Silvicultural Practices and Costs in Coastal British Columbia: A Case Study

Sen Wang, G. Cornelis van Kooten, and Bill Wilson

*Forest Economist, Canadian Forest Service, Victoria, British Columbia, Canada,
Professor, Department of Economics, University of Victoria, Victoria, British Columbia, and
Director, Industry, Trade, and Economic Programs, Canadian Forest Service, Victoria, British Columbia, Canada*

In 1987, the Government of British Columbia transferred responsibility for basic silviculture from the Provincial Ministry of Forests to the major forest licensees, and the introduction and implementation of the Forest Practices Code in 1995 intensified forest company responsibilities for silvicultural activities. The highly prescriptive Forest Practices Code also dictates how silvicultural objectives of public forest lands are to be operationally delivered. In this paper, primary data on silvicultural practices and costs of a forest company operating in Coastal British Columbia are analyzed. Our findings indicate that, although British Columbia forest companies have accepted the legislated transfer of postharvest silvicultural obligations, public policy encourages companies to treat silviculture as a cost of doing business rather than an investment. Because of these institutional signals, forest companies seek to confine their operations to basic silviculture. Furthermore, silvicultural costs are positively correlated with the intensification of government regulations, particularly the Forest Practices Code. Finally, the research indicates that innovative approaches are required to efficiently deliver socially desirable silvicultural investments. Tree Planters' Notes *50(1): 50-57; 2003.*

In British Columbia (BC), more than *95%* of forest land is publicly owned. Before *1987,* the Provincial Government, as owner, was responsible for all postharvest silvicultural activities, including planting. Because of economic factors, the government amended forest land legislation and transferred responsibility for basic silviculture (getting trees to the free-to-grow stage) to the major forest companies, which hold timber-harvesting licenses on public forest lands. Then, in response to growing pressure from environmentalists and social interests, the BC Government took steps to reduce the environmental impacts of commercial timber operations. The most important step was the Forest Practices Code (BC *1994)* (hereafter, the Code), which passed into law in *1994* and came into effect in *1995.* The Code established a stratified set of legislative and administrative rulesregulations, standards, and field guides-that collectively govern public forest land practices. The Code stipulated that all regulations and standards were mandatory, whereas field guides provide recommended procedures, processes, targets, and evaluation criteria. Once inserted into forest management plans, prescriptions, and contracts, the field guides are interpreted as rules that are legally binding and subject to enforcement (Wang and van Kooten *2001).*

The rationale of the Code was to simplify institutional complexities by consolidating and updating regulations and guidelines, but its purpose was to establish mandatory requirements for forest practices and to set compliance and penalties. The Code brought about many positive changes in BC forest practices, such as spatially defined adjacency conditions, inter-temporally specified green-up requirements, and administratively mandated planning procedures. However, while the Code contributes to the protection of nontimber amenity values of the forest, as well as timber values, it significantly increases operating costs of forest companies (Thibodeau *1994;* McIntosh and others *1997).* For instance, a BC forest industry survey estimated that to comply with the Code, forest companies collectively generated nearly half a million sheets of planning materials in the 1st *2 y* following the introduction of the Code. The burden was not only felt by the industry, but also by the Province as more resources and staff time were required by the Ministry of Forests to process "an avalanche of information"(Gregory *1997).* Further, a comprehensive, social cost-benefit analysis of the Code, that included nonmarket values, indicated that society lost more than it gained (van Kooten and Bulte *2000).*

Prior to *1987,* the BC Forest Service directly hired workers to deliver the silvicultural activities, which were limited to seedling production and small-scale tree planting. With an expansion in the scale and scope of silvicultural operations, the government increasingly opted to use the emerging silvicultural contractors for financial and administrative reasons. Wang and others *(1998)* provide an account of the historical forces shaping the evolution of the BC silviculture sector.

While responsibility for silviculture was shifted to the private sector in *1987,* silvicultural practices further changed in response to newly adopted government policies, including a joint Federal-Provincial initiative to fund reforestation of a backlog of lands that had not been satisfactorily restocked (Thompson and others *1992).* The Code was subsequently designed to guide forest management in the light of sustainability principles and as a response to environmental and social pressures. From an industry perspective, however, it was the financial implications of these policy shifts that were important. Given the rising costs associated with meeting the various requirements of the Code, it is important to understand the structure, determinants, and actual levels of silvicultural costs.

Our objectives in this paper are to investigate trends in the changing structure and components of corporate silvicultural programs and costs in the decade after 1987, and to review the effect of the Code on silvicultural activities and costs. We gathered information from a case study of a forest company operating on the BC Coast (referred to as the Company). As a significant player, this company is seen to be reasonably representative of major timber-harvesting licensees in the coastal region with regard to silvicultural performance. We conducted in-person interviews, and reviewed and analyzed Company data on silvicultural activities from 1987 through 1996. We then used regression analyses to examine the link between government policy and silvicultural costs and performance. The effects of the Code on silvicultural activities and costs were analyzed by comparing costs before and after the Code went into effect. Finally, we discuss BC's silvicultural strategy in light of recent Provincial forest policy.

Company Profile

The Company is composed of several divisions that operate primarily on the BC Coast, and it has an allowable annual cut exceeding 3 million m^3 (1.27 billion board ft). In addition to some private forest land, it has timber cutting rights on public forest land in the form of tree farm licenses, timber licenses, and forest licenses (see Wang and van Kooten 2001 for a description of these tenures). A separate silviculture division exists at both the corporate and operations levels. In total, the Company has over 50 permanent silvicultural employees on staff. Each operation (also known as a woodlands division) typically has less than 10 silviculturalists, with 2 or 3 having registered professional forester status.

