Tree Planters' Notes

U.S. Department of Agriculture—Forest Service

Volume 48, Nos. 3 & 4—Summer/Fall 1997

Comments

Tree Planters' Notes
is published quarterly by the State and Private Forestry Staff, Forest Service, U.S. Department of Agriculture, Washington, DC 20250. The Secretary of Agriculture has determined that the publication of this periodical is necessary in the transaction of public business required by law of this Department.

Articles in all sections except the "Practical Tips" and "Little-Known Classics" are peer-reviewed by two outside, anonymous referees. Articles in the "Practical Tips" section are reviewed by a technology transfer specialist and a scientist on the advisory board. "Little-Known Classics" are chosen and adapted by members of the editorial board from regional and state newsletters and publications already in print.

Cover: Seedlot tags in an Oregon nursery, 1987 (photograph by Rebecca Nisley, USDA Forest Service, Hamden, CT).

Good News About the Future of *Tree Planters' Notes!*

Friends and colleagues—at last, we can make an official announcement about the future of *TPN* and it is good! George Hernandez, the new State & Private Forestry RNGR (Reforestation, Nurseries, and Genetic Resources) team member from the South, is taking over as editor-in-chief of *TPN*, beginning with the first 1999 issue. I will continue as managing editor, my former role. George will be able to do many more of the things that are necessary for the health of *Tree Planters' Notes*, such as visiting nurseries, attending meetings, keeping up-to- date on our readers' needs, and soliciting articles. He also has the help of a good clerical staff.

For those of you who don't know George yet, here is a brief biography: George Hernandez has a BS degree in Agriculture/Horticulture from the University of Kentucky, and the MS and PhD degrees in Forest Resources from Clemson University. George came to the USDA Forest Service in 1995 after a long career in horticultural nurseries, including managing perennial and shrub nurseries for Wayside Gardens, managing greenhouses for Klehm Nurseries, and doing teaching and consulting work independently. He also served in the Peace Corps in Colombia and the Marine Corps in Viet Nam.

George & I and the other members of the RNGR team—the USDA Forest Service's Regeneration, Nurseries, and Genetic Resources National Team—plus Dick Tinus, other Forest Service folks, and the other members of the editorial board have lots of interesting ideas about the future of *TPN*. An important part of our renewal plan is renewing our commitment to technology transfer. We are planning to have regular columns on tech transfer by members of the RNGR team and our contributing editors. We may even have a question & answer column! Please let us know about your information needs and nursery problems so that we can feature them in articles. We will continue our commitment to publishing relevant peer-reviewed research articles. We will be enlisting our old editorial board members as either contributing editors or reviewers.

We are also working on correcting our time lag. We plan to do 3 issues per year. One of these will be the USDA Forest Service's annual Tree Planting Report (which used to be part of *TPN* in "the old days") that is prepared by Robert Moulton; the other 2 will be regular issues. Note that we will no longer use the seasonal designations and skip 1998 but continue the volume and issue numbers. Thus the next issue you will be receiving will be marked 1999, volume 49, number 1.

We are already putting back issues of *TPN* on the world-wide web. However, because *TPN* is a subscription magazine/journal, only the Table of Contents of a current issue will be posted until 1 year has passed since publication. Check out the new *TPN* web page at

>> http://willow.ncfes.umn.edu/snti/tpnlist.htm <<

We are developing a new Instructions to Authors section and a submission form for authors to send in with their manuscripts. These will be found in the back of the magazine and on the website. In this issue, we list a contact person & address for readers to make changes of address. We hope that these small logistical additions can make things easier for our readers and authors. We welcome your ideas and feedback; please give George or myself a call.

The RNGR team is also working actively to develop another journal/magazine, called *Native Plants Journal,* with Kas Dumroese of the University of Idaho's Forest Research Nursery as editor and the University as well as USDA ARS & NRCS as partners. Growing native plants (including shrubs, grasses, herbaceous plants, and many non-timber trees) has become an import new aspect of nursery management for many of the RNGR team's customers and the team hopes to move into the forefront of technology transfer and information management on this exciting new field.

Rebecca Nisley
USDA Forest Service
Northeastern Research Station
Hamden, Connecticut

Please note that the next issue published after this one will be marked 1999 (Volume 49, No. 1). There will be NO *Tree Planters' Notes* marked 1998.

Contents

Volume 48, Numbers 3 & 4 — Summer/Fall 1997

COMMENTS

Good News About the Future of *Tree Planters' Notes* 45
Rebecca Nisley

PEER-REVIEWED RESEARCH REPORTS

Control of Growing Medium Water Content and Its Effect on Small Seedlings Grown in Large Containers 48
Gil Lambany, Mario Renaud, and Michel Beauchesne

Effects of Distillery Wash Derivatives and Stratification on Germination of Italian Alder and Douglas-fir Seeds 55
Giovanni Di Monte, Luigi Mezzalana, Fernando Pierandrei, Beti Piotto, and Elvira Rea

An Assessment of Ponderosa Pine Seedlings Grown in Copper-Coated Polybags 60
R. Kasten Dumroese and David L. Wenny

Growth Regulation and Frost Hardening of Silver Birch Seedlings with Short-Day Treatment 65
Jaana Luoranen and Risto Rikala

Effect of Phytophthora Root Rot on Survival and Growth of Fraser Fir Christmas Trees 72
Coleman A. Doggett, Charles E. Cordell, and Donald Rogers

Growth of Root-Pruned Seedlings in a Thermally Impacted Area of South Carolina 76
Evaden L. Funderburk and William H. Conner

SPECIES SPOTLIGHT

Osage-orange: A Pioneering Stewardship Species 81
James P. Barnett and James D. Burton

See Cover

See page 61

See page 83

Control of Growing Medium Water Content and Its Effect on Small Seedlings Grown in Large Containers

Gil Lambany, Mario Renaud, and Michel Beauchesne

Forestry engineer and forestry technician, Direction de la Recherche Forestière , Forêt Québec, Ministère des Ressources Naturelles, Sainte Foy, Québec; and forestry technician, Pépinière de Grandes-Piles, Ministère des Ressources Naturelles, Grandes-Piles, Québec

Results of an experiment carried out in a tunnel house confirm that real-time operational monitoring of water content in a peat–vermiculite substrate is possible using equipment based on the principles of time domain reflectometry. Irrigation management can still be easy despite the use of air-slit containers. Soil water content can be significantly reduced without affecting tree seedling development. Small seedlings, which have low soil water requirements and a large quantity of water in each cavity, may explain these results. However, reduction in soil water content did not prevent roots from growing from one cavity to the next. Tree Planters' Notes 48 (3/4): 48-54; 1997.

During the last 20 years, public and private nurseries have developed expertise based on the production of small seedlings cultivated in low-volume cavities-50 cm^3 (3.1 in^3) and 110 cm^3 (6.7 in^3). However, for the last 5 years, the trend in techniques has been in moving towards growing large seedlings (Dancause 1995) in containers with a large cavity volume— > 200 cm^3 (12.4 in^3) (Gingras 1993). More recently, important studies have led to the refinement of air-slit containers that improve air pruning of roots (Ford 1995; Gingras 1993).

Presently, substrate water content is maintained at too-high a level due to the combination of 2 operational factors. First of all, in the first year, a small seedling with low water requirements growing in a large root plug capable of holding a large quantity of water is produced in a tunnel house. Second, due to the presence of slits all along the cavities, there is a tendency to over-irrigate cultures in order to compensate for the rapid drying of containers located at the edge of the tunnels (Biernbaum 1992; Ford 1995). This situation results in the specific problem of inadequate pruning of the root apexes along the slits, which is followed by root colonization from one cavity to another in the first year. In the second year, it is then difficult to extract the seedlings. This problem may be caused by the sturdiness of the roots of white spruce—Picea *glauca* (Moench) Voss—or lower efficiency of root air pruning (Ford 1995). However, it is not clear that producers have sufficient knowledge of the real water requirements of the species that they cultivate (Tyler and others 1996), particularly in terms of root development (Biernbaum 1992).

Several studies have underlined the role played by water in tree seedling development (Heiskanen 1993; Langerud and Sandvik 1991; Khan and others 1996; Rao and others 1988) and the impact of the combination of water and fertilizer (McClain and Armson 1976; Tyler and others 1996) on tissue concentrations. In 2 recent studies on Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco) and Scots pine *(Pinus sylvestris* L.), respectively, Khan and others (1996) and Heiskanen (1995) emphasized the negative effects on seedling growth of keeping peat too moist. The development of better irrigation schedules therefore provides significant cultural benefits, that is, improved seedling quality (Heiskanen 1995; Khan and others 1996; Seiler and Cazell 1990), reduced leaching of fertilizers (Cresswell 1995; Pelletier and Tan 1993) and a decreased incidence of disease (Beyer-Ericson and others 1991). In this context, regular monitoring of water content remains a prerequisite for establishing efficient irrigation management (Cresswell 1995; Or 1995; Phene and others 1989; Werkhoven 1993). However, the absence of reliable and precise technologies has limited the development of operational methods for measuring peat water content.

In 1995, a new generation of field equipment using the principles of time domain reflectometry (TDR) was found to have some success in container-grown tree seedling productions (Lambany and others 1997). It was nevertheless difficult to determine water content in the peat–vermiculite mixture used. It is possible that the problem originates in the substrate used, although studies demonstrate that TDR functions adequately in this organic medium (Pépin and others 1992); it is also possible that the single-diode probes were inoperable in a container characterized by an alternation of space, air, and peat (Lambany and others 1997).

Given the context described above, this study has 2 aims. On the one hand, it attempts to evaluate the operation of equipment that, except for being equipped with 2-diode probes, is identical to that used in 1995. On the other hand, the study attempts to specify the effect of reducing peat water content on plant morphology, particularly on root development.

Material and Methods

In May 1996, white spruce seedlings—Picea *glauca* (Moench) Voss, provenance 94P64—were sown in air-slit containers (IPL 25-350A). The substrate was made up of a mix of peat (Nyrom type B), vermiculite, and water (volumetric ratio 3:1:1) adjusted to an approximate density of 1.1 g/cm^3 (0.63 oz/in^3)

In July, after thinning and planting out of seedlings, an experimental design was set up comprised of 2 treatments in tunnel no. 21: in one, the substrate water content was maintained at 25% (cm^3 H_2O/cm^3 peat) (43% of saturation weight of the container) and in the other at 40% (57% of saturation weight of the container). Normally, such percentages do not lead to either a drying out or an excessive saturation of the substrate that would be harmful to seedling growth (Gonzalez and d'Aoust 1990). Each treatment was replicated 6 times and distributed randomly in the units, which comprised 72 containers. In order to reduce edge effects, buffer zones were set up between each replication. The experiment took place over a period of 15 weeks, from mid-July to the end of October.

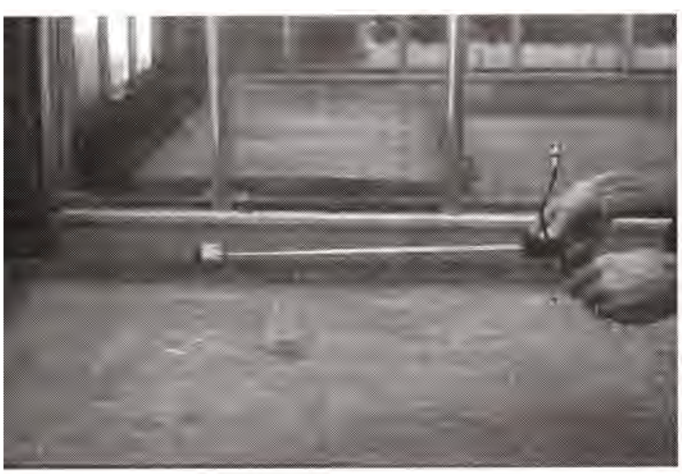
Relative air moisture and peat water content. Relative air moisture (percent) in the tunnel house was recorded using 2 HMP35C probes (Campbell Scientific) installed 2 m (6.6 ft) from the soil. A data logging system (Campbell Scientific Model CR-10) was programmed to compile data obtained from a probe every 5 minutes and to calculate hourly averages. Mean daily and monthly moisture levels were determined by a program developed using SAS™ software.

Substrate water content was monitored with an MP-917 (ESI Environmental Sensors Inc., Div., Victoria); each probe was made up of 2 stainless steel rods (length, 39 cm or 15.4 in; diameter, 3.17 mm or 0.12 in) and equipped with 2 diodes (figure 1). The first was incorporated at the base of the probe and the second was attached manually to the ends of the rods. Each probe was inserted horizontally through the 5 cavities halfway up the container. The principle of water content estimation (percent, vol/vol) inside a medium made up alternately of air and water has been described previously (Lambany and others 1997; Young 1995). In each replication, 2 moisture probes were placed in distinct, randomly selected containers.

The following measurements were made weekly, in the morning, in each replication: reading from each of the 2 probes Monday and Friday (total: 12 probes/treatment) and a reading from 1 probe on Wednesday (total: 6 probes/treatment). Once the line from the equipment to the fixed probe was established, 2 consecutive measurements were taken to verify the reproducibility of the results. If the difference between the 2 values obtained was greater than 2%, a third reading was made. The 2 closest values were then used to calculate the averages. When the water content of the 25% and 40% treatments decreased in the center of the cavities to below 22% and 37%, respectively, irrigation was carried out with a motorized robot (Aquaboom Harnois model) used at a pressure of 2.3 kg/cm^2 (32 lbs/in^2).

Depending on the characteristics of the device (nozzle model, ramp height, spacing between nozzles and robot speed), the robot's return trip increased the water content of the substrate by approximately 1.6% vol/vol. When irrigation was carried out in the morning, a second measurement was then taken in the early afternoon to validate the prescription made earlier. In this experiment, constant water content levels were maintained at the center of each cavity for each of the schedules. By using this approach, nutrient leaching could be limited while maintaining substrate fertility at an optimal level so as to ensure the development of the seedling.

a



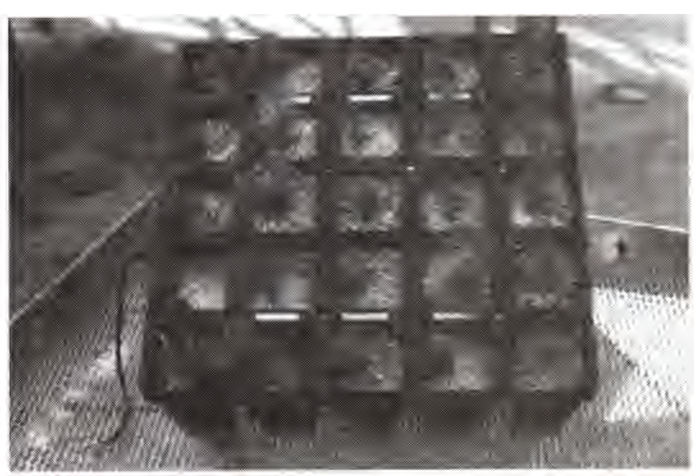


Figure 1—*Characteristic of a 2-diode probe (a) and insertion of a probe through 5 cavities of an air-slit container (b).*

Seedling morphology. On October 21, the height (centimeters) and diameter (millimeters) of each tree seedling were measured (15 seedlings/replication, 90 seedlings/treatment). Each root system was digitized individually with a scanner (Hewlett Packard ScanJet 4C/T model, 500 dpi resolution). WinRhizo ™ (version 3.2) software was used to analyze the image and quantify the total length (centimeters) of the roots according to their diameter (15 classes: 0 to 1.5 mm). The aerial and underground parts of the seedlings were then put into separate groups of three (5 groups of stems and roots/replication), oven-dried (60° C) and weighed (milligrams). To evaluate root pruning, 5 containers per replication and per treatment were selected randomly within the design (total: 30 containers per treatment). For each container, all roots coming out of the slits of the cavities and crossing from one plug to another were removed and counted.

The Student t-test (t-test) or the Kolmogorov-Smirnov test were performed on the data using SAS software (version 6.11). The non-parametric Wilcoxon test was used instead of the Student t-test for data without a normal distribution. The significance level of the hypotheses was set at 5%. Normality of the data was tested using the Shapiro-Wilk test.

Results

Rapid and often large variations in the relative moisture of tunnel house air occurred during the season and often ranged between minimum and maximum values of 66% and 100%, respectively. Condensation on the canvases and formation of small drops of water on the polyethylene lining of the tunnel walls were noticed regularly. Monthly averages for July (partial), August, September, and October (partial) were 85.2, 82.5, 87.2, and 91.8%, respectively.

Between July 12 and October 11, regular fluctuation in peat substrate water content of each treatment was observed (figure 2). Standard deviations recorded during the monitoring were generally similar; parallel profiles and a systematic absence of overlap of the standard deviations indicate an adequate differentiation between the 2 treatments (data not processed statistically). Data synthesis confirmed that targeted water contents of 25% and 40% at the beginning of July were reached and maintained precisely during the season (table 1). Standard deviations varied little from one treatment to the next. Means obtained from the sub-sampling carried out on Wednesdays (table 1) remained slightly lower than those recorded in the complete sampling done every Monday and Friday (table 1). Reducing the number of measurement points by half had little effect on the value of the standard deviations of each treatment.

The analysis of morphological data confirms that water content did not have significant effects on height, diameter and seedling mass at the end of the first growing season (table 2). More specifically, between September 16 and October 21, a period characterized by a significant growth in root mass (treatment 25% vol/vol = 120%; treatment 40% vol/vol = 121%), water content had no visible effects on this parameter (data not presented).

The majority of roots in the two treatments had diameters of 0.2 to 0.3 mm and 0.3 to 0.4 mm (figure 3). Water contents had no significant effects on the general profile

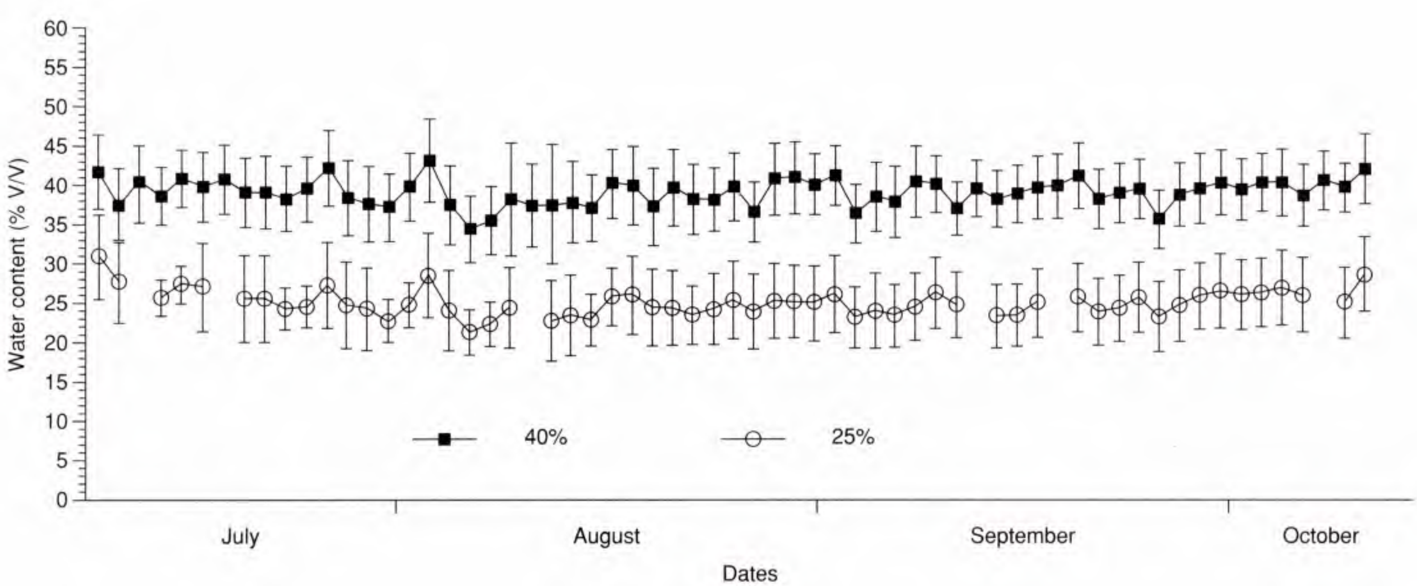


Figure 2—*Variations in peat substrate moisture of air-slit containers according to water content.*

Table 1—*Average water contents measured in peat substrates according to sampling intensity and 2 water content levels (values are means ± standard deviation)*

	Treatments	
Sampling period	25% v/v	40% v/v
Monday, Wednesday, & Friday	25.2 ± 4.6	39.2 ± 4.5
Wednesday (6 measurements/treatment)	24.4 ± 3.6	38.7 ± 4.1
Monday & Friday (12 measurements/treatment)	25.4 ± 2.4	39.3 ± 4.6

Table 2—*Morphological characterization of white spruce seedlings grown at 2 substrate water contents*

	Treatments	
Parameters	25% v/v	40% v/v
Stem length (cm)	7.7 a	8.1 a
Root collar diameter (cm)	1.85 a	1.90 a
Stem dry masss (mg)	485 a	519 a
Root dry weight (mg)	190 a	196 a

When the table is read horizontally, different letters represent significant differences at $P = 0.05$ (Student *t*-test); crop of 90 seedlings/treatment (15 seedlings/ replication × 6 replications).

