# Comments

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***Cover:*** Lodgepole pine seedling and lupine growing on the Beaverhead National Forest in Montana.

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# The Effect of Containerless Transport on Desert Shrubs

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*The cost of shipping can be reduced if desert shrub seedlings can be removed from containers and transported to the field with roots wrapped in moist fabric "jellyrolls." But desert environments can desiccate exposed roots. In a laboratory experiment performed on bur-sage* (Ambrosia dumosa) *seedlings, no difference was found in moisture potential between seedlings in jellyrolls and those in containers. In a field experiment on catclaw* (Acacia greggii) *seedlings, no differences were found in survival, health, or growth 1 year after outplanting between shrubs transported in jellyrolls and those in containers.* Tree Planters' Notes 45(3):82-85 1994

Because direct seeding is often unsuccessful in the deserts of the Southwest, planting seedlings is a common revegetation practice (Romney and others 1989, Bainbridge and Virginia 1990). Most desert perennials are easy and inexpensive to grow in a nursery. But the heavy sand mixes and bulky containers in which plants are grown are expensive to transport from the greenhouse to revegetation sites. Eliminating containers and substrate before transporting would greatly reduce shipping weight and bulk. However, many desert shrubs have fragile roots, and the hot, dry desert environment can quickly desiccate bareroot seedlings. Wrapping them in moist fabric (a technique known as "jellyrolling") may adequately protect seedling roots, improving outplanting efficiency.

Foresters commonly use jellyrolls with insulated shipping and planting bags to provide moisture to seedlings during transport (Lopushinsky 1986, Laird 1992). However, the use of jellyrolls in arid environments or in place of containers and substrate has been little studied. Jellyrolls are substantially lighter and less bulky than plants in containers: a rack of 98 sandfilled Ray-Leach™ supercells (164-ml containers) weighs more than an ice chest holding 500 jellyrolled plants and ice. Moreover, preliminary studies suggest that planting from jellyrolls is 1.5-2 times faster than planting from supercells. By removing plants from their containers at the nursery (where conditions are less stressful for workers and plants), expenses are reduced.

This paper presents results from two experiments assessing moisture stress and outplanting success of jellyrolled seedlings from two desert species, bur-sage *(Ambrosia dumosa* [A. Gray] Payne) and catclaw *(Acacia greggii* A. Gray). Moisture stress at planting is a major factor in reducing outplanting success (Rietveld 1990). In the first experiment, the moisture status of jellyrolled and containerized bur-sage seedlings was tested in a laboratory setting over a 24-hour period.

Preliminary studies suggested that survival of desert species shipped in jellyrolls to revegetation sites in the Sonoran and Mojave Deserts was comparable to that of plants shipped in containers (Bainbridge, unpublished data). But high variability and the relatively low number of plants shipped made a larger study desirable. In the second experiment, catclaw seedlings were transplanted in jellyrolls and containers to a mine spoils pile at a Mojave Desert gold mine. Survival, health, and height of the seedlings were tracked and compared over a 1-year period.

## Methods

**Laboratory study.** In August 1992, approximately 150 bursage seeds were germinated on paper and planted in sandfilled supercells in a greenhouse. In December 1992, 90 seedlings of uniform size were taken from the greenhouse to a laboratory. Thirty-four seedlings were removed from containers and placed in four jellyrolls, two with 8 seedlings and two with 9 seedlings. In all four rolls, the seedlings were placed 10 cm (3.9 in) apart on 1-m (3.3-ft) sections of moist Kimtex™. The edges of the fabric were folded towards the center (covering shoot tops and root tips), and then the Kimtex™ was rolled up, completely enclosing the seedlings (figure 1). All 90 seedlings were left overnight in a dark, humid room at 20 /C (68 /F) so that the plants would not photosynthesize (and transpire) prior to (or during) the experiment.

A 3-by-2 incomplete factorial design was arranged for three packaging conditions (supercell, jellyroll, and bareroot) under two temperatures (unchilled, at 20 /C, or 68 /F; and chilled, at 4 /C, or 39 /F). The laboratory experiment measured seedling xylem pressure poten-

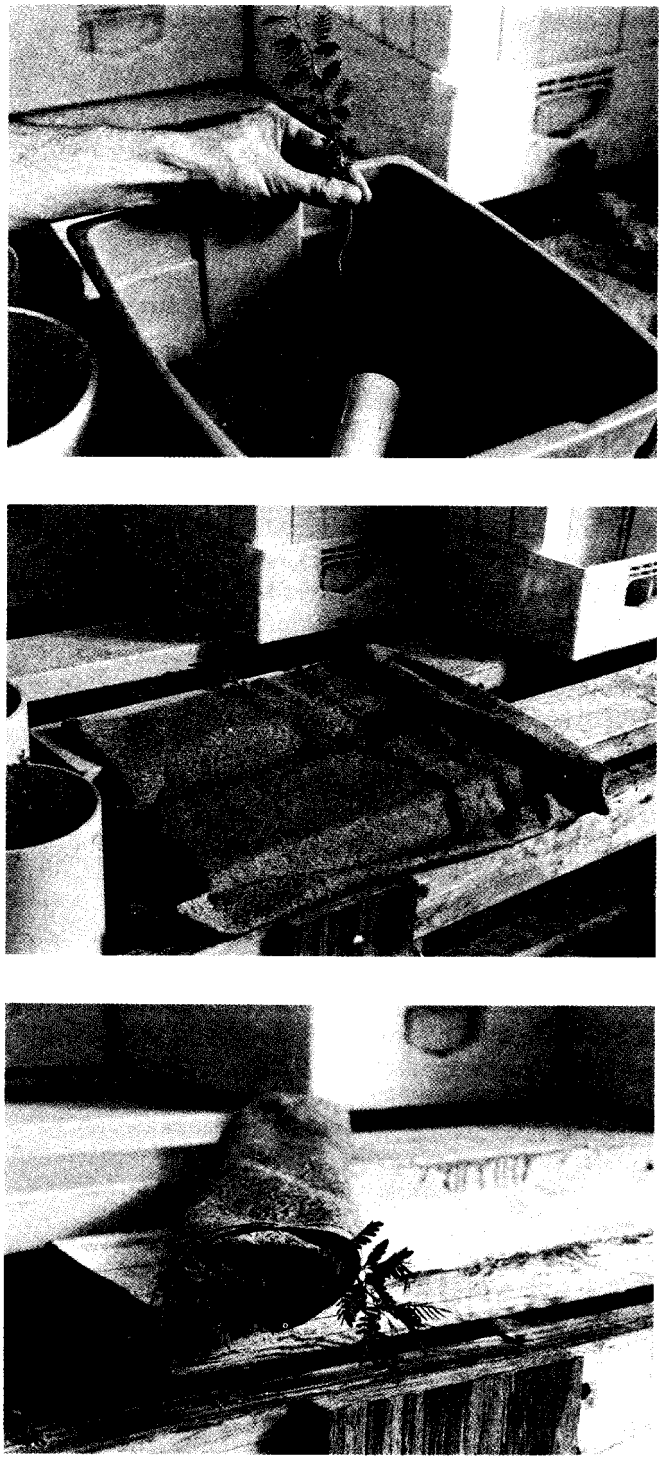


**Figure 1—***Sequence for jellyrolling seedlings: (**A**) seedlings removed from supercells and rinsed to wash sand from roots; (**B**) seedlings placed 10 cm (3.9 in) apart on sections of moistened fabric; and (**C**) fabric rolled up around seedlings.*

tial (XPP, a measure of moisture status) over 24 hours for five treatments:

- *Supercell*— Plants left in supercells at room temperature (20 /C, or 68 /F).
- *Jellyroll*— Plants removed from supercells and rinsed to wash sand from roots, then wrapped in moist Kimtex™ (a non-woven synthetic fabric) and kept in an open tub at room temperature (20 /C, or 68 /F).
- *Bareroot*— Plants removed from supercells and rinsed to wash sand from roots, then kept in an open tub at room temperature (20 /C, or 68 /F), without being wrapped in fabric.
- *Chilled supercell*— Plants left in supercells and kept in an ice chest at 4 /C (39 /F).
- *Chilled jellyroll*— plants jellyrolled (as in treatment 2) and kept in an ice chest at 4 /C (39 /F).

The unchilled bareroot treatment was included as a control: if the bareroot seedlings did not show significantly more moisture stress than other seedlings during the experiment, then it could be concluded that conditions were inappropriate (i.e., too cool and humid) for testing the effect of jellyrolling on XPP.

The following morning, the XPP of 5 seedlings was measured immediately prior to treatment. Stems for sampling were cut with a sharp razor blade about 2 cm (0.8 in) above the root, and the shoots were immediately placed in individual ziploc bags until a measurement could be taken (Meron and others 1987). XPP was measured with a pressure bomb, as described by Waring and Cleary (1967). Only one measurement was taken per plant. The mean XPP of the 5 plants measured served as the potential at time zero for all five treatments.

Two jellyrolls were then chilled and two left unchilled. The remaining 51 plants were randomly divided among the other three treatments (17 seedlings per treatment). Two hours after treatment began, the XPP of 5 plants from each treatment was measured. After 4, 6, and 24 hours, the XPP of 4 plants per treatment was measured. Data were log transformed (to normalize them), and an analysis of variance (ANOVA) was used to compare differences in water potential between packaging conditions, temperature, and packaging-temperature interaction effects.

**Field study.** In May 1993, 300 catclaw seeds were germinated on paper and placed in sand-filled supercells in a greenhouse at San Diego State University (SDSU). In July, 280 seedlings of uniform height

and appearance were selected for outplanting at Castle Mountain Mine, in the east Mojave Desert. One day before planting, 140 plants were randomly selected and jellyrolled in the greenhouse. Seedlings were removed from containers, sand was washed from their roots, and the plants were placed 10 cm (3.9 in) apart on 1-m (3.3-ft) sections of moist Kimtex™, in sets of ten. The ends were folded over, and the plants were rolled up in the fabric (figure 1). The jellyrolls were placed in a chest with ice, and the remaining 140 plants were left in supercells. The ice chest and racks of supercells were loaded into an enclosed truck bed and transported from SDSU to Castle Mountain Mine (360 miles from San Diego). Plants remained in jellyrolls for approximately 24 hours.

The seedlings were planted on the top of an unvegetated mine spoils pile. A 30- by 60- m (98.4- by 196.8-ft) plot running east to west was ripped 60 cm (23.4 in) deep to reduce compaction, facilitate planting, and encourage root growth. Plants were spaced 80 cm (31.2 in) apart in four rows 5 m (16.4 ft) apart. Seedlings from jellyrolls were alternated with seedlings from supercells. As they were planted, seedlings were assigned protection and/or amendment treatments and given 1 liter (1.1 qt) of water. The temperature during planting ranged from 32 to 38 /C (90 to 100 / F), and humidity was low. Supplemental irrigation1 liter (1.1 qt) of water per plant-was provided four times between August and October 1993.

Survival, health, and height were recorded in July 1994 (1 year after planting). Plant health was rated on the following scale: 0 = dead; 1 = green stem, but no leaves; 2 = few leaves, chlorotic; 3 = some green leaves; 4 = many green leaves. Survival data were analyzed using a log rank test (Pyke and Thompson 1986); health ratings were analyzed using a Mann-Whitney U test (Sokal and Rohlf 1969); and height data were log transformed and analyzed by ANOVA.

## Results

**Laboratory study.** The XPP of bareroot seedlings was more negative (seedlings were more moisturestressed) at every measurement time. After 6 hours, the XPP of bareroot seedlings was significantly ($P < 0.05$) more negative than that of all other treatments (figure 2). After determining differences among the three packaging conditions (bareroot, jellyroll, and supercell), the bareroot data were excluded, and data were reanalyzed as a 2- by-2 complete factorial.

After 2 and 4 hours, seedlings in jellyrolls had significantly ($P < 0.001$ at 2 hours, $P < 0.01$ at 4 hours) less negative XPP's than seedlings in supercells. Temperature did not affect XPP, and there was no significant interaction between temperature and packaging condition.

After 6 hours, plants packaged in jellyrolls continued to have significantly ($P < 0.001$) less negative XPP's than plants in supercells. But temperature had a significant ($P < 0.05$) effect on XPP: chilled seedlings had more negative XPP's than unchilled seedlings. There was no interaction effect between temperature and packaging condition.

After 24 hours, the XPP of plants in jellyrolls (both chilled and unchilled) remained significantly ($P < 0.01$) less negative than plants in supercells. Temperature also remained significant, but chilled seedlings now had less negative ($P < 0.01$) XPP's than unchilled seedlings. There was a significant interaction effect between temperature and packaging condition; plants in the chilled jellyroll treatment had less negative XPP's than plants in the unchilled jellyroll treatment (figure 2). In addition, the XPP of seedlings in unchilled jellyrolls was slightly more negative than the XPP of seedlings in unchilled supercells, but the difference was not significant. The decrease in XPP of plants in unchilled jellyrolls that occurred between 6 and 24 hours caused significant time-packaging condition (jellyroll) and time–packaging condition– temperature interaction effects (not shown).

**Field experiment.** Differences in survival, health, and height were not significant ($P > 0.50$) for plants shipped in jellyrolls and those shipped in supercells. Survival was 88% for jellyrolled seedlings and 91% for containerized plants; mean health ratings were 2.0 and 2.1, and mean heights were 8.9 cm and 8.5 cm, respectively. There was no interaction effect between jellyrolls or containers and other experimental treatments.

## Discussion

Jellyrolls were found to improve the moisture status of bur-sage seedlings for 24 hours under lab conditions similar to those in an enclosed truck. Because the hydrating effect of jellyrolls is immediate, the XPP of jellyrolled plants became less negative by approximately 1 MPa after 2 hours (figure 2), and stayed that way for an additional 4 hours. In general, seedlings did not become more moisture-stressed over time. However, after 24 hours, the XPP of plants in unchilled jellyrolls was significantly more negative than in chilled jellyrolls, and slightly more negative than in supercells. Chilling jellyrolls may thus be

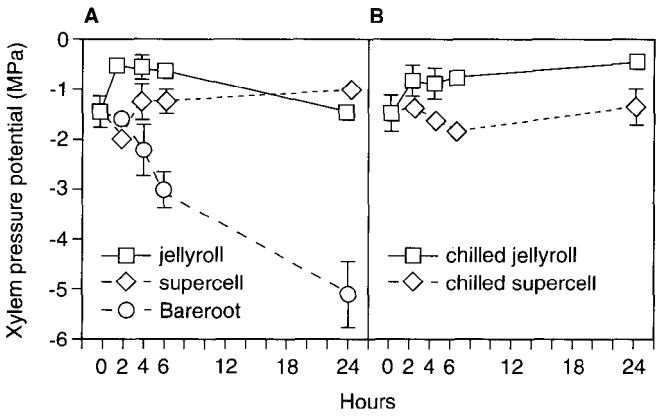


**Figure 2**—*Mean xylem pressure potential over 24 hours for bursage seedlings stored (**A**) unchilled at 20 °C (68 °F), and (**B**) chilled at 4 °C (39 °F). Bars indicate standard errors.*

unnecessary for durations of 6 hours or less, but is desirable for longer periods. Jellyrolls are not only less expensive to transport than heavy and bulky containers, they also reduce moisture stress.