The silvicultural program of the Company consists of 3 components: planting, brushing and weeding, and regeneration surveying. Based on terminology from the BC Ministry of Forests, these activities are classified as basic silviculture (BC 2000). Planting and brushing and weeding are primarily contracted out, although some seasonal workers, mostly summer students, are hired directly to do the planting. The Company's employees undertake the majority of regeneration surveying but, in some operations, contractors perform 30% or more of surveying work. The payment methods that the Company uses for directly hired, seasonal workers include hourly wages, piece rates, and salary. While the Company uses piece rates and hourly wages to pay for planting and brushing and weeding, surveyors are on salary. Summer students are paid a monthly salary, with many doing supervisory work due largely to their university training and forestry knowledge. Many students use summer employment as a form of internship, with some subsequently becoming permanent employees after 2 or 3 summers. Seasonal employment ranges from 3 to 6 mo each year.

When contracting out, the contract period averages about 2 mo. There are 2 major types of contracts, "preferred contractor" (used in Company-funded projects) and "lowest bid" (used in projects funded by the BC Ministry of Forests). Usually 4 to 7 contractors are available, with 30% to 70% coming from local communities. The selection criteria are, in descending order of importance: (i) successful relationship in the past, (ii) reputation, (iii) local community employment, and (iv) competitive price. Practically all silvicultural contracts are short term; some contracts have built-in provisions for revision or renegotiation, while others allow settling of disputes anytime upon request from either party. During the 10-y period from 1987 through 1996, the Company and its operations did not resort to arbitration or litigation; disputes were settled by negotiation.

Silvicultural Programs

During 1987 through 1996, the Company undertook planting, brushing and weeding, and regeneration surveying (figure 1).

Planting. The area planted by the Company increased over the study period. On average, 3467 ha (8567 a) were planted each *year* using some 3 million seedlings. However, the average planting density of 845 stems per ha (340 stems per a) is considerably lower than the provincial average of 1186 stems per ha (480 stems per a) over the same period. Possible explanations for this include the use of larger seedlings, different species, partial natural regeneration, and adoption of company-specific harvesting and silvicultural methods (for example, the use of seed-tree methods).

The Company's planting costs increased considerably during the 10-y period (figure 2). Contract costs are the largest portion, representing 65.8% of the total (table 1). In comparison, Company labor and seedling costs represent 10.3% and 23.9%, of total planting costs, respectively. The average overhead cost of $0.18 is embedded, but not listed separately in table 1. The average overall planting costs per tree is $0.92. On average, 708 person-days were spent managing the planting program each year, or 0.2 person-days per regenerated hectare.

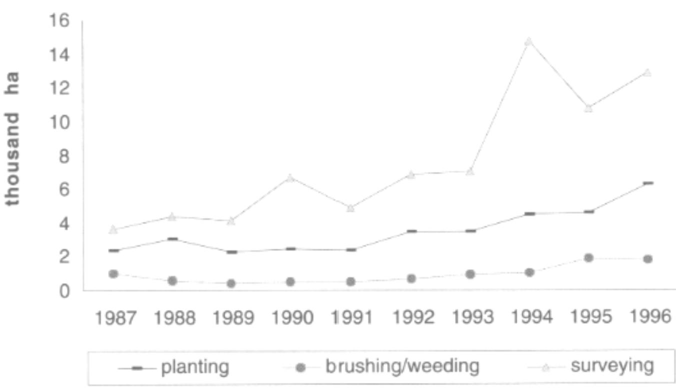

Figure 1—*The Company's silvicultural programs during the decade 1987 to 1996. One acre equals 0.4047 ha.*

Figure 2—*Planting costs, in Canadian dollars, during the decade 1987 to 1996. One acre equals 0.4047 ha.*

Table 1—*Average planting costs incurred by the Company from 1987 through 1996, based on an average planting density of 845 trees/ha (340 trees/a)*

Planting component	Cost[a] ($/tree)
Seedling cost	0.221
Contract cost	0.607
Company labor cost	0.095
Total planting cost	0.923

[a]In Canadian dollars.

Planting costs for the Company are compared with planting costs for the Vancouver Forest Region (the BC Coast) rather than the Provincial average; cost data were not available for other Coastal licensees (figure 2). Silvicultural activities in the Coastal region are undertaken by a variety of licensees, that consist of several large-scale timber companies as well as a significant number of independent loggers. In addition, the Provincial Ministry of Forests conducts silvicultural activities through its Small Business Forest Enterprise Program. For a better understanding of the licensee composition and related issues in the BC Coast, **see** BC Ministry of Forests (1995), Drushka (1999), and Wang and van Kooten (2001).

Concerning planting costs, during the 1980s and the early 1990s, the Company's unit area costs were basically on a par with the regional average. These costs include average on-site operating costs such as equipment, transportation, and wages, but do not include overhead costs. However, from 1993 onwards, a significant divergence occurred (figure 2). While regional average costs declined slightly, the Company's unit area costs rose.

During the 1990s, in view of the green-up and adjacency constraints required by the Code, forest companies adopted a variety of strategies to comply with the new regulations while attempting to contain costs. Benskin and Bedford (1994) report the wide **use** of partial cutting and "quick-fix" regeneration, which includes planting more trees per hectare, using larger seedlings, and planting fast growing species. However, the Company took a different approach. Instead of increasing planting density in response to the requirements of the Code, the Company chose to pay greater attention to prompt crop establishment by promoting natural regeneration, as well as planting the appropriate tree species at various sites. This strategy was perceived to lower silvicultural costs over the entire phase leading to the freeto-grow stage.