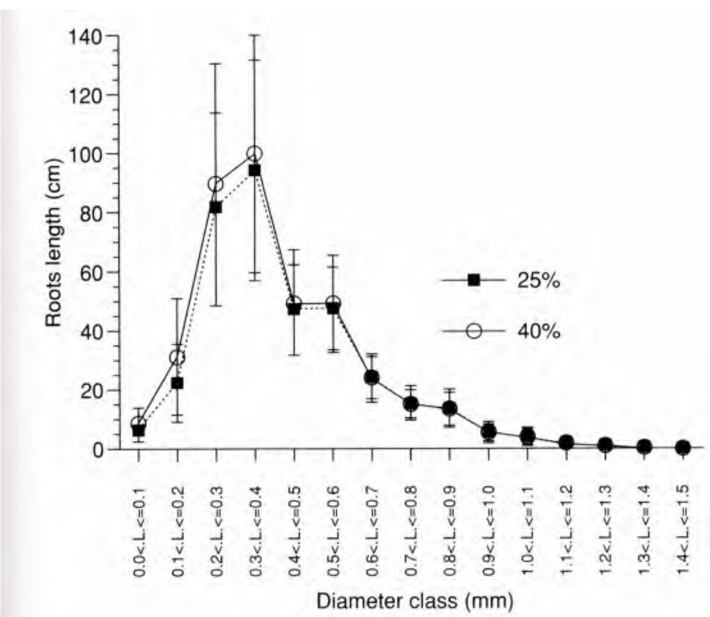


Figure 3—*Total root length per diameter class in seedlings grown at 2 water contents.*

of root classes ($P >$ Ksa = 0.9883). However, as the figure shows, the means of the largest root classes (0.1 to 0.9 mm) had large standard deviations.

Finally, water contents had no significant effect on the number of roots that grew from one cavity to another ($P >|T| = 0.4527$). The number of roots recorded for water contents of 25% and 40% were 4.9 (cv = 2.8) and 5.7 (cv = 3.8), respectively. These roots tended to be located in the upper part of the cavities where the space between the cavities is narrower. With this model of container, water content levels are generally lower at this spot than in the center or at the bottom of the cavity.

Discussion and Conclusion

The high relative humidity in the tunnel house is caused mainly by 3 factors. First, the peat remains a constant source of moisture. Second, evapotranspiration of a high number of seedlings, despite their small size, regularly releases water into the ambient air. Third, the 3 canvases located on each side of the tunnel house are closed alternately during the day. This technique reduces air circulation and maintains high moisture and temperature conditions, which favor the plants' steady development (Landis and others 1992).

The precise monitoring of water carried out during 4 months confirms that the water content in an organic substrate can be measured accurately using TDR (Pepin and others 1992; Werkhoven 1995). The reading of more than 3,000 measurements taken in real time (15 sec/ measurement) indicates that the MP-917 is a reliable and precise field instrument. The addition of a second diode at the end of each probe improves the quality of reflection of the electromagnetic signal (Hook and others 1992) and allows a more accurate estimation of wave propagation delay (Young 1995). Results indicate that the erroneous values recorded previously (Lambany and others 1997) with a similar device, but equipped with a single diode, were probably due to incorrect identification of the end of the probe, in particular in a medium that was alternately made up of air and peat. The need to take a third reading on only 1.8% of all of the data indicates that the algorithms used to calculate water content were very reliable. However, it should be noted that it was particularly difficult to attach a second diode to the end of the rods and that there was corrosion on the copper parts of the diode. These problems caused the recording of outliers in 0.24% of the measurements. The probe's conical end explains the inadequate attachment of the second diode while a constantly moist environment under the containers produces progressive corrosion of the copper poles.

The regular water content profiles and constant standard deviations may be explained by several factors.

First, uniform peat density was maintained in the potting room. Such homogeneity creates a more uniform vertical moisture gradient in the root plugs (Heiskanen 1993). The height of the cavity allows the water to percolate more efficiently (Bilderback and Fonteno 1987) and a possibly more homogeneous air-water ratio at the cavity's mid-depth to be maintained (Landis and others 1989). Second, the motorized robot ensures a uniform application of water and fertilizing solutions compared to a jet spraying system (Landis 1994; Landis and others 1989). Third, by maintaining a high air moisture level and minimizing evapotranspiration from each seedling, variations in peat water content were limited substantially given the large quantities of water contained in each cavity. Finally, 2 other factors helped maintain more uniform moisture profiles in each of the treatments: (1) sample points placed in each of the homogeneous sectors and (2) for each probe, an average water content measured in peats of 5 adjacent cavities. The results tend to confirm that, in spite of the presence of slits along the cavities, the use of an air-slit container does not create particular problems of water content control. This finding supports the approach that favors the application of special irrigation in this type of culture: an extra one for the edges and the other for the entire production. In this way, the risks of overirrigating may be minimized and seedling quality, particularly that of the roots, may be improved.

The fact that similar results were obtained for the complete (Monday and Friday) and partial (Wednesday) sampling may be explained by the particularly homogeneous growing conditions and rigorous irrigation management during the experiment. In an operational context, based on these results, irrigation schedules with a reduced number of measurement points within each tunnel house could be developed. In the medium term, it will be possible to precisely establish the water requirements of each species cultivated (Wraith and Baker 1991). However, this recommendation can still be applied to irrigation systems that use a motorized robot.

The 15% reduction of substrate water content does not affect the morphology of white spruce seedlings. These results confirm those of Khan and others (1996) in their study on Douglas fir within a similar moisture range (29 to 53%). However, other studies have found that optimal growth in red pine—*Pinus resinosa* Ait.— is generally achieved with high water contents (Timmer and Armstrong 1989; Timmer and Miller 1991). In similar conditions, Heiskanen (1995) observed deficient growth in Scots pine. These contradictory results may reveal the different biological needs of cultivated species. However, although saturated substrates generally allow higher growth in the aerial part, other equally important factors should motivate producers to define a water content level that takes more than the single criterion of morphology into account (Biernbaum 1992; Herms 1996). Resistance to water stress, cold, insects, and disease should be noted. Some researchers have observed that the available air-water ratio in the peat should always be situated within a range fluctuating between 20 to 30% vol/vol (Bugbee and Frink 1986; Verdonck and others 1983). More specifically, Verdonck and others (1983) mention that in order to ensure balanced seedling growth, air content remains the most important factor to be controlled in peat substrates. However, within the moisture ranges used in the present experiment, this did not seem to be a limiting factor for ensuring the adequate growth of white spruce. These results seem to confirm that the slow growth of a small seedling in the first year, as Heiskanen (1993) has underlined, may justify the application of a more conservative irrigation schedule. Bik (1973) points out that maintenance of adequate oxygen concentrations in the root environment is ensured mainly by evapotranspiration from the needles. Small seedlings produced in a large cavity make it difficult to achieve this objective during the first year. In this context of seedling cultivation in air-slit containers, water content levels should be maintained below the field capacity.

Decreasing water content does not change root development in white spruce. Increased porosity of the substrate and consequently of oxygen concentrations (Liang and others 1996), as a result of reduced water content, do not seem to change the root structure at the end of season. Timmer and Armstrong (1989) noted that maintaining a high water content promotes the production of more fibrous roots in red pine; however, results of the study by Tyler and others (1996) on cotoneaster and by Gonzalez and d'Aoust (1990) on black spruce—Picea *mariana* (Mill.) B.S.P.—were similar with regard to lower water contents. Two factors may explain the development of a similar root structure despite the maintenance of different water contents in the present study. First, it is possible that this species is less sensitive to increases in the air-water ratio, particularly in an air-slit container. Second, it is possible that reducing water content does not produce a great enough impact to modify the significant development of roots during autumn.

The decrease in water content neither eliminates nor reduces the number of roots that cross through the air space between the cavities. This result may be explained by 3 hypotheses. First, the space between the 2 cavities remains small in the upper part of the container, which allows the roots to cross the gap more easily. Second, the environment under the containers is closed despite the presence of an adequate air space, which possibly favours the maintenance of a high air-moisture level even when substrate water content is lower. However, given the experimental design used, no conclusion could be reached regarding whether the roots are in fact able to survive winter conditions because of their probable later development in the autumn. Third, the cavities have slits characterized by a line angle which is not necessarily optimal for containing roots that grow close to the opening (Gingras 1997). Thus, these 3 factors appear to have a greater influence than actual water content on the development of this type of root.

Address correspondence to: G. Lambany, Direction des Programmes Forestièrs, Ministère des Ressources Naturelles, 880 Chemin Sainte-Foy, Québec (Québec) G1S 4X4. e-mail:
» gil.lambany@mrn.gouv.qc.ca «

Acknowledgments

The authors would like to thank Jeannine Claveau, statistician (Direction de la recherche forestière) and Pierre Ballester (Environmental Sensors Inc., Victoria) for their technical and professional support. We would like to thank Fabien Caron, Benoit-Marie Gingras and Linda Veilleux (Direction de la recherche forestière) who very kindly edited this article.

References

Beyer-Ericson L, Damm E, Unestam T. 1991. An overview of root dieback and its causes in Swedish forest nurseries. European Journal of Forest Pathology 21: 439-443.

Biernbaum JA. 1992. Root-zone management of greenhouse container-grown crops to control water and fertilizer use. HortTechnology 2(1): 127-131.

Bik RA. 1973. Some thoughts on the physical properties of substrates with special reference to aeration. Acta Horticulturae 31: 149-160.

Bilderback TE, Fonteno WC. 1987. Effects of container geometry and media physical properties on air and water volumes in containers. Journal of Environmental Horticulture 5(4): 180-182.

Bugbee GJ, Frink CR. 1986. Aeration of potting media and plant growth. Soil Science 141(6): 438-441.

Cresswell GC. 1995. Improving nutrient and water management in nurseries. Combined Proceedings of the International Plant Propagators' Society 45: 112-116.

Dancause A. 1995. Plants de fortes dimensions: oil en est le dossier? Le Progrès Forestier (Avril-Mai): 52-54.

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

Gingras BM. 1997. Bilan provisoire des essais expérimentaux réalisés avec des recipients a parois ajourées. Note Rech. For. 56. Sainte-Foy, QC: Ministère des Ressources Naturelles, Direction de la Recherche Forestièr. 8 p.

Gingras BM. 1993. Bilan des essais expérimentaux sur la production en recipients de plants de fortes dimensions. [Report presented 1993 March 11-12.] Sainte-Foy, QC: Ministère des Ressources Naturelles, Direction de la Recherche, Service de l'amélioration des arbres. 20 p.

Gonzalez A, d'Aoust A. 1990. Le regime hydrique et la nature du substrat dans la culture des semis en conteneurs. Proceedings, Troisième atelier québécois sur la culture des plants forestiers en recipients; 1988 Novembre 9-10; Chicoutimi, QC. St. Foy, QC: Ministère de l'Energie et des Ressources (Forêts): 134-152.

Heiskanen J. 1995. Irrigation regime affects water and aeration conditions in peat growth medium and the growth of containerized Scots pine seedlings. New Forests 9: 181-195.

Heiskanen J. 1993. Favourable water and aeration conditions for growth media used in containerized tree seedling production. Scandinavian Journal of Forest Research 8: 337-358.

Herms DA. 1996. Growing, growing, gone. American Nurseryman. July 15: 52-58.

Hook WR, Livingston NJ, Sun ZJ, Hook PB. 1992. Remote diode shorting improves measurement of soil water by time domain reflectometry. Soil Science Society of America Journal 56: 1384-1391.

Khan SR, Rose R, Haase DL, Sabin TE. 1996. Soil water stress: its effects on phenology, physiology, and morphology of containerized Douglas-fir seedlings. New Forests 12: 19-39.

Lambany G, Robidas L, Ballester P. 1997. Measurement of soil water content in a peat-vermiculite medium using time domain reflectometry (TDR) : a laboratory and field evaluation. Tree Planter's Notes 47(3): 88-93.

Landis, TD. 1994. Cultural perspectives: the nursery effect. Forest Nursery Notes: 19-26.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1992. The container tree nursery manual. Volume 3, Atmospheric environment. Agric. Handbk. 672. Washington, DC: USDA Forest Service. 145 p.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1989. The container tree nursery volume. Volume 4, Seedling nutrition and irrigation. Washington, DC: USDA Forest Service. 119 p.

Langerud BR, Sandvik M. 1991. Transpiration of containerized *Picea abies* seedlings grown with different irrigation regimes. Scandinavian Journal of Forest Research 6: 79-90.

Liang J, Zhang J, Wong MH. 1996. Effects of air-filled soil porosity and aeration on the initiation and growth of secondary roots of maize *(Zea mays).* Plant and Soil 186: 245-254.

McClain KM, Armson KA. 1976. Effect of water supply, nitrogen, and seedbed density on white spruce seedling growth. Soil Science Society of America Journal 40: 443-446.

Or D. 1995. Stochastic analysis of soil water monitoring for drip irrigation management in heterogeneous soils. Soil Science Society of America Journal 59: 1222-1233.

Pelletier G, Tan CS. 1993. Determining irrigation wetting patterns using time domain reflectometry. HortScience 28(4): 338-339.

Pepin S, Plamondon AP, Stein J. 1992. Peat water content measurement using time domain reflectometry. Canadian Journal of Forest Research 22: 534-540.

Phene CJ, Allee CP, Pierro JD. 1989. Soil matric potential sensor measurements in real-time irrigation scheduling. Agricultural Water Management 16: 173-185.

Rao NH, Sarma PBS, Chander S. 1988. Irrigation scheduling under a limited water supply. Agricultural Water Management 15: 165-175.

Seiler JR, Cazell BH. 1990. Influence of water stress on the physiology and growth of red spruce seedlings. Tree Physiology 6: 69-77.

Timmer VR, Armstrong G. 1989. Growth and nutrition of containerized *Pinus resinosa* seedlings at varying moisture regimes. New Forests 3: 171-180.

Timmer VR, Miller BD. 1991. Effects of contrasting fertilization and moisture regimes on biomass, nutrients, and water relations of container grown red pine seedlings. New Forests 5: 335-348.

Tyler HH, Warren SL, Bilderback, TE. 1996. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. Journal of Environmental Horticulture 14(4): 199-204.

Verdonck 0, Penninck R, De Boodt M. 1983. The physical properties of different horticultural substrates. Acta Horticulturae 150: 155-160.

Werkhoven G. 1993. Time-domain reflectometry and tensiometers for detecting soil moisture content. Acta Horticulturae 335: 491-496.

Wraith JM, Baker JM. 1991. High-resolution measurement of root water uptake using automated time-domain reflectometry. Soil Science Society of America Journal 55: 928-932.

Young GD. 1995. Use of single diode probes in seedling pots: MP-917. Tech. Brief 14. Victoria, BC: Gabel Corporation. 14 p.

Effects of Distillery Wash Derivatives and Stratification on Germination of Italian Alder and Douglas-fir Seeds

Giovanna Di Monte, Luigi Mezzalana, Fernando Pierandrei,
Beti Piotto, and Elvira Rea

Graduate, Istituto Sperimentale per la Nutrizione delle Piante;
technician, Centro di Sperimentazione Agricola e Forestale; technician, Istituto Sperimentale per la Nutrizione delle Piante;
researcher, Centro di Sperimentazione Agricola e Forestale;
researcher, Istituto Sperimentale per in Nutrizione delle Piante, Rome, Italy

The effects of distillery wash derivatives (DWD) and stratification on germination were studied for 2 species with different seed structure and dormancy: Italian alder (Alnus cordata *Loisel) and Douglas-fir* (Pseudotsuga menziesii *(Mirb.) Franco). Seeds were subjected to 2 pretreatments before germination tests: (1) prechilling at 4 °C (39 °F) for 21 days or (2) no prechilling. Subsequently, germination tests were conducted in water (control) or DWD solutions (10 and 30 ppm). The use of DWD solutions (10 and 30 ppm) for imbibition during germination test did not affect germination in Douglas-fir but did increase the speed and early germination percentage (third day) in Italian alder.* Tree Planters' Notes 48(3/4): 55-59; 1997.

Delayed germination of trees and shrubs seeds due to seed dormancy can be a serious problem in the nursery. Germination over a 1- to 3-year period represents a powerful biological strategy to aid natural propagation, but its occurrence in the nursery leads to irregular stocking. If the seeds do not germinate together, the final grade-out of the seedlings will greatly vary, because seedlings emerging early will tend to suppress the growth of those emerging later (Cullum and Gordon 1993). Increased speed of germination, thus avoiding uneven and erratic plant emergence, reduces the risk of fungal attacks and leads to the production of planting stock of more homogeneous size (Bonner and others 1974).

At present, there are commercially available natural and synthetic products containing amino acids, hormones, carbohydrates, enzymes, vitamins that stimulate many physiological processes and can be used to improve germination, growth, harvest, stress resistance, water, and nutrient uptake (Halmer 1989; Heydecker and Coolbear 1977; Oplinger and others 1978; Orsi and Tallarico 1983; Siviero 1993). A natural product that we have called DWD (distillery wash derivatives), which is not available for market, has improved germination rate in different species of agricultural seeds (Di Monte and others 1995). DWD is a light-brown, dense and viscous syrup, a by-product of sugar beet processing that contains amino acids, betaine, glycerol, various fatty acids, esters, and unfermented sugars. Because of its composition and positive effects on agricultural seeds, this product could also improve tree seed germination. The aim of this paper is to study the effects of DWD on seed germination in Italian alder *(Alnus cordata* Loisel) and Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco).

These 2 species show differences in seed structure and the cold requirements for germination. Seeds of Italian alder are small nuts, 350,000 to 550,000/kg (160,000 to 250,000/1b) (Piotto 1992), containing no endosperm and with a thin seedcoat in comparison to that of Douglas-fir. Seed viability is generally low (30 to 60%) and dormancy is shallow, for ISTA (1993) rules do not prescribe prechilling before germination tests. No germination inhibitors have been found in seedcoats of Italian alder. When the seedcoats are removed, germination is rapid and complete; their mechanical resistance seems to cause dormancy (Rinallo 1979). Italian alder is often sown at the end of winter, to benefit from natural provided cold-moist conditions, or in spring after a prechilling for 3 to 4 weeks.

Seeds of Douglas-fir number 70,000 to 95,000/kg (32,000 to 434,000/1b), have a thicker seedcoat, contain endosperm, often show a germination percentage over 80%, and exhibit a type of dormancy that is broken by cold—moist pretreatments. Prechilling improves germination rate and germination percentage (Owston and Stein 1974), but marked differences can be observed between seedlots. For this reason, ISTA (1993) rules prescribe double testing (prechilling and no prechilling) before germination of Douglas-fir. Dormancy depends on seedcoat inhibition and immature embryos, with extreme variablity because some seedlots are able to germinate promptly without any pretreatment (Vanesse 1974; Gordon 1979). Most nurseries first soak Douglas-fir seed in tapwater and then cold treat for 3 to 8 weeks before spring sowing.

Materials and Methods

Italian alder and Douglas-fir seeds were collected, respectively, in 1991 in Tivoli, Rome (41,58 N; 12,48 E; 50 m asl) and in 1980 in Albany, Oregon (44,38 N; 123,06 W; 700 m asl). They were stored at —3 °C (27 °F).

For Italian alder, germination percentage was 48%; purity, 89%; moisture content, 7%; and the number of cleaned seeds per kilogram, 540,000. For Douglas-fir, germination percentage was 84.5%; moisture content, 8.5%; and the number of cleaned seeds per kilogram, 88,500. Seeds for trials were obtained from four 50-g (1.7-oz) samples withdrawn at random from both seedlots.

The DWD composition was sucrose, 50%; betaine, 20%; valine, 10%; isoleucine, 5%; leucine, 3%; tyrosine, 10%; glycine, glutamic acid, and serine, trace; other components, 2%. For each species, a 2-factor split-plot (Gomez and Gomez 1984) design with 4 replications was used in the experiment. There were 2 pregermination treatments; (A1) prechilling at 4 °C (39 °F) for 21 days and (A2) no prechilling. Three concentrations of DWD were tested: (B1) Control (0 ppm); (B2) 10 ppm; (B3) 30 ppm. The 6 treatments resulting from treatment combinations are shown in table 1.

During the chilling period, seeds were placed in germination boxes with water. They were then rinsed in water and put in new boxes containing DWD solutions at different concentration (0, 10, or 30 ppm) for the germination test. Unchilled seeds were soaked in water for 24 hours at room temperature and then placed in germination boxes containing DWD solutions (0, 10 or 30 ppm). Prechilling was performed so that all seeds could begin germination tests at the same time in a cabinet germinator. In both species, four 50-seed replicates were prepared for each of the 6 experimental treatments (table 1). Seeds were placed on top of filter paper in covered germination boxes (diameter = 16 cm) in which water or solutions uptake was easily allowed through strips of filter paper from a reservoir at the bottom (figure 1A&B). Germination boxes contained 250 ml of water or DWD solutions, depending on experimental treatment.