Planting catclaw seedlings from jellyrolls was quicker and easier than planting from supercells, and survival and growth were unaffected by packaging conditions. The fact that jellyrolls did not reduce outplanting survival in the xeric environment where the field study took place indicates that jellyrolling did not damage the sensitive seedling roots and provided excellent protection from desiccation during transport. Similar success is likely to be found in climates where temperatures are lower, humidity is higher, and seedling moisture status may be less critical than in the Mojave Desert.

Some projects may require that seedlings spend several days in transport or storage before planting. Although survival of plants jellyrolled for more than 1 day has not been thoroughly studied, anecdotal evidence indicates that plant reactions to extended periods in jellyrolls vary from species to species. Twenty out of 24 creosote bush *(Larrea divaricata* [DC.] Cov.) seedlings left in jellyrolls for 9 days survived after being planted in pots in a greenhouse, but only 20% of bladder-pod *(Isomeris arborea* Nutt.) seedlings survived under the same conditions (Bainbridge, unpublished data). Species-specific reactions to fabric moisture content have also been observed. Although creosote bush has been successfully shipped in jellyrolls, seedlings that spent several days in a saturated batch of rolls died, presumably from poor root oxygenation (Bainbridge, unpublished data). The species being shipped and the time plants will spend in jellyrolls should be considered to ensure planting success. If used carefully, jellyrolls are a safe and cost effective alternative to transporting plants in containers.

## Acknowledgments

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# Insects and Diseases of Oak Seedlings Grown in Tree Shelters

Kurt Allen

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*Tree shelters are a new technology used in regenerating oak. Oak seedlings typically have insect and disease associates that may become pests on seedlings grown in shelters. In this study, insects and diseases found on sheltered seedlings were listed over a 1-year period, and their effects on sheltered and unsheltered seedlings were compared. Despite sustaining greater damage from insects and disease, sheltered seedlings showed more height growth than unsheltered seedlings. But potential problems were indicated that warrant further study.* Tree Planters' Notes 45(3):88-90; 1994.

Regeneration of oak seedlings is one of the most challenging tasks facing land managers in the Northeast. Oak seedlings are often crowded out by faster-growing vegetation or browsed by deer. Land managers have searched for ways to protect this valuable forest tree in order to preserve its place in forest ecosystems.

Tree shelters are a new technique being tried on some national forests and elsewhere (figure 1). Tree shelters are plastic tubes that can be placed over seedlings, whether naturally regenerated or grown from planted seed or nursery stock (Windell 1992).

**Figure 1**—*Tree shelters are plastic tubes placed over seedlings to enhance their growth and to protect them from deer browsing and competing vegetation.*

Tree shelters protect seedlings from browsing and provide a microenvironment that enhances height growth, helping oak seedlings to outgrow competing vegetation (Minter and others 1992, Lantagne and others 1990).

One drawback of shelters is cost. Because the technology is new, purchasing and installing shelters can cost up to $3 per seedling. Sheltered seedlings thus represent a much higher investment than unsheltered plants, making damage from insects and disease a major concern (Lamson 1991). But very little is known about how insects and diseases interact with seedlings in shelters.

This paper presents results from the first year of a study of insects and diseases on sheltered and unsheltered (control) seedlings.

## Methods

Following the initial cut of a shelterwood harvest, the Green Mountain and Finger Lakes National Forests installed 1.5-m (5-ft) Tubex tree shelters over planted acorns and naturally regenerated oak seedlings on 5 sites. At each of 3 sites on the Green Mountain National Forest, 25 sheltered seedlings on a transect were marked; and on each of 2 sites on the Finger Lakes National Forest, 30 sheltered seedlings on a transect were marked. For each sheltered seedling, a nearby open-grown seedling (if present) was chosen as a control. The seedlings were first examined during the week of May 17, 1993, then reexamined monthly, with the last visit occurring during the week of September 6, 1993.

The kind and number of insects and diseases found were noted and scored on a monthly basis. Amount of missing foliage (in 10% intervals) was estimated monthly, and stem damage caused by insects or disease was recorded. Because damage data were not cumulative across months, total defoliation on a seedling could decrease as new growth occurred. Seedling height was measured at the beginning and end of the growing season to determine the impact of insects and diseases on vertical growth.

**Results and Discussion**

**Insects and diseases.** Most insects and diseases found on both sheltered and unsheltered seedlings were common associates of oak, including:

- Leaf rollers and tiers, such as oak leaftier *(Croesia semipurpurana)* (Kearfott) and oak leafroller *(Archips semiferanus)* (Walker)
- Gypsy moth *(Lymantria dispar)* (L.)
- Leaf galls *(Acraspis erinacei* Beutenmueller and *Cecidomyia niveipila* Osten Sacken )
- Sawflies *(Acordulecera* spp.*)* and oak slug sawfly *(Caliroa fasciata)* (Norton)
- Assorted unidentified loopers (family *Geometridae)*
- Oak anthracnose *(Apiognomonia quercina)* (Kleb) v.Hoehne
- An unidentified leaf-eating weevil
- Twig galls *(Callirhytis quercuspunctata* (Bassett) and *Callirhytis cornigera* (Osten Sacken))

Insects and diseases found changed during the season, with early-season and late-season defoliators appearing both inside and outside the shelters at the same time. In May and June, seedlings were frequently attacked by rollers and tiers, rarely found later in the season. Loopers, by contrast, were rare early on, but increased in July and peaked in August. Early in the season, more insects were found on sheltered than on unsheltered seedlings, and defoliation in May was higher on sheltered seedlings on both national forests (table 1). Shelters may provide a good environment for insect survival and growth early in the season, when temperatures outside may still be too cold for insects to flourish. Early-season defoliation can be a major stress when seedlings are just leafing out. Leaf diseases showed up late in the season, possibly adding a second period of defoliation for the season.

**Impact.** Most seedlings suffered less than 20% defoliation over the period of study (table 1), a level of damage not usually considered to cause mortality or growth loss in mature hardwood trees. It is not known how this level of damage will affect the seedlings, although no pest-related mortality was found. There were no outbreak populations of insects or diseases in the forest during the year of study, so damage was done by endemic populations and can be expected to recur every year. Some seedlings were heavily defoliated when 1 or 2 gypsy moths got into the shelters, although many of the defoliating insects found could produce the same level of damage.

Twig galls caused several instances of main-stem dieback, but in each case seedlings were already resprouting. Overall, height growth was greater in sheltered than unsheltered seedlings (figure 2), indicating that increased damage by defoliators (table 1) was more than offset by the benefits of shelters. Damage

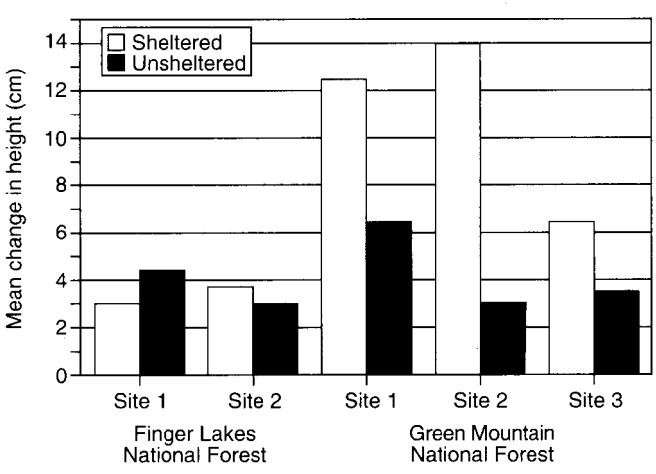


**Figure 2**—*Mean height growth of sheltered and unsheltered oak seedlings, Finger Lakes and Green Mountain National Forests, 1993.*

**Table 1** -*Mean percentage defoliation of attacked oak seedlings on the Finger Lakes and Green Mountain National Forests by month (1993)*

| | Finger Lakes NF | | Green Mountain NF | | Total | |
|---|---|---|---|---|---|---|
| Month | Sheltered | Control | Sheltered | Control | Sheltered | Control |
| May | 15 | 11 | 18 | 15 | 17 | 13 |
| June | 14 | 14 | 19 | 13 | 17 | 13 |
| July | 13 | 12 | 21 | 17 | 17 | 15 |
| August | 16 | 13 | 17 | 27 | 17 | 20 |
| September | 20 | 13 | 16 | 22 | 18 | 18 |
| Average | 16 | 13 | 18 | 19 | — | — |

was limited to loss in leaf area rather than height growth, although it is unknown how this reduction in leaf area affected potential growth. A major benefit of shelters (and a reason for greater height growth) was reduced deer browsing on sheltered seedlings. Most unsheltered seedlings were browsed back, and some even suffered negative height growth.

Despite low damage levels shown in the study, possible future problems are indicated. The seedlings that were infected with leaf diseases are likely to be infested and defoliated every year. When leaves drop in fall, they are trapped in the shelters, leaving inoculum in close contact with seedlings. Leaf and stem tissue of seedlings grown in shelters is more succulent than that of open-grown seedlings, which could attract insects and diseases. Moreover, shelters provide an excellent growing environment for insects and diseases, although it is hard to say whether this environment will actually attract them. Finally, shelters may provide pests with protection from natural enemies.

## Conclusions

Tree shelters appear to be a very good way of regenerating oak seedlings in forests. Although more insects and diseases attacked sheltered seedlings than unsheltered ones, the sheltered seedlings still produced more height growth. The ultimate impact of higher levels of insect and disease infestation found in sheltered seedlings is unknown; economic damage thresholds will be crossed sooner because of the higher value of sheltered seedlings. It is also unknown how other factors (such as site and competing vegetation) play into the picture. These could be major factors in seedling performance. Further monitoring is called for as a step toward developing an integrated pest management that minimizes insect and disease losses.

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# Nantucket Pine Tip Moth Infests Longleaf Pine Seedlings in a North Carolina Nursery

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*An infestation of Nantucket pine tip moth* (Rhyacionia frustrana *Comstock) was found in spring-seeded longleaf pine* (Pinus palustris *Mill.*) *seedlings in a North Carolina Division of Forest Resources nursery. Infestation began in newly emerged seedlings, eventually resulting in death. About 3.59% of the spring-seeded crop was affected.* Tree Planters' Notes 45(3):86-87; 1994

During the week of June 20, 1994, a routine inspection of longleaf pine *(Pinus palustris* Mill.) seedlings in Claridge Nursery (Goldsboro, North Carolina) revealed seedling buds infested with insects. On June 29, during a followup evaluation, plots were taken to determine causal agent and extent of damage.

## Methods

Infested seedlings were dissected and any insects found were saved for identification. Magnitude of damage was determined by randomly dropping a 2-$ft^2$ (.19-$m^2$) counting frame across longleaf pine beds and then counting healthy and infested seedlings inside the frame. This procedure was repeated 151 times. Counts were added and percentage infestation was derived by dividing number of infested seedlings by total number of seedlings inside the frame. Percentage infested was then multiplied by the number of seedlings in the nursery to estimate total damage.

## Results and Discussion

Late-instar larvae and pupae collected from damaged longleaf pine seedlings were identified as Nantucket pine tip moth *(Rhyacionia frustrana* Comstock, figure 1). Longleaf pine had not been reported as a host for the species (Anon 1985, Yates 1960).

Longleaf pine seeds are planted at Claridge Nursery twice each year, once in the fall (mid-September) and again in the spring (mid- to late April). Examination of fall-seeded plants revealed no damage, but damage was visible in springseeded trees.

Based on information about the Nantucket pine tip moth's life cycle (Yates 1960) and on seedling age when the infestation was first noticed, oviposition must have occurred shortly after the seedlings emerged, probably about the time they shed their seedcoats. Attacking larvae hollowed out chambers inside terminal buds, killing surrounding needles. Four or 5 dead needles were evident around each afflicted bud, surrounded by healthy needles. Gradually, the larvae bored downward from the terminal bud, killing more needles; by the time of pupation, most seedlings were dead. Pupation occurred in the stem or root system of the seedling, either near or just below ground line. The loss at Claridge Nursery was estimated at 3.59% of the spring-seeded crop, or about 168,119 seedlings. In addition to infestation in field-grown stock, we observed scattered infestation of containerized longleaf pine seedlings of about the same age as the field-grown seedlings.

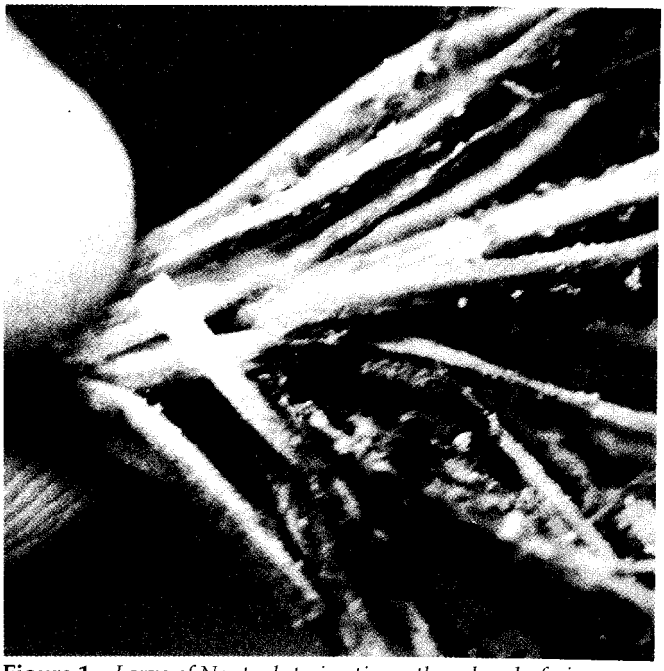

**Figure 1**—*Larva of Nantucket pine tip moth on longleaf pine seedling.*

In view of its magnitude, we suspect that the problem was not new to the nursery. Because infested seedlings are so small, damage may well have been misdiagnosed at first as postemergence damping off. Nursery managers producing longleaf pine seedlings should pay particular attention to mortality in young seedlings. If damage is caused by Nantucket pine tip moth, and if economic analysis indicates that control measures are warranted, a carefully timed application of a currently registered insecticide should reduce damage to acceptable levels.