Brushing and weeding. Over the decade ending in 1996, the Company undertook, on average, 927 ha (2290 a) of brushing and weeding per year. In 1987, it was 1,004 ha (2480 a), but then dropped to below 400 ha (988 a) 2 y later (figure 1). Although the decreasing trend was reversed in the early 1990s, this aspect of silviculture did not recover to its 1987 level until 1994, but it did nearly double in 1995 to 1,845 ha (4557 a). The variation in the brushing program from year to year was primarily due to Company staffing, employee workload, and changing regulations with respect to the use of chemicals, rather than with acreage needing brushing treatment. For example, the Company reduced its use of chemicals dramatically in the late 1980s, and steadily thereafter, due to changes in societal values and increasing difficulty in obtaining pesticide **use** permits for aerial operations. The corporate strategy was to reduce aerial application and shift to ground spraying, manual brushing, and other methods, such as girdling.

Contract costs (on a per-ha basis) were the largest component of brushing and weeding costs, constituting 64% of entire unit-area costs. Chemical costs were relatively small, but Company labor constituted 12% of costs, which is, in relative terms, slightly higher than Company labor costs in the planting program. In terms of unit-area costs for brushing and weeding, the Company paid more during the period than the average for the Vancouver Forest Region (the BC Coast) and the Province as a whole (table 2), especially since the beginning of the 1990s. As expected, the BC Interior incurred lower costs than coastal companies due to differences in terrain and vegetation in the 2 regions. Within a region, larger companies generally incurred higher costs than smaller ones because larger companies are subject to a higher degree of public scrutiny for regulatory compliance (Wang and van Kooten 2001).

Regeneration surveying. On average, 7,607 ha (18,790 a) per year were surveyed by the Company for regeneration during the decade, reaching a peak in 1994 (figure 1). Regeneration surveying costs have 2 major components-labor and travel (including room and board). Due to the labor-intensive feature of this activity, it is not surprising that Company labor expenses account for 85% of total costs. Labor costs remained high relative to travel costs, and the difference between the two seems to have been growing.

Using the BC Ministry of Forests (2000) data as a baseline, the Company spent consistently more for regeneration surveys than the average for the Vancouver Forest Region and the Province as a whole (table 2). Interestingly, as with planting and brushing and weeding, the discrepancy in the unit area costs for surveying widened after 1993. However, the magnitude of the divergence is difficult to quantify due to differences in the terminology and categorization employed, and the unavailability of disaggregate data for forest regions and the province.

In summary, although costs increased for all 3 silvicultural activities over the decade 1987 through 1996, brushing and weeding exhibited the most cyclical pattern. The 10-y average costs incurred by the Company for these activities are 1.2 to 2.5 times the average for the Vancouver Forest Region and the Province (table 2). However, a note of caution is in order. As emphasized in our interviews by a corporate-level silvicultural manager of the Company, to make meaningful comparisons in silvicultural costs, contract costs must be used. Since independent contractors perform the majority of BC's basic silvicultural activities (Wang and others 1998), the competitive nature of the Province's silvicultural contracting market tends to reduce differences in the levels of payments by various licensees. As shown in table 2, the relative proximity of the Company's contract costs to the regional and provincial average costs is a case in point. This means that variation in overhead is the biggest difference in costs. Although the size and composition of overhead costs of the Company's silvicultural activities can be determined, comparable information on the structure and levels of overhead costs for forest regions and the province is unavailable. Thus, it is not possible to definitely conclude that the average costs of the Company's silvicultural operations are higher than the regional average. Aggregate costs for basic silviculture cannot be determined from the available data, because costs for individual activities are not additive.

Table 2—*Comparison of costs per hectare for basic silviculture incurred by a specific company or groups of companies*[a]

Company(s)	Planting	Brushing/ weeding	Surveying
BC Coast case study Company ($/ha)	749.7	725.8	29.5
Contract costs ($/ha)	518.2	468.4	none
Labor costs ($/ha)	52.2	86.6	19.8
Labor (person-days/ha)	0.204	0.198	0.053
Vancouver Forest Region ($/ha)	432.8	437-598[b]	13.1-14.5[c]
BC Province average ($/ha)	490.1	324-538[b]	12.0-13.3[c]

[a]Source: Interviews and data provided by a major British Columbia (BC) Coast licensee; BC (1997, 2000). Costs are in Canadian dollars. One acre equals 0.4047 ha.
[b]The 2 figures for brushing and weeding refer to per-hectare costs by chemical and manual means, respectively.
[c]The 2 figures for surveying refer to basic regeneration and incremental silviculture surveying, respectively.

Empirical Analysis of Silvicultural Costs

Regression analyses provide insights into the costs of silvicultural activities undertaken by the Company. To the extent that this company is representative of other firms on the BC Coast, the results provide insights into more general silvicultural activities. In particular, the results provide insights into the impact of government policy emphasizing silvicultural investments by private firms on public land. Since management and institutional factors are of interest (rather than estimating economic cost functions), simple linear functional forms with average cost (denoted *Cost* in the equations below) as the dependent variable are used. The data used in the regressions comprise both time series and cross sectional data. Specifically, for the period 1987 through 1996, observations available for regression analysis include 477 for the planting program, 234 for the brushing and weeding program, and 386 for the regeneration surveying program. To control for the inflation rate, all silvicultural costs are converted to 1994 constant Canadian dollars using the Bank of Canada's GDP deflators. Cost functions were estimated for on-the-ground basic silviculture-planting, brushing and weeding, and surveying-followed by an analysis of overhead costs related to these silvicultural activities.