Germination conditions were those prescribed by the ISTA (1993) rules: 8 hours at 30 °C (86 °F) in light plus 16 hours at 20 °C (68 °F) in dark. Experimental treatments A2B1 for Italian alder and A1B1 and A2B1 for Douglas-fir are to be considered under the standard conditions as they followed ISTA (1993) recommended pregermination treatments: no prechilling for Italian alder, double test (prechilling and no prechilling) for these 2 species as already stated. Germination was recorded when the radicle length exceeded 2 mm (Danielson and Tanaka

Table 1—*Prechilling (factor A) and distillary wash derivative (DWD) (factor B) treatments applied to Italian alder and Douglas-fir seeds*

Pregermination treatment	DWD conc. (ppm)
Prechilling (A1)	0 —control (B1)
	10 (B2)
	30 (B3)
No prechilling (A2)	0—control (B1)
	10 (B2)
	30 (B3)

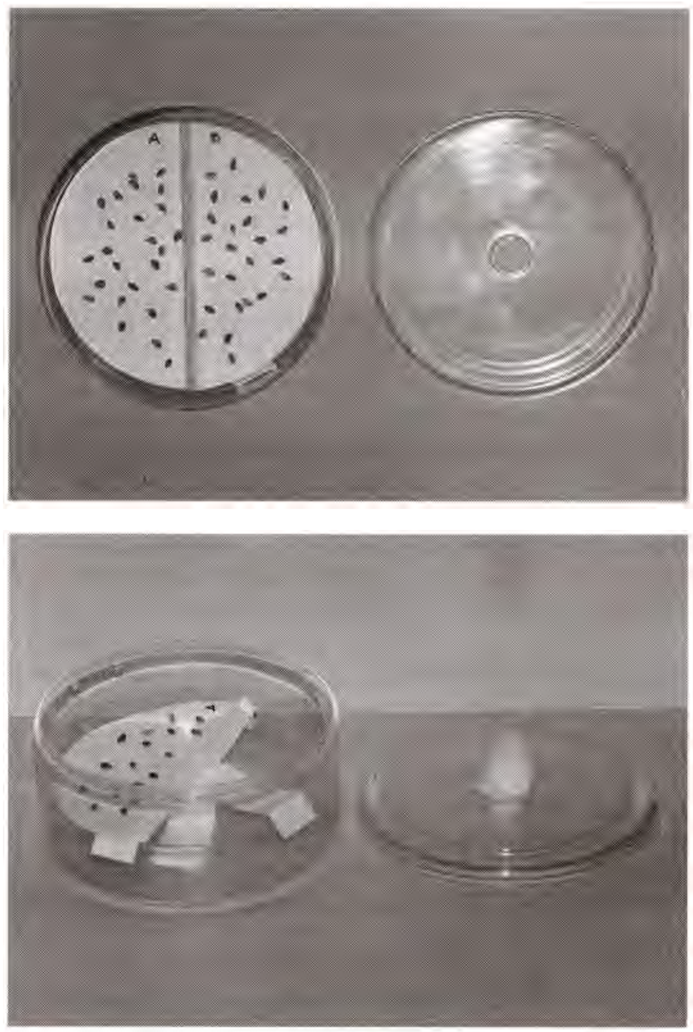


Figure 1—*Germination box, seen from the top* (A); *detail of the box showing uptake water or solutions system (B).*

1978; De Matos Malavasi and others 1985). The germinated seeds were counted every 2 or 3 days until the 28th day to calculate the germination percentage (G%) on the 3rd, 7th, and 28th day (final germination) and the mean time to complete germination (MTG) (Bewley and Black 1986). MTG is a measure of the speed of germination:

$$\Sigma(t * n) / \Sigma n$$

where:
t = the time in days, starting from the day of the beginning of the test
n = the number of seeds completing germination on day t

Quicker germination is associated with lower MTG values (Bewley and Black 1986).

Statistical differences were estimated on the basis of the analysis of variance (Gomez and Gomez 1984) of MTG's and G% at arcsin V% (tabulated values are the untransformed data). Comparison of means was performed following the Duncan's multiple range test (Harter 1960) at $P < 0.01$.

Results and Discussion

Data presented in tables 2 and 3 show that statistically significant differences were only attributable to main factors. In Italian alder, MTG was more influenced than percentage germination, with this effect being more noticeable at the beginning than at the end of the germination process. Rapid germination processes are often associated with remarkable early G%'s. In Douglas-fir, both cold treatment and DWD treatment affected speed and total germination.

Pregermination treatments (factor A). In both species, seeds that were not subjected to prechilling (A2) showed a low G% at the beginning of the trial (3rd day in Italian alder and 7th day in Douglas-fir). Final germination (28th day) of pretreated Italian alder seeds did not significantly differ from those that were stratified (A1). In Douglas-fir, cold—moist pretreatment resulted in higher early and final germination of prechilled seeds in comparison to untreated seeds (table 2).

Germination speed, expressed as MTG, was always improved by stratification (table 2). On the 3rd day, G% was equal to almost 70% of final germination percentage in stratified Italian alder seeds (A1), whereas no germination could be observed in untreated seeds. Such an effect was expected in both species because it shows consistency with widespread nursery practice in which both Italian alder or Douglas-fir seeds are subject to stratification before spring sowing (Gordon and Rowe 1982). Although this trial was conducted with only 1 provenance, the results suggest a probable need of modification of ISTA rules, that prescribe prechilling before the germination test for Italian alder.

DWD concentration during germination test (factor **B**). The use of DWD solutions during germination did not affect the rate or the completeness of germination in Douglas-fir but it did accelerate the germination process in Italian alder (table 3). Furthermore, DWD solutions increased early G% (3rd day), and thus germination speed, in the latter species. There was no difference between 10 and 30 ppm (table 3). It was hypothesized that the combination of sucrose and amino acids present in DWD might have resulted in rapid embryo development in Italian alder. Douglas-fir seeds were not affected by the DWD concentrations tested, probably due to their thicker seedcoat.

Conclusions

Results of the study have indicated that:

- The use of DWD solutions (10 and 30 ppm) during germination tests accelerated the germination process in Italian alder but did not affect the rate or the completeness of germination in Douglas-fir. We hypothesize that differences in seed coat structure could explain different behaviours and responses.
- Stratification strongly influenced both early G% and MTG in Italian alder and early, final G% and MTG in Douglas-fir. Although prechilling is prescribed by ISTA (1993) rules for germination tests in the former species it is not indicated for Italian alder. These results could suggest a probable need of modification of ISTA rules.

Although preliminary in nature, the results show that DWD improved tree seed germination in 1 species. Further research is required on a wider range of species, as DWD is cheap, safe, and easy to use.

Address correspondence to: Dr. Elvira Rea, Istituto, Sperimentale per la Nutrizione delle Plante, Via della Navicella 2-4, 00184, Roma, ITALY; e-mail: fisveg@www.inea.it « Dr. Piotto is currently affiliated with the Ministero dell'Ambiente SIAR, Via della Ferratella in Laterano 33, 00187 Roma, Italy.

Table 2-*Germination percentages on the 3rd, 7th, and 28th days and mean time to complete germination (MTG) of seeds of Italian alder and Douglas-fir subjected to different pregermination treatments*

	Italian alder		Douglas-fir	
	Prechilling	No prechilling	Prechilling	No prechilling
Germination (%)				
3rd day	35.0 B b	0.01 A a	ng	ng
7th day	46.9 A a	51.9 A a	35.9 B b	4.2 A a
28th day	48.2 A a	57.0 A b	73.5 B b	67.5 A a
MTG (days)	3.9 A	6.3 B	9.2 A a	14.8 B b

Note: ng = no germination observed. Values are averages for 3 distillery wash derivative (DWD) solutions. For each species, means within a row followed by different capital letters are significantly different at $P < 0.01$ according to the Duncan's multiple range test (Harter 1960); means within a row followed by different lowercase letters are significantly different at $P < 0.05$.

Table 3-*Germination percentages on the 3rd, 7th, and 28th day and mean time to complete germination (MTG) of seeds of Italian alder and Douglas fir imbibed with distillery wash derivative (DWD) solutions of 0,10, & 30 ppm during the germination test*

	Italian alder			Douglas-fir		
	0 ppm	10 ppm	30 ppm	0 ppm	10 ppm	30 ppm
Germination (%)						
3rd day	6.9 A a	12.8 B b	10.7 AB b	ng	ng	ng
7th day	52.6 A a	49.3 A a	47.8 A a	16.7 A a	14.6 A a	19.7 A a
28th day	56.3 A a	52.4 A a	49.3 A a	66.6 A a	70.7 A a	75.0 A a
MTG (days)	5.6 b B b	4.9 AB a	4.8 A a	12.4 A b	12.0 A ab	11.5 A a

Note: ng = no germination observed. Values are averages for 2 pregermination treatments. For each species, means within a row followed by different capital letters are significantly different at $P < 0.01$ according to the Duncan's multiple range test (Harter 1960); means within a row followed by different small letters are significantly different at $P < 0.05$.

References

Bewley JD, Black M. 1986. Seeds, physiology of development and germination. New York: Plenum Press. 4 p.

Bonner FT, McLemore BF, Barnett JP. 1974. Presowing treatment of seed to speed germination. In: Schopmeyer CS, tech. coord. Seeds of woody plants in the United States. Agric. Handbk 450. Washington, DC: USDA Forest Service: 126-135.

Cullum FJ, Gordon AG. 1993. Dormancy release of tree and shrub seeds using a compost activator pretreatment. Proceedings of the International Plant Propagators' Society 43: 125-130.

Danielson HR, Tanaka Y. 1978. Drying and storing stratified ponderosa pine and Douglas fir seeds. Forest Science 24(1): 11-16.

De Matos Malavasi M, Stafford SG, Lavender DP. 1985. Stratifying, partially redrying and storing Douglas-fir seeds: effects on growth and physiology during germination. Annales des Sciences Forestieres 42(4): 371-384.

Di Monte G, Bragaloni M, Pierandrei F, Rea E. 1995. Effect of distillery washes on seed germination. Giornale Botanico Italiano 129(4): 999-1000.

Gomez KA, Gomez AA. 1984. Statistical procedures for agricultural research. New York: John Wiley & Sons: 97-107.

Gordon AE. 1979. The effect of seed maturity on the dormancy and the viability of British produced Douglas-fir and Sitka spruce seeds. In: Bonner F, ed. Proceedings, Symposium on Flowering and Seed Development in Trees; 1979. Starkville, MS: USDA Forest Service, Southern Forest Experiment Station: 362.

Gordon AE, Rowe DC. 1982. Seed manual for ornamental trees and shrubs. Forestry Commission Bulletin 59: 120-128.

Halmer P. 1989. The use of plant growth regulators in the production and treatment of seeds: a commercial prospective. In: Pinfield NJ, Back M, eds. British Plant Growth Regulator Group, Monograph 15: 77-92.

Harter HL. 1960. Critical values for Duncan's new multiple range test. Biometrics 16: 675-685.

Heydecker W, Coolbear P. 1977. Seed treatments for improved performance: survey and attempted prognosis. Seed Science and Technology 5: 353-425.

ISTA [International Seed Testing Association]. 1993. International rules for seed testing 1993. Seed Science and Technology 21 (suppl.): 160-186.

Oplinger ES, Anderson IR, Johnson RR. 1978. Effect of seed and foliar applications of Ergostim on soybeans and corn. In: Abdel Rahman M, ed. Proceedings, 5th Annual Meeting of the Plant Growth Regulator Working Group (PGRWG); Blacksburg, VA; 1978 June 25-29: 124-128.

Orsi S, Tallarico R. 1983. Fitoregolatori e biostimolanti su grano ed orzo. L'lnformatore Agrario 38: 539-541.

Owston PW, Stein WI. 1974. *Pseudotsuga* Carr., Douglas-fir. In: Schopmeyer CS, tech. coord. Seeds of woody plants in the United States. Agric. Handbk. 450: 674-680.
Piotto B. 1992. Semi di alberi e arbusti coltivati in Italia, come e quando seminarli. Rome: SAF [Centro di Sperimentazione Agricola e Forestale]: 78.
Rinallo C. 1979. Alcuni aspetti della biologia dello sviluppo in ontano napoletano (*Alnus cordata* Loisel). Annali dell'Accademia Italiana di Scienze Forestali 28: 207-226.
Siviero P. 1993. Effetti di applicazioni di biostimolanti su pomodoro e melone. L'Informatore Agrario 45: 55-60.
Vanesse R. 1974. Evolution du degré de dormance des graines de sapin de Douglas (*Pseudotsuga menziesii* (Mirb.) Franco). Bulletin de la Societe Royale Forestiere de Belgique 81(3): 149-158.

An Assessment of Ponderosa Pine Seedlings Grown in Copper-Coated Polybags

R. Kasten Dumroese and David L. Wenny

Research associate and professor/director, Forest Research Nursery, Department of Forest Resources, University of Idaho, Moscow, Idaho

Ponderosa pine—Pinus ponderosa *Dougl. ex Laws.—seedlings grown in copper-treated polybags had heights, root collar diameters, and biomass values that were similar to those of seedlings grown without copper. However, untreated seedlings were characterized b1 an abundance of spiraling roots concentrated in the bottom of the polybag. These spiraled roots were matted, often very thick, usually devoid of secondary roots, sometimes kinked, and probably accounted for the 33% greater root volume, 32% greater root mass, and significantly lower shoot–root ratio than that of copper-treated seedlings. Copper-treated seedlings produced a much finer, fibrous root system that was well-distributed throughout the polybag.* Tree Planters' Notes 48(3/4):60-64; 1997.

In developing countries, nursery production of stock in polybags is a common practice. Polybags are usually filled with native soil and placed on the ground during production of the nursery crop (Mexal 1996). Often, seedlings grow roots out the bottom of polybags and into soil, making subsequent harvest more difficult for the laborer. In addition, the resulting cutting or tearing of roots to free nursery stock from soil may unsatisfactorily influence seedling viability. Further, root spiraling, or coiling, is common in polybags and often results in root girdling after outplanting (Sharma 1987; Mexal 1996). After outplanting, seedlings with coiled root systems often grow poorly and die (Sharma 1987).

Copper compounds on interior surfaces of containers have effectively reduced root coverage on exteriors of root plugs at the container wall interface, promoted fine root development, improved root development in the upper portions of containers, decreased root circling, kinking, and production of matted roots at the container bottom, and often increased the number of white, unsuberized root tips in temperate conifers (Burdett 1978; McDonald and others 1981; Saul 1968; Wenny and Woollen 1989), temperate hardwoods (Arnold 1996; Arnold and Struve 1989, 1993; Arnold and Young 1991), and subtropical hardwoods (Schuch and Pittenger 1996; Sparks 1996; Svenson and others 1995). Often, copper-induced changes in root system morphology were associated with improved mechanical stability (Burdett 1978) and increased survival (Struve 1993) of seedlings after outplanting.

We grew ponderosa *pine—Pinus ponderosa* Laws. var. *ponderosa—in* copper-coated polybags to assess resulting seedling form.

Materials and Methods

One-liter polybags were provided by Griffin Corporation (Valdosta, Georgia). Each black bag was constructed of 2-mil, high-density polyethylene coated on the interior with Spin Out® Root Growth Regulator, a coating based on copper hydroxide—$Cu(OH)_2$. Each bag had eight 0.6-cm (0.25-in) diameter drainage holes, 4 side holes about 0.6 cm (0.25 in) up from the bottom, and 4 bottom holes. The treatment consisted of using the polybags as intended, with the copper coating on the inside of the polybag. For controls, we turned the bags inside-out so that the copper coating was on the outside of the polybag. We used 20 polybags for control and 20 polybags for the treatment. In March, all polybags were filled with 1:1 peat–vermiculite medium (Pacific Soil, Hubbard, Oregon); 2 to 3 seeds were sown; and the seeds covered with a 1-cm-deep (0.4-in) layer of silica grit.

Filled polybags were randomly placed inside 1 of 2 wooden frames with 32 x 56 cm (12.5 x 22 in) inside dimensions and wire mesh bottoms-0.6-cm (0.25-in) openings—that were placed on a bench within a greenhouse used to produce an operational crop of ponderosa pine seedlings grown in Copperblock 160/90's, with volumes of 90 ml (5 in^3). The polybags had a surface area of about 64 cm^2 (10 in^2), were about 15 cm (6 in) deep, and had a growing density of about 135 bags/m^2 (12.5/ft^2). After germination was complete, we thinned out extra seedlings, leaving 1 seedling/polybag.

We "fertigated" (fertilizer in irrigation water) the seedlings about twice each week for 35 weeks using various formulations of fertilizer that provided seedlings with about 385 mg of N total (120 mg before bud initiation at week 12). Photoperiod was extended with intermittent all-night lighting using 300-watt incandescent bulbs for the first 12 weeks of the growing cycle.

In December, we removed seedlings from the polybags and gently washed the roots. Heights were measured from ground line to the tip of the terminal bud. Root collar diameter (RCD) was measured at ground line. We used Burdett's (1979) water displacement technique to determine root volume. Shoots and roots were separated, dried for 72 hours at 60 °C (140 °F), and weighed to determine seedling biomass. Height, RCD, root volume, and biomass data were analyzed with an analysis of variance.

Results and Discussion

Seedling height and RCD were unaffected by treatment (figure 1). Although dry root weight was reduced on treated seedlings, dry shoot weight was increased by the treatment, resulting in similar seedling biomass regardless of treatment (table 1). The copper treatment also decreased root volumes (table 1). Shoot–root ratios were significantly higher when seedlings grew in contact with copper (table 1). At our nursery, several studies have shown ponderosa pine height, RCD, and biomass were unaffected by copper-coated containers (Wang 1990; Wenny 1988; Wenny and Woollen 1989).

Roots of seedlings exposed to the copper coating did not penetrate bottom drainage holes. Seedlings grown without exposure to copper readily grew roots through bottom drainage holes and subsequent growth made removing control seedlings from polybags more difficult than removing treated seedlings. Roots were obvious on the surface of root plugs in control polybags, but absent when roots grew in contact with copper (figure 2). Similar results were found on temperate and subtropical hardwood species (Arnold and Struve 1993; Schuch and Pittenger 1996; Svenson and others 1995). Seedlings with copper-pruned roots generally had more uniform root distribution throughout the medium (figure 3), and lacked dense accumulation of spiraled roots in the bottom of polybags, as was the usual growth of untreated seedlings (figure 4). Spiraled roots in the bottom of untreated polybags were usually thick-2 to 6 mm diameter (1/16 to 1/4 in).

The reduction in root mass of treated seedlings in our study may have been attributable to an absence of roots at the interface between polybag and medium, as was concluded by Furuta and others (1972) for *Eucalyptus viminalis* Labill., and/or by the reduction of thick spiraled roots at the bottom of polybags. However, a change in biomass induced by Spin Out, especially of root mass, may be species specific, as *Pinus montezumae* Lamb. and *Pinus pseudostrobus* Lindl. both showed significant increases in root weight, stem weight, and

Figure 1— *Ponderosa pine seedlings growing in polybags with Spin Out copper coating in contact with the root system (left), or with copper coating facing away from roots (right).*

Table 1—*Means (± standard errors) for morphological characteristics of ponderosa pine seedlings grown in polybags with Spin Out copper coating inside the bag (available to roots; copper) or outside the bag (unavailable to roots; control)*

Treatment	Height (cm)	RCD (mm)	Root volume (ml)	Dry weight (g) Shoot	Dry weight (g) Root	Biomass (g)	Shoot–root ratio
Control	21.1 ± 0.7	5.77 ± 0.30	31.4 ± 2.9	6.2 ± 0.4	6.6 ± 0.6	12.8 ± 1.0	0.94 ± 0.06
Copper	22.2 ± 0.8	6.38 ± 0.21	23.5 ± 2.8	7.5 ± 0.6	5.0 ± 0.5	12.5 ± 1.0	1.50 ± 0.11
P value	0.38	0.14	0.05	0.05	0.07	0.90	0.00

Note: RCD = root collar diameter; n = 20 seedlings/treatment; *P* values from an analysis of variance for each seedling characteristic are provided.