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Tree Planter's Notes, Volume 45, No. 3

# An Evaluation of Dazomet and Metam-Sodium Soil Fumigants for Control of *Macrophomina phaseolina* in a Florida Forest Nursery

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*Field trials with dazomet (Basamid®-Granular) and metamsodium (Busan®1020) soil fumigants were conducted under operational conditions in a Florida forest tree nursery for control of* Macrophomina phaseolina *Tassi (Gold.), the causal agent of charcoal root rot. Both materials significantly reduced soil populations of the pathogen; dazomet appeared more effective than metam-sodium. Tree* Planters' Notes 45(3):91-95; 1994.

Forest tree nurseries in the United States are routinely fumigated (on varying schedules) with various formulations of methyl bromide and chloropicrin for control of soilborne pathogens, insects, and weeds (Boyer and South 1984, Cordell and others 1989, Dixon and others 1991, Fraedrich and Smith 1994, Kelley and Cordell 1984). In recent years, however, interest in alternative chemical soil fumigants has increased due to the costs, safety concerns, and possible environmental hazards associated with methyl bromide. Most recently, concerns regarding the ozone-depleting potential of methyl bromide have led the Environmental Protection Agency to ban production, importation, and use of methyl bromide in the United States by the year 2001 (EPA 1993), in accordance with the Clean Air Act (Civerolo and others 1993).

Dazomet (under such brand names as Basamid® and Mylone®) and metam-sodium (under such names as Vapam®, Soil-Prep®, and Busan®1020) are currently among the most popular and perhaps most promising chemical alternatives to methyl bromide. These materials have been tested in a number of North American forest tree nurseries, with varying results (Alspach 1989, Campbell and Kelpas 1988, Chapman 1992, Enebak and others 1990a and 1990b, Fraedrich and Smith 1994, Hildebrand 1991, Hildebrand and Dinkel 1988, Hoffman and Williams 1988, McElroy 1986, McIntyre and others 1990, Shugert 1989, Tkacz and Ramirez 1988).

Researchers often indirectly assess the suitability of soil fumigants for forest tree nurseries by evaluating crop production parameters such as seed germination and/or the survival and quality of seedlings grown in treated soils. A more direct method of evaluating fumigant efficacy is to assess pre- and posttreatment populations of soilborne pests. This method has been employed in several studies on the efficacy of dazomet and metam-sodium in forest tree nursery soil fumigation (Campbell and Kelpas 1988, Enebak 1990a, Hildebrand 1991, Hildebrand and Dinkel 1988a and 1988b, Hoffman and Williams 1988, McElroy 1986, Tkacz and Ramirez 1988). However, most of these trials have been limited to assessments of *Fusarium, Pythium*, and nematode populations.

In the South, especially in Florida, *Macrophomina phaseolina* (Tassi) Goid., the causal agent of charcoal root rot and a factor in the development of black root rot (together with *Fusarium* spp. and, possibly, nematodes), has been and still is considered a problem in some forest tree nurseries (Barnard and Gilly 1986, Fraedrich and Smith 1994, Hodges 1962, Rowan 1971, Seymour and Cordell 1979, Smith and others 1989). The labeling for Basamid®-Granular lists *M. phaseolina* among the organisms against which it is active. However, we were (and are) unaware of any published data comparing pre- and postfumigation populations of *M. phaseolina* in forest tree nursery soils operationally treated with dazomet or metam-sodium. Accordingly, we conducted two field trials to evaluate the relative efficacy of Basamid® Granular (dazomet) and Busan®1020 (metam-sodium) soil fumigants for control of *M. phaseolina* under operational conditions at the Florida Division of Forestry's Andrews Nursery. This paper summarizes our results.

## Materials and Methods

Field trials were conducted in 1988 and 1989. The Andrews Nursery was selected for study due to its history of *M. phaseolina*-related root disease. Trials were established in seedbeds where losses of loblolly

pine *(P. taeda* L.) seedlings due to charcoal root rot were severe in 1987.

In 1988, test seedbeds were disced, and on July 7 prefumigation soil samples were collected. Samples were taken from each of 18 plot centers, with 6 plot centers for each of 3 treatments. Plot centers were distributed linearly at 8.1-m (26.6-ft) intervals along the length of 3 parallel seedbeds (1 seedbed per treatment). Each sample consisted of composites of 10 2.5- by 10-cm (1- by 4-in) soil cores collected at random around each plot center (1 composite sample for each plot center).

On July 8, the study area was preirrigated for 1 hour (from 7 to 8 a.m.). With irrigation continuing, metam sodium was then applied to one set of 6 plots at 467.3 L/ha (50 gal/acre) and to another set of 6 plots at 934.6 L/ha (100 gal/acre). A tractor-drawn sprayer was used, operating at 2.9 kg /$cm^2$ (40 lb/ $in^2$) of pressure. For about 1 hour (from 8 to 9 a.m.). The third set of 6 plots were irrigated but left untreated, as a check. Irrigation was continued for about 1 to 2 hours after treatment. Thus there was continuous irrigation from 7 to 10 a.m., and fumigant application from 8 to 9 a.m. In the afternoon, irrigation was resumed for an additional hour (from 2 to 3 p.m.). On July 20, 12 days after fumigation, posttreatment soil samples were taken in the same manner as for pretreatment samples.

On May 17, 1989, test seedbeds were disced, and on May 18 prefumigation samples were collected as described above. Treatment plots were 2.4 by 4.6 m (8 by 15 ft) in size, with 8 replicates for each of 3 treatments. Plots were deployed in a randomized complete block design, and samples were taken around each of the 24 plot centers. The study site was then periodically irrigated during the week of May 22 to ensure adequate soil moisture.

On May 26, a hand-held applicator was used to apply dazomet soil fumigant at 392.5 kg/ha (350 lb/ acre) to one set of 8 plots. A tractor-drawn rototiller was then used to incorporate the fumigant into the soil. On the evening of May 30, metam-sodium was "chemigated" at 373.8 L/ha (47 gal/acre) onto another set of 8 plots using the nursery's irrigation system. During chemigation, the 8 dazomet plots and the 8 check plots were covered with polyethylene tents. On June 13, posttreatment soil samples 0-10 cm (0-4 in) deep were collected, and on June 26, a second set of samples 0 to 15 cm (0 to 6 in) deep were collected.

All soil samples were immediately carried to the laboratory and assessed for *M. phaseolina* as described by Barnard and others (1995), following procedures developed by McCain and Smith (1972). Comparative populations of the fungus were evaluated on the basis of colony-forming units (CFU) per gram of air-dried soil. Data were subjected to ANOVA, and differences among treatment means were analyzed by comparing these differences to calculated least significant differences (LSD's) at P # 0.05 (Snedecor and Cochran 1967).

**Results and Discussion**

In the 1988 trial, metam-sodium significantly (P # 0.05) reduced soil populations of *M. phaseolina* (figure 1). However, differences between the two rates of application were not significant, and in neither treatment was the pathogen completely eradicated from treated soils. In the 1989 trial, both dazomet and metam-sodium significantly reduced *M. phaseolina* populations (figure 2). Soils treated with dazomet were almost pathogen-free, but due to the high level of variability among individual samples, differences between soils treated with dazomet and those treated with metam-sodium were not statistically significant (P # 0.05).

Our data indicate that both materials show promise as alternatives to methyl bromide for the control of *M. phaseolina,* and that dazomet appears somewhat more effective than metam-sodium. However, these data should be treated with caution in view of their limited applicability. Different results may and undoubtedly will be obtained when other methods and rates of application are used, and where soil types, temperatures, and moisture content are different. Nonetheless, the results of these trials are encouraging, especially in light of the fact that *M. phaseolina* typically survives in soil by means of potentially fumigation-resistant microsclerotia (Barnard and Gilly 1986, Seymour and Cordell 1979, Smith and others 1989).

Since 1989, both metam-sodium and dazomet have been employed operationally as soil fumigants for certain crops in compartments of the Andrews Nursery, with no significant adverse effects. Other forest nurserymen in Florida have conducted trials with dazomet, and no major biological drawbacks to its use have emerged from these studies that we know of to date. In a recent field trial, we found dazomet to be as effective as methyl bromide, if not more so, in reducing soil populations of *Fusarium* and *Pythium* spp. *(M. phaseolina* was not detected; Barnard and others 1992). However, some forest nursery managers have found dazomet less effective than methyl bromide in controlling weeds, especially nut sedges *(Cyperus* spp.*)* (Fraedrich and Smith 1994). Nonetheless, our data should encourage forest nursery managers facing the

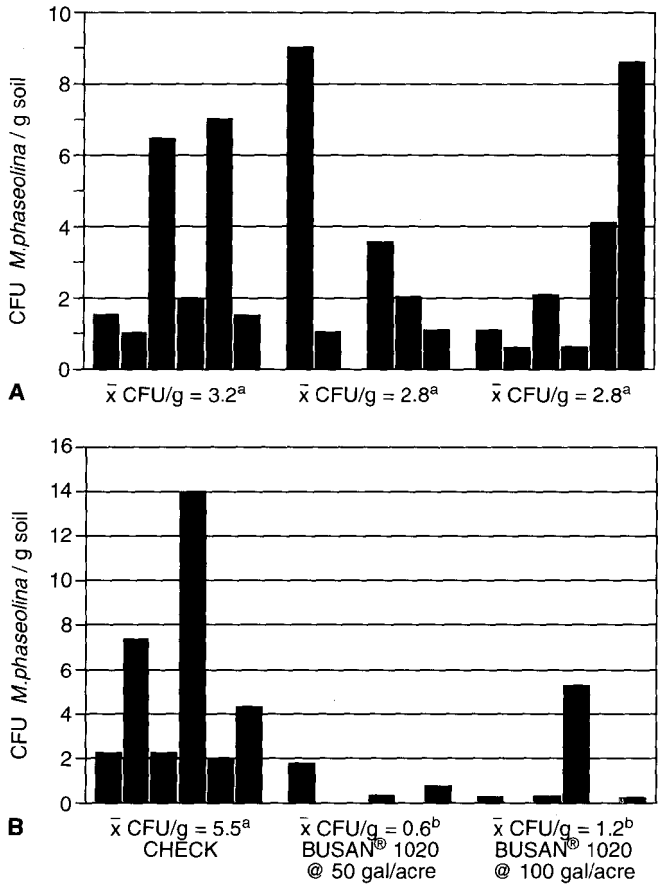


**Figure 1**—*Colony-forming units (CFU) of* Macrophomina phaseolina *in soil from a Florida forest nursery before (on July 7, 1988 [**A**]) and after (on July 20, 1988 [**B**]) treatment with Busan®1020 (metam-sodium) soil fumigant. Each bar represents an individual soil sample. Within sample dates, treatment means ($\bar{x}$) accompanied by the same letter do not differ significantly ($P \leq 0.05$).

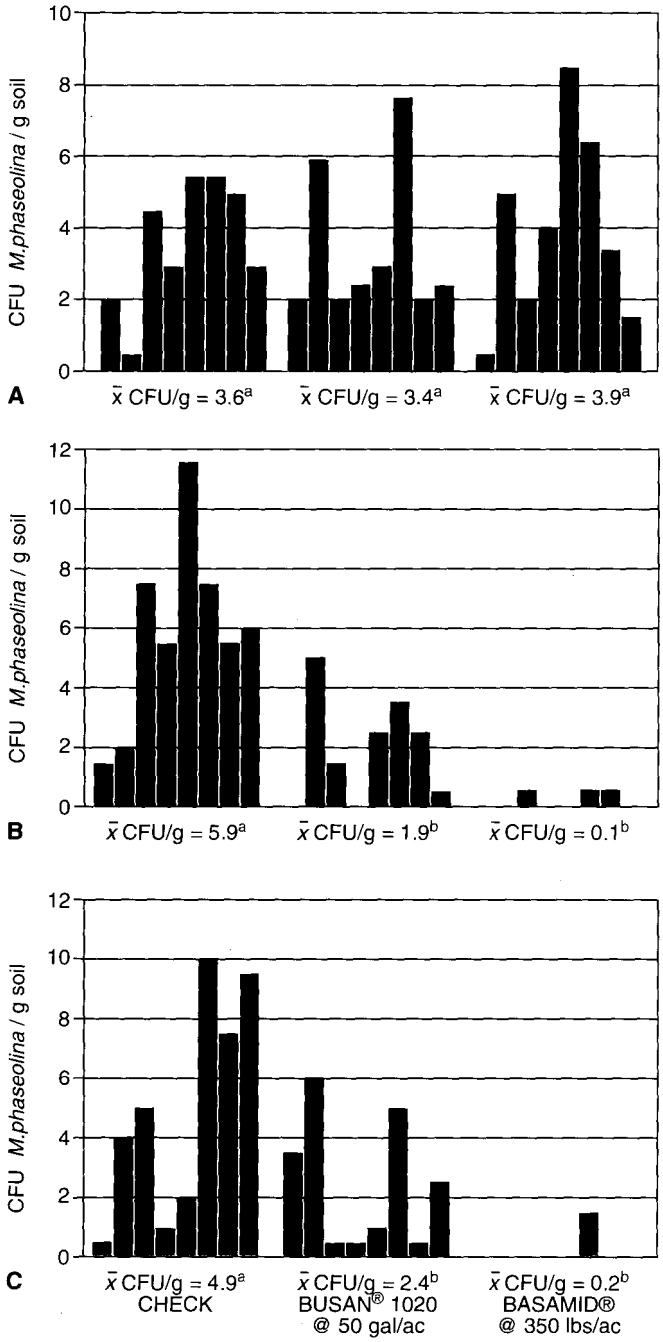


**Figure 2**—*Colony-forming units (CFU) of* Macrophomina phaseolina *in soil from a Florida forest nursery before (on May 18, 1989 [**A**]) and on 2 dates after (June 13 [**B**] and June 26, 1989 [**C**]) treatment with Busan®1020 (metam-sodium) and Basamid®-Granular (dazomet) soil fumigants. Each bar represents an individual soil sample. Within sample dates, treatment means ($\bar{x}$) accompanied by the same letter do not differ significantly ($P \leq 0.05$).

loss of methyl bromide as a soil fumigant. We recommend additional field trials and experimentation.

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Tree Planter's Notes, Volume 45, No. 3

# Benomyl Root Dip and Scalping Improve Early Performance of Longleaf Pine on Pest-Infested Agricultural Croplands

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*A kaolin clay-benomyl root dip and scalping independently improved first-year survival of longleaf pine seedlings on pest-infested agricultural croplands in northern Florida. The root dip treatment, however, appeared to have little or no impact on seedling growth after 2 years in the field, whereas scalping provided significant improvements in seedling emergence from the grass stage and height growth over the same time period.* Tree Planters' Notes 46(3):93-96; 1995.