Basic silviculture. Separate regressions are required for the 3 silvicultural activities because comparable data are not available for identical sites. For the planting program, we expect planting costs to be a function of the area planted, site conditions, and specific methods of regeneration. Stone (1992) used average slope as an indication of site conditions. Because the Company did not record topography data for the sites involved, and because data on regeneration methods were unavailable, planting density was used as a proxy. Planting density is expected to encompass information about site conditions, methods of regeneration, and so on. The regression equation for planting is:

(1) $Cost\ (\$/\text{ha}) = a_0 - a_1 \times \text{area planted} + a_2 \times \text{planting density} + a_3 \times \text{Code dummy}$

where the coefficients to be estimated are all positive (a_i?0). The plus and minus signs preceeding the parameters reflect the a priori expectations regarding the positve or negative nature of the correlation with cost. Average cost is expected to fall with increasing area planted due to hypothesized economies of scale; as more acreage is planted, per unit costs (for example, supervisory costs) fall. Average cost increases with increasing planting density. Finally, a dummy variable represents the period when the Code was in effect; it has a value of 1 when the Code was

(2) $Cost\ (\$/\text{ha}) = b_0 - b_1 \times \text{area treated} - b_2 \times \text{treatment dummy} + b_3 \times \text{Code dummy}.$

in effect (starting in 1995) and zero otherwise.

Similarly, the cost function regression equation for brushing activities is:

Since the parameters are positive, the a priori expectations are indicated by the signs. Brushing cost is negatively correlated with area treated because of economies of scale. Treatment methods consist of conventional approaches like ground and aerial treatments, plus other methods such as girdling and biological control (for example, with sheep). The treatment method is a dummy variable (I =conventional treatment, O=alternative methods), with the sign on this variable hypothesized to be negative. Thus, we expect nonconventional methods to be associated with higher treatment costs due to lack of experience and the extent of human attention required. Again, a dummy variable represents the impact of the Code.

Finally, the data also permit an estimate of the costs of regeneration surveying as a function of the area surveyed, which is expected to be negative as a result of scale economies, and the implementation of the Code. The regression equation for regeneration surveying is:

(3) $Cost\ (\$/\text{ha}) = c_0 - c_1 \times \text{area treated} + c_2 \times \text{Code dummy}.$

The error terms (not shown) for each of the 3 regression equations are assumed to be independently and identically distributed, with a mean of zero. Statistical tests indicated that heteroscadasticity, but not autocorrelation, might be a problem; it was corrected for in the regressions using the method outlined by White (1980); see also White and others 1990.

Regression results obtained from the ordinary least squares estimation for each of the 3 silvicultural activities (table 3) confirm that there are economies of scale in planting, brushing and weeding, and, to a lesser extent, silvicultural surveying. Specifically, planting costs are positively correlated with planting density, and the Company paid a premium for using nontraditional methods in brushing treatments. Further, the highly significant and positive coefficient for the Code dummy variable indicate that the Code did indeed raise basic silvicultural costs. Admittedly, the values of the coefficient of determination, R^2, are not high (table 3). Possible explanations for this are the omission of other explanatory variables because of data limitations, or the highly disaggregated level of the observations; generally, the higher the aggregation level, the higher the R^2 value.

To determine the effects of the Code on silvicultural costs, the costs are estimated from the regressions for both the pre-Code (dummy variable set to 0) and postCode (dummy variable set to 1) periods. The difference

Table 3—*Regression analysis (simple linear) of basic silvicultural activities as performed by the British Columbia Coast case-study Company*

Variable	Estimated coefficient	*t*-ratio[a]
Planting		
Area planted (ha)	-1.1695	-5.36
Planting density (trees/ha)	0.3199	2.44
Code dummy (1=1995, 1996; 0=other)	409.33	6.34
Constant	621.17	5.30
N = 477		
R^2 adjusted = 0.164		
Brushing/Weeding		
Area treated (ha)	-3.273	-4.25
Treatment method (1=aerial/ground; 0=other)	-343.62	-4.31
Code dummy (1=1995, 1996; 0=other)	161.82	1.82
Constant	1115.4	12.38
N = 234		
R^2 adjusted = 0.171		
Regeneration Surveying		
Area surveyed (ha)	-0.015	-2.191
Code dummy (1=1995, 1996; 0=other)	23.928	7.517
Constant	30.622	16.58
N = 386		
R^2 adjusted = 0.181		

[a]All estimated coefficients are statistically significant at the 5% level except for that of Code dummy under the brushing program, which is significant at the 10% level. One acre equals 0.4047 ha.

is assumed attributable to the Code. The regression results indicate that the Code has increased planting costs by $409 per ha, brushing and weeding costs by $162/ha, and surveying costs by less than $24/ha. However, the estimates of the impact of the Code could be exaggerated because the results are based on observations from the 1st 2 y of the existence of the Code (1995 and 1996). Since it is usually a learning process for forest companies when responding to new regulations, opportunities are likely to emerge for firms to adjust their costs under new circumstances.

Project management and supervision costs. Data on overhead costs are available for both planting and brushing. It is hypothesized that program management and supervision costs are a function of contract size, which is indicated by the amount of contract costs or the payments made to contractors. These payments increase in proportion to the size of the silvicultural activities undertaken. Additionally, it is hypothesized that, with the introduction of the Code, major licensees incurred higher overhead costs related to compliance. The respective regression equations for planting and brushing and weeding are:

$$\textit{Overhead Cost}\ (\$) = d_0 - d_1 \times \text{area planted} - d_2 \times \text{planting density} + d_3 \times \text{contract cost} + d_4 \times \text{Code dummy},$$

and

$$\textit{Overhead Cost}\ (\$) = e_0 - e_1 \times \text{area treated} - e_2 \times \text{treatment method} + e_3 \times \text{contract cost} + e_4 \times \text{Code dummy}.$$

The other variables are as in the earlier regressions. The results provided only partial evidence that the Code also increased overhead costs because the results confirm this only for the planting program (table 4).