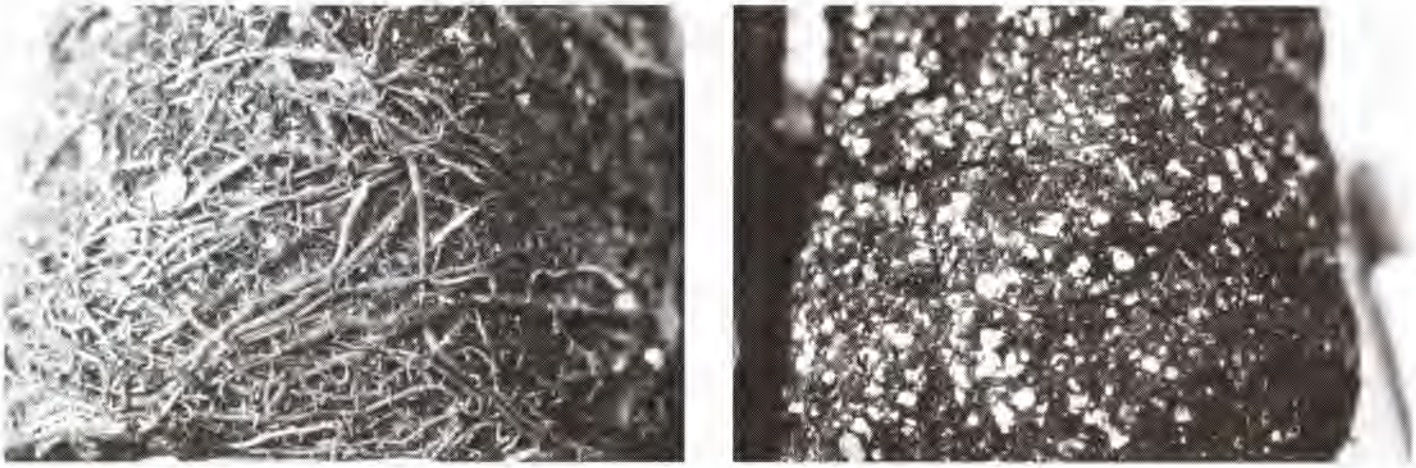


Figure 2—*Ponderosa pine roots growing on the surface of the root plug in control polybags (left) were absent on root plugs grown in Spin Out—treated polybags (right).*

Figure 3—*Ponderosa pine roots were uniformly distributed, fibrous, and lacked any spiraling when grown in contact with Spin Out (left). Control roots were poorly distributed and generally concentrated at the bottom of the polybag (right).*

Figure *4-Ponderosa pine roots spiraling in the bottom of a control polybag.*

height when grown in copper-coated polybags (R. Phillips, see Crawford (1997)). Our observations that copper compounds applied to interior walls of containers promoted a more fibrous root system and more uniform root distribution and that an absence of copper promoted an accumulation of roots at container bottoms have also been reported by others (Arnold and Struve 1989; Schuch and Pittenger 1996).

We observed kinking (particularly in bottom folds), circling, and matting of roots of ponderosa pine at the base of untreated polybags (figure 4). Such root deformities were absent when those seedlings were exposed to copper, as was the case for coarse-rooted temperate hardwood species (Arnold and Struve 1993).

Conclusion

Ponderosa pine seedlings grew well in copper-coated polybags. Our assessment indicates that copper-coated polybags offer an opportunity to improve seedling viability. Root systems of seedlings grown in Spin Out-treated polybags were more fibrous and better distributed throughout the polybag; lacked kinking, spiraling, and other root deformities; and failed to grow out of the drainage holes in the bag.

Address correspondence to: Dr. Kas Dumroese, Forest Research Nursery, Department of Forest Resources, University of Idaho, Moscow, ID 83844-1137; e-mail: » dumroese@uidaho.edu. «

Acknowledgments

The authors thank Sue Morrison and Kenneth E. Quick of the Forest Research Nursery for growing the seedlings, and Daniel Swanson for helping collect the data. This is Idaho Forest, Wildlife, and Range Experiment Station Contribution 849.

Literature Cited

Arnold MA. 1996. Mechanical correction and chemical avoidance of circling roots differentially affect post-transplant root regeneration and field establishment of container-grown Shumard oak. Journal of the American Society of Horticultural Science 121: 258-263.

Arnold MA, Struve DK. 1989. Growing green ash and red oak in CuCO3-treated containers increases root regeneration and shoot growth following transplant. Journal of the American Society of Horticultural Science 114: 402-406.

Arnold MA, Struve DK. 1993. Root distribution and mineral uptake of coarse-rooted trees grown in cupric hydroxide-treated containers. HortScience 28: 988-992.

Arnold MA, Young E. 1991. CuCO3-painted containers and root pruning affect apple and green ash root growth and cytokinin levels. HortScience 26: 242-244.

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

Burdett AN. 1979. A non-destructive method for measuring the volume of intact plant parts. Canadian Journal of Forest Research 9: 120-122.

Crawford MA. 1997. Update of copper root control. In: Landis TD, Thompson JR, tech. coords. National Proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. PNW-419. Portland, OR: USDA Forest Service, Pacific Northwest Research Station: 120-124.

Furuta T, Jones WC, Humphrey W, Mock T. 1972. Chemical control of root growth in containers. California Agriculture 26:10-11.

McDonald SE, Tinus RW, Reid CPP. 1981. Root morphology control in forest tree seedling containers. In: Proceedings of Intermountain Nurseryman's Association and Western Forest Nursery Council; 1980 August 12-14; Boise, ID. Gen. Tech. Rep. INT-109. Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station: 40-45.

Mexal JG. 1996. Forest nursery activities in Mexico. In: Landis TD, South DB, tech. coords. National Proceedings, Forest and Conservation Nursery Associations. Gen. Tech. Rep. PNW-GTR-389. Portland, OR: USDA Forest Service, Pacific Northwest Research Station: 228-232.

Saul G. 1968. Copper safely controls roots of tubed seedlings. Tree Planters' Notes 19(1): 7-9.

Schuch UK, Pittenger DR. 1996. Root and shoot growth of Eucalyptus in response to container configuration and copper carbonate. HortScience 31: 165.

Sharma RD. 1987. Some observations on coiling of roots in nursery raised plants. Journal of Tropical Forestry 3: 207-212.

Sparks AJ. 1996. An evaluation of tree root system control using Spin-Out pre-treated plastic bags [senior thesis]. Gatton, Lawes: University of Queensland, Faculty of Applied Science.

Struve DL. 1993. Effect of copper-treated containers on transplant survival and regrowth of four tree species. Journal of Environmental Horticulture 11: 196-199.
Svenson SE, Johnston DL, Coy BL. 1995. Shoot and root responses of eight subtropical species grown in cupric hydroxide-treated containers. HortScience 30: 249-251.
Wang Z. 1990. Effects of cupric carbonate on container-grown seedlings of ponderosa pine during greenhouse production [Master of Science thesis]. Moscow, ID: University of Idaho.
Wenny DL. 1988. Growth of chemically root-pruned seedlings in the greenhouse and the field. In: Landis TD, tech. coord. Proceedings, Combined Meeting of the Western Forest Nursery Associations: Western Forest Nursery Council, Forest Nursery Association of British Columbia, and Intermountain Forest Nursery Association; 1988 August 8-11; Vernon, BC. Gen. Tech. Rep. RM-167. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 32-37.
Weeny DL, Woollen RL. 1989. Chemical root pruning improves the root system morphology of containerized seedlings. Western Journal of Applied Forestry 4: 15-17.

Growth Regulation and Cold Hardening of Silver Birch Seedlings With Short-Day Treatment

Jaana Luoranen and Risto Rikala

Doctoral student and senior research specialist, Finnish Forest Research Institute, Suonenjoki Research Station, Suonenjoki, Finland

Height growth and cold hardening of silver birch—Betula pendula *Roth—seedlings was controlled with short-day treatment at different times in summer. If the goal is both to retard height growth and to hasten cold hardening, the seedlings should be treated after midsummer; and if the goal is only to hasten cold hardening, seedlings should be treated in late summer. Earlier flushing in the spring following the treatment may expose treated seedlings to late spring frost and cold.* Tree Planters' Notes 48 (3/4): 65-71; 1997.

The production of silver *birch—Betula pendula* Roth—seedlings in Finland increased from 3.6 million to 16.0 million seedlings/year from 1980 to 1994, and the proportion of container seedlings from 5 to 78%/year (Aarne 1995). The target height of the container birch seedlings for outplanting is normally 50 to 80 cm (20 to 32 in). Due to different weather conditions, however, it is difficult to decide the right sowing time and growing schedule to obtain seedlings of this size. In warm summers, seedlings tend to grow too tall compared to the size of the container. Sometimes seedlings harden too late, and autumn frosts kill millions of seedlings.

Manipulation of the irrigation and fertilization regime (Landis and others 1989) and regulation of photoperiod (Landis and others 1992) have been used to retard height growth and to initiate hardening of container seedlings. The use of synthetic growth regulators has also been studied as a method of regulating height growth (Aphalo and others 1997; Weston and others 1980). The most promising method is the use of regulated photoperiod. In Canada and in Sweden, photoperiod control, also called short-day (SD) treatment, is used routinely in growing conifer seedlings. As far as we know, SD treatment has not been used in the production of deciduous seedlings. Nystrom (1992, 1993) presented preliminary results that showed that SD treatment of silver birch seedlings resulted in cessation of height growth. Photoperiod regulation may also have other consequences. In several conifers, early flushing after SD treatment has been reported (for example, Bigras and D'Aoust 1993; Dormling and others 1968). According to Grossnickle and others (1991), SD treatment also increased the root growth capacity of western hemlock—Tsuga *heterophylla* (Raf.) Sarg—seedlings at low root temperature, although there were no differences in the root growth capacity at the optimum root temperature.

The purpose of this study was to determine whether SD treatment could be used to stop excessive height growth and hasten hardening of birch seedlings at different times during summer without negative effects on further development after planting. The hypothesis was that SD treatments for 3 weeks stop height growth but not diameter or root growth of silver birch seedlings, and that SD treatment does not affect the root growth capacity the following spring.

Material and Methods

Silver birch seeds (seed orchard 379, M29-92-0001) were sown on peat-filled flats in a greenhouse at Suonenjoki Research Nursery, which is located at 62°39'N, 27°03'E, altitude 142 m asl (= above mean sea level) in Finland, on May 2. Germlings were pricked on May 22 to 26 to Plantek 25 trays (25 cavities/tray, 380 ml/cavity, 156 cavities/m^2; from Lännen Plant Systems, Finland) filled with fertilized sphagnum peat (Kekkilä, Finland). Seedlings were irrigated according to normal nursery practice by keeping the water content of peat at 30 to 60% by volume during the growing season. Seedlings were fertilized 7 times with liquid fertilizer. The total amount of nutrients (including basic and liquid fertilizers) given was 126 mg N, 56 mg P, and 156 mg K (plus micronutrients) per seedling. Seedlings were grown in a greenhouse until the plastic cover was removed on June 20. At the beginning of August, short-day (SD)-treated seedlings showed spores of birch *rust—Melampsoridium betulinum* (Pers.) Kleb. All seedlings were sprayed twice with triadimefon 0.05% (Bayleton 25), on August 3 and 17.

Short-day treatments (8 hours a day for the 3 weeks) were started on June 29 (SD 1), on July 17 (SD 2), and on July 31 (SD 3). The control treatment was natural day length (CO). The natural day lengths at the beginning and the end of SD-treatment periods are listed in table 1. Seedlings of SD 1 were treated by using a plastic hood

Table 1— *The dates, the heat sums (dd), and the natural day lengths (hours) at the beginning and the end of short-day (SD) treatment periods and at the time of height growth cessation*

Treatment	Begin			End			Growth cessation	
	Date	dd	ndl	Date	dd	ndl	Date	ndl
SD1	June 29	644	20:07	July	823	18:42	Aug 29	12:50
SD2	July 16	782	18:57	Aug 7	1107	16:58	July 26	09:14
SD3	July 31	968	17:41	Aug	1237	15:33	Aug 9	10:83
CO							Aug 16	11:37

Note: dd = degree-days; ndl = natural day length.

(1.5 mx1mx1 m, black inside, white outside, with a photon flux density 0.85 mmol/m^2/sec inside the hood under 1,700 mmol/m^2/sec of sunlight). Seedlings in SD 2 and SD 3 were moved to the greenhouse, where the seedlings were SD-treated automatically using a shade cloth (LS-100, a photon flux density 0.6 mmol/m ^{2}/sec under 1,300 mmol/m^2/sec of sunlight). There were 8 trays with 25 seedlings in each treatment, giving a total of 32 trays and 800 seedlings. The accumulation of heat sum—threshold value > 5 °C (41 °F)—was calculated from the time of sowing. Heat sums at the beginning and the end of the SD treatment periods and at the time of cessation of height growth are presented in table 1.

Shoot lengths of the same randomly selected 8 seedlings/tray in all 8 trays were measured weekly from June 27, except SD 3 from July 5, to September 14. Cessation of growth was defined as the date when seedlings reached 95% of their final height. Leaf abscission, defined as when leaves had dropped, was recorded weekly.

In the autumn, after the leaf fall, 10 seedlings/treatment were harvested, and their heights and diameters at 2 cm (.8 in) above the container surface were measured. Stems and roots were separated, the roots were washed, and both roots and shoots were dried for 48 hours at 60 °C before weighing. Stems were pooled into 1 sample/treatment for the nutrient analysis. Nitrogen concentration was determined with a LECO CHN-600 analyzer (Leco Co, USA) and concentrations of P, Ca, K, Mg, Cu, and B were determined from dry-digested (2 M HCl) samples (Halonen and others 1983) using plasma emission spectrophotometric analysis (ICP, ARL 3800).

The procedures used for determination of water content were as described in Rosvall-Ahnebrink (1977) for conifer seedlings and Calmé and others (1995) for hardwood seedlings, but with slight modifications. The seedlings were watered a day before sampling. The uppermost 5 cm (2 in) of 10 randomly selected seedlings/treatment were cut in the morning between 7:30 and 9:00 a.m. Cut apices were put into plastic bags and weighed without leaves within 1 hour (fresh weight), then put into paper bags, dried in an oven for 24 hours at 105 °C (221 °F) and weighed again (dry weight). Water content was expressed as the ratio of fresh weight minus dry weight to fresh weight. Water content was determined weekly from July 19 to October 11.

The cold hardiness of the seedlings was determined using the relative conductivity method (or freeze-induced electrolyte leakage test) described in Aronsson and Eliasson (1970) with modifications. Cold hardiness was tested twice on August 28 and September 25. Fourteen randomly selected seedlings were sampled from each treatment. Each seedling was divided into 3 parts: from the uppermost 5 cm (2 in), water content was determined; the next 16 cm (6.3 in) was divided into two 8-cm (3.1-in)—long samples. Both of the latter samples were cut into four 1-cm (.4-in)—long pieces, which were washed in deionized water and put into 2 test tubes with 0.5 ml of water. There were 4 test tubes/test temperature per treatment: 2 upper and 2 lower parts of the stem in each. On the first testing date the samples were placed in air-cooled chambers to 0, –4, –8, –12, –15.5, and –19.5 °C (32, 24.8, 17.6, 10.4, 4.1, –3.1 °F) test temperatures, and on the second date to –6, –12, –18, and –24 °C (21.2, 10.4, –4, –11.2 °F) test temperatures. Temperatures in the freezers were lowered 6 °C /hour, kept 3 hours at the minimum, and then raised 6 °C (6.5 °F)/hour to 20 °C (68 °F). On both testing dates the control temperature was +4 °C (39 °F).

After freezing and return to 20 °C (68 °F), 11.5 ml water was added to the tubes, which were then shaken in a to-and-fro motion (110/min) for 22 hours at room temperature. The conductivity of the bathing solution was then measured in a radiometer (CDM 83, with a cell constant of 1.008 mS at room temperature). The samples were then held in a water bath at 90 °C (194 °F) for 20 minutes and retested. The second conductivity measurement was made after another 22-hour shaking period. The values for relative conductivity were calculated by dividing the conductivity after freezing by the conductivity after killing. Due to problems with measuring cold hardiness we could not calculate the LT_{50} values. According to the results of others (for example, Aronsson and Eliasson 1970) the lower the relative conductivities, the hardier the seedlings.

On October 11, 10 seedlings/treatment were randomly selected for root growth capacity (RGC) tests and 32 seedlings/treatment for a planting experiment. These were packed in plastic bags and stored at —4 °C (24.8 °F) until February 19 when the RGC seedlings were thawed in darkness for 4 days at +5 °C (41 °F) followed by 4 days at +10 °C (50 °F). After thawing, the seedlings were planted in 0.75-liter plastic boxes filled with sand and randomized in a heated greenhouse (day/night temperature: +20 to +22 °C (69 to 71.6 °F)/ +15 °C (59 °F), with supplemental illumination of 150 pmol/m^2/sec from metal halide lamps (HQI-400W Power Star, Osram), photoperiod: 18/6 hours) for 4 weeks. The seedlings were hand-watered daily with tap water. At planting, the height of the shoot was measured. Flushing was checked weekly by measuring the length of the same 3 leaves of each seedling. On March 27, all seedlings were harvested, and their heights and diameters were measured. Roots that had grown out from the peat plug into the sand ("new" roots) were cut and washed, and the shoot was divided into stem and leaves. The roots in the peat plug ("old" roots) were separated from the peat. All plant parts were then dried in an oven for 48 hours at 105 °C (221 °F) and weighed.

On May 22, 8 seedlings from cold storage were planted in the field in a randomized block design (4 blocks, 8 seedlings/treatment/block). At planting and at the end of the first growing season, the heights and diameters were measured.

Height growth was analyzed using an MGLH procedure for repeated measurements in Systat 5.05. Before analysis of variance, all the measured morphological variables, except height to diameter ratio in autumn and height growth in the RGC test, were log-transformed to obtain normal distribution. Results shown in the figures and in the tables are back-transformed. Because the variances were unequal, the estimates of water content were analyzed using Kruskal-Wallis one-way analysis of variance. Frost hardiness and nutrients were not analyzed statistically because there were too few independent samples. Difficulties with the relative conductivity method will be discussed later.

Results

The first visible signs that seedlings responded to the SD treatments were that the uppermost leaves turned from reddish to pale green. All leaves turned dark green about 1 week after the end of the treatment period. In the autumn, the leaves of the SD 2 seedlings fell first (September 28) and the leaves of the SD 3 seedlings fell a week later. In the SD 1 treatments and control seedlings, the leaves did not fall until October.

In SD 2 and 3 treatments, the height growth of the seedlings stopped during the 3 weeks of treatment. In treatment SD 1 some seedlings continued their height growth later in August (table 1, figure 1). The earlier the blackout treatment, the shorter the seedlings ($P < 0.001$, figure la).

Early blackout treatment (SD 1) did not result in a difference in diameter and root growth as compared to the control. SD 2 and 3 treatment resulted in significantly smaller diameter and less root growth than SD 1 and control seedlings (table 2). The earlier the photoperiod was shortened, the lower was the height-to-diameter ratio and the shoot-to-root ratio (table 2). The regrowth of the SD 1 seedlings increased the variability in all variables measured compared to other treatments, except for dry mass of the roots in the SD 2 treatment.

Concentrations of N, P, K, Ca, Mg, Cu, and B were higher in the SD-treated seedlings (table 3). The nutrient concentration in control seedlings was only half that in the SD-treated seedlings.

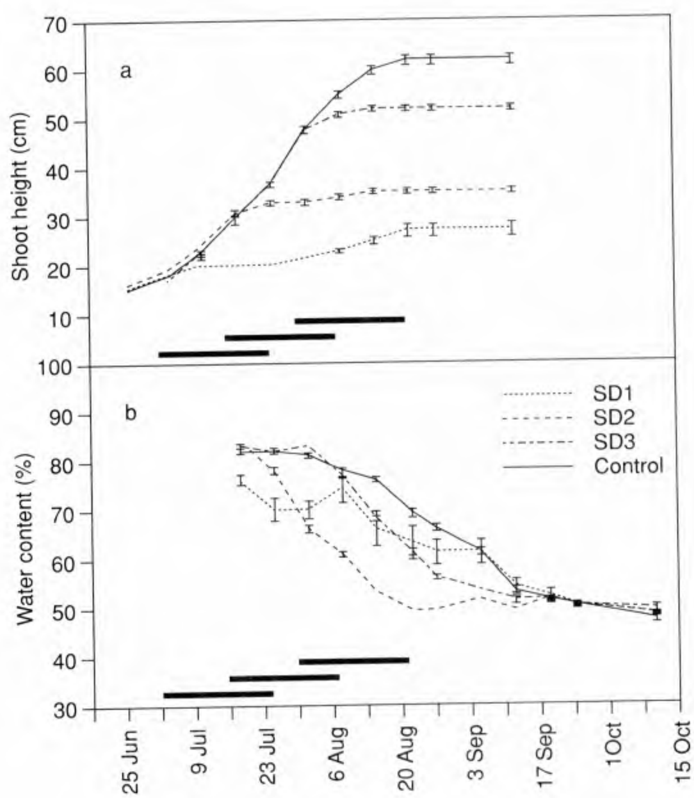


Figure 1— *Mean weekly height growth (a) and water content (b) of the uppermost 5 cm of silver birch seedlings in short-day (SD)—treated and control seedlings during the autumn 1995. The vertical bars are the standard errors of the means. Horizontal bars indicate blackout treatments.*

Table 2 —*Mean height, diameter, shoot, and root dry mass of 64 silver birch seedlings blacked out on different dates in 1995 (height-to-diameter and shoot-to-root ratios are also shown for 10 seedlings sampled in autumn)*

Treatment	Height (cm)		Diameter (mm)		Shoot (g)		Roots (g)		Height:diam		Shoot:root	
	mean	CV %	mean	CV %	mean	CV %	mean	CV %	mean	CV %	mean	CV %
SD 1	27 a	35	5.5 a	11	1.73 a	38	2.81 a	22	4.3 a	25	0.61 a	26
SD 2	34 b	11	4.2 b	7	1.45 a	15	2.30	24	7.9 b	13	0.65	19
SD 3	52 c	10	5.0 c	7	2.48 b	24	2.04 b	12	10.3 c	11	1.21 b	20
CO	62 d	11	5.8 a	7	4.05 c	15	2.83 a	12	10.9 c	7	1.44	17
P	<.001		<.001		<.001		<.001		<.001		<.001	

Note: CV represents coefficient of variation; differences in mean values followed by the same letter are not statistically significant at $P < 0.05$ as determined by Tukey's HSD test.