Longleaf pine *(Pinus palustris* Mill.) has been considered a difficult species to regenerate (Barnett and others 1990, Mann 1969). Its reputation for poor survival and delayed or slow early growth has limited its use in reforestation. Occasionally, however, researchers have reported good results when planting longleaf pine, especially when care is taken in handling and planting and when weed competition is adequately controlled (Barnett and others 1990, Mann 1969, Shipman 1958). Specific procedures showing promise with respect to improving survival and growth of planted longleaf pines include scalping (Shoulders 1958, Cordell and Marx 1995), and kaolin clay-benomyl root dips (Kais and others 1986a, 1986b; Kais and others 1981); the latter designed primarily for control of brown spot needle blight caused by *Mycosphaerella dearnessii* Barr [= *Scirrhia acicola* (Dearn.) Siggers]. As part of a larger study involving slash pine *(Pinus elliottii* Engelm. var *elliottii)* seedlings on pest-infested agricultural croplands (Barnard and others 1995b), we evaluated the performance of longleaf pine seedlings planted on scalped soils and longleaf pine seedlings planted after being root-dipped in a benomyl-amended kaolin clay slurry. This paper summarizes our results.

**Materials and Methods**

Individual study sites were selected in Okaloosa, Madison, and Holmes Counties in northern Florida (Barnard and others 1995). Each site was uniformly cleared of herbaceous weed growth and agricultural stubble by mowing in the fall (October-November) of 1989 before the study plantings were established. In January 1990, longleaf pine seedlings representing each of three treatments were machine-planted at a spacing of about 1 by 3 m (4 by 10 ft) in parallel 75-tree row plots in each of 5 replicate blocks on each of the three study sites (that is, 375 seedlings/treatment/site). The following treatments were used:

SCALP— seedlings were planted on soils mechanically scalped 4 to 6 weeks prior to planting; that is, sod/stubble and soil removed with a tractor-drawn plow blade leaving a "furrow"about 0.75 m (30 in) wide and 7.5 to 10 cm (3 to 4 in) deep.

DIP— seedling roots were dipped in a 2.5% ai benomyl (Benlate® 50WP)/kaolin clay slurry (380 g clay + 20 g benomyl/liter of $H_20$ according to the method of Barnett (personal communication) and planted with no site preparation except the fall mowing.

CHECK— seedlings received no special treatment and were planted with no site preparation except the fall mowing.

Study sites were visited at approximately monthly intervals from April through December 1990. On each visit, all dead and dying seedlings were carefully dug, placed in plastic bags, and carried to the laboratory where they were individually examined for evidence of insect or pathogen activity. Seedling roots were examined visually for evidence of insect feeding typical of whitefringed beetles (*Graphognathus* spp.) (Barnard and others 1995, Dixon 1988, Filer and others 1977, Price 1988) and the presence of internal resin-soaking (resinosis) indicative of possible fungal pathogenesis (Barnard and others 1993, Barnard and others 1995b, Barnard and Blakeslee 1980). Roots were also examined with a 10× hand lens or stereomicroscope as needed for microsclerotia of *Macrophomina phaseolina* (Tassi) Goid., the charcoal root rot fungus (Barnard and others 1995b).

During January-February of 1992, after two complete growing seasons in the field, survival and growth of seedlings in the scalped and check treatments were assessed. The height of seedlings greater than or equal to 10 cm (4 in) tall was measured to the nearest centimeter (3/8 in). Seedlings less than 10 cm (4 in) in height were simply recorded as "grass stage." Seedlings treated with the benomyl root dip were not measured because, upon cursory inspection, their growth appeared no different than that of the check seedlings.

First-year plot survival data was subjected to standard analysis of variance (ANOVA) and differences among treatment means across all three study sites were evaluated for significance at P# 0.05 using Duncan's new multiple range test. Treatment means (scalped versus check only) for second-year survival, grass stage, and height data were evaluated for significant differences within each study site using a simple t test at P#0.05andP#0.01.

**Results**

At the end of the first growing season (December 1990), survival varied appreciably among sites and among treatments within two of the sites (figure 1). Survival of seedlings on the Holmes Co. site was outstanding (>94%) across all three treatments and did not differ significantly among treatments (P #0.05). On the Okaloosa Co. and Madison Co. sites, significant differences among treatments were clear (P # 0.05). On both of these sites, survival was best in scalped rows (plots), worst in check rows, and intermediate in rows with root-dipped seedlings.

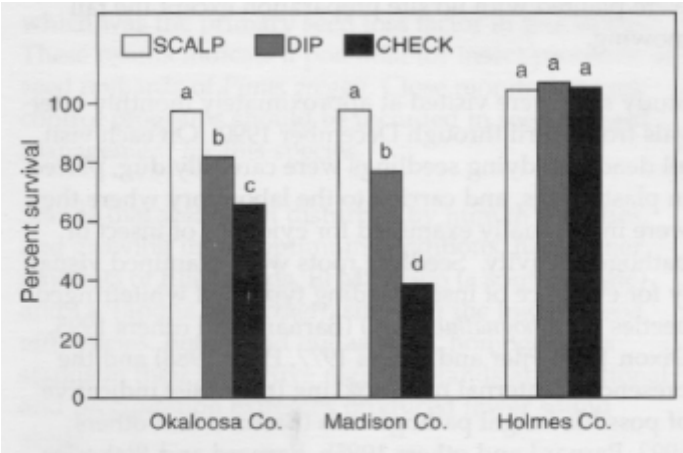



**Figure 1**— *First-year survival of longleaf pine seedlings on pest-infested agricultural croplands in northern Florida for check (CHECK), root-dipped (DIP,) and scalped (SCALP) treatments. Survivals depicted by bars with same-letter superscripts did not differ significantly at P≤ 0.05.*

Evidence of insect feeding damage and potential fungal pathogen activity (that is, resin-soaked roots and/or the presence of microsclerotia of *M. phaseolina)* was detected on dead and dying seedlings from all three sites (figure 2). Insect feeding damage, predominantly that attributable to whitefringed beetles, was clearly most prevalent on seedlings from the Okaloosa Co. site, whereas *M. phaseolina* was most prevalent on seedlings from the Madison Co. site. Resin-soaked roots, although detected in seedlings from all sites, were generally not a frequent feature on seedlings from any site.

On each of the three outplanting sites, root-dipped seedlings exhibited less root resinosis than their respective checks. Respectively, 50% (9 of 18), 12% (19 of 152), and 2.5% (6 of 236) of the check seedlings at the Holmes, Okaloosa, and Madison County sites exhibited root resinosis. None (0 of 12) of the root-dipped seedlings at the Holmes Co. site and only 6% (6 of 100) and 1.7% (2 of 114) of the root-dipped seedlings on the Okaloosa and Madison Co. sites exhibited this symptom.

The occurrence of microsclerotia of *M. phaseolina* on root-dipped seedlings was similarly less than that on the check seedlings on both the Okaloosa and Madison Co. sites. Microsclerotia were detected on 12% (18 of 152) of the check seedlings and on only 7% (7 of 100) of the root-dipped seedlings removed from the Okaloosa Co. site. On the Madison Co. site, only 22% (26 of 114)

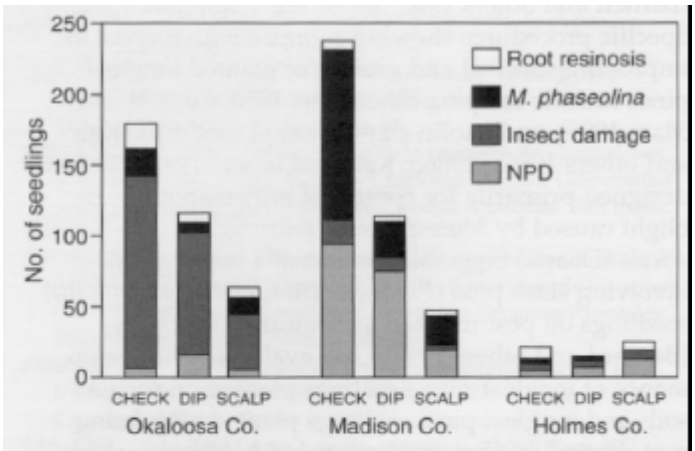



**Figure 2**— *Relative incidence of first-year mortality of longleaf pine seedlings on pest-infested agricultural croplands in northern Florida and associated occurrence of root resinosis, microsclerotia of* Macrophomina phaseolina, *and insect feeding damage. Vertical scale indicates total number of dead and dying seedlings removed and assessed by treatment (CHECK = check, DIP = root-dipped, SCALP = scalped) through the first year following outplanting; total bar heights sometimes slightly higher than actual number of dead and dying trees since more than one pest indicator occurred on some trees. NPD = no pests or pest indicators detected.*

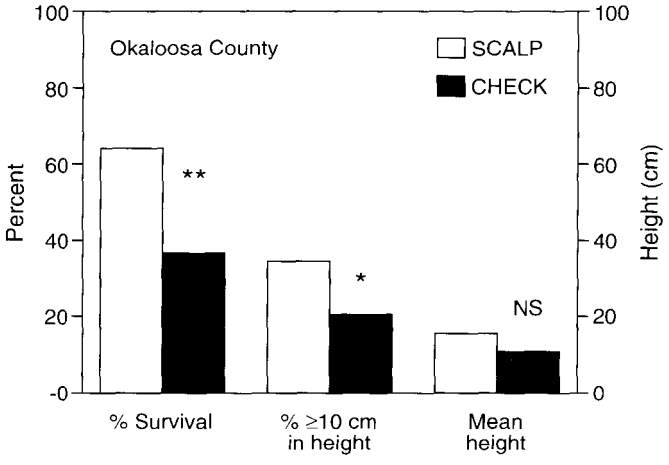
of the root-dipped seedlings displayed microsclerotia, whereas these fungal structures were detected on 51 % (121 of 236) of the check seedlings. In Holmes Co., where the numbers of seedlings examined was notably low, 11 % (2 of 12) of the root-dipped seedlings exhibitec microsclerotia of *M. phaseolina,* while 5% (1 of 18) of the check seedlings were counted as microsclerotia-positive

No patterns or trends between the scalping treatment and the occurrence of root resinosis or microsclerotia of *M. phaseolina* on dead and dying seedlings were evident Similarly, there were no apparent relationships between any of the treatments and the occurrence of the insect feeding damage detected on the dead and dying seedlings.

After two growing seasons, differences in survival, numbers of seedlings out of the grass stage [that is, seedlings $10 cm (4 in) in height], and height growth were clearly evident between seedlings planted in scalped and check rows (figure 3). Treatment differences were more pronounced on the Okaloosa and Madison County sites where pest pressures were high and performance of the check trees was relatively poor. However, performance of seedlings in scalped rows was consistently superior to that of the checks on all three sites.

**Discussion**

Results of this study clearly demonstrate the utility of scalping as a silvicultural practice when planting longleaf pines on similar pest-infested agricultural croplands. The marked improvements in survival and growth recorded for longleaf pine in this study closely parallel those recorded for slash pine in a larger and related study (Barnard and others 1995b). Results of the current study also parallel results reported by Shoulders (1958). He reported that scalping improved survival of longleaf, slash, and loblolly (*P. taeda* L.) pines on grass roughs in central Louisiana. We believe that the improved seedling performance recorded in our study is the combined result of reduced weed competition, improved moisture relations, reduced pressure from certain pathogens (for example, *M. phaseolina),* reduced insect feeding damage, and probably improved planting efficacy (for example, facilitated operation of seedling planters on soil surfaces cleared of residual stubble and organic debris) (Barnard and others 1995b).



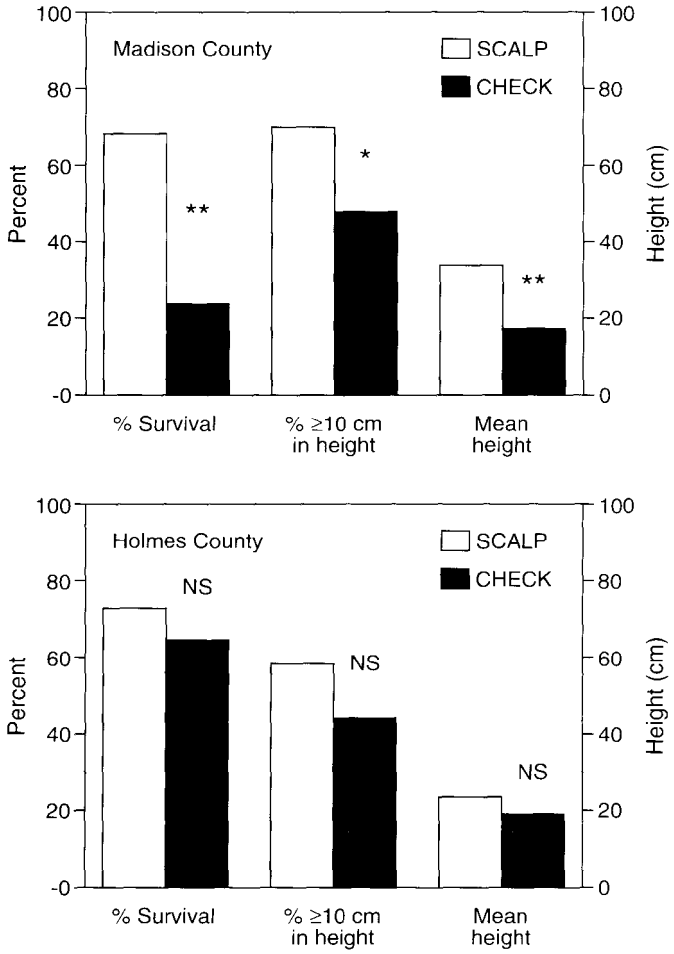




**Figure 3**— *Comparative status of longleaf pine seedlings in check and scalped planting rows after 2 years on pest-infested agricultural croplands in northern Florida. Seedlings were considered out of the grass stage if their height was equal to or greater than 10 cm (4 in). Mean heights (3rd column pair) reflect heights of seedlings out of the grass stage (≥ 10 cm) only. Within each planting site paired bars reflect significant (P ≤ 0.05), highly significant (P ≤ 0.01), and non significant differences, where accompanied by *, **, and NS, respectively. Holmes County comparisons based on only four replications, because one replicate was inadvertently destroyed during the second growing season.*

Benomyl root dips have shown variable, but generally positive, effects on the survival and growth of longleaf pine seedlings in the southern United States (Kais and others 1986a, 1986b; Kais and others 1981), in part due to their effects on reducing brown spot needle blight infections. In our study, brown spot was not a factor on any of the three study sites. Nonetheless, we observed significantly improved survival for seedlings root-dipped in the kaolin clay-benomyl slurry on two of our three study sites. This observation, coupled with the generally reduced frequency of root disease indicators (that is, root resinosis and microsclerotia of *M. phaseolina)* detected on dead and dying seedlings removed from root- dipped plots, suggests that the benomyl may have granted some protection from root pathogens. Similar observations and speculations were reported for similarly treated slash pine seedlings on the same sites (Barnard and others 1995b). The possibility requires further study for verification.