Table 4—*Regression analysis (simple linear) of silviculture overhead costs incurred by the British Columbia Coast case-study company*

Variable	Estimated coefficient	t-ratio[a]
Planting		
Area planted (ha)	-0.0007	-7.26
Planting density (trees/ha)	-0.0002	-4.54
Contract cost for planting per ha	0.1025	2.92
Code dummy (1=1995, 1996; 0=other)	0.1469	5.33
Constant	0.3309	5.55
N = 477		
R^2 adjusted = 0.425		
Brushing		
Area treated (ha)	-1.0557	-2.93
Treatment method (1=aerial and ground; 0=other)	-8.5953	-0.21
Contract cost per ha	0.245	4.63
Code dummy (1=1995, 1996; 0=other)	-9.2683	-0.24
Constant	107.69	2.006
N = 234		
R^2 adjusted = 0.15		

[a]All estimated coefficients are statistically significant at the 5% level except for that of treatment method and the Code dummy under the brushing program. One acre equals 0.4047 ha.

Discussion

Using data on silvicultural expenditures by a BC Coastal forest company over the study period, we show that changing Provincial forest policies significantly increased private silvicultural costs. First, policies shifted responsibility for silviculture from the public owner to the private tenure holder. Second, increasing government environmental regulations in the forest sector, manifest in the Code, led to increased silviculture costs. The transfer in silviculture accountability to the forest licensee did not alter the structure with respect to the security of tenure. In addition to the standard risks inherent with investing in long-term timber rotations (for example, fire, pests, and storm events), the licensee investor must assume a high degree of institutional risk due to the uncertainty in a renewable forest license on public forest lands. Growing trees is capital-intensive, and encouraging investment without secure tenure is highly problematic. Given the forest tenure structure, forest companies treat silviculture as an expense rather than an investment, and, as a result, make no effort at silvicultural treatments beyond the bare minimum required under the law, essentially basic silviculture. Focusing on planting, brushing and weeding, and regeneration surveying, the Company operated to minimize silvicultural activity.

Further, in the actual performance of silvicultural activities, companies rely on contracting out as the main vehicle for the delivery of silvicultural programs. For instance, the Company contracted out most of its planting and brushing and weeding activities, while using its directly hired workers to undertake regeneration surveying. The rationale for such a delivery is to minimize transaction costs (Wang and van Kooten 2001).

Policy changes result in the restructuring of the institutional environment in which firms operate. It is frequently argued within the forest industry that company silvicultural costs tend to be positively correlated with the intensification of government regulations. Our empirical results lend support to this argument because the dramatic post-Code increase in planting and brushing and weeding costs (table 3) provides evidence of a structural change in 1995, when the Forest Practices Code came into effect.

One legitimate question is: "What do companies do differently because of the Code?" The forest industry certainly has taken steps to adjust to the institutional changes resulting from the Code. For instance, helicopter logging, a rarity prior to the Code, now accounts for some 15% of the coastal harvest (Allington 1998). In addition to helicopter logging, companies also harvest more of their privately held lands, because private forest lands are subject to less stringent environmental requirements. A further incentive to harvest private forest lands is that log exports are less restricted by government controls. Admittedly, forest practices in the interests of sustainable development and environmental protection are not realized without additional costs. For instance, silvicultural prescriptions such as leaving wildlife trees, creating riparian zones, and using partial cutting systems tend to result in increased costs. It is estimated that meeting the information requirements of (paperwork associated with) the Code alone cost approximately \$10 per m^3 (\$23.60 per Mbf) of commercial wood (Gregory 1997).

There are lessons to be drawn from the case study. A new institutional environment often calls for the adoption of innovative approaches in firms' delivery of required programs, but new measures often result in higher costs. In the case study, as new brushing and weeding methods emerged, the adoption of these new methods tended to increase costs (table 3). However, high costs may not persist as firms move along the learning curve. Besides, if the institutional environment is such that firms have sufficient freedom to pursue their goals and perform their tasks, there will be opportunities for them to reduce costs. Indeed, the regression results suggest that there may be economies of scale in the performance of silvicultural activities. As the scale of silvicultural activities increases, forest companies appear to become more efficient in performing them, whether done in-house or contracted out to a silvicultural specialist.

Since early 1998, the cost implications of the Code have increasingly been recognized. As a result, efforts to streamline the Code to enable forest managers at the field level to use their judgment and location-specific knowledge in operational decisions have been included. The Ministry of Forests, recognizing the inefficiency of managing by prescription rather than by objective, has moved to introduce changes in delivery of the Code. In 2000 the Ministry introduced a pilot program that provided the option for licensees to develop forest land operational plans that would meet the objectives of the Code without implementing the dictates of the Code. The Forest Practices Code Pilot Project still requires the participation of all stakeholders in the design of any alternative to the Code and includes a formal approval by the government. The initiative seeks to test resultsbased forest management techniques on the ground to enhance efficiency and save costs for both the forest industry and the government (Wilson and Wang 2001). While this policy move has won widespread support from the forest industry, its effectiveness will depend upon, among other things, a genuine relaxation of stringent regulations. It is open to debate as to the extent to which regulations should be relaxed and implemented. Given the complexity of the Code, it is possible that new adjustments could initially complicate rather than simplify field-level forest operations because, to fully understand the meaning of each new policy change, forest managers have to be well versed in all existing and previous rules under the Code.