Table 3—*Nutrient concentration in harvested short-day-treated (SD 1, SD 2, & SD 3) and control (CO) stems; pooled samples are consisted of 10 seedlings*

Treatment	N (%)	P (g/kg)	K (g/kg)	Ca (g /kg)	Mg (g/kg)	Cu (mg/kg)	B (mg/kg)
SD 1	1.20	1.81	4.61	2.33	1.01	5.3	13.3
SD 2	1.61	2.38	4.79	3.00	1.50	5.9	12.3
SD 3	1.78	2.19	4.95	2.50	1.20	4.4	9.7
CO	0.84	1.39	4.24	1.79	0.79	2.4	6.7

Water content of seedlings decreased rapidly after the treatment period, especially in SD 2 (figure 1b). The regrowth of some SD 1 seedlings after the treatment period increased the water content. The water content of SD 2 and SD 3 seedlings reached a value of 55% within 2 weeks after the end of the SD treatments (August 16 and September 6, respectively), but the water content of SD 1 and control seedlings did not reached that value until September 20.

Cold hardiness of the seedlings differed between treatments (figure 2, results shown only for the test of August 28). On both testing dates, the SD 2 seedlings were slightly hardier than the SD 3 seedlings, and both were hardier than the control or the SD 1 seedlings. The SD 1 seedlings sampled to —16 °C (3.2 °F) temperature had low relative conductivity because they did not continue their height growth after blackout as did the seedlings sampled to other test temperatures.

The following spring the SD 1 and SD 2 seedlings flushed earlier in the RGC test than did the SD 3 or control seedlings. After 2 days in the greenhouse, all SD 1 and SD 2 seedlings and 80% of the control and SD 3 seedlings showed signs of flushing. However, during the first week in the greenhouse, the leaves of the control seedlings grew faster than those of the seedlings in other treatments. After 2 weeks, the leaves of the SD 3 seedlings were longer than those of other seedlings. The SD treatments decreased the root growth capacity of the seedlings, but increased the height growth the following spring (table 4). The earlier the seedlings were treated, the higher was their relative growth rate for height.

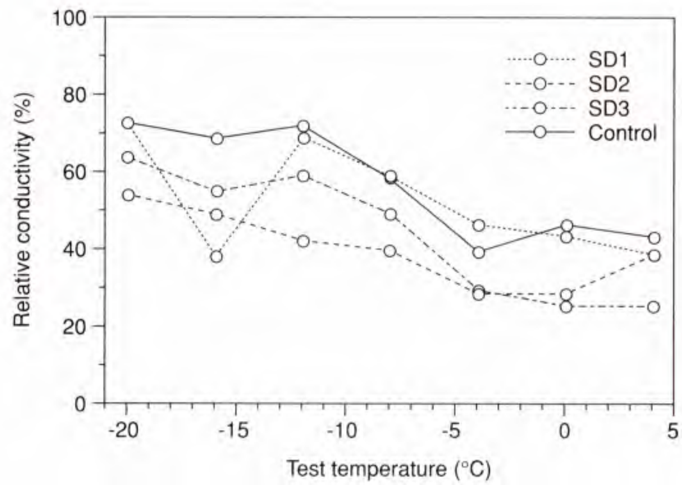


Figure 2— *Relative conductivity values after the first freezing test at 7 test temperatures on August 28-29, 1995. Lower values indicate greater cold hardiness. Each symbol is the mean of 2 independent samples (2 seedlings).*

Table 4—*Mean height increment and new root dry mass of 10 RGC-tested silver birch seedlings in spring 1996*

Treatment	Height increment (cm)		New roots (mg)	
	mean	CV %	mean	CV %
SD 1	18 a	18	17	95
SD 2	16 ab	23	12	145
SD 3	14 ab	27	20	45
CO	13 b	20	28	101
P	0.023		0.109	

Note: CV represents coefficient of variation and differences in mean values followed by the same letter are not statistically significant at $P < 0.05$ as determines by Tukey's HSD test

Seedlings with a high relative growth rate for height had a low relative growth rate for roots.

During the first growing season in the field, the SD 1 seedlings grew most; but the difference was significant only for the SD 3 seedlings, which grew least. On the other hand, the diameter growth of SD 3 was greatest (table 5). SD treatment increased the number of leaders per seedling. The earlier the seedlings were treated, the more seedlings there were with multiple leaders (table 5).

Discussion

SD treatments that ended August 7 (SD 2) and August 21 (SD 3) stopped height growth during the 3-week treatment periods. Treatment ending 20 July (SD 1) resulted in some seedling regrowth in August, at 3 weeks after treatment. Koski and Sievänen (1985) suggested that the behavior of the birch seedlings during their first growing season was a combined effect of heat sum and night length. According to Koski and Selkäinaho (1982), the effect of the photoperiod seemed to increase gradually and to be proportional to night length. Koski and Sievänen (1985) predicted that the different provenances of birch stop growth after the accumulation of about two-thirds of the total heat sum for an average growing season. The heat sum for the provenance used here is about 1,100 degree-days. When the SD 1 treatment began, the heat sum was 644 degree-days (table 1). For permanent dormancy, the heat sum should have been about 750 degree-days at the beginning of the treatment period. In the other SD treatments, the heat-sum requirements suggested by Koski and Sievänen were fulfilled.

The diameter of the seedlings was decreased in SD 2 and SD 3 treatments, but not in SD 1. According to Håbjorg (1972), the maximum diameter growth of *Betula pubescens* occurrs at a photoperiod of 18 hours. After the SD 1 treatment, the photoperiod was still long enough for diameter growth. The later height growth stopped, the higher was the shoot–root ratio. During growth, shoots and roots compete for the same photosynthates. The carbohydrates produced could be allocated more to root growth, when height growth was stopped by SD treatment but the photosynthesis continued.

Almost all the nutrient concentrations measured were higher in the SD-treated seedlings than in control seedlings. The results of Skre (1991) agree with these findings: nitrogen and phosphorous concentrations were higher in seedlings growing in short days than those growing in longer days. Due to earlier cessation of growth in SD treatments, seedlings could accumulate more nutrient in their tissues.

SD treatment increased the height increment of the shoot, but decreased the root growth the following spring. The SD-treated seedlings flushed earlier and grew more than the untreated seedlings. Early spring flushing and increased height growth after the SD exposure have been reported previously in conifers (Bigras and D'Aoust 1993; Dormling and others 1968; Odium and Colombo 1988). Dormling and others (1968) also showed that the day length and temperature during bud maturation of Norway *spruce—Picea abies* (L.) Karst.—decisively influence time of initiation of flushing. In addition, nitrogen concentration has been shown to cause flushing earlier in the next spring (Benzian and others 1974).

The poor capacity for root growth after SD exposure found here is opposite to the results of Grossnickle and others (1991). In their research, new root growth of western hemlock—Tsuga *heterophylla* (Raf.) Sarg.—seedlings was greater after short-day treatment than in long-day treatment. As far we know, the root growth capacity of SD-treated deciduous seedlings the following spring is not reported in the literature.

We can only speculate as to the reasons for the SD-treated seedlings having multiple leaders after the first growing season in the field. In March, none of the RGC-tested seedlings had unflushed buds, so the top buds of SD-treated seedlings were damaged after that. Due to earlier flushing, SD-treated seedlings were more susceptible to spring frost, insects, winds, etc. Krasowski and others (1993) reported that photoperiod length was asso-

Table 5—*Mean height, diameter, and height and diameter growth of 32 seedlings per treatment at the end of the first growing season in the field*

Treatment	Height (cm)		Diameter (mm)		Height growth (cm)		Diameter growth (mm)		Leaders	
	mean	CV-%	mean	CV-%	mean	CV-%	mean	CV-%	2	> 2
SD 1	49 a	28	6.6 a	12	24 a	35	1.6 ab	48	16	25
SD 2	52 a	18	5.8 b	8	19 ab	44	1.9 ab	20	22	16
SD 3	67 b	11	6.5 a	10	16 b	45	2.1 a	28	19	3
CO	80 c	12	6.9 a	11	20 ab	40	1.6 b	54	3	3
p	<.001	<0.001	0.004	0.016						

Note: Seedlings with 2 or more leaders are expressed as a percentage of all seedlings in a treatment. Differences in mean values followed by the same letter are not statistically significant at $P < 0.05$ as determined by Tukey's HSD test.

ciated with the number of unflushed terminal buds of seedlings of Engelmann and white spruce-Picea *engelmannii* Parry ex Engelm. and *P. glauca* (Moench) Voss-the shorter the photoperiod, the greater the number of unflushed terminal buds. In our experiments, the photoperiod was 8 hours, shorter than any photoperiod length in the experiment of Krasowski and others (1993).

Evaluation of the hardening of conifer seedlings by determining the water content in the top of the seedlings has become routine in nursery practice in Sweden (Dunsworth 1997). For deciduous species this method has been studied by Calmé and others (1995) in seedlings of yellow birch *(B. alleghaniensis* Britton) and red and bur oak *(Quercus rubra* L. and *Q. macrocarpa* Michx.). The present findings were similar to theirs: water content was lower in SD-treated seedlings. They suggested that a dry matter content higher than 45% (water content lower than 55%) corresponded to seedlings with LT_{50} of -10 °C (14 °F) or less. Due to difficulties in assessing cold hardiness, we could not compare the values of cold hardiness and water content.

Short-day treatments increased the cold hardiness of the seedlings, but because of difficulties in the method of assessment, we could not interpret the results precisely. Since the work of Dexter and others (1930, 1932), the relative conductivity method has been widely used to measure the degree of cold hardiness of different plant tissues. In woody species, this method has been used in both deciduous (for example, Deans and others 1995; Wilner 1960) and conifer trees (for example, Aronsson and Eliasson 1970). According to Deans and others (1995), killing tissues in boiling water is not an effective method for destroying the cell membranes, and the incubation time should be at least 5 days. Because of the method we used, the conductivity values of the killed samples were only partial and the relative conductivities were higher than they would have been if all membranes had been destroyed. Unpublished data of the first author indicate that the leakage from hardened tissues is slower than that from unhardened tissues. This could explain the lower relative conductivities of SD 2 samples compared to the conductivities of the other samples.

Conclusion

Short-day treatment is a promising method for control of height growth and cold hardening of silver birch seedlings. In order to succeed in SD treatment, nursery managers should treat seedlings after two-thirds of the average heat sum for the provenance used is accumulated but before the critical night length is achieved naturally. SD treatment does not affect seedling growth after planting, but could cause multiple leaders in seedlings during the first growing season in the field. More studies are needed to determine the suitable length of treatment and examine the possibility of using a photoperiod that is longer than 8 hours or is gradually shortened.

Address correspondence to: Jaana Luoranen, Finnish Forest Research Institute, Suonenjoki Research Station, Juntintie 40, FIN-77600 Suonenjoki, Finland; email: » Jaana.Luoranen@metla.fi «

References

Aarne M, ed. 1995. Statistical yearbook of forestry 1995. Helsinki: Finnish Forest Research Institute, Agriculture and Forestry. 354 p.

Aphalo P, Rikala R, Sanchez RA. 1997. Effect of CCC on the morphology and growth potential of containerised silver birch seedlings. New Forest 14: 167-177.

Aronsson A, Eliasson L. 1970. Frost hardiness in Scots pine *(Pinus silvestris* L.): 1. Conditions for test on hardy plant tissues and for evaluation of injuries by conductivity measurements. Studia Forestalia Suecica 77.30 p.

Benzian B, Brown RM, Freeman CR. 1974. Effect of late-season top-dressing of N (and K) applied to conifer transplants in the nursery on their survival and growth on British forest sites. Forestry 47(2): 153-184.

Bigras FJ, D'Aoust AL. 1993. Influence of photoperiod on shoot and root frost tolerance and bud phonology of white spruce seedlings *(Picea glauca)*. Canadian Journal of Forest Research 23(2): 219-228.

Calmé S, Margolis HA, Bigras FJ, Mailly D. 1995. The relationship between water concentration and frost tolerance in shoots of hardwood seedlings. Canadian Journal of Forest Research 25: 1738-1745.

Deans JD, Billington HL, Harvey FJ. 1995. Assessment of frost damage to leafless stem tissues of *Quercus petraea:* a reappraisal of the method of relative conductivity. Forestry 68(1): 25-34.

Dexter ST, Tottingham WE, Graber LF. 1930. Preliminary results in measuring the hardiness of plants. Plant Physiology 5: 215-223.

Dexter ST, Tottingham WE, Graber LF. 1932. Investigations of the hardiness of plants by measurement of electrical conductivity. Plant Physiology 7: 63-78.

Dormling I, Gustafsson A, von Wettstein D. 1968. The experimental control of the life cycle in *Picea abies* (L.) Karst. Silvae Genetica 17: 44-64.

Dunsworth, GB. 1997. Plant quality assessment: an industrial perspective. New Forests 13(1/3): 439-448.

Grossnickle SC, Arnott JT, Major JE, Tschaplinski TJ. 1991. Influence of dormancy induction treatments on western hemlock seedlings: 1. Seedling development and stock quality assessment. Canadian Journal of Forest Research 21(2): 164-174.

Halonen 0, Tulkki H, Derome J. 1983. Nutrient analysis methods. Research Notes from the Finnish Forest Research Institute 121: 1-88.

Håbjorg A. 1972. Effects of photoperiod and temperature on growth and development of three latitudinal and three altitudinal populations of *Betula pubescens* Ehrh. Meldinger fra Norges Landbrukshogskole. 51(2): 1-27.

Koski V, Selkäinaho J. 1982. Experiments on the joint effect of heat sum and photoperiod on seedlings of *Betula pendula*. Communicationes Instituti Forestali Fenniae 105: 1-34.

Koski V, Sievänen R. 1985. Timing of growth cessation in relation to the variations in the growing season. In: Tigerstedt PMA, Puttonen P, Koski V, eds. Crop physiology of forest trees. Helsinki: Helsinki University Press: 167-194.

Krasowski MJ, Letchford T, Eastham AM. 1993. Growth of short-day treated spruce seedlings planted throughout British Columbia. FRDA Report 209. Forestry Canada and the British Columbia Ministry of Forests. 39 p.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1989. Seedling nutrition and irrigation. Volume 4, The container tree nursery manual. Agric. Handbk. 674. Washington, DC: USDA Forest Service. 119 p.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1992. Atmospheric environment. Volume 3, The container tree nursery manual. Agric. Handbk. 674. Washington, DC: USDA Forest Service. 145 p.

Nystrom C. 1992. Odlingsteknik for täckrotsplantor av björk: ett faktablad frail avd. for skogsförnyelse skogshögskolan, Garbenberg. Plantnytt 6: 1-4.

Nyström C. 1993. Beskogning av åkermark . Ett faktablad från avd. for skogsförnyelse skogshögskolan, Garbenberg. Plantnytt 5/6: 1-8.

Odium KD, Colombo SJ. 1988. Short day exposure to induce budset prolongs shoot growth in the following year. Gen. Tech. Rep. RM-167. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 57-59.

Rosvall-Åhnebrink G. 1977. Artificiell invintring av skogsplantor i plantväxthus [Summary: Artificial hardening of spruce and pine seedlings in plastic greenhouses]. Rapporter och Uppsatser, Sveriges Lantbruksuniversitet Institutionen Förskogsgenetik 27: 153-161.

Skre 0.1991. Chemical composition of mountain birch (*Betula pubescens* Ehrh.), and lowland birch (*Betula pendula* Roth.) seedlings, grown at varying temperature, light and photoperiod. Norsk Institutt for Skogforskning Meddelelser fra Skogfork 44(8): 1-28.

Weston GD, Carlson LW, Wambold EC. 1980. The effect of growth retardants and inhibitors on container-grown *Pinus contorta* and *Picea glauca*. Canadian Journal of Forest Research 10(4): 510-516

Wilner J. 1960. Relative and absolute electrolytic conductance tests for frost hardiness of apple varieties. Canadian Journal of Plant Science 40: 630-637.

Effect of Phytophthora Root Rot on Survival and Growth of Fraser Fir Christmas Trees

Coleman A. Doggett, Charles E. Cordell, and Donald Rogers

Senior staff forester (retired), North Carolina Division of Forest Resources, Raleigh; vice-president, technical services, Plant Health Care, Inc., Asheville; and program head, pest control, North Carolina Division of Forest Resources, Raleigh, North Carolina

A study was conducted in Avery County, NC, to determine the effect of phytophthora root rot and a chlorosis (yellowed foliage) of Fraser fir (Abies fraseri *(Pursh) Poir.) on survival and growth. Seedlings in 4 symptom categories-1. Nonsymptomatic seedlings from a nondiseased area (nonsymptomatic), 2. Chlorotic seedlings from a nondiseased area (chlorotic), 3. nonsymptomatic seedlings from* Phytophthora *spp.–infected nursery seedling beds (nonsymptomatic from diseased beds), and 4. seedlings with advanced symptoms, including wilting and discolored foliage, necrotic roots, and stem and/ or root collar resinosis—were planted on a well-drained Christmas tree site in 1974. Tree survival and growth were monitored through 1984. Trees in the chlorotic category survived as well as nonsymptomatic trees throughout the study period and by the third growing season the chlorosis had disappeared. Nonsymptomatic trees from diseased seedbeds had significantly more first-year mortality than nonsymptomatic trees. Survival of the trees with advanced symptoms was the lowest (only 49%) by the end of the first year. Mortality in all categories was relatively minimal after the first growing season. Surviving trees in the advanced symptoms category grew faster than those in the other 3 categories, probably caused by the larger initial size at planting date and increased growing space as a result of first-year mortality.* Tree Planters' Notes 48(3/4): 72-75; 1997.

The Fraser fir Christmas tree industry is a multimillion dollar source of income to the southern Appalachian region. Since the early 1960's, phytophthora root rot, caused by several *Phytophthora spp.*, has been associated with significant damage to Fraser *fir—Abies fraseri* (Pursh) Poir.—seedlings (Kuhlman and Hendrix 1963; Kuhlman and others 1989). Losses caused by the disease have also become an increasingly serious problem in Fraser fir Christmas tree plantations. Several species of *Phytophthora—including P. cinnamomi, P. parasitica, P. citricola,* and *P. drechleri—* have been repeatedly isolated from diseased root and soil samples (Campbell 1971; Grand and others 1973). Advanced disease symptoms and associated mortality occur in both seeded (1+0, 2+0, 3+0) and transplanted (2+1, 2+2, 3+2) fir seedling beds and are correlated with abnormally high moisture conditions and poor soil drainage (Cooley and others 1985; Kuhlman and others 1989). These conditions are promoted and sustained by frequent precipitation and/or irrigation combined with poor internal soil drainage.

In addition to the phytophthora disease problem, a chronic foliage chlorosis (yellowing) condition was observed in localized Fraser fir seedling beds at the Linville River North Carolina State Nursery. An intensive survey of the chlorotic seedlings that included laboratory culturing of symptomatic seedlings for *Phytophthora* spp. was conducted in 1972. There was little fir seedling mortality (less than 5%) and a low recovery of *Phytophthora* spp. Consequently, it was concluded that the chlorotic foliage symptoms were not primarily associated with *Phytophthora* but were more likely associated with physiological, environmental, and/or cultural management factors.

The occurrence and damage associated with phytophthora root rot on Fraser fir seedlings in nursery seedling beds has been well-documented (Grand and others 1973; Kuhlman and others 1989). Comparatively little information, however, is available concerning the survival and/or growth of diseased Fraser fir seedlings in Christmas tree plantations. Also, there is no available information concerning the survival and/or growth response of fir seedlings with chlorotic foliage symptoms in Christmas tree plantations. Therefore our primary objectives were to determine the effect of phytophthora root rot and the foliage chlorosis upon the survival, growth and Christmas tree production of Fraser fir seedlings on a typical well-drained Christmas tree planting site in western North Carolina.