Even if the benomyl-kaolin clay root dip did provide protection for seedlings roots against soilborne root pathogens, it is clear that the overall efficacy of this treatment on our test sites was far less than that of scalping. Seedlings in scalped rows not only survived significantly better than root-dipped seedlings on two of our three sites (figure 1), they clearly grew better as well. Improving seedling performance on sites such as those used in our study requires mitigation of a variety of impeding factors including weed competition, insect feeding, etc. (Barnard and others 1995b). This is apparently provided by the scalping treatment.

Scalping has been routinely employed for silvicultural purposes on pasturelands and hayfields in Florida for many years with good success, and preliminary comparative statistics (Barnard and others 1995a) give this procedure high marks when compared to other site preparation practices. We recommend further trials and utilization of this procedure for improving regeneration successes with longleaf pine.

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# Sprouting and Growth of *Paulownia tomentosa* Root Cuttings

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*Two studies were completed to determine (1) number and diameter distribution of root cuttings obtained from 1-yearold field-grown paulownia —* Paulownia tomentosa *(Thunb.) Steud.— seedling sprouts, and (2) sprouting success and growth of these cuttings under field and greenhouse conditions. The seedling sprouts yielded an average of 7.7 root cuttings ranging in size from 1.3 cm (0.5 in) to more than 5 cm (2 in) in diameter and from 7.6 cm (3 in) to 22.8 cm (9 in) in length. Sprouting success of the root cuttings was 95% in the greenhouse and ranged from 19 to 58% in the field. Variation in field-sprouting success was associated with soil moisture conditions at planting time and incipient root cutting rot. First-year height growth ranged from 21 to 112 cm (8.2 to 43.7 in), showing significant differences among field sites, but not among root cutting diameter classes.* Tree Planters' Notes 45(3):95100; 1994.

Plantations of *Paulownia tomentosa* (Thunb.) Sueud. can be established using many types of planting stock, including seeds, bareroot seedlings, containerized seedlings, and root cuttings (Beckjord 1982, Graves and Stringer 1989). Although containerized seedlings are the most widely used planting stock in the United States, their production and use can be expensive. Producers often ship nondormant containerized stock during the early part of the growing season, requiring large amounts of care after outplanting. Root cuttings are preferred for vegetative propagation of *Paulownia* spp. in many parts of the world (Stephen 1988). Because they require minimal effort for storing, transporting, and planting, root cuttings may also provide a viable planting stock for plantation establishment. Although root cuttings can be obtained from wild trees, producing cuttings in paulownia plant beds can be an effective method of ensuring a source of planting stock. Plant bed techniques and seedling densities for producing 1- and 2-year-old nursery stock have been established (Stringer 1986). These techniques can also be employed to produce root cutting beds.

This paper presents results from two studies. The first study was aimed at determining the number and size of root cuttings from field-grown 1-year-old paulownia *(Paulownia tomentosa)* trees. The second study compared the sprouting success of paulownia root cuttings of different diameters and the subsequent growth of the sprouts relative to planting site and root cutting diameter.

## Methods

**Study 1: Root cutting yield.** In a greenhouse, 100 2-monthold half-sib containerized paulownia seedlings were grown from seed collected from a naturalized tree located at lat. 37° 30' N. and long. 84° 30' W. Seedlings were grown in 2-L (2.1qt) containers for 2 months prior to outplanting. Coppiced containerized root systems were outplanted in May 1989 in a field located in the outer bluegrass region of Kentucky (lat. 38° N. and long. 84° 50' W.). The field was dominated by Kentucky 31 tall fescue *(Festuca elatior* var. KY-31). The soils in the field, located adjacent to a small stream, were classified as Ashton silt loam (fine-silty, mixed, mesic Mollic Hapludalfs) with a rooting depth greater than 1 m (3.3 ft), and capable of yielding a *Quercus rubra* site index of 90 ft, base age 50 years (McDonald et al. 1983). This soil series has been classified as "suited" for paulownia establishment and growth (Stringer and others 1994). Prior to planting, competing vegetation was treated with a 2% glyphosate solution (Roundup®) in a 0.5-m (l.7-ft) radius around each planting spot. Planting spots were arranged on a 3- by 3-m (9.8- by 9.8-ft) grid. Each planting hole was dug 40 cm (15.6 in) wide and 50 cm (19.5 in) deep, then backfilled after planting with extracted soil. Seedling sprouts were allowed to develop throughout the 1989 growing season and then to overwinter. They were excavated by hand spade on April 12,1990. Primary roots 1m (3.3 ft) long and lateral roots 30 cm (11.7 in) long were divided into cuttings using hand shears. Cuttings were grouped into four diameter classes: small (1.3 to 2.5 cm, or 0.5 to 1.0 in), medium (2.6 to 3.8 cm, or 1.0 to 1.5 in), large (3.9 to 5.1 cm, or 1.5 to 2.0 in), and the remaining root collar (>5.1 cm, or >2.0 in). An attempt was made to

divide the root system into cuttings with little variation in diameter along their length; a typical cutting scheme is shown in figure 1. Although the length of cuttings varied among size classes, minimum length was 7.6 cm (3 in). Number and length of cuttings in each class was then determined.

**Study II: Sprouting success and sprout growth.** This study involved determining (1) sprouting percent of paulownia root cuttings of four different diameter classes (treatments), and (2) annual height of the sprouts for each root cutting diameter class.

***Site descriptions.*** Test sites included both field and greenhouse environments. Sites I, II, and III were fields dominated by Kentucky-31 fescue. They were located in the outer bluegrass region of Kentucky (in Woodford County, at lat. 38° N. and long. 84° 50' W.), but did not coincide with the site used in Study I. Sites I and II, which adjoined each other at the top of a 10% north-facing slope, were originally planned as a single test site. But on April 12, 1990, heavy rainfall interrupted planting, which only resumed after the soils had drained for 10 days. This created differences in planting conditions and times between plantings;

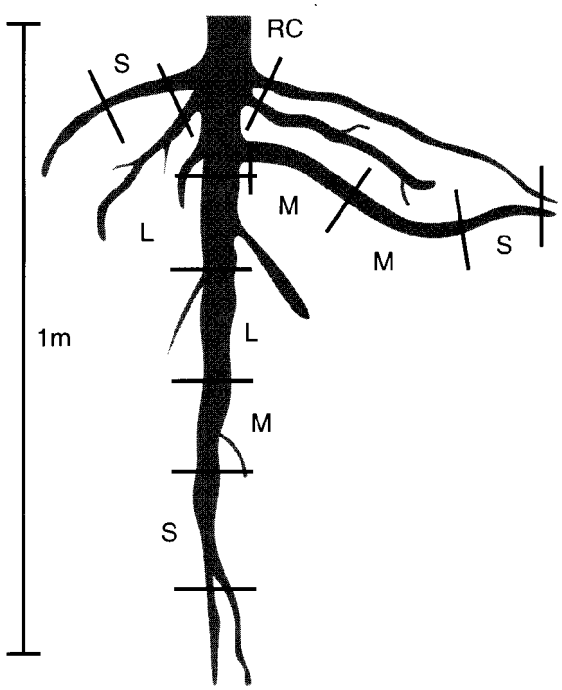


**Figure 1—***Typical division of the root system of 1-year-old Paulownia tomentosa seedling sprouts. RC = root collars (>5.1 cm), L = large-diameter cuttings (3.9-5.1 cm), M = medium-diameter cuttings (2.6-3.8 cm), S = small-diameter cuttings (1.3-2.5cm).*

accordingly, the area planted was treated as two separate sites. Site III was located 1,000 m (3,280 ft) from Sites I and II at the top of a 10% west-facing slope.

Soils at all three sites were classified as Faywood silt loam (fine, mixed, mesic Typic Hapludalfs). They were moderately deep, well-drained soils with a 15-cm (5.9-in) dark grayish-brown silt loam surface layer and a yellowish brown silty clay or clay subsoil extending down to limestone bedrock at a depth of 76 cm (29.6 in). Supporting a *Quercus rubra* site index of 70 ft, base age 50 years (McDonald and others 1983), this soil series has been classified as "questionable" for paulownia establishment and growth (Stringer and others 1994). The range of characteristics associated with this series includes soils well suited for paulownia growth as well as those with clay content above that considered acceptable.

Site IV was located in a greenhouse in Lexington, Kentucky. Four-L (4.2-qt) pots were filled with sterilized potting media consisting of equal parts of perlite, top soil, and sand.

***Test site design and establishment.*** A complete block design with split plots was used for field plantings. Field sites were made up of linear replicate blocks (corresponding to rows) spaced 3 m (9.8 ft) apart. Each block (or row) consisted of 5 linear plots, each of which contained 7 root cuttings planted 3 m (9.8 ft) apart along the row. Within each block/plot combination, all four cutting diameter classes (treatments) were planted. Due to the unequal number of cuttings available for each diameter class, each plot consisted of 1 root collar and 1 large-, 2 medium-, and 3 smalldiameter cuttings randomly distributed in the 7 planting spots. Root cuttings were obtained from Study 1. The number of blocks, plots, and root cuttings by diameter class for each field site are shown in table 1.

Ground cover at all field sites, which consisted primarily of Kentucky-31 tall fescue, had been treated in fall 1989 with a 2% glyphosate (Roundup®) solution in a circle 0.7 m (2.3 ft) in diameter around each planting spot. Each spot was prepared by digging a hole about 40 cm (15.6 in) wide and 50 cm (19.5 in) deep using a tractor-mounted posthole digger.

Root cuttings were excised from the root systems on April 12, 1990, and dried for 10 days prior to planting. At planting time, the cut ends were dry to the touch. Cuttings were oriented vertically in the holes, with the basipetal end approximately 2.5 to 5.0 cm (1 to 2 in) below the surface. Root collars were planted with the distal end of the cutting 2.5 to 5.0 cm (1 to 2 in) below the surface. The holes were then backfilled with

Table 1 -*Number of blocks, plots, and root cuttings by diameter class for each field site*

| Site | Blocks | Plots | Cuttings by diameter class | | | |
|---|---|---|---|---|---|---|
| | | | Small | Medium | Large | Root Cellar |
| I (north slope) | 6 | 30 | 90 | 60 | 30 | 30 |
| II(north slope) | 3 | 15 | 45 | 30 | 15 | 15 |
| III(west slope) | 9 | 45 | 135 | 90 | 45 | 45 |

extracted soil. Planting of Site I was completed on April 23,1990, when soils were wet; a saturating rain halted further planting. After the soil had been allowed to drain for 10 days, Sites II and III were planted. In the interim between plantings, cuttings were stored in a ventilated shed. Other than the initial application of herbicide, no cultural treatments were applied to the field sites.

Root cuttings were planted in the greenhouse (Site IV) on April 22, 1990. Five root collars and 5 large-, 10 medium-, and 15 small-diameter cuttings were placed in individual pots with the same orientation as described for Site 1. Plants were watered thoroughly every other day.

**Analysis.** On July 27, 1990, sprouting percent, sprout survival, and total height were determined at all sites. In January 1991, sprout survival and total height were determined at sites I, II, and III. Arc sin transformation of sprouting percent data (Steel and Torrie 1980) along with untransformed data of the other variables were subjected to Wilk-Shapiro/rankit plots to test for normality. Statistical analysis using ANOVA (Type III SS) (Shaw and Mitchell-Olds 1993) and LSD pairwise *t*-test were used to determine differences among the various sites and root cutting diameters in sprouting percent as well as in sprout growth and survival (P

## Results and Discussion

**Study 1: Root cutting yield.** Ninety-eight of the 100 coppiced containerized seedlings survived, averaging 1.86 m in height. Root cuttings per root system averaged 7.7, for a total of 753 cuttings from the 98 sprouts. Average yield of cuttings per root system was 1 root collar and 1 large-diameter, 2.1 medium-diameter, and 3.6 small-diameter cuttings (table 2). Cutting length varied by diameter class, ranging from 7.6 to 22.8 cm (3 to 9 in) (table 2). Where trees are allowed adequate growing space and given proper care, root cutting yield per seedling sprout should be comparable to that obtained in this study. However, root cutting yield from similar-aged trees may not be this great if grown where competition is present or where soil-site factors are less than favorable for paulownia growth.

Table 2-*Diameter distribution of root cuttings from 1-year-old Paulownia tomentosa seedling sprouts*

| Diameter class (cm) | Cutting length (cm) | Number of cuttings[1] | |
|---|---|---|---|
| | | Total | per tree |
| Root collar (>5.1) | 7.6-12.7 | 98 | 1.0 |
| Large (3.9-5.1) | 7.6-17.8 | 98 | 1.0 |
| Medium (2.6-3.8) | 7.6-17.8 | 205 | 2.1 |
| Small (1 .3-2.5) | 7.6-22.8 | 352 | 3.6 |

*1 Ninety-eight 1-year-old seedling sprouts produced a total of 753 cuttings.*

**Study II: Sprouting success and sprout growth.** There were differences in sprouting percent among sites, but no significant differences among cutting diameter classes. Sprout survival was excellent at all sites. Both midseason and first-year sprout height growth varied greatly among sites, but there was little difference in height growth among cutting diameter classes.

***Sprouting percent and sprout survival.*** Data pooled by diameter class showed a significant difference (P sprouting percent among test sites (table 3). The 95% sprouting of root cuttings planted in the greenhouse (Site IV) was significantly greater than at any of the field sites. Fifty-eight percent of the cuttings at Site II produced sprouts, a significantly higher percentage than at Site I or III, where cuttings sprouted at rates of 19 and 23%, respectively. Although cuttings with larger diameters tended to have a higher sprouting percent, no statistical difference in sprouting percent was found among diameter classes within sites.