In addition, the Ministry is actively reviewing the Code in an effort to shift the *modus operandi* to a resultsbased code from management by prescription. This review is a challenge because it seeks to balance improvements in operational efficiency with the social and environmentalist expectations on public forest land protection. The Ministry of Forests' commitment to upgrading delivery of the Code is both necessary and commendable.

It is often argued that institutional changes have implications for costs at both the planning and operational levels, and that adequate economic incentives enable firms to operate more efficiently under less stringent institutional constraints. Based on this study, we conclude that, unless society deems it necessary, compliance-based regulations, especially those highly complex ones such as BC's Forest Practices Code (BC 1994), need to be assessed against alternative mechanisms to achieve the objective without the same degree of deadweight losses to society from inefficiencies. The inefficiency costs are, first and foremost, borne by the forest company, but ultimately they constitute a cost to all of society because the forests are publicly owned. BC is in the process of developing a Provincial silvicultural strategy to ensure sustainable forest management in the 21st century, which encompasses a triple bottom line of environmental, social, and economic objectives. Some important lessons can be learned from the Code in order that policies will emerge to protect the integrity of forest ecosystems, enhance the productive capacity of the resource base, and serve the long-term interests of the forest stakeholders.

Address correspondence **to:** Sen Wang, Natural Resources Canada, Canadian Forest Service, 506 West Burnside Road, Victoria, BC, Canada V8Z 1M5; e-mail: < senwang@pfc.forestry.ca >.

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GC van Kooten was Professor, Department of Applied Economics and Statistics, University of Nevada, Reno, NV, when this paper was written.

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Production and Establishment of Trees in the Great Plains: A Question and Answer Session

Richard W. Tinus

Former Plant Physiologist, USDA Forest Service, Southern Research Station, Flagstaff, AZ

Questions posed by members of the South Dakota Association of Conservation Districts are answered. Topics include tree species identification and physiology, as well as nursery seedling production, handling, and outplanting techniques for the Great Plains. Tree Planters' Notes 50(1): 5-8; 2003.

I was asked to review the tree planting programs of 2 South Dakota Conservation Districts. As a result of my visit and report to them, I gave a presentation at the annual convention of the South Dakota Association of Conservation Districts in Pierre, SD. My talk was based on questions submitted by the districts. Although the questions were specific to South Dakota, the answers were widely applicable. Where questions or answers overlapped, I consolidated them for *Tree Planters' Notes.*

Q: Can evergreens take up water through their leaves? A: Yes. This is how foliar feeding works and how sprayed-on herbicides get into plants. Because of the foliar structure and waxy coatings, conifers take up less water this way than do hardwoods. The amount of water that enters through the foliage is tiny compared to the needs of trees. Can trees do without roots? Absolutely not!

Q: How do you tell Rocky Mountain juniper *(Juniperus scopulorum* Sarg.) and eastern redcedar *(Juniperus virginiana L.)* apart?
A: Eastern redcedar and Rocky Mountain juniper are closely related and hybridize where their ranges meet in South Dakota and Nebraska, making them hard to distinguish. As seedlings, both species have sharp pointed juvenile leaves 0.18 to 0.25 in (4.8 to 6.4 mm) long that project from the branchlet almost perpendicularly. The foliage of the two overlaps in color, except in winter when eastern redcedar takes on a reddish purple color. The mature foliage of eastern redcedar is about 0.06 in (1.6 mm) long with rounded tips, and the branchlets are smooth to the touch. Mature foliage of Rocky Mountain juniper is about 0.12 in (3.2 mm) long, and the sharp tips diverge from the branchlet making it feel rough.

The cones are about 0.25 to 0.30 in (6.4 to 8.5 mm) in diameter and look like green (unripe) or blue (ripe) berries. Eastern redcedar cones ripen in 1 y, but Rocky Mountain juniper cones ripen in 2 y. If you see 2 age classes of cones, it is Rocky Mountain juniper. If there is only 1 age class, it is probably eastern redcedar. However, junipers are either male or female, but not both. This means that only half of the trees will ever have cones. Identifying trees in a shelterbelt is not as difficult as identifying individual trees because a few cone-bearing trees are almost certainly present, and all of the junipers in question are likely from the same seedlot.

Q: Are cottonless cottonwoods more susceptible to disease than cottonwoods with seeds?
A: No. Cottonwoods *(Populus deltoides* Bartr.) that produce no cotton are either males or sterile females, and this has no bearing on their disease resistance. However, new cottonless trees vegetatively propagated for distribution in the retail market have been selected based on high survival in test plantings, rapid growth, lack of dieback, and insect and disease resistance. So, I would expect the new cottonless cottonwoods to be more disease resistant than the average wild native would.

Q: How long a life span should we expect from cottonwoods?
A: On the Great Plains, life span depends primarily on the site on which they are planted. On a rich bottomland soil with a water table within 6 ft (2 m) of the surface, cottonwoods are very fast growing and reach a large size. Expect deterioration to begin over age 60, although they may live twice that long. On a typical upland site, cottonwoods are surprisingly drought resistant, but growth will be slower and the life span about half what it would be on an ideal site. Cottonwoods planted on saline sites perform poorly and may not survive the 1st year.

Q: Is it normal for hybrid poplar to lose its foliage in early August, while cottonwood still has full foliage?