Methods

In 1974, a Fraser fir Christmas tree planting was established on private land in Avery County, NC. The site was located on a steep (30%+) north-facing slope, was well drained except for the benches on several terraces, and was considered an average site for Fraser fir Christmas tree production. The fir seedlings were divided into 4 categories for outplanting:

1. Nonsymptomatic seedlings with no evidence of root rot symptoms selected at random from apparently nondiseased seedbed locations (nonsymptomatic)
2. Seedlings with chlorotic or yellowed foliage symptoms selected at random from apparently nondiseased seedbed locations (chlorotic)
3. Nonsymptomatic seedlings with no evidence of root rot symptoms selected at random from diseased seedbed locations (nonsymptomatic from diseased beds)
4 Seedlings with easily discernible symptoms (advanced symptoms) (that is, advanced foliage discoloration, necrotic roots and/or significant reduction of feeder roots, and root collar or basal stem resinosis) selected at random from diseased seedbed locations

Two hundred 3+2 (3 years in seedbed plus 2 years in transplant beds) Fraser fir seedlings in each of the 4 symptom categories were selected for field planting. In addition, 50 seedlings in the advanced symptoms category were processed and cultured for the presence of *Phytophthora* spp. using standard laboratory bioassay techniques. The seedlings were planted in April 1974 in a randomized block design. The design consisted of 5 blocks with each block containing two 20-seedling rows per symptom category and planted at a 4-ft x 4-ft (1.2-m) spacing. An 8-foot (2.4-m) (double row-width) isolation strip was maintained between each block.

After outplanting, the study area was maintained by the landowner using standard, recommended cultural practices for Fraser fir Christmas tree plantations including mechanical and chemical weed control, fertilization, pest management, and shearing.

Tree measurements—including tree survival and heights of surviving trees—were made annually during the dormant season. It is important to remember that recommended shearing of Fraser fir Christmas trees involves both lateral and terminal shoots. Consequently, total tree heights are decreased as compared with unsheared trees. Because all trees were subjected to the same shearing practices, however, the shearing effects should be comparable between treatment categories.

Because the quantity of trees harvested represents the most tangible "bottom-line" benefit to the grower, data were collected concerning numbers of trees harvested by symptom category. The first Christmas trees were harvested in 1982 and the study was terminated in 1984, providing 3 years of tree harvest data. Data were analyzed using Tukey's multiple range test.

Results

There was no significant difference in survival between the nonsymptomatic (96.5%) and chlorotic symptom (92.5%) categories throughout the study period (table 1). First-year survival in the nonsymptomatic from diseased beds symptom category was 86%. Seedlings in the advanced symptoms category survived at 49%, whereas nonsymptomatic seedlings had 100% survival. Both of these survival differences were significant at the .05 significance level (table 1).

Phytophthora spp., primarily *P. cinnamomi*, were isolated from 84% of the cultured seedlings. The vast majority of the total Fraser fir mortality in all 4 symptom categories occurred during the first growing season. Following the first-year mortality, additional mortality in all 4 categories during the remainder of the study was low, averaging 6.1% over the remaining 9 years. At the end of the third growing season, seedlings in the chlorotic category had normal coloration with no additional negative effect on their value as Christmas trees.

After 3 years and before the trees were sheared, there were no significant differences in tree height growth between any of the 4 symptom categories with the exception of the advanced symptoms category. The surviving trees from this category grew faster than trees in any of the other 3 categories throughout the study period (table 1). By 1982, when tree harvest began, none of the other 3 symptom categories differed in average tree height growth (table 1) with a range from 101.6 to 109.1 cm. As expected, the total number of trees harvested for Christmas trees by category was closely correlated with first-year survival. The number and percentage of Christmas trees harvested by the end of the study period (1984) per category was healthy, 118 (59.0%); chlorotic, 100 (50%); healthy from diseased beds, 72 (36.0%); and advanced symptoms, 66 (33.0%) (table 1). However, when excluding the first-year mortality, the percentage of surviving trees harvested for Christmas trees per symptom category was advanced symptoms, 67.3%; healthy, 59%; chlorotic, 50.5%; and healthy seedlings from diseased beds, 41.9%.

Discussion and Conclusions

This study clearly demonstrates the negative effects of *Phytophthora* root rot on first-year Fraser fir survival in a Christmas tree plantation, as reflected by both nonsymptomatic seedlings from diseased areas and advanced symptoms seedlings having significantly lower survival than nonsymptomatic seedlings..

The seedlings with advanced symptoms used in the study would normally be culled at the nursery. Surprisingly, after the severe (51%) first-year mortality

Table 1—*Fraser fir survival, height growth, and Christmas tree production, by disease symptom category, Avery County, North Carolina, 1974-1982*

Category	Survival (%) 1974	Survival (%) 1982	Height (cm) 1974	Height (cm) 1982	8-yr Height increase (cm)	Trees harvested 1974-82
1	100 a	96.5 a	16.3 b	125.4	109.1 ab	59
2	99.0 a	92.5 a	18.3 b	122.8	103.5 ab	50
3	86.0 b	75.5 b	14.0 c	115.6	101.6 b	36
4	49.0 c	45.0 c	21.1 b	134.1	113.0 a	33

Note: 1 = nonsymptomatic seedlings from nondiseased areas; 2 = chlorotic seedlings from nondiseased areas; 3 = nonsymptomatic seedlings from diseased areas. 4. Advanced symptoms seedlings. A total of 200 trees were planted per category, making 40 trees in each of 5 blocks. Numbers followed by the same letter are not significantly different at the .05 confidence level according to Tukey's multiple comparison test. cm × .3937 = inches.

occurred, these seedlings as well as those in the other 3 categories sustained only minimal additional mortality during the remainder of the study period. This shows that even diseased seedlings transplanted to a favorable, well-drained site may grow as well as healthy trees, although initial survival is lower.

The study shows that chlorotic Fraser fir seedlings have equal potential for acceptable tree survival, growth, and Christmas tree production as healthy seedlings when planted on average quality, well-drained Fraser fir sites. This indicates that chlorotic seedlings are acceptable and should not be discriminated against in the selection process. It also shows that chlorosis alone is not a diagnostic symptom of phytophthora root rot.

At the end of the study, the trees surviving after the first year in the advanced symptoms category were taller than those in the other categories, including the nonsymptomatic category. Also following the severe first-year mortality in the advanced symptoms category, the largest percentage (but not the highest total number) of surviving trees was harvested for Christmas trees in this category. A comparison of initial seedling height measurements shows that the advanced disease symptoms category had the largest seedlings (table 1). The increased seedling growth occurred in the advanced diseased symptoms seedbeds with higher mortality. This resulted in lower seedling density, less competition, and larger seedlings. Reports from a variety of field planting studies consistently show the positive correlation between larger seedlings at planting date and increased tree growth. Therefore, this is a likely factor associated with both the observed increase in Fraser fir average heights and the earlier Christmas tree harvest of the surviving trees in the advanced diseased symptoms category. If we examine growth increases between planting and harvest dates (table 1), however, the growth advantage of the seedlings in the advanced symptoms categories largely disappears, and is only significantly better than the nonsymptomatic category seedlings from diseased areas. Standardization of initial seedling heights may have reduced differences in tree growth and Christmas tree production.

A second factor affecting the performance of the advanced category seedlings was the increased first-year mortality in this category. This results in increased growing space and less competition for the surviving trees, which may have contributed to their growth and earlier harvest.

In conclusion, phytophthora root rot, like all plant diseases, is associated with 3 primary factors—a susceptible host plant, a favorable environment for disease development (excessive moisture and/or poorly drained soil), and a pathogenic agent (several *Phytophthora* spp.). All 3 factors must be simultaneously present for the disease to occur. The effect of the disease can be reduced by the reduction of any factor. The 2 factors that can be most practically ameliorated to control phytophthora root rot in the nursery and Christmas tree plantings are elimination or significant reduction of the fungus (primarily in nursery and transplant beds) and selection of nursery and field planting sites that are unfavorable to the fungus.

Selections and treatments of Fraser fir nursery, seedling, transplant bed, and field planting sites are very important in maintaining phytophthora root rot at tolerable levels. All nursery seedbeds and transplant beds should be fumigated with a soil fumigant comparable to MC-33 (methyl bromide, 67%; chloropicrin, 33%) before seedbed sowing and/or transplanting. Nursery, transplant beds, and Christmas tree plantation sites should be selected that are favorable for Fraser fir survival and growth and unfavorable for disease development. Selected sites should have well-drained soils without excessive surface or subsurface water accumulation. Low areas or "pocket" depressions are also favorable areas for disease development and consequently should be avoided in site selection.

Address correspondence to: Donald Rogers, North Carolina Department of Environment and Natural Resources, Division of Forest Resources, 1616 Mail Service Center, Raleigh, NC 27699-1616; e-mail: » don_rogers@mail.enr.state.nc.us «

References

Campbell WA. 1971. Personal communication. Athens, GA: University of Georgia.

Cooley SJ, Hamm PB, Hansen EM. 1985. Management guide to phytophthora root rot in bareroot conifer nurseries of the Pacific Northwest. Portland OR: USDA Forest Service, Pacific Northwest Region. 14 p.

Grand LF, Suggs EG, Lapp NA. 1973. Phytophthora root rot of Fraser Fir. Second International Congress of Plant Pathology [abstr. 0690].

Kuhlman EG, Hendrix FF. 1963. Phytophthora root rot of Fraser fir. Plant Disease Reporter 47(6): 552-553.

Kuhlman EG, Grand LF, Hansen EM. 1989. Phytophthora root rot of conifers. In: Cordell CE and others, eds. Forest nursery pests. Agric. Handbk. 680. Washington, DC: USDA Forest Service: 60-61.

Growth of Root-Pruned Seedlings in a Thermally Impacted Area of South Carolina

Evaden F. Brantley and William H. Conner

Watershed coordinator, Weeks Bay Watershed Project, Fairhope, Alabama, and professor, Clemson University, Baruch Institute of Coastal Ecology and Forest Science, Georgetown, South Carolina

Flooding of Pen Branch delta on the Department of Energy's Savannah River Site near Aiken, SC, by thermal effluents from 1954-1989 resulted in the death of most existing vegetation, with little re-establishment of desirable tree species since hot water discharges ceased. Re-establishment of desirable tree species may require planting. Four habitat types in the delta were identified for planting: cleared (grass cut), grass, willow, and muck. Species chosen for planting in this study were baldcypress (Taxodium distichum (L.) *Rich.), water tupelo* (Nyssa aquatica L.), *swamp blackgum* (Nyssa sylvatica *var.* biflora *(Walt.) Sarg.), and green ash* (Fraxinus pennsylvanica *Marsh.). Roots of seedlings were pruned to facilitate planting under wet conditions and to compare growth responses to seedlings with intact roots. Samples were collected at 0, 4, 7, and 14 months to determine differences in height growth and in stem and root biomass. Differences between pruned and non-pruned seedlings were variable depending on the species and area in which they were planted, but moderate pruning of roots was not detrimental to seedling growth and establishment and represents a quick and easy method of planting flooded sites.* Tree Planter's Notes 48(3/4): 76-80; 1997.

Swamp forests in the Pen Branch delta area on the U.S. Department of Energy's Savannah River Site near Aiken, SC, originally consisted of a closed canopy dominated by baldcypress *(Taxodium distichum* (L.) Rich.) and water tupelo *(Nyssa aquatica* L.). From 1954 to 1989, thermal effluents—water temperatures during times of release from nuclear reactor cooling towers ranged well over 50 °C (or 122 °F)—were discharged into the delta. High water temperatures combined with increased water levels, increased siltation rates, and anthropogenic flooding events asynchronous with natural events were considered to be responsible for the death of most of the existing vegetation on the delta (Sharitz and others 1974, 1990). Severe canopy loss occurred within 152 ha (376 ac) of swamp (alike and others 1994).

Muzika and others (1987) theorized that the restoration of a forest similar to predisturbance conditions in thermally impacted stream systems was unlikely. The re-establishment of baldcypress, water tupelo, swamp blackgum *(Nyssa sylvatica* var. *biflora* (Walt.) Sarg.), and other flood-tolerant species that were once found in the Savannah River swamp is also limited by inappropriate environmental conditions and seed dispersal problems (Sherrod and others 1980). Limited re-establishment of some flood-tolerant hardwoods on the delta was also attributed to limited seed availability because few, if any, parent trees remained following thermal discharge (Dunn and Sharitz 1987; Scott and others 1985; Sharitz and Lee 1985; Sherrod and others 1980).

Hydrology is not only important for seed dispersal (Schneider and Sharitz 1988) but also affects seedling establishment and growth. The construction of upstream dams on the Savannah River is responsible for changes in the natural flooding pattern of the delta (Sharitz and others 1990, Sharitz and Lee 1985). The natural pattern of winter flooding followed by low flow during the growing season gives seeds an opportunity to germinate. Although baldcypress and water tupelo seeds are dispersed by water, the seeds require aerobic conditions for germination and will not germinate when submerged in water (Mattoon 1916). The lack of open, moist microsites that would provide a chance for seeds to become established, allowing seedling growth without the threat of overtopping flood waters, may be attributed to anthropogenically altered hydrology of the Savannah River (Sharitz and Lee 1985).

Without natural seed sources and changes to natural seasonal flood events, recovery to former conditions may take many years without active restoration efforts. Regeneration of flood-tolerant wetland species is now possible because the reactors are inactive. Two planting strategies may improve seedling growth and survival as well as simplify the actual process of planting:

- moderate pruning of the roots to ease planting in mucky substrates where planting holes are difficult to keep open
- manipulation of the planting area such as removal of competition

Materials and Methods

The Savannah River Site, located near Aiken, South Carolina, is a 750-km^2 (290-mi^2) tract of land bordered by 37 km (23 mi) of the Savannah River along its southwestern boundary (Sharitz and others 1974). It is the property of the United States Government and is managed by the U.S. Department of Energy. The Pen Branch delta is fed by Pen Branch Creek, which enters the swamp about 5 km (3.1 mi) from the river and flows southeastward. The delta is characterized by shallow, slowly moving water that covers the experimental area year-round.

Within the Pen Branch delta, 4 habitat types were identified for planting: cleared, grass, willow, and muck. All vegetation in the cleared area was removed using a weed eater in late January 1994, while the grass area was left uncleared. The willow area consists of an impinging canopy of black willow *(Salix nigra* L.). The muck area is characterized by less grass competition and deeper surface water than the other plots. All seedlings in the 4 areas were subject to standing water conditions and competition from surrounding herbaceous vegetation.

Two 12- x 12-m (39.4- X 39.4-ft) blocks were established in each of the areas in January 1994. Each block had 4 randomly assigned plots measuring 3 x 12 m (9.8 x 39.4 ft) containing a single species planted on a 0.6 m x 0.6 m spacing. Species chosen for planting were baldcypress, water tupelo, swamp blackgum, and green ash *(Fraxinus pennsylvanica* Marsh.). One-year-old seedlings were obtained from the USDA Forest Service at the Savannah River Site. Before planting, the seedlings were divided into 2 groups. The lateral roots of 1 group of seedlings were pruned to approximately 2.5 cm (1 in) and the taproot pruned to 20 cm (7.9 in) using anvil-style garden clippers. The second group was left unpruned. Pruned seedlings were planted by holding the seedling at the root collar and pushing them into the soil. Unpruned plants were planted using a shovel. Planting occurred the last week of February—first week of March 1994.

Height of each seedling was recorded after planting was completed. Seedlings that had pruned roots (P) and those seedlings whose roots were not pruned (NP) were harvested in May and August 1994 and in March 1995. Five root-pruned and 5 non-root-pruned seedlings of each species were harvested from each plot at each sample date. Root collar diameter and height of harvested seedlings from root collar to terminal bud were measured and seedlings were separated into root and stem components. Each sample was dried at 80 °C (176 °C) for 48 hours and weighed.

During the August 1994 harvest, light quality and quantity measurements were taken within 2 hours of solar noon (to ensure maximum sunlight) with a Licor LI-1800 portable spectroradiometer. Photosynthetically active radiation (PAR) and the red-to-far red ratio (R:FR) were computed. In each plot, 8 different locations were measured at 2 heights: low = 60 cm (2.36 in) and high = 115 cm (45.3 in). Also, the amount and type of competing vegetation in each plot were analyzed in a biomass survey (August 1994). A randomly selected 0.25-m^2 (.27-ft^2) area in the root-pruned and non-root-pruned treatment for each species in each plot was clipped and the vegetation identified, dried at 80 °C (176 °F) for 48 hours, and weighed.

Differences due to root pruning treatment were determined using ANOVA. Significance was at the 0.05 level. Variables analyzed included diameter of root collar, height from root collar to terminal bud of seedling, dry root weight, and dry stem weight.

Results

Seedling growth, There were few significant differences between pruned and non-pruned seedlings at either harvest date in any of the 4 areas. Therefore, only end-of-the-year values are discussed (table 1). Baldcypress root-pruned seedlings had significantly greater diameters (11.9 vs. 9.4 mm) and stem biomass (7.9 vs. 4.3 g) in the cleared area than did non-pruned seedlings. Root biomass of green ash seedlings in the willow area was significantly less than non-pruned seedlings (24.4 vs. 34.2 g). Root-pruned seedlings of water tupelo in the muck and willow areas were significantly shorter (74.1 vs. 80.8 cm and 79.0 vs. 99.1 cm, respectively) than non-pruned seedlings. Other than these differences, there was no definite pattern *of* pruned seedlings being greater or less in diameter, height, root biomass, or stem biomass after 1 year in the field (table 1).

Competition and light. Eight different genera were identified as competing vegetation: *Scirpus cyperinus* (L.) Kunth, *Boehermia cylindrica* (L.) Schwartz, *Polygon um* spp., *Salix* spp., *Ludwigia* spp., *Panicum* spp., *Juncos* spp., and *Typha* spp. Although it depended on the plot as to which genus was the most abundant, *Scirpus* was usually the major component of biomass samples. On the other hand, *Ludwigia* and *Panicum* appeared most frequently in the samples even if they were only a small portion of the total sample weight. Competing vegetation biomass differences between areas are presented in figure 1. By the end of the summer, herbaceous vegetation was taller than planted seedlings.

There was no significant difference between areas for variables measured except for PAR measured at the upper level (115 cm). The cleared area mean was significantly different $(P < 0.05)$ than the willow area mean according to the Ryan-Einot-Gabriel-Welsch multiple F-test for the upper level PAR. Both levels (115 and 60 cm) of R:FR as well as the low level of PAR were not significantly different between these areas.

The level of competition measured in *each* plot (none, light, or dense competition) may help explain the lack of significance in light measurements. Biomass of competi-

Table 1—*Diameter, height, root biomass, and stem biomass of root-pruned (P) and non-pruned (NP) seedlings after 1 year*

Area & treatment	Diameter (mm)	Root height (cm)	Stem biomass (g)	biomass (g)
Baldcypress				
cleared, P	11.9 (0.8)*	70.7 (4.1)	7.9 (1.4)	7.9 (1.6)*
cleared, NP	9.4 (0.6)	66.1 (3.8)	5.4 (1.0)	4.3 (0.6)
grass, P	13.2 (0.9)	75.0 (4.1)	9.0 (1.5)	9.3 (1.1)
grass, NP	13.3 (1.2)	77.9 (3.4)	10.8 (2.1)	10.5 (1.7)
muck, P	12.6 (0.9)	71.6 (8.1)	6.8 (0.7)	9.9 (2.3)
muck, NP	12.0 (0.8)	75.5 (3.7)	8.3 (1.7)	8.8 (1.4)
willow, P	11.1 (0.7)	74.2 (4.3)	6.5 (0.9)	6.9 (0.9)
willow, NP	12.0 (0.7)	85.4 (3.9)	7.6 (1.1)	7.3 (0.7)
Green ash				
cleared, P	16.7 (1.2)	107.4 (6.2)	18.4 (3.3)	33.0 (5.1)
cleared, NP	16.6 (1.1)	117.0 (6.4)	26.7 (3.8)	36.7 (6.2)
grass, P	16.1 (1.3)	100.3 (8.3)	19.7 (3.9)	33.6 (8.5)
grass, NP	16.6 (1.0)	109.9 (5.1)	27.8 (4.8)	37.3 (6.2
muck, P	17.9 (1.3)	121.1 (4.4)	17.5 (2.6)	45.5 (7.0)
muck, NP	16.4 (1.1)	113.7 (5.3)	15.6 (2.4)	34.0 (5.3)
willow, P	19.5 (1.0)	138.8 (9.5)	24.4 (2.2)*	54.0 (6.6)
willow, NP	21.3 (1.1)	129.6 (7.7)	34.2 (3.2)	57.4 (6.5)
Swamp blackgum				
cleared, P	14.4 (0.6)	67.7 (6.8)	7.6 (1.0)	10.0 (1.8)
cleared, NP	13.0 (0.4)	80.7 (4.7)	8.7 (0.9)	11.3 (0.9)
grass, P	12.0 (0.3)	73.9 (5.9)	4.2 (0.5)	8.7 (0.8)
grass, NP	12.5 (1.1)	64.4 (6.2)	5.6 (0.8)	7.9 (1.5)
muck, P	15.0 (1.0)	80.9 (6.3)	6.2 (0.9)	13.1 (2.0)
muck, NP	12.7 (1.3)	75.4 (7.8)	7.2 (2.1)	9.0 (1.0)
willow, P	14.0 (0.7)	90.0 (7.7)	5.8 (0.5)	13.0 (0.7)
willow, NP	13.1 (0.9)	87.0 (6.9)	6.8 (1.2)	10.8 (1.3)
Water tupelo				
cleared, P	11.4 (0.4)	76.7 (1.2)	5.1 (0.8)	8.1 (0.8)
cleared, NP	12.3 (0.7)	78.4 (2.9)	6.9 (1.2)	8.6 (1.0)
grass, P	13.1 (0.8)	75.8 (3.0)	7.1 (0.9)	9.7 (1.2)
grass, NP	12.4 (0.5)	70.6 (3.4)	8.5 (1.0)	9.8 (0.9)
muck, P	13.4 (0.6)	74.1 (2.3)*	5.2 (0.5)	9.4 (0.8)
muck, NP	15.0 (1.2)	80.8 (2.0)	8.9 (1.7)	12.0 (1.8)
willow, P	13.5 (0.8)	79.0 (4.4)*	6.9 (1.1)	11.1 (1.2)
willow, NP	14.5 (1.0)	99.1 (6.3)	8.5 (1.2)	13.5 (1.6)

Note: Number in parentheses represents 1 standard error; * = a significant difference between root treatments within an area at the P = 0.05 level; 1 mm = .04 inches; 1 cm = .4 inches; 1 g = .04 ounces.