The sprouting percent obtained for cuttings planted into drained soils at Sites I and IV were comparable to

**Table 3**—*Sprouting percent of* Paulownia tomentosa *root cuttings*

| | Site | | | |
|---|---|---|---|---|
| Diameter class | I | II | III | IV |
| Root collar | 22.3 | 66.7 | 14.0 | 100.0 |
| Large | 16.7 | 60.0 | 36.0 | 100.0 |
| Medium | 23.3 | 53.3 | 24.4 | 96.7 |
| Small | 14.6 | 53.3 | 18.0 | 83.3 |
| Mean[1] | 19.5 a | 58.3 b | 23.1 a | 95.0 c |

[1] Significant differences, as determined by ANOVA (Type III SS) and LSD at $P < 0.05$, among sites for survival are indicated by different letters.

those found by Rin (1979) for Taiwan paulownia (*Paulownia taiwaniana*) cuttings of similar size. In sprouting studies of Taiwan paulownia cuttings, Fang and Hwang (1979) found that root collars did not perform as well as true root cuttings. In the present study, however, the percentage of root collars producing sprouts was similar to that of other cutting diameter classes. Examination of cuttings 1 month after planting revealed that unsprouted cuttings were entirely rotten, whereas unrotted or partially rotted cuttings were either developing buds or in the process of sprouting. Examination of the cuttings in the greenhouse found little evidence of rot.

Sprout survival was excellent. One hundred percent of the established sprouts survived the first growing season at Sites II, III, and IV, and 96% survived at Site I. Accordingly, overall plantation mortality can be attributed to a lack of initial sprouting. Observational evidence suggests that failure to sprout resulted from rot developing in the cuttings prior to sprout development. It may be possible to prevent rot development by reducing the time the cuttings are in the soil prior to shoot development. This could be accomplished by pretreating the cuttings to initiate budding, or by planting late, after soils have warmed. It may also be possible to reduce rot by treating root cuttings with a fungicide solution prior to outplanting. The results of this study suggest that prescriptions for dipping paulownia whole-root systems in fungicide (Beckjord 1984) should be applied to root cuttings as well.

***Sprout growth (midseason).*** Within diameter classes, midseason height growth differed significantly ($P \leq 0.05$) among sites (table 4). Greenhouse-grown sprouts (Site IV) were taller than field-grown sprouts across all cutting diameter classes. But midseason sprout height was generally only weakly related to cutting diameter. Simple linear regression of sprout height and cutting diameter yielded an $r^2 = 0.58$ ($y = -9.064 + 28.207 \cdot X$). Analysis of data pooled over all sites indicated no significant differences among diameter classes for sprout height. The only significant intrasite difference among diameter classes was found at Sites I and IV (table 4). At Site I, small-diameter cuttings had shorter sprouts (averaging 27.4 cm, or 10.7 in) than medium-diameter cuttings (which averaged 46.0 cm, or 17.9 in). At Site IV, small-diameter cuttings had significantly shorter sprouts (averaging 61.0 cm, or 23.8 in) than other diameter classes, and root collars produced significantly taller sprouts (averaging 91.3 cm, or 35.6 in) than other diameter classes. Still, the general lack of growth differential

**Table 4**—*Midseason heights (cm) of sprouts from* Paulownia tomentosa *root cuttings (measured July 27,1990)*

| | | Diameter class[1] | | | |
|---|---|---|---|---|---|
| Site | Root collar | Large | Medium | Small | Mean |
| I (north slope) | 36.5 ab | 39.6 ab | 46.0 a | 27.4 a | 35.8 a |
| II (north slope) | 46.0 a | 54.9 a | 45.0 a | 45.0 b | 46.5 b |
| III (west slope) | 24.4 b | 30.5 b | 30.4 b | 21.3 a | 25.7 a |
| IV (greenhouse) | 91.3 c | 76.2 c | 73.2 c | 61.0 c | 71.0 c |
| Mean[2] | 49.6 | 50.3 | 48.7 | 38.7 | — |

*Note:* Values within a column with the same letter are not significantly different using ANOVA (Type III SS) and LSD at $p < 0.05$.

[1] No statistical differences were found among diameter classes within a site, except for Site I, where sprouts from small cuttings were shorter than those from medium cuttings, and Site IV, where sprouts from small cuttings were shorter and those from root collars larger than those from other diameter classes ($p > 0.05$).

[2] No statistical difference was found among diameter classes for data pooled across all field sites.

among diameter classes within field sites was unexpected.

Observation of the sprouts showed that height growth within a cutting diameter class was positively related to the amount of rot present in the cutting. Smaller sprouts were found where much of the cutting had rotted, whereas larger sprouts were from cuttings with little or no rot. Rot may have reduced the amount of carbohydrates available for root and shoot development. Variation in rot development in the cuttings may have masked differences in height growth relative to cutting diameter. However, the performance of the small- and medium-diameter cuttings was favorable, because a planting bed can produce a greater number of smaller cuttings than larger ones.

***Sprout growth (annual).*** In early September 1990, hail damaged approximately one-half of the leaves and broke the tops out of approximately 15% of the sprouts. The damage may have affected total height growth, but it was consistent across all cutting diameter classes and sprout sizes, and damaged sprouts (except for those with top damage) were used in the analysis.

As was the case at midseason, significant differences in height growth among sites within diameter classes were found (table 5). After the first growing season, sprout height growth from cuttings planted at Site II (which averaged 93.6 cm, or 36.5 in) exceeded growth at Site I (which averaged 65.7 cm, or 25.6 in) by more than 25 cm (9.8 in). Height growth varied greatly within each diameter class across sites, with standard deviation approaching 50% of total height. But no statistical difference in total height was found among root cutting diameter classes within sites at the end of the first growing season.

Analysis of data pooled over all diameter classes showed that Site III had significantly less height growth (26.5 cm, or 10.3 in) than Sites I and II, despite identical slope, elevation, and soil series. The primary difference was aspect: whereas Sites I and II faced north, Site III faced west. The greater height growth at Sites I and II may reflect increased moisture availability due to the northerly exposure of the slope. Results suggest that planting trials are necessary to determine suitability of a potential plantation site where the mapped soil series has a range of characteristics, portions of which are not recommended for the species.

## Management Implications

Given reasonable planting conditions, root cuttings are a viable planting stock for establishing paulownia plantations. However, when cuttings are planted under conditions that would be acceptable for bareroot seedlings, rot may develop, and lower sprouting percent or sprout height growth may result. Avoiding extremely wet soils and planting into relatively warm soils should decrease the danger of rot. This might best be accomplished by planting at the beginning of the growing season, a time considered late for bareroot seedling establishment. In addition, using fungicide dips and pretreating cuttings to stimulate sprouting before outplanting may help to reduce rot.

Table 5 -*First-year height growth (cm) of sprouts from* Paulownia tomentosa *root cuttings (measured January 1991)*

| | Diameter class[1] | | | | |
|---|---|---|---|---|---|
| Site | Root collar | Large | Medium | Small | Mean |
| I (north slope) | 54.9 a | 67.1 a | 91.4 a | 51.8 a | 65.7 a |
| II (north slope) | 85.39 a | 112.8 a | 82.3 a | 97.5 b | 93.6 b |
| III (west slope) | 21.3 b | 30.4 b | 30.4 b | 24.4 c | 26.5 c |
| Mean[2] | 53.8 | 70.1 | 68.3 | 57.9 | — |

Note: Values within a column with the same letter are not significantly different using ANOVA (Type III SS) and LSD at $p < 0.05$.

[1] No statistical difference was found among diameter classes within sites.

[2] No statistical difference was found among diameter classes for data pooled across all field sites.

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# Fungicide Treatment Increases Sprouting Percentage and Sprout Growth for *Paulownia tomentosa* Root Cuttings

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*Root cuttings are widely used to propagate paulownia*—Paulownia tomentosa (Thunb.) Steud.—*for nursery bed establishment, and they can be used to establish plantations. However, the success of outplanted cuttings may be limited by rot. This study showed that paulownia root cuttings soaked in a general-purpose fungicide solution had higher sprouting success (68.3%) than untreated cuttings (21.2%) when planted in silty clay soils. When planted in silty loam soils, sprouting success was similar for treated and untreated cuttings. But treated cuttings in silty loam soils produced sprouts of greater average height (74.1 cm, or 28.9 in) at midseason than did untreated cuttings (48.6 cm, or 19.0 in).* Tree Planters' Notes 45(3):101–103; 1994.

Vegetative propagation via root sprouts is one of the primary methods used throughout the world for establishing *Paulownia* spp. (Stephen 1988). Although root cuttings are relatively easy to obtain and outplant, survival of the root sprouts and subsequent sprout growth can be influenced by cutting size (Fang and Hwang 1979), desiccation (Rin 1979), and cutting rot (Stringer 1994). Root cuttings are generally obtained from plant beds containing 1- or 2-year-old trees. Root systems are excavated and divided into cuttings; then fibrous roots are removed and the cuttings are exposed to the air until the ends have dried. Investigation of the sprouting success and growth of Taiwan paulownia (*Paulownia taiwaniana*) found that after 7 days of ventilated drying, cuttings had lost less than 7% of their moisture, and survival of planted root cuttings exceeded 92% (Rin 1979). However, continued moisture loss was negatively correlated to root cutting survival. Survival decreased to less than 25% when the cuttings were at 54% moisture content (MC), and to 0% when they were at 34% M.C. The timing of sprout development, sprout root weight, and sprout top growth were also correlated to loss of MC (Rin 1979).

Although maintaining root cutting MC at relatively high levels is important for successful plantation establishment, initial air-drying of cuttings is critically important in protecting from rot after cuttings are outplanted. Initial drying seals cutting ends, forming a barrier to fungal penetration. But despite initial drying, outplanted paulownia (*Paulownia tomentosa*) root cuttings in North America remain susceptible to rot, especially if subjected to saturated soil conditions (Stringer 1994). Outplanting at appropriate ground temperatures and moisture levels may reduce rot formation. But rot has been found to decrease sprout growth even when planting conditions are reasonably good; it is the most important factor in planting failures (Stringer 1994). Fungicide treatments have been used to reduce rot in root cuttings of several hardwood species (Keresztesi 1988) and have been suggested for use in paulownia propagation (Beckjord 1984, Graves and Stringer 1989, Stringer 1994).

The objective of this study was to determine the effectiveness of a fungicide treatment on the sprouting percent and initial sprout growth of paulownia root cuttings. The study was conducted on two sites, one with soils considered good for paulownia growth, and one with a history of rot in outplanted cuttings but with acceptable subsequent sprout growth (Stringer 1994).

## Methods

**Root cutting treatment.** Paulownia root cuttings were obtained from 1-year-old half-sib field-grown sprouts averaging 1.92 m (6.34 ft) in height. The root systems of these sprouts were excavated in March 1991. A total of 640 root cuttings from 7.6 to 22.8 cm (3 to 9 in) in length were excised from primary roots and laterals between 1.3 and 5 cm (0.5 and 2 in) in diameter (see Stringer 1994). Cuttings were air-dried in a ventilated shed for 10 days until ends were dry to the touch. One-half of the cuttings (325) were randomly selected and submerged in a fungicide solution for 15 minutes. The solution was a mixture of captan (47.3% ai) and benomyl (Benelate® 50% ai) at 1 g per 416 ml

water (2 lb per 100 gal) and 1 g per 833 ml water (1 lb per 100 gal), respectively. Cuttings were allowed to air-dry another 7 days prior to outplanting.

**Field planting.** On April 12, 1991, cuttings were planted into two fescue-dominated fields in Woodford County, in the outer bluegrass region of Kentucky. Field 1 was located along an alluvial floodplain with less than 5% slope (see Stringer 1994, Study I, for a description). The soils in Field 1 were classified as Ashton silt loam (McDonald and others 1983) and were rated "suitable" for paulownia (Stringer and others 1994). Field 2 was located at the top of a 10% north-facing slope (see Stringer 1994, Study II, Site II, for a description). Soils were classified as Faywood silt loam (McDonald and others 1983) and were rated "questionable" for establishment of paulownia (Stringer and others 1994). Previous studies had shown this field to produce acceptable sprout growth, although rot developing in outplanted root cuttings had resulted in less than 50% survival of the cuttings (Stringer 1994).

Prior to planting in both fields, competing vegetation, primarily Kentucky 31 tall fescue (*Festuca elatior*), was treated with a 2% glyphosate solution (Roundup®) in a 0.75-m (2.5-ft) radius around each planting spot. Planting spots were arranged on a 1.5- by 3-m (5- by 10-ft) grid, and each planting hole was 15 cm (5.9 in) wide and 30 cm (11.7 in) deep. Cuttings were placed vertically in each hole, with the basipetal end approximately 2.5 cm (1 in) below the surface. Holes were backfilled with extracted soil after planting. Each field consisted of four linear planting blocks (or rows) containing 80 cuttings each. Treatments were systematically assigned to blocks, with even-numbered blocks containing treated cuttings and odd-numbered blocks containing untreated cuttings. This resulted in a total of 160 cuttings per treatment in each field. The plantings received no cultural treatments other than the initial competition control. Sprouting percent, total height (to apical bud), and basal diameter were measured in July 1991. Arc sin transformation of sprouting percentage (Steel and Torrie 1980) along with untransformed data of other variables were subjected to statistical analysis using two-sample *t*-tests ($P \leq 0.05$). Comparison between treatments, both within and among sites, were made.

## Results and Discussion

**Sprouting percent.** In Field 2, fungicide treatment produced a significantly ($P \leq 0.05$) higher sprouting rate (68.3%) than did nontreatment (21.1%; figure 1).

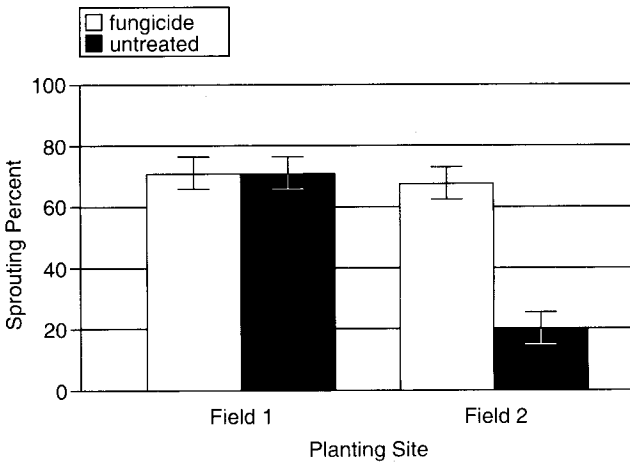


**Figure 1**—*Sprouting percent of Paulownia tomentosa root cuttings. Bars represent mean and associated standard error of treated (fungicide-soaked) and untreated cuttings planted into tw fields.*

However, fungicide treatment had no effect on sprou ing rate in Field 1, where both treated and untreated cuttings had sprouting rates of about 72%. The treatment/site interaction may have resulted from lower clay content and better soil drainage in Field 1, whicl inhibited rot development in the cuttings. Sprouting percent for treated cuttings in Field 2 and for all cuttings in Field 1 was within the range of 67.5-92.5% (mean = 82%) found by Fang and Hwang (1979) for cuttings of Taiwan paulownia of similar size.

