrofoam (right) container. The volume of the untreated container cavity was slightly larger than that of the cooper-coated cavity. Note the long laterals growing downward in the root system of the untreated seedling, whereas the root system of the cooper-treated seedling is more fibrous and lacks long, descending lateral roots.](image)

![Figure 2.—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% shorter (heights normalized to 100%) 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% taller than those grown in nondipped containers.](image)

Cleary’s 3336® (thiophanate-methyl), Bayleton® (triadimefon), and Bravo® (chlorothalonil) would work well because all 3 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 the crop is harvested, a thorough cleaning of the growing area (floors, benches, containers, and so on) between crops is an important step in any IPM program (James and others 1990). Proper container cleaning is a prudent sanitation step. In one of our studies, we found that using pressurized hot water to wash containers, alone or in combination with other chemicals like 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 over time (Figure 2). Although Figure 2 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 James, 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 71°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 see if both the volume and frequency of pesticide applications can be reduced. Our focus on an IPM plan at the Research Nursery, stressing sanitation, proper irrigation, and container cleaning, has allowed us to drastically reduce the amount of pesticide applied (Figure 3). Reducing pesticide use saves money, makes it easier to comply with provisions of the EPA’s Worker Protection Standard, lowers concerns our neighbors have with inadvertent pesticide drift or groundwater contamination issues, 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, particularly cultural practices will be successful despite changing markets. Developing some criteria for the “optimum” longleaf pine seedling, at least in terms of 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.

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