A: It depends on why the hybrid poplar *(Populus deltoides* x P. sp.) loses its foliage. One possibility is based on genetically determined physiology. The response of trees to day length depends on the latitude of their origin, and trees from high latitudes tend to finish their summer growth and go dormant earlier than trees from lower latitudes. The parents of hybrid poplars come from many places and may be from farther north than the cottonwood. Alternatively, that particular hybrid poplar may be less drought resistant than the cottonwood. Premature leaf drop is a common response to drought. Another possibility is that the hybrid poplar is susceptible to a leaf rust that the cottonwood is not. Late summer defoliation will reduce growth, but is usually not serious.

Q: How should we care for trees in the cooler at the district, prior to giving them to producers?
A: When the bareroot trees arrive from the Big Sioux Nursery (Watertown, SD; owned by the districts) in waxed boxes, open a sample of the boxes and check for proper moisture. The tops should be dry. The roots should be damp to the touch, but not sopping wet. If beginning to dry, water the roots with a mist nozzle, being careful not to get them too wet. Keep the amount of water applied to a minimum. There should not be any free water in the box. Do not try to humidify the whole cooler. Letting the humidity go down in the cooler greatly lessens the load on the refrigeration system, making it more reliable and cheaper to operate. Continue to check the seedlings twice a week after their arrival. If they are drying out in that length of time, check them more often. The boxes should retain the moisture. Keep the seedlings in their boxes and the boxes closed and in the cooler until the day they are to be planted.

When the seedlings are to be planted, thoroughly wet the roots or soak them for a few hours. Soaking overnight is acceptable, but no longer. The purpose of soaking the roots is to bring the seedlings to full hydration. Soaking for a few hours will be beneficial, but they will be fully hydrated in 12 h or less, so longer is not better. Furthermore, roots need to breathe, so it is important that the water not become anaerobic. Species differ greatly in their ability to tolerate low oxygen, so it is hard to say how long they can soak without damage.

When taken to the planting site, the roots should be wet, and the whole tree protected from direct sun and wind until planted.

Q: What is the best temperature for a tree storage cooler?
A: Most coolers work fine when set at 34 to 36 °F (1 to 2 °C). The Big Sioux Nursery stores trees over winter at about 26 °F (-3.3 °C), but by the time the districts get them in the spring, they should be thawed. After thawing, they should not be refrozen because this may cause injury. Temperatures in the cooler fluctuate as the evaporator cycles on and off, and the temperature will vary a bit in different parts of the cooler depending on airflow patterns. This means that some margin for error is needed so none of the seedlings freeze. At the other end of the range, air temperature should not rise above 40 °F (4.4 °C).

Q: How do you prevent mold from growing on the seedlings in the cooler?
A: The best way is by proper temperature and moisture control. Upon arrival, open and examine a sample of boxes to check on the condition of the seedlings. If there is any mold present, look at it carefully. Some molds are saprophytes growing on dead tissue on the surface and don't injure the seedlings. If the fungus has entered the seedlings, there will be rot present, and that is not good. If the seedlings still look adequate, get them outplanted as quickly as possible.

A little shingletoe (shavings from the manufacture of wooden shingles) in the box is helpful to keep the trees off the bottom of the box and to acidify the water present. Mold is inhibited by acid conditions. With the trees in the boxes, there is no reason to add moisture to the cooler. The lower humidity will enable the cooling system to maintain a more stable temperature so it can operate reliably closer to freezing. The lower and more stable the temperature, the less the likelihood of mold proliferation.

Q: Is a root dip beneficial?
A: Sometimes. There are mixed reports on whether or not a root dip is helpful, but it may give some margin for error when handling is not as good as it should be. While it can be used on any tree or shrub, many nurseries use it only as a preventive measure or at the insistence of their customers. If everything is done right in storing, handling, and planting, it should not be necessary. It is messy for the planters to handle. The trick is to keep it on the roots and off the tops.

Q: We plant in both clay and sandy soils. Is it better to use a root dip in the sandy soils to help maintain moisture?
A: Yes. You are much more likely to get a positive effect in sandy soils than in clay. There are 2 kinds of dip. One is kaolinite, which is a clay, and clay soils don't need more clay. The other is a polyacrylamide, which is very hydrophilic and forms a syrup or gel when dissolved in water. It helps the water adhere to the roots while the seedlings are being handled. Once in the ground, it helps retain moisture near the roots. However, this is beneficial only if the soil has a low moisture holding capacity. If the moisture holding capacity is already high, as in a clay soil, more moisture will mean less air, and the roots may suffer from lack of oxygen.

Q: Which is more detrimental to the tree: deep planting or shallow planting?

A: Shallow planting is generally more detrimental than deep planting. Ideally, the groundline after outplanting should be somewhat deeper than it was in the nursery, by how much depends on the size of the stock and the species. After planting, the groundline is likely to change. In most instances, it will be lowered by settling and washing of the loose soil, and that is why deep planting is beneficial. By "deep planting," I mean placement of the ground line 1 to 3 in (2.5 to 7.6 cm) below where it was in the nursery. Excessive burial of the root system is, of course, detrimental.

Species differences in optimum planting depth do exist. Many hardwoods can be planted several inches deeper than the original ground line. Spruce can be planted up to the lowermost live branches and will grow adventitious roots on the buried stem. Junipers can be planted with some of the lowermost branches buried. But pines native to the Dakotas should be planted no more than 1 in (2.5 cm) deeper than the original ground line.

General guidelines for all species would include the following. Do not leave any roots exposed. The exposed roots will die, leaving the tree with a smaller root system, less wind firmness, and less chance for survival. On the other hand, do not wad up the roots to fit the hole. Dig the hole to fit the roots. Prune only the occasional long root if necessary so the root system can be planted straight.