**Height and basal diameter growth.** Although sprouting rates were similar for both treated and untreated cuttings in Field 1, treated cuttings produc sprouts significantly ($P \leq 0.001$) taller by midseason, averaging 74.1 cm (28.9 in) in height compared to an average of 48.6 cm (19.0 in) in height for untreated cuttings (figure 2A). Despite a similar disparity in Fie 2 in height growth of sprouts from treated and untreated cuttings, in this case the difference was not significant. Previous observations indicated that increased rot in root cuttings decreases sprout growt (Stringer 1994). Loss of carbohydrate supply or rot moving from the cutting to the sprout could account for the reduction in sprout growth.

But it is unclear why sprouts from untreated cuttings did not perform as well in Field 1 as they di in Field 2. Perhaps untreated cuttings that sprouted i Field 2, though fewer in number than those in field 1 were substantially free of rot, and therefore capable matching the height growth of sprouts from treated cuttings. Untreated cuttings in Field 1, however, ma have contained enough rot to inhibit sprout growth,

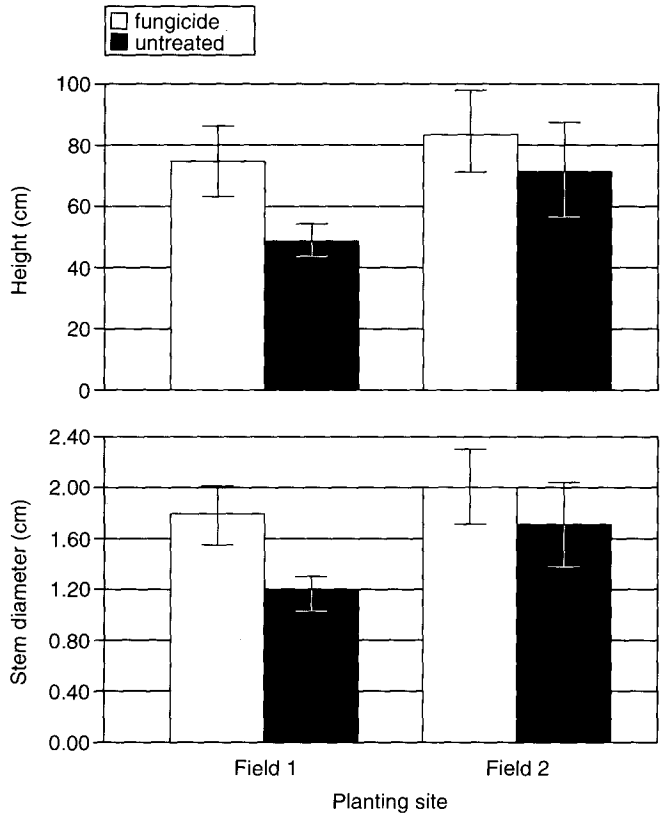


**Figure 2**—*Height (**A**) and basal diameter (**B**) of Paulownia tomentosa root cutting sprouts at midseason (July 1991). Bars represent mean and associated standard error of treated (fungicide-soaked) and untreated cuttings.*

but not enough to produce sprout failure.

These results indicate that soils in Field 2 may not be as conducive to root cutting establishment as soils in Field 1. But after root cuttings are successfully established, soils in Field 2 may produce as much sprout growth as those in Field 1. Although fungicide treatment produced different effects on the different sites, it improved planting success on both sites by increasing sprouting percent on one site and height growth on the other.

Basal diameter growth showed a trend similar to height growth (figure 2B). Field 2 showed no significant difference between sprouts of treated (2.0 cm, or 0.8 in) and untreated (1.7 cm, or 0.7 in) cuttings. But in Field 1, sprouts from treated cuttings averaged 1.8 cm (0.7 in) in diameter, compared to 1.2 cm (0.5 in) for sprouts from untreated cuttings, a significant difference at $P \leq 0.01$.

## Conclusions

The success of new plantations using paulownia root cuttings can be enhanced by soaking air-dried cuttings in a general-purpose fungicide solution. In soils considered questionable for paulownia growth, and where previous studies had shown unacceptable sprouting success, 68% of cuttings soaked in fungicide sprouted, compared to 21% of untreated cuttings. In soils considered suitable for paulownia establishment, fungicide treatment had no effect on sprouting percent, but did produce greater sprout height and diameter growth. Fungicide treatments are relatively inexpensive and should be considered for use under all planting conditions for paulownia root cuttings.

## Acknowledgments

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# Atlantic White-Cedar Propagation by Seed and Cuttings in New Jersey

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*Atlantic white-cedar*— Chamaecyparis thyoides *(L.) B.S.P.---propagation was tested using seeds and cuttings. Photoperiod played an important role in seed germination. Under 16-hour daylength, 31.9%* of *fresh seeds germinated, compared to 0.7% under 10-hour daylength. Cold stratification and gibberellin treatments could substitute for the photoperiod requirement. There was great variation in viability among seedlots from different cedar swamps. For seed propagation, 30-day stratification on sphagnum at 4 ºC is recommended. Optimal rooting (97.5%) was obtained on cuttings 6 to 7 cm (2.3 to 2.7 in) long taken from juvenile trees in November, dipped in powdered Hormodin #2, and stuck in a well-drained mix of Pro-Mix BX, peat moss, and sand under intermittent mist with bottom heat (24-26 ºC). Sturdy, well-developed root systems developed within 3 months.* Tree Planters' Notes 45(3): 104-111; 1994.

Atlantic white-cedar *(Chamaecyparis thyoides* (L.) B.S.P.) is one of eastern North America's most unique wetland species. Ranging along the eastern seaboard and gulf coast of the United States (figure 1), it is important both economically for its timber and ecologically as a habitat for many species of flora and fauna not common to other freshwater wetlands (Kantor 1976). Natural regeneration of cedar is difficult because of deer browsing, competing hardwoods, and variable seed germination rates (Little 1950). Much has been written about cedar germination variability due to poor seed quality and set, insect damage, and varying degrees of embryo dormancy (USDA 1974; Laderman 1987). Cedar, an intolerant species, needs disturbance to reestablish; yet disturbance often results in the conversion of cedar swamps to other wetland types (Roman and others 1987).

We compared sexual and asexual propagation techniques that could assist regeneration and reforestation efforts in places where Atlantic white-cedar has failed to regenerate or cedar swamp establishment is desired for wetland mitigation. Seed propagation is relatively inexpensive, requires little technology, and promotes genetic diversity. But seed germination varies greatly among seedlots from different swamps, and cedar seeds may not germinate until 2 or 3 years after seedfall (Laderman 1989). Rooted cuttings capture a tree's full genetic potential, allowing for the selection of desirable individuals. However, vegetative propagation may be more expensive, requiring facilities such as hedge orchards and a greenhouse.

**Figure 1**—*Range of Atlantic white-cedar* (Chamaecyparis thyoides *(L.) B.S.P.) (Little 1971).*

We addressed the following questions: Does daylength make a difference in germinating seeds? What length of stratification is needed? Can gibberellins substitute? Is pH important? Can potassium nitrate increase germination? For rooting of cuttings, does soil type matter? Can cuttings be rooted without mist? Does misting improve rooting? Do auxins

increase rooting success? Does the age of the donor tree influence rooting success? What are the relative advantages and disadvantages of seed propagation and rooting of cuttings?

## Materials and Methods

A two-part design was implemented for this study. The first part dealt with seed viability and germination, and the second part with vegetative propagation.

**Seed propagation.** Cedar cones were collected in fall 1991 from eight different swamps in New Jersey (table 1, figure 2). In six swamps (Belleplain, Double Trouble, Greenwood, Lebanon, Manchester, and Penn), the cones were collected from a mix of trees of varying sizes: greater than 6 m (20 ft), about 3 m (10 ft), and 1.5 m (5 ft) or less. These were often found on the edges of swamps or near blowdowns, because the best cone production was in full sun. The cones were collected with a pole pruner, or if a tree was large enough it was climbed. At Cheesequake, cones were collected from a single midsized tree, the only tree heavily coning. At High Point, all cones were collected from old even-aged trees, because no others were available. Seeds were collected from early October through early November.

Seed extraction was accomplished by heating the cones in an oven at 35 to 37 ºC until they opened (USDA 1974). Most seeds could easily be removed at this point, but in some cases cones had to be soaked


**Figure 2—***Atlantic white-cedar swamps sampled.*

**Table 1** -*Viability and germination of Atlantic white-cedar seed by New Jersey swamp of origin*

| | Viability | | | | | Germination | |
|---|---|---|---|---|---|---|---|
| Swamp | Bad seed[1] | Insect damage | Empty seed | Rate(%) | *T*-grouping[2] | Average rate[3] (%) | *T*-grouping[2] |
| Belleplain | 70 | 0 | 0 | 30 | C | 7.3 | F |
| Cheesequake | 47 | 2 | 0 | 51 | AB | 21.0 | CD |
| Double Trouble | 32 | 15 | 11 | 42 | BC | 24.5 | C |
| Greenwood | 36 | 2 | 0 | 62 | A | 17.5 | DE |
| High Point | 2 | 0 | 43 | 55 | AB | 46.7 | A |
| Lebanon | 35 | 6 | 1 | 58 | A | 13.2 | E |
| Manchester | 1 | 0 | 39 | 60 | A | 30.0 | B |
| Penn | 39 | 1 | 9 | 51 | AB | 19.7 | CD |

[1] Brown or deformed embryos present.

[2] Percentages with the same T-group letter are not significantly different.

[3] Average germination rate for all experiments conducted on seeds from the indicated swamp.

overnight in water and reheated. Cedar seeds are very tiny, with a diameter of 2 to 3 mm (0.8 to 1.2 in), and removal of seed debris proved difficult. Attempts were made to pass the seeds through a metal mesh straining screen, but debris the same size as the seeds remained. The most effective method proved to be gently shaking the seeds across a Styrofoam plate. Static electricity helped keep the debris on one side of the plate while the heavier seeds slid to the other.

The cleaned seeds were then grouped by swamp into lots of 100. Tetrazolium seed tests for viability were attempted as prescribed by the International Seed Testing Association, but were difficult to read and often inconclusive. (However, the National Tree Seed Laboratory has successfully conducted tetrazolium studies on North Carolina seed.) Because of this difficulty, seed viability was estimated by dissection. One hundred seeds from each swamp were dissected. Seeds with fresh-looking embryos were counted as viable, whereas empty seeds or those with insect-damaged or discolored embryos were counted as nonviable.

Germination tests were conducted under various conditions, including daylength, stratification, and additional liquid treatments with water at pH 7 (as a control), water at low pH levels, potassium nitrate, and gibberellin. One hundred seeds from each test lot were placed on filter paper in a petri dish. In preliminary tests with apparently viable seed on filter paper that was merely moist, germination had usually not occurred. Adding extra water seemed to facilitate imbibition, so treatment liquid was added until the seeds floated. As the liquid in the dishes dried out, water was added until the seeds refloated. The dishes were moved every 5 days to minimize the effect of position within the germinator. The germinator contained 6 "Gro and Sho" lights producing 645,840 lumens $m^2$ (lux) and was kept at a temperature between 22 and 26 ºC. All germination studies were done under this light and temperature regime. At 3 weeks, as germination was beginning, the germinants were counted and removed. Remaining seeds were checked daily, and subsequent germinants were counted, added to the totals, and removed. Germination rates were recorded for a period of 2 months, or until fungal or bacterial contamination stopped the experiment.

***Daylength.***. A trial testing 16-hour ("long-day") photoperiod was conducted on seeds from seven different swamps (there were insufficient seeds to conduct the test for Cheesequake). Two petri dishes were prepared for each swamp (14 dishes in all), each containing 100 seeds. An identical trial was conducted under a 10-hour ("short-day") photoperiod. These tests were performed with water alone, not in combination with potassium nitrate or other additives. Short-day seeds that did not germinate after 2 months were exposed to long-day conditions. Data comparing germination of seeds from the seven swamps under 16-hour daylength were tested by pairwise chi-square analysis, and data on germination under 10-hour daylength were tested by chi-square analysis comparing one swamp (where some seeds germinated) to six other swamps (where none germinated).

***Stratification***. *To* test the effect of cold stratification, three groups of test seeds were prepared (one group for each time period to be used). In each group, about 500 seeds from each of four swamps (Greenwood, Lebanon, Manchester, and Penn) were used. The seeds were first placed on moistened sphagnum in plastic bags in a cold box at 4 ºC. The first group of seeds was removed after 30 days, the second after 60 days, and the third after 90 days. After removal from the cold box, the seeds were washed off the sphagnum, and four replicate dishes were prepared for each of the four swamps (16 dishes in all). Each dish contained 100 seeds, floated as described above. Two dishes from each swamp were tested under the 16-hour photoperiod and two others from each swamp under the 10-hour period. As the liquid in the dishes dried out, water was added until the seeds refloated; dishes were moved within the germinator every 5 days.

***Liquid treatments.*** Experiments with seven different liquid treatments were performed under the germinator conditions described above. Seeds from each swamp were used, although not enough seeds from High Point were available to perform all seven tests. Seeds were tested with three replications per swamp, each dish containing 100 seeds. The seven treatments included pH 7 (control water), pH 3, pH 4, pH 5, cedar swamp water (pH 4.3), 0.2% potassium nitrate, and gibberellin. Tap water was used for the pH 7 control (preliminary tests had shown that distilled water made no difference). The three lower pH values were achieved by titration with hydrochloric acid to the desired level. In the gibberellin test, a 3,000-ppm gibberellic acid solution was added to the petri dishes for 24 hours. The dishes were then drained, and water was added. Seeds were floated in all seven treatment liquids, and water was added when solutions evaporated. All treatments were performed under 16-hour daylength at 22 to 26 ºC; the gibberellin treatment was also done under short-day conditions.

A generalized linear model (SAS GLM procedure) with least significant difference T-grouping test ($P = 0.05$) was used to statistically test the effects of cold

stratification, pH, potassium nitrate, and gibberellin treatments on germination rate and to determine significance of variation among seeds from different swamps (SAS 1990).

**Rooting of cuttings.** The second part of the experiment examined methods of vegetative propagation of cedar. Only two swamps (Greenwood and Manchester) were used for the cutting experiments. Half of the cuttings were from mature wood (branches that carried cones), and the other half were from juvenile trees about 1 m (3.3 ft) high and without cones. All cuttings were from the ends of branches (laterals and terminals) and were taken from current-season growth. Cuttings averaged 5 to 7 cm (2.0 to 2.7 in) in length and were taken with an extra "heel" (a piece of woody tissue at the base) (Hartman and others 1975). Cuttings were taken in early October (Dirr 1990) and again in November. They were placed in plastic bags to prevent desiccation and stored at 4 C until they were stuck.