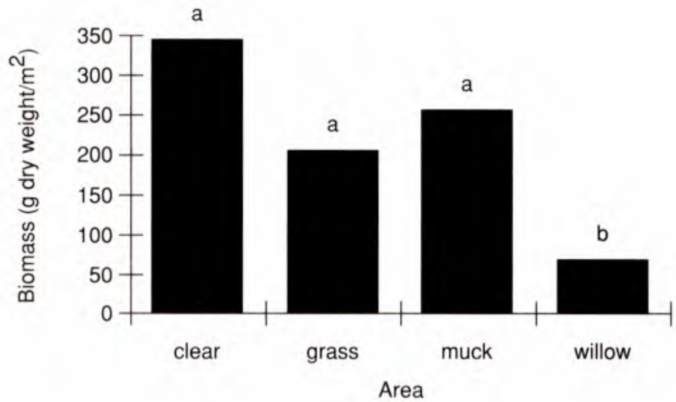


Figure 1—*Biomass of competing herbaceous vegetation in 4 areas planted with wetland species.*

tion differed by area as did light quantity (PAR) at the upper level. High-level PAR measurement differences explain differences in amounts of competition. The lower level PAR measurements indicated how the amount of light available to planted seedlings is affected by competition. Herbaceous biomass and PAR were related (figure 2).

A relationship was apparent between R:FR and biomass for the cleared, muck, and grass area (figure 3). An increase in biomass was related to a decrease in the R:FR for these areas. The willow area R:FR was lower than other areas even though its biomass was not as great as the other areas due to the impinging vegetative canopy of *Salix* species, which filtered out most of the red light.

Discussion

Based on data from the U.S. Geological Survey, water depth was at or above the soil surface for most of the study period, with increased flooding during August 1994 and February and March of 1995. Flooding during the growing season has been shown to be detrimental to roots of some trees. Coutts and Nicoll (1990) reported that the roots of Sitka spruce *(Picea sitchensis* (Bong.) Carr.) subjected to waterlogging in the fall suffered substantial dieback. The reason given for the dieback and poor survival of the spruce was that roots were still active when flooded out of season (usual flooding occurs in the winter and so seedlings were affected detrimentally because they still required oxygen transport).

Root pruning to ease planting in the delta is probably not detrimental in that seedling survival and performance is more likely affected by herbivory, the level of competition, and the duration and depth of flooding events. Similar results were reported by Conner and Flynn (1989), who reported 3-year survival rates of 70%

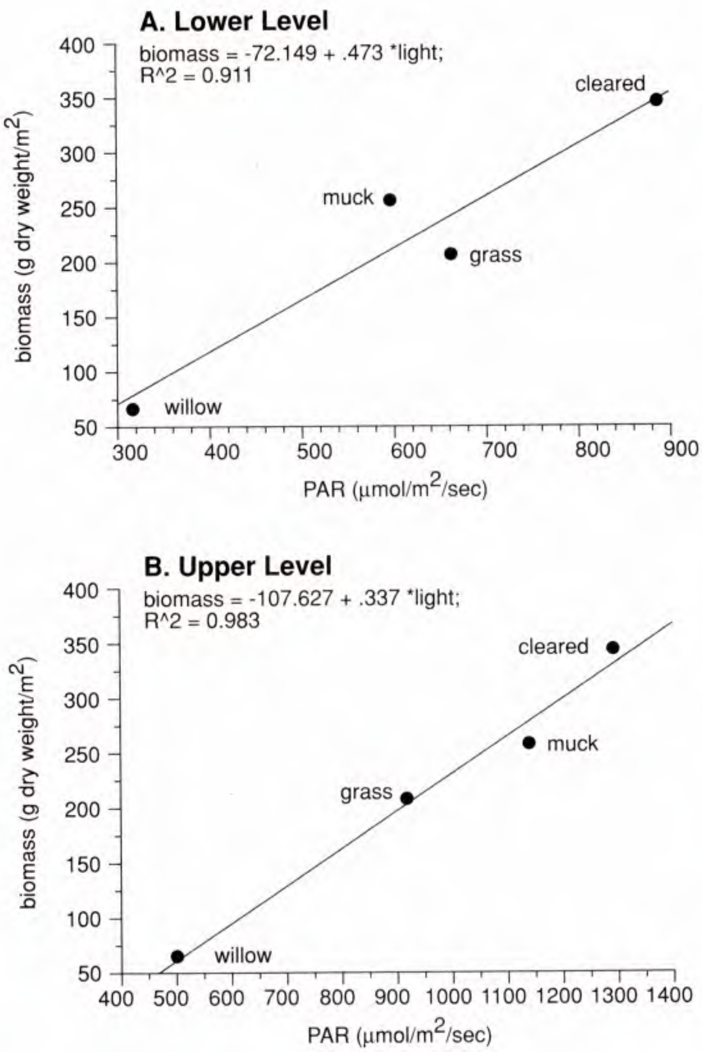


Figure 2—*Relationship between biomass of competition and photosynthetically active radiation (PAR) at lower* (A , *60 cm) and tipper* (B, *115 cm) levels.*

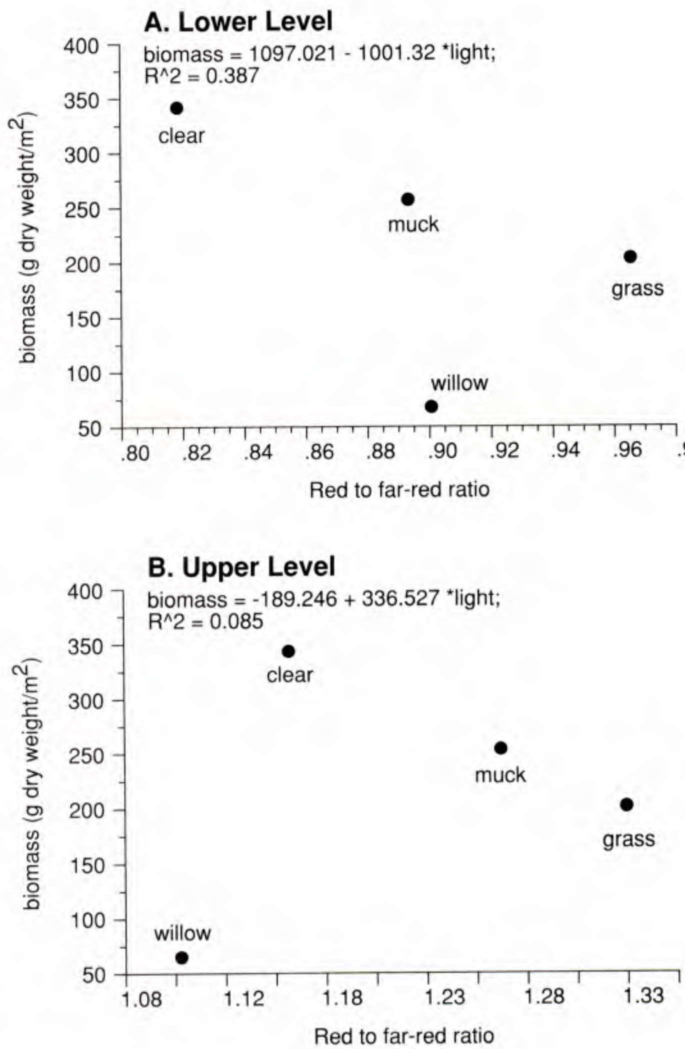


Figure 3—*Relationship between biomass of competition and red-to-far red light (R:FR) at lower* (A, *60 cm) and tipper (B, 115 cm) levels.*

for root-pruned baldcypress that were protected from herbivory. In another study, survival rates for root pruned baldcypress seedlings ranged from 80 to 100% after 2 years (Conner 1993). McLeod and others (1996) also concluded that moderate root pruning of seedlings to be planted in mucky substrates is successful for baldcypress and water tupelo. Furthermore, they suggested that the limiting factor for success is the relative flood tolerance of a species.

Differences between pruned and non-pruned seedlings were not great for any of the field harvest dates. The pruned ash seedlings allocated more biomass to above-ground parts than the other species at the final harvest date. Root systems of plants that are continuously flooded have low root—shoot ratios and shallow root systems (Megonigal and Day 1992). With a decrease in root—shoot ratio of seedlings in flooded conditions, the demand for oxygen is decreased and tolerance to waterlogged soils is increased (Keely 1979). Even with a shallow rooting zone, baldcypress is able to allocate more carbon to above-ground biomass when continuously flooded if ample nutrients are present (Megonigal and Day 1992).

All 4 species planted in this experiment had a decrease in the root—stem ratio from the first harvest (May 1994) to the second harvest (August 1994) regardless of root pruning treatment. The root—stem ratio held constant from the August 1994 harvest to the 1-year harvest in March 1995. After the initial dieback of roots under continuously flooded conditions, loss of main roots was compensated for by the formation of water roots. However, water roots did not increase the root-stem ratio. Increasing root mass was not necessary for growth of seedlings planted on Pen Branch delta as nutrients were readily available (judging from the healthy appearance of harvested seedlings) and water was not limited. It may be inferred that all 4 species in this experiment with pruned roots will establish and grow as well as those seedlings that are not pruned as long as nutrients and water are available. However, long-term studies are needed to determine if root-pruned seedlings will continue to perform as well as non-pruned seedlings.

Address correspondence to: Dr. William H. Conner, Baruch Institute of Coastal Ecology and Forest Science, Box 596, Georgetown, SC 29442; e-mail: » wconner@clemson.edu «

Acknowledgments

Funding came from the USDA Forest Service Center for Forested Wetlands Research, Charleston, SC. We give special thanks to Wayne Inabinette, Amy Rozelle, Linda Copeland, Martha McKevlin, Jeff Vernon, and Dave Gartner. This publication is contribution 97:02 from the Belle W. Baruch Forest Science Institute.

Literature Cited

Conner WH. 1993. Artificial regeneration of baldcypress in three South Carolina forested wetland areas after Hurricane Hugo. In: Brissette JC, ed. Proceedings, 7th Biennial Southern Silviculture Research Conference. Gen. Tech. Rep. SO-93. New Orleans: USDA Forest Service, Southern Forest Experiment Station: 185-188.

Conner WH, Flynn K. 1989. Growth and survival of baldcypress *(Taxodium distichum* [L.] Rich.) planted across a flooding gradient in a Louisiana bottomland forest. Wetlands 9: 207-217

Coutts MP, Nicoll BC. 1990. Waterlogging tolerance of roots of Sitka spruce clones and of strands from *Thelephora terrestris* mycorrhizas. Canadian Journal of Forest Research 20: 1894-1899.

Dunn CP, Sharitz RR. 1987. Revegetation of a *Taxodium-Nyssa* forested wetland following complete vegetation destruction. Vegetatio 72: 151 157.

Keely JE. 1979. Population differentiation along a flood frequency gradient: physiological adaptations to flooding in *Nyssa sylvatica.* Ecological Monographs 49(1): 89-108.

Mattoon WR. 1916. Water requirements and growth of young cypress. Proceedings of the Society of American Foresters 11: 192-197.

McLeod KW, Reed MR, Ciravolo TG. 1996. Reforesting a damaged stream delta. Land and Water 40(4): 11-13.

Megonigal JP, Day FP. 1992. Effects of flooding on root and shoot production of bald cypress in large experimental enclosures. Ecology 73(4): 1182-1193.

Muzika RM, Gladden JB, Haddock JD. 1987. Structural and functional aspect of succession in southeastern floodplain forests following a major disturbance. American Midland Naturalist 117: 10-16.

Rozelle AA. 1996. Use of morphological and physiological traits to assess seedling response to flooding of four wetland tree species [MSci thesis]. Clemson, SC: Clemson University.

Schneider RL, Sharitz RR. 1988. Hydrochory and regeneration in a bald cypress water tupelo swamp forest. Ecology 69: 1055-1063.

Scott ML, Sharitz RR, Lee LC. 1985. Disturbance in a cypress-tupelo wetland: an interaction between thermal loading and hydrology. Wetlands 5: 53-68.

Sharitz RR, Lee LC. 1985. Limits on regeneration processes in southeastern riverine wetlands. In: Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. Gen. Tech. Rep. RM-120. Ft. Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station: 139-160.

Sharitz RR, Gibbons JW, Gause SC. 1974. Impact of production-reactor effluents on vegetation in a southeastern swamp forest. In: Gibbons JW, Sharitz RR, eds. Thermal Ecology. AEC Symposium Series (Conf-730505): 356-362.

Sharitz RR, Schneider RL, Lee LC. 1990. Composition and regeneration of a disturbed river flood plain forest in South Carolina. In: Gosselink JG, Lee LC, Muir TA, eds. Ecological processes and cumulative impacts: illustrated by bottomland hardwood wetland ecosystems. Chelsea, MI: Lewis Publishers: 195-218

Sherrod C Jr, Somers DE, McLeod KW. 1980. Potential for baldcypress establishment in thermally altered streams. Journal of Thermal Biology 5: 107-111.

Wike LD, Shipley RW, Bowers JA, Bryan AL, Cummins CL, Del Carmen BR, Friday GP, Irwin JE, Mackey HE Jr, Mayer JJ, Nelson EA, Paller MH, Rogers VA, Specht WL, Wilde EW. 1994. SRS ecology: environmental information document. WSRC-TR-93-496. Aiken, SC: Westinghouse Savannah River Co.

Osage-orange: A Pioneering Stewardship Species

James P. Barnett and James D. Burton

USDA Forest Service, Southern Research Station, Pineville, Louisiana

Osage-orange, a small tree with a number of unique characteristics, played an important role in the settlement of the prairies. One of the more significant contributions was in the use of the species for hedges. The thorny, low-spreading crowns provided excellent fencing when properly maintained. This use, plus its later used in shelterbelts, exert a continuing influence on the environment of the Middle West and the Great Plains. Osage-orange grows well on a wide range of sites and is a good candidate for planting on mine spoils and other disturbed sites. A thornless variety does well in difficult urban conditions. Tree Planters' Notes 48(3/4): 81-86; 1997.

There have been a number of the stewardship program initiatives in the last few years that have been designed to encourage landowners and managers to practice management that stresses reforestation and a number of other land conservation issues. It is interesting to note that, well over 100 years ago, a tree species that is little considered today played an important role in converting the prairies into productive agricultural land communities. Although most of the trees that markedly influenced the early settlement and economy of the United States were harvested for export, ship building, and other specialized needs, the Osage-orange—Maclura *pomifera* (Raf.) Schneid.—was never used for lumber or fiber, but it still influenced the early development of the United States. The wood of the Osage-orange tree was used by Native Americans for their bows and arrows, and the trees were well known for their large, plum-, apple-, or orange-type fruit.

As settlers moved into areas where range cattle and sheep were allowed free rein, they needed to fence out these animals in order to begin farming. Because not enough wood was available on the prairie grasslands to build fences, the early settlers of the area had to rely on planted hedges, and Osage-orange trees proved to be excellent for this role. Together with the railroad, the steel plow, and the water-pumping windmill, the Osage-orange hedge (along with the later development of barbed wire) helped to make possible the agricultural settlement of the grasslands and sustained its productivity.

Early Species Distribution and Common Names

The wood of the Osage-orange tree was used by Native Americans for their bows and arrows and the tree was well known for its large fruit of the plum, apple, or orange type. The Osage-orange, called *bois d'arc* (bowwood) by the French explorers of interior North America, may be responsible for the mountains in Arkansas and Missouri being named "Ozark" (Steyermark 1963). A French trading post, established in that area in the 1700's, was named *Aux Arc* from the bois d'arc trees that were abundant nearby. The English name "Ozark" is probably a corruption of the French *Aux Arc*.

Thomas Jefferson advocated exploration of the western two-thirds of North America as early as 1783. After he became President, he sent 3 expeditions west: the M. Lewis and W. Clark expedition started up the Missouri River in May 1804; the W. Dunbar and G. Hunter expedition traveled up the Red, Black, and Ouachita Rivers into Arkansas in October 1804; and the T. Freeman and P. Curtis expedition traveled up the Red River in May 1806. Each of these 3 American exploratory parties traveled northwest via a major river and discovered a number to new plants, including the Osage-orange. In each instance, the Osage-orange trees they saw were not naturally regenerated but had been planted. The report of the Freeman-Curtis expedition contains what may be the first botanical description of the Osage-orange to be printed in English (McKelvey 1995).

The Osage-orange tree that Freeman and Curtis saw was within a mile of the town of Natchitoches, LA. It was about 30 feet (9.7 m) tall, with a bole 7 to 8 feet (2 to 2.5 m) in circumference, and was bearing fruit. Similar trees, of natural origin, were said to be abundant along a nearby creek also called Bois d'Arc. Curtis believed that this tree represented a new genus, but he did not assign a name to it. Meriwether Lewis wrote to President Jefferson in March 1804 that he was sending some cuttings of the "Osage plum," or "Osage apple," for propagation. He explained that the "Osage apple" was native to the interior of North America and that the cuttings were from the garden of Pierre Chouteau in St. Louis, MO. Chouteau had obtained young plants at the Great Osage Village from a Native American of the

Osage Nation who said that he got them about 300 miles west of the village (McKelvey 1955), which was situated near the present-day town of Nevada, MO.

A British explorer, John Bradbury, traveled up the Missouri River in 1811 to the Arikara villages in what is now South Dakota. He described one of the bows used by the Arikara as being made from wood called *bois d'arc*. He felt that the wood came from the same tree species that Lewis had found in the garden of Pierre Chouteau in St. Louis, and said that the Arikara hunters called the tree "Osage-orange" (Bradbury 1817).

Josiah Gregg reported in 1844: "In many of the rich bottoms from the Canadian to Red River... is found the celebrated *bois d'arc*... usually corrupted in pronunciation to *bowdark*... *It* is one of the hardest, firmest, and most durable of timbers, and is much used by wagon-makers and millwrights, as well as by the wild Indians, who make bows of the younger growths" (Gregg 1844). Most authorities believe that the natural range of the species within historic times was confined to the Red River drainage of Texas, Oklahoma, and Arkansas and to the blackland prairies, post oak savannas, and Chisos Mountains of Texas (Burton 1973) (figure 1). Other authors include portions of Missouri, most of eastern Oklahoma, northwestern Louisiana (Morton 1963), and parts of Kansas (Britton 1908) in its natural range. The Osage-orange may be found in forests but usually is not abundant (Ajilvsgi 1979). These conflicting reports may be accounted for in part by disjunct, still-changing distributions of the species.

Figure 1 — *Map of the known natural range of Osage-orange in historical times. The range has been extended greatly by planting.*

Characteristics of the Osage-orange Tree

The Osage-orange is a short tree with a massive bole and a thorny, low-hanging, wide-spreading crown (figure 2). It averages about 30 feet (9.7 m) in height at maturity, but this is extremely variable (Harrar and Harrar 1962). Isolated trees on deep, fertile soils with ample moisture may grow to a height of 70 feet (21 m). Branchlets in full sunlight on young trees bear sharp, stout thorns (figure 3), and most trees are so well "armed" that it is difficult to measure or even approach them. As trees mature, new twigs high in the crown tend to be thornless, but the thorny lower branches are retained. The heartwood is very hard, heavy, strong, tough, resistant to abrasion, extremely durable in contact with the soil and immune to termites; it will shrink very little in drying. However, it is difficult to glue or machine and requires extraordinary care to prevent splitting.