The first experiment, run in the greenhouse without mist, was designed to compare (1) cutting sources (Greenwood and Manchester); (2) maturity states (adult and juvenile); (3) times of year (October and November); (4) rooting medium (Pro-Mix BX; peat moss and sand; and equal parts Pro-Mix BX, peat moss, and sand); and (5) rooting hormones (powdered Hormodin dips: Hormodin #1 (active indole-3-butyric acid 0.1%); Hormodin #2 (IBA 0.3%); and Hormodin #3 (IBA 0.8%)). Twenty cuttings were tested in a full factorial design combining swamp, maturity state, time of year, rooting medium, and rooting hormone. Cuttings were stuck in individual Leach tubes (10-in$^3$ Supercells) filled with medium and placed in 98-tube racks. Each treatment other than medium was randomly selected for spacing in the rack. Racks were moved around the greenhouse weekly to minimize position effect. Temperatures in the greenhouse ranged from 16 to 21 ºC at night to 18 to 22 ºC during the day. Ambient light was used, with daylength at our latitude varying from 11.5 hours in early October to 9.25 hours on December 21.

A second rooting experiment was done using mist. The rooting medium was made up of equal parts sand, peat moss, and Pro-Mix BX. The same variables were examined, including cutting sources (Greenwood and Manchester), maturity states (adult and juvenile), times of year (October and November), and rooting hormones (Hormodin #1, #2, and #3). The design was full factorial, with 20 individual cutting replicates made for each combination of swamp, maturity, month, and rooting hormone. Because Leach tubes were not compatible with bottom heat, flats were used in a propagating bench with bottom heat (24 to 27 ºC) and intermittent mist (6 seconds every 6 minutes).

All cuttings were evaluated for rooting after 3 months, and a generalized linear model (SAS GLM procedure) was used for the analysis of variance in rooting experiments. The model related the percentage rooted to cutting source (swamp), maturity state, month of collection, rooting medium, hormone, and whether or not mist was used.

## Results

**Seed viability and germination rates.** Seed dissections showed variation in viability among seeds from different swamps (table 1), due principally to occurrence of brown or deformed embryos in some seedlots. Generally, it took about 3 weeks of soaking to penetrate the cedar seed coat and induce germination. Although most long-day seeds germinated in 3 weeks, sporadic germination continued thereafter throughout the 2-month period in the germinator. There was significant variation in germination rates among seedlots from different swamps. Seeds from High Point had the highest germination rate (table 1).

Photoperiod played an important role in seed germination (table 2). Under long-day conditions, germination equaled or exceeded 40% in seeds from Double Trouble, High Point, Lebanon, and Manchester swamps, whereas germination was 19% or less in seeds from Belleplain, Greenwood, and Penn. Pairwise chi-square analysis showed that these were two significantly different groups. Under short-day conditions, only 7 of 1,400 seeds (0.5%) germinated, all from High Point; no seeds from the other six swamps germinated. Chi-square analysis showed the 7-seed germination from the High Point seedlot to be significant. After 2 months, when short-day seeds were exposed to long-day conditions, many of them germinated (including 39 more seeds from High Point), although total germination was not as high as for seeds originally exposed to long-day conditions.

Liquid treatments other than water at pH 7 were not particularly effective (table 3). Only the combination of gibberellin and short daylength yielded significantly higher germination rates than water alone; low pH and cedar swamp water produced lower rates of germination. But results varied among swamps (table 4): two seedlots (from Greenwood and Penn) that did not germinate well on water alone showed some improvement under other treatments.

The GLM statistical procedure produced an $r^2$ of .8573 ($P \leq .0001$). The highest germination rates were achieved for short daylength with 30-day cold stratifi-

**Table 2**-*Germination rates of fresh Atlantic white-cedar seed on water (pH 7), by New Jersey swamp of origin and daylength*

| | 16 hours | | 10 hours | |
|---|---|---|---|---|
| Swamp | Germination rate (%) | Pairwise chi-square | Rate | Chi-square |
| Belleplain | 18 | B | 0% | B |
| Double Trouble | 40 | A | 0% | B |
| Greenwood | 19 | B | 0% | B |
| High Point | 43 | A | 3.5%[1] | A |
| Lebanon | 45 | A | 0% | B |
| Manchester | 45 | A | 0% | B |
| Penn | 15 | B | 0% | B |

[1] Seven seeds germinated.

**Table 3**-*Germination of Atlantic white-cedar seed from eight New Jersey swamps, by liquid treatment*

| Treatment[1] | Germination rate (%) | *T*-grouping[2] |
|---|---|---|
| Gibberellin | | |
| 10-hour daylength | 22.7 | A |
| 16-hour daylength | 16.1 | BC |
| Water (pH 7) | 19.9 | AB |
| Potassium nitrate | 18.2 | AB |
| pH5 | 15.8 | BC |
| Cedar swamp water (pH 4.3) | 14.7 | BC |
| pH3 | 11.9 | C |
| pH4 | 11.6 | C |

[1] Daylength was 16 hours for every liquid treatment except gibberellin.
[2] Percentages with the same T-group letter are not significantly different.

cation, and for long daylength with 30- and 60-day cold stratification (table 5). There was no significant difference among these treatments. Cold stratification for 90 days could not be analyzed, because bacterial contamination became so serious that none of the seeds germinated. Other treatment effects are shown in tables 3 and 4.

**Rooting of cuttings.** The $r^2$ of the GLM model was .7897, with an F-value of 25.87 ($P < 0.0001$) (table 6). The most important variable was the month when the cutting was taken: only 19.9% of cuttings taken in October rooted, whereas 84.2% of the November cuttings did. A significant difference was also noted between juvenile cuttings (which rooted at a rate of 34.9%) and mature cuttings (which rooted at 26.4%). There was no statistically significant difference in rooting rates for the two swamps (Greenwood rooted at 33.8% and Manchester at 27.5%). For rooting without mist, differences among media were significant: Pro-Mix BX produced a rooting rate of 40.4%; ProMix/peat/sand, a 36.1%; sand, 25.4%; and peat moss, 9.6%. Although no rooting occurred without hormone treatments, there was no statistical difference among the three kinds: averaged across month, maturity state, and rooting medium, Hormodin #3 yielded a rooting rate of 34.4%; Hormodin #2, 29.6%; and Hormodin #1, 27.9%. Cuttings under mist with bottom heat (not shown in the tables) rooted more often (at a rate of 53.9%) than cuttings without mist (19.7%). The best rooting was obtained in November under mist, with juvenile cuttings averaging 94% (Hormodin #1, 92.5%; #2, 97.5%; and #3, 92.5%), and mature cuttings averaging 74% (Hormodin #1, 60.0%; #2, 72.0%; and #3, 90.0%).

## Discussion

**Seed viability and germination.** The superior germination of High Point seed may be related to maturity of the large trees found in this swamp. High Point is not a mixed-age swamp and has the largest trees of any swamp tested. Historically, more mature trees are credited with producing more viable seed (Laderman 1989). The low germination of Belleplain seed may be partially explained by the amount of bad seed (70%) found in this seedlot. Viability rates for Greenwood and Manchester seedlots were both high (62 and 60%, respectively), but germination rates for these seedlots (17 and 30%, respectively) differed

Table 4-*Germination rates of Atlantic white-cedar seed, by New Jersey swamp of origin and liquid treatment[1] (percent)*

| Swamp | Water | Cedar swamp water | pH 3 | pH 4 | pH 5 | $KN0_3$ | $GA_3$ 16-h | $GA_3$ 10-hr |
|---|---|---|---|---|---|---|---|---|
| Belleplain | 14.2 | 9.7 | 2.7 | 4.0 | 3.3 | 5.7 | 10.0 | 13.0 |
| Cheesequake | 25.3 | 27.0 | 19.0 | 23.3 | 20.3 | 21.3 | 7.6 | 15.0 |
| Double Trouble | 45.5 | 36.5 | 10.0 | 11.3 | 26.3 | 20.3 | 20.0 | 28.0 |
| Greenwood | 7.9 | 9.0 | 9.7 | 8.3 | 12.0 | 12.7 | 12.5 | 9.0 |
| High Point[2] | 51.0 | n.a. | n.a. | n.a. | n.a. | 42.5 | 33.0 | 48.0 |
| Lebanon | 18.6 | 2.0 | 2.3 | 2.7 | 10.7 | 17.7 | 4.0 | 37.0 |
| Manchester | 20.4 | 13.3 | 28.3 | 16.3 | 24.3 | 18.0 | 33.0 | 27.0 |
| Penn | 8.4 | 12.7 | 11.0 | 15.3 | 13.7 | 15.3 | 13.5 | 17.0 |

n.a. Not applicable (test not conducted).

[1] Daylength was 16 hours for every liquid treatment except gibberellin. For gibberellin, daylength was 10 hours and 16 hours.

[2]Insufficient seed was available to conduct all experiments.

**Table 5**-*Germination of Atlantic white-cedar seed from eight New Jersey swamps, by stratification*

| Stratification | Germination rate (%) | *T*-grouping[1] |
|---|---|---|
| 30-day | | |
| 10-hour daylength | 46.8 | A |
| 16-hour daylength | 46.7 | A |
| 60-day | | |
| 10-hour daylength | 45.4 | A |
| 16-hour daylength | 37.3 | B |
| 90-day [2] | | |
| 10-hour daylength | 0 | C |
| 16-hour daylength | 0 | C |

[1]Percentages with the same T-group letter are not significantly different.

[2] 90-day stratification had bacterial contamination.

**Table 6**-*Rooting for Atlantic white-cedar cuttings from two New Jersey swamps, by treatment*

| Treatment | Average rooting rate[1] (%) | *T*-grouping[2] |
|---|---|---|
| *Month of cutting collection* | | |
| November | 84.2 | A |
| October | 19.9 | B |
| *Maturity state of cutting* | | |
| Juvenile | 34.9 | A |
| Mature | 26.4 | B |
| *Swamp* | | |
| Greenwood | 33.8 | A |
| Manchester | 27.5 | A |
| *Rooting medium* | | |
| Pro-Mix BX | 40.4 | A |
| Pro-Mix BX/peat/sand | 36.1 | AB |
| Sand | 25.4 | B |
| Peat moss | 9.6 | C |
| *Rooting hormone* | | |
| Hormodin #3 | 34.4 | A |
| Hormodin #2 | 29.6 | A |
| Hormodin #1 | 27.9 | A |

' Figures for each treatment were averaged over other treatments. Figures for rooting medium were for no-mist only, but averaged over other treatments.

[2]Percentages with the same T-group letter are not significantly different.

sharply, suggesting that mechanisms other than light were at play.

The importance of photoperiod in controlling germination of Atlantic white-cedar seed is shown by the failure of nearly all fresh seeds to germinate under short-day conditions, and by their subsequent germination when exposed to long daylength. The behavior of Atlantic white-cedar seed is consistent with phytochrome response to red light and farred light. The seed dormancy exhibited by cedar is an important delaying mechanism, allowing seed to wait before germinating for favorable conditions to develop that will increase the likelihood of successful establishment.

For example, cedar is an intolerant tree that would benefit from a mechanism preventing germination under dense shade, likewise, a germination strategy

oriented toward daylength would ensure that seeds germinate at the right time of year. Many plants with small seeds need light to germinate. The small Atlantic whitecedar seeds may not have sufficient stored energy to push through the soil if buried too deeply. Light is an absolute requirement for germination in many swamp species (Deno 1994). For germination to occur, seeds from these species may need to be on the top of a hummock where both light and moisture conditions are right.

Several conifers have seeds that require light to germinate; most of these seeds have coat-imposed dormancy (Bewley and Black 1985). The phytochrome response can occur only in fully imbibed seeds. This interaction between light and the water-penetrability of the seed coat may control germination.

Cold stratification is known to affect the phytochrome response and could substitute for the photoperiod requirement. Chilling is thought to increase the production of gibberellins; we attribute the 23% germination of gibberellin-soaked seed (table 3) to the phytochrome-gibberellin interaction.

The fact that liquid treatments with cedar swamp water and at pH3, pH4, and pH5 did not improve germination indicates that low pH by itself does not stimulate germination. In each case, bacterial and fungal contamination became a problem, preventing whole petri dishes from germinating.

**Rooting of cuttings.** It was not surprising that cuttings from younger, more juvenile twigs rooted better than those from mature wood. Nursery managers have long used hedging and pruning to produce juvenile sprouts, and these techniques could probably be used on Atlantic whitecedar. Time of year when cuttings are taken is often the most important variable in rooting; endogenous hormone levels dictated by daylength and the number of cold days influence rootability (Hartman and others 1975).

In the no-mist rooting experiments, we compared rooting media to determine whether a low-tech approach (without greenhouse or mist bed) might work. Most narrow-leaved evergreen cuttings benefit from moist conditions that prevent the excess evapotranspiration that leads to death. Pro-Mix BX without mist gave relatively good results, with rooting averaging 40.4% and replicates rooting at rates varying from 10 to 75%. Further work on time of year and environmental temperature and humidity conditions may produce optimal rooting without the need for a greenhouse and mist bed. With mist, however, Atlantic white-cedar appears to root easily at more than one time of year (Hinesley and others 1994).

## Conclusion

How does this information translate into practical applications for the propagator? For seed propagation, 30day stratification on sphagnum at 4 ºC is recommended. The seeds should be washed off the sphagnum and floated in a container with water under longday conditions for about 3 weeks, until radicles appear. Then they should be spread onto a flat of ProMix BX, but they should not be covered with soil, because they need exposure to light. Instead, they should be poured out and gently pressed into the medium. Special care should be given to watering; until true leaves emerge, a light mist nozzle should be used to avoid knocking down the tiny seedlings. Atlantic white-cedar seedlings grow very slowly and require months to reach outplanting size.

Vegetative propagation can be utilized where reforestation depends on mass-producing stecklings of plantable size (Russell 1993). This method can be combined with plus-tree selection to capture superior trees' genetic potential, and then a mixture of plus clones can be planted. Rooting rates of more than 97% can be achieved with cuttings 6 to 7 cm (2.3 to 2.7 in) long taken from juvenile trees in November, dipped in powdered Hormodin #2; and stuck in a well-drained mix of sand, peat moss, and Pro-Mix BX under mist (6 seconds every 6 minutes) with bottom heat (24 to 26 ºC). Sturdy, well-developed root systems fully occupy the containers within 3 months. Cuttings started in November are 7 to 8 cm (2.7 to 3.1 in) tall and actively growing by early June. By contrast, seedlings started during the same winter are only 2 cm (0.8 in) tall. But there is some evidence that seedlings may grow faster than cuttings after outplanting (Gardner and Summerville 1992), so there is room for work on both approaches.

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