The Osage-orange is easily propagated from seeds or cuttings (Williams and Hanks 1976), is characteristically deep rooted (Bunger and Thompson 1938), but thrives in shallow soils, tolerates alkaline soils, and is one of the most drought-enduring tree species in North America (Read 1964). Natural regeneration of Osage-orange is most abundant on overgrazed grasslands, around abandoned farmsteads, in ravines, and on disturbed sites.

The ripe fruit, 3 to 6 inches (7 to 15 cm) in diameter and often more than 2 pounds (.9 kg) in weight, resembles an orange (figure 3b). As soon as it ripens, the fruit falls to the ground and may be eaten by mammals. Some authors assert that it is inedible or unpalatable and is shunned by native wildlife (Robinson 1961); however, other writers state that fallen fruits are eaten by fox squirrels, raccoons, opossums, and blacktail deer. They also state that the seeds are eaten by squirrels, bobwhite quail, crossbills, and other birds (Harmon 1948; Vines 1960).

The Need for Hedges on the Prairies

The prairie lands of the Midwest and the Great Plains were acutely deficient in wood, water, and field stone. Wood shortage was second only to water shortage in retarding settlement of the Great Plains by farmers (McCallum and McCallum 1965). Actual availability of wood was reduced further by the use of rail fences and the pattern of settlement. The first English-speaking settlers took possession of the isolated pockets and stream-side strips of timber, using most of the wood to con-

Figure 2— *Mature Osage-orange trees typically have short, curved boles and low, widespreading crowns. Even in closed stands on good sites, less than half the stems contain a straight log that is 10 feet (3 m) long, sound, and free of shake. This open-grown tree stood in a pasture near Bastrop, LA, in March 1971. (Photograph by James D. Burton.)*

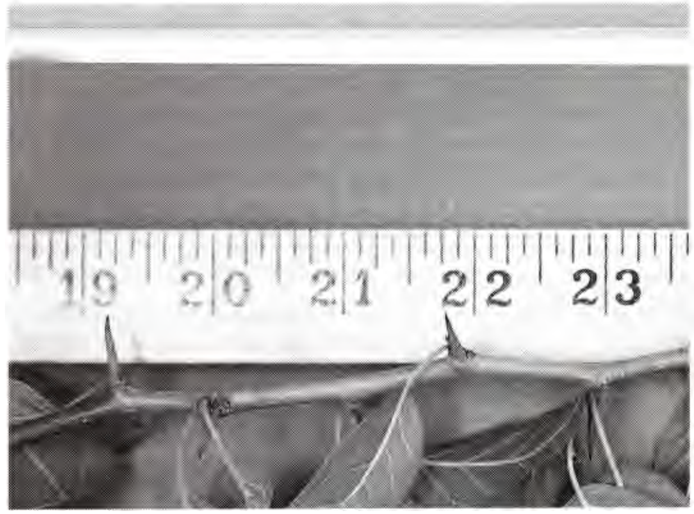


Figure 3—*Thorns occur in the leaf axils on fast-growing 1-year-old shoots in full sunlight (scale in inches). (Photograph by James D. Burton.)*

struct rail fences and temporary dwellings. Immigrants arriving later found no available timber. Unregulated grazing of the public lands by herds of cattle ar feral hogs was widespread (Lewis 1941). Any land not enclosed was treated as commons, regardless of the ownership. The fencing problem of the 19th century was general and traumatic; its severity and the depth of feelings it engendered are difficult for late 20th-century Americans to imagine.

Farmers always were the primary fence builders; without fences, crop farming was impossible. Although no part of the United States was free of the vexing problem of fencing, the need for fences was most severe in the prairie regions because of free-roaming cattle and hogs. The cost of fencing was greater than the selling value of the land, and fence maintenance required about one-twelfth of the farmer's annual labor (Danhof 1944).

On the prairies, the most common type of fence was the board fence, made of pine timber from Wisconsin, Minnesota, and Michigan; the second most common was the mud fence, with an earthen wall about 3.5 feet (1 m) high, frequently augmented by one or more rails. A great variety of other temporary barriers were improvised, such as ditch-and-bank fences, sod fences, and hurdle fences (Meredith 1951), but none adequately protected the farms of the settlers. In the Edwards Plateau of Texas, many fields were protected by stone walls, which required a tremendous amount of labor to build (Hayter 1939).

Smooth wire was used as fencing by many farmers, but it was made of iron, which rusted rapidly and was weak. However, there was still no wood for posts. In spite of repeated failures, farmers continued to try wire fences, but they also began to experiment with hedges.

Landowners in the East planted hedges as early as 1800 (Danhof 1944). The first plants used for hedges on a large scale were the hawthorns *(Crataegus* spp.), because they made notably successful fences on farms in England. In some United States localities, hawthorns and honeylocusts *(Gleditsia* spp.) made effective fences, but throughout most of the country south of latitude 40° N, Osage-orange was the overwhelming favorite.

Uses of Osage-orange

Development of hedges, The Osage-orange hedge was vigorously promoted, for different reasons, beginning in January 1841 by John S. Wright, editor of the Chicago periodical, "Prairie Farmer," and in 1847 by Professor Jonathan B. Turner of Illinois College, Jacksonville, IL. Wright was interested in scientific agriculture as the basis for an enlarged general economy. Turner wanted Illinois to establish public schools as the basis for an informed, active democracy, and only in sedentary agricultural communities could the population density ever be great enough for a public school system to be established (Carriel 1961). Both men were very convincing, and the resulting movement was described by contemporary observers as a "hedge mania." The Osage-orange hedge was endorsed by several agricultural societies and received legislative approval in some states as a legal fence (Danhof 1944).

It was also the only fence the average farmer could afford.

A thriving new industry came into existence. Nurseries in the South, principally Arkansas and Texas, shipped Osage-orange plants and seeds northward. Raising plants in one region to be transplanted several hundred miles away was an innovation (Danhof 1944). In 1868, the Osage-orange seed trade in Illinois, Indiana, and Ohio totaled 18,000 bushels (634,000 liters). The price of seeds ranged from $8/bu in the 1840's to $50 in the 1870's ($5/1b in Illinois).

Entrepreneurs offered to plant and care for hedges at $100/mile; this was much cheaper than the cost of any other kind of fence. In 1854, the Illinois Central Railroad began to hedge the right-of-way from Chicago to Cairo (Danhof 1944). Soon, other railroads began to hedge their rights-of-way. Land speculators planted hedges to increase the value of their land. In the spring of 1855, 9,000 miles (14,400 km) of Osage-orange hedges were planted. Farmers in Kansas planted 39,400 miles (63,000 km) of single-row hedges between the middle of the 19th and 20th centuries (Stoeckeler and Williams 1949). Osage-orange hedges were also planted in the East in many localities where wood had become expensive.

Osage-orange hedges flourished and endured. They not only fenced fields, protected crops, and restrained livestock, they also exerted more permanent effects upon the character and appearance of the landscape and the development of communities on the prairies. Many hundreds of miles of hedges, particularly in Missouri, Kansas, and Nebraska, remained well into the 1950's. Many Osage-orange hedges still exist untended today, a rectilinear pattern of artificial-looking, squatty trees with spreading crowns and shiny yellowish leaves on long, thorny branches (figure 4).

Living fences. As a living fence, Osage-orange was a notable success when well established and properly cared for. Although failures were more frequent than successes, it was still the best option available at the time. Well-informed proponents of hedging had from the beginning emphasized the care needed: site preparation, viable planting stock, proper planting, an artificial fence to protect the young Osage-orange hedge during the first 3 to 4 years, protection from prairie fires, cultivation for 3 years, and trimming every year. Cutting back to 5- to 6-foot (1.5- to 1.8-m) height forced additional branch development at the base of the plant. The long-tough, thorny branches were then interwoven to make an impenetrable wall, and all invading woody plants, principally hackberry *(Celtis* spp.), were removed. The width of the hedge usually was maintained at about 4 feet at the base and 2 to 3 feet at the top. Thus trimmed, a hedge excluded livestock but did not obstruct the view of the landscape.

Figure 4—*Ripe fruit (scale in inches). (Photograph by James D. Burton.)*

Farmers customarily clearcut the hedge every 10 to 16 years, obtaining about 400 posts/mile (1.6 km) of hedge. The stumps resprouted to grow new fences, and slash was piled over the stumps to protect new sprouts from browsing (particularly by sheep). The sprouts grew rapidly and soon formed a new hedge. Many prairie farmers had mixed feelings about their hedges, and the severe winters of 1855-56 and 1856-57 resulted in widespread damage to hedges in Ohio and Illinois. In 1856, the contractors abandoned the Chicago-to-Cairo fence of the Illinois Central Railroad (Danhof 1944).

Barbed wire was invented and developed independently and almost simultaneously by several different men, possibily with the mental image of the Osage-orange's thorny branches (figure 3) hanging on a smooth wire fence. These inventors were not northeastern industrialists—they were midwestern prairie farmers. When barbed wire became generally available (about 1880), the boom in the production of Osage-

Figure 5—*Typical bole of an Osage-orange tree showing crookedness and defects common to the species. (Photograph by James D. Burton.)*

orange seeds and seedlings ended. However, barbed wire still required posts, which the Osage-orange hedges provided.

Regular care of most Osage-orange hedges ceased with the advent of barbed wire. The neglected hedge trees then grew tall and developed spreading crowns, and roads with hedges on both sides became tunnels. Farmers then began to destroy the hedges because they spread and occupied much space. This destruction proceeded slowly at first but accelerated in the 1950's, when bulldozers, previously used in World War II, became available.

Shelterbelt plantings. Windbreak plantings in the United States began long before the dust storms of the 1930's. The earliest English-speaking settlers in Kansas planted Osage-orange windbreaks as well as hedges (Barnes 1960).

A Great Plains Shelterbelt program was proposed by President Franklin D. Roosevelt as a means to control the runaway soil erosion and to provide early temporary economic relief from the Great Depression. Osage-orange figured prominently in the shelterbelts. In the southern and central Plains, south of the Platte River, Osage-orange was very successful; north of the Platte it suffered winter-kill. Along with bur oak *(Quercus macrocarpa* Michx.), Osage-orange survived better than any other broadleaf tree on upland sites. It was frequently planted in shrub rows but grew too tall for a shrub; it performed better where it could be used as a short tree (figure 5). The Osage-orange suffered less from insects and diseases than did most other species in the shelterbelt plantings.

Other uses. Osage-orange wood was in great demand for manufacturing rims, hubs, and spokes of wagon wheels in the Southwest, and the supply became scarce long before metal wheels replaced wooden ones. The rim of a wooden wheel is made of many segments called "felloes." Ten to twelve thousand wagons with Osage-orange wheel rims were being manufactured annually in the United States when a USDA Forest Service survey was made in 1911 (FPL1955). Only a small proportion of a typical Osage-orange log actually consists of sound, intact wood, but every piece of this wood was used. Pieces of wood too small to utilize as felloes were turned into insulator pins as a byproduct. The volume of Osage-orange wood used in the manufacture of felloes and insulator pins was about 20% of the annual cut.

Osage-orange hedges were planted in nearly all of the 48 conterminous states. These trees produced seeds abundantly and readily escaped from cultivation almost everywhere east of the Rocky Mountains and south of the Platte River and the Great Lakes, excluding the Appalachian Mountains.

For a time, the species was the basis of a domestic silk industry. Osage-orange belongs to the Mulberry family, and silkworms produced as much silk on Osage-orange leaves as on mulberry leaves in the United States, but the Osage-orange silk was said to be brittle, and the enterprise was not commercially successful (FPL 1955).

Osage-orange Today

Although the species contributed significantly to stabilizing and sustaining the agricultural economy of the prairie regions in the 19th and early 20th century, Osage-orange is relatively unimportant in agricultural economy of the United States today. Farmers on the Great Plains are still planting some single-row windbreaks, and trees have been used in reclamation plantings on strip-mined land (Ashby and Kolar 1977; Haywood and others 1993).

However, urban tree planters and landscape planners are using the Osage-orange, particularly the thornless, nonfruiting (male) line, because it is long lived, not too large, and seldom injured by ice or wind (Hightshoe 1978). Compared to other suitable trees, Osage-orange is rarely attacked by insects and diseases.

Many miles of Osage-orange hedges still stand today in the Middle West and the Great Plains. No estimate of the mileage is known. Untended for many years, these hedges have grown to about 30 feet (9 m) in height with long limbs. They form a prominent component of the prairie landscape and constitute an important part of environment for game and nongame birds and mammals. We hope that these hedges will be characteristic of mid-America for many years to come as symbols of Osage-orange's historical role in the early development of the Great Plains and in establishing a stewardship ethic that is a model for current times.

Address correspondence to: Jim Barnett, USDA Forest Service, Southern Research Station, 2500 Shreveport Highway, Pineville, LA 71360; e-mail: » jbarnett/srs_pineville@fs.fed.us «

Acknowledgments

A version of this article was previously published as: Burton JD, Barnett JP. 1995. Osage-orange: a small tree with a big role in developing the Plains. Res. Pap. 285. New Orleans: USDA Forest Service, Southern Forest Experiment Station. 8p.

Literature Cited

Ajilvsgi G. 1979. Wild flowers of the Big Thicket. College Station: Texas A&M University Press. 360 p.

Ashby WC, Kolar CA. 1977. A 30-year record of tree growth in strip mine plantings. Tree Planter's Notes 38: 18-21,31.

Barnes L. 1960. An editor looks at early-day Kansas. Kansas Historical Quarterly 26: 267-301.

Bradbury J. 1817. Travels in the interior of North America in the years 1809, 1810, 1811; including a description of Upper Louisiana, together with the States of Ohio, Kentucky, Indiana, and Tennessee, with Illinois and Western Territories, and containing remarks and observations useful to persons emigrating to these countries. Liverpool: Smith and Galvay. 346 p.

Britton NL. 1908. North American trees. New York: Henry Holt & Co.: 366-367.

Bunger MT, Thompson HJ. 1938. Root development as a factor in the success or failure of windbreak trees in the southern high plains. Journal of Forestry 36: 790-803.

Burton JD. 1973. Osage-orange: an American wood. FS-248. Washington, DC: USDA Forest Service. 7 p.

Carriel MT. 1961. The life of Jonathan Baldwin Turner. Urbana: University of Illinois Press: 61-63.

Danhof CH. 1944. The fencing problem in the eighteen-fifties. Agricultural History 18: 168-186.

FPL [USDA Forest Service, Forest Products Laboratory]. 1955. Wood handbook. Agric. Handbk. 72. Washington, DC: USDA Forest Service. 528 p.

Gregg J. 1844. Commerce of the prairies: or the journal of a Santa Fe Trader. New York: Henry G. Langley: Volume 1: 199.

Harmon WH. 1948. Hedgerows. American Forests 54: 448-449,480.

Harrar ES, Harrar GJ. 1962. Guide to the southern trees. 2 ed. New York: Dover: 256-259.

Haywood JD, Tiarks AE, Barnett JP. 1993. Survival and growth of trees and shrubs on different lignite minespoils in Louisiana. Tree Planters' Notes 44: 166-171.

Hayter E W. 1939. Barbed wire fencing: a prairie invention. Agriculture History 12:189-207.

Hightshoe GL. 1978. Native trees of urban and rural America: a planting design manual for environmental designers. Ames Iowa State University Research Foundation. 95 p.

Lewis L. 1941. John S. Wright, prophet of the prairies. Chicago: Prairie Farmer Publishing Company: 140,211.

McCallum HD, McCallum FT. 1965. The wire that fenced the West. Norman: University of Oklahoma Press: 7.

McKelvey SD. 1955. Botanical exploration of the Trans-Mississippi West, 1790-1850. Jamaica Plain, MA: Arnold Arboretum: 67.

Meredith M. 1951. The nomenclature of American pioneer fences. Southern Folklore Quarterly 15: 109-151.

Morton CV. 1963. Freeman and Curtis' account of the Red River Expedition of 1806, an overlooked publication of botanical interest. Journal of the Arnold Arboretum 48: 431-459.

Read RA. 1964. Tree windbreaks for the central Great Plains. Agric. Handbk. 250, Washington, DC: USDA Forest Service. 68 p.

Robinson GR. 1961. Osage-orange tree: ornamental and useful. Horticulture 39:425.

Steyermark JA. 1963. Flora of Missouri. Ames: Iowa State University Press: 563-564.

Stoeckeler JH, Williams RA. 1949. Windbreaks and shelterbelts. In: Stefferud A, ed. Trees: the yearbook of agriculture. Washington, DC: U.S. Department of Agriculture: 191-99.

Vines RA. 1960. Trees, shrubs, and woody vines of the Southwest. Austin: University of Texas Press. 1104 p.

Williams RE, Hanks SH. 1976. Hardwood nurserymen's guide. Agric. Handbk. 473. Washington, DC: USDA Forest Service. 798 p.

Instructions for Authors

Tree Planters' Notes is dedicated to the publication of technology transfer and research information relating to nursery propagation, harvesting, storage, and outplanting of trees, shrubs, and native plants for reforestation, restoration, and conservation. In addition, materials on tree improvement, seed orchards, seed harvest, storage, and preparation are topical for our readers. Please write to us if you have developed or successfully used a new piece of equipment; a new or improved nursery operation; a new technique or method for packing seedlings, improving seedling growth, or preparing sites; new techniques in applied tree planting, tree improvement, plantation culture, and other topics related to nurseries, tree improvement, and reforestation; or any other aspects of nursery operations (including computers) that you wish to share with other nursery managers.

For scientists and engineers working in nursery-related research, including plant physiology and pathology, seed technology, outplanting, habitat restoration, and tree improvement, we publish several sections of peer-reviewed, refereed papers— "Research Reports," "Research Reviews." These articles will be anonymously peer-reviewed by 2 outside referees. If you have a topic for a review that you would like to write about, please call and discuss your ideas. We also publish "Little-Known Classics," papers from regional and state newsletters and other publications that we believe are still pertinent today. You are welcome to submit candidates.

We also encourage you to consider writing for the "Comments" section. Our concept of this section is that it should be a place to publish opinions and ideas relating to the reforestation profession. We invite you to discuss ideas for commentaries you wish to write. The views expressed in the "Comments" section are solely those of the author(s) and do not necessarily reflect those of the *Tree Planters' Notes* editorial staff, the Forest Service, or the U.S. Department of Agriculture.

• • •

Send us one one hard copy of your article with EVERYTHING, including references, printed out DOUBLED-SPACED (except the bodies of tables, which may be single-spaced) plus a 3 ½-inch high-density disk (preferably IBM-PC-compatible, in WordPerfect for Windows or Microsoft Word). We also would find a Mac disk of any charts, graphs, and artwork very useful. If you can e-mail documents, we are happy to accept electronically submitted copies. If you have any questions, please call and discuss things.

Please photocopy and send along the filled-out manuscript submission form along with your manuscript. We will notify you of receipt of the manuscript and its acceptance. You will be sent page proofs that should be proofread carefully; return these promptly to Rebecca Nisley, 51 Mill Pond Road, Hamden, CT 06514; tel: 203-230-4304; FAX: 203-230-4315; e-mail: rnisley@ct2.nai.net

The article should be accompanied by a brief abstract (100 words or less) summarizing its conclusions. For research reports, we encourage the use of separate sections for Results and Discussion as well, and also a Conclusions section that summarizes the usefulness of the findings to practical nursery operations. References should be listed alphabetically by author(s) and cited in the text by author and date.

Follow the style of this issue. We follow the general style of the 1984 Government Printing Office Style Manual and the technical style of the Council of Biology Editor's sixth edition of the CBE Style Manual; for nomenclature of trees, we follow the Checklist of United States Trees, Agriculture Handbook 541, by Elbert L. Little, Jr. Use common names of

Subscriptions ($8 per year domestic, $10 per year foreign) are available from New Orders, Superintendent of Documents, PO Box 371954, Pittsburgh, PA 15250-7954. A subscription blank is available on the back cover. Please send address updates to Ms. Eula Emanuel, USDA FS, Office of Communications, Auditors Building 2C, PO Box 96090, Washington, DC 20090; tel: 202-205-0819 or e-mail: eemanuel/wo@fsfed.us

Printed on recycled paper.

trees in the title and in the text; at first mention in the abstract and in the text, provide the scientific name in parentheses. Binomials for long lists of trees may be presented in a table. Numeral values should be presented in both metric and U.S.-style units.

Send clear, glossy black and white photographs, original color slides (we will convert them to black and white prints), or black ink drawings and graphs (or computer files of charts).

Authors will be furnished with 5 copies of the issue in which their article appears; please feel free to make photocopies. Information in this publication is public property and may be reproduced without permission. We ask, however, that you include a credit line providing the name of the author(s) and the volume and issue of *Tree Planters' Notes.* There are no page charges.

Note: An updated and detailed version of these instructions will soon be available on our website: » http://willow.ncfes.umn.edu/snti/tpnlist.htm «