Q: Can dark fabric weed barrier cause heat stress injuries that jeopardize survival?
A: I expect it is no different than dark colored bare soil. Most heat stress injuries to seedlings occur on the stem at the ground line. There would have to be a substantial transfer of heat from the fabric to the stem to cause damage after fabric installation. However, when weed fabric is laid out over the tops of the seedlings on a sunny day, you have only a matter of minutes to cut the slits and pull the tops upright before they overheat.

Q: What are the pros and cons of 3- X 3-ft (1- X 1-m) tree mats versus the rolled fabric?
A: The 1st consideration is how big an area around the newly planted seedling needs to be weed free. West of the Missouri River, a 3- x 3-ft (1- X 1-m) patch should be big enough, but as you move east and the weeds get bigger, it may not be. On the other hand, the rolled fabric may be covering more ground than you need to cover, and the fabric is expensive.

The other consideration is logistics. A 500-ft (152-m) roll of fabric is heavy and almost has to be laid out by machine with a crew of 2 or more, although with the right equipment, it goes on rather quickly. Alternately, patches are installed by hand, which is slower and more labor intensive, but this can be done by 1 person with no special machinery.

Q: Is 1 fabric better than another?
A: There are 2 materials used. One is a fiberglass mat and the other is woven polypropylene. Fiberglass will probably last longer exposed to the weather, but polypropylene is probably cheaper and will last long enough for the trees to get above the weeds and shade them out.

Q: When wooden shingles are used for tree protection, on which sides of the tree should they be placed?
A: Shingles serve 2 purposes. They protect the seedling from intense sunlight to reduce the moisture stress until the roots can begin supplying adequate water, and they protect the stem at the ground line from overheating until the seedling can grow thicker bark. So, a shingle on the south side would be a good start. Two shingles on the southeast and southwest sides at right angles to each other with the open "V" facing north would provide even better shade. For more protection, I would use a plastic tube tree protector.

Q: How long should plastic tube tree protectors stay around the tree?
A: A protector should remain until the seedling grows above it. That may be a year for most hardwoods, but possibly several years for conifers. Conifers probably benefit more from tubes than most hardwoods for this reason.

Q: What is the difference in survival between fall-lifted and spring-lifted conifers?
A: My answer applies to climates with cold winters and not to the Deep South. For successful spring lifting, stock must still be dormant, that is, with no root or bud activity. Both fall- and spring-lifted stock can theoretically be in that proper physiological condition. The differences in survival often have to do with logistics at the nursery and whether achieving that condition is possible and practical.

In the fall, trees cannot be lifted until they have reached an adequate level of dormancy and cold hardiness; otherwise, they will not store well over winter. Then it is a race against time to get them lifted and into storage before the ground freezes. For long-term storage, trees need to be properly packaged to retain moisture and stored in a reliable cooler or freezer. Some species store better than others do over the winter.

In the spring, the nursery cannot begin lifting until the ground thaws. This is important to districts in milder climates than the nursery climate because they may be ready to plant before the nursery can begin spring lifting. Once lifting begins, it is a race against time to lift everything before it loses dormancy and breaks bud. After budbreak, field survival can be expected to be poor. Some species, such as larch *(Larix* spp.), are very difficult to lift before budbreak. These are best fall-lifted or grown as container stock. Spring-lifted stock is stored only a matter of weeks and cannot be frozen. Districts in colder climates than the nursery climate must be concerned about planting delays that extend spring storage for durations that result in loss of stock quality.

Q: Can we plant in the fall? If so, what species should we try?
A: The time to plant is when the weather and soil conditions are favorable for establishment, and the stock is physiologically ready. In the northern Great Plains, the peak rainfall months are May and June, with lots of year-to-year variation. Because the soil is warming and the rains keep it moist, spring is a good time to plant so the trees become established and grow. Fall is normally drier and soil temperatures are falling. Fall planting needs to be done using stock with active roots but with buds that will not break until the following year. Planting must be early enough so that there will be at least a few weeks with soil temperature above 45 °F (7 °C) for roots to grow and gain access to soil moisture before winter. This is best attempted on wetter sites.

The species to fall plant is not nearly as important as the stock type. Bareroot stock needs to harden off in the fall before it can be lifted and transplanted successfully. By the time it is ready to lift, the fall planting season is about over. However, container stock that has been hardened in the late summer in a climate similar to where it will be planted is ready to plant whenever the soil moisture *is* adequate and there is still time to grow new roots before winter.

Q: Why is mortality higher for outplanted cedar *juniperus* spp.) and pine *(Pin us* spp.) than for outplanted hardwoods?
A: Conifers are more difficult to establish on the Great Plains than hardwoods because they have different strategies for survival. Outplanting produces drought stress until the roots grow into the soil and are able to deliver enough water to meet the needs of the plant. In response to this stress, hardwoods die back; they abandon what they cannot support in order to save the rest. After new roots are able to supply enough water again, they sprout and grow back. In addition, spring-planted hardwoods do not lose much moisture because they have no leaves when planted (or should not have).

Most of the conifers we plant are evergreens, and they do have foliage when outplanted. Conifer leaves lose less water than leaves of deciduous trees because of their structure and waxy coatings, but conifers do not sprout readily. Their strategy is to close the stomata tightly and try to avoid dying back. On the Great Plains, the hardwood strategy seems to work better.

Q: What causes eastern redcedar to turn brown and dead-looking shortly after planting; then, when rechecked in the fall, it is found to be green and lush? Is this some type of dormancy?
A: The color change is a response to drought stress and is the same color that redcedar develops in response to cold stress in the winter. After root growth reestablishes water supply to the leaves, they turn green again. The deep red-to-purple color is caused by an anthocyanin pigment that is formed from sugars when the leaves cannot export sugars as fast as they are accumulating. This occurs when the trees are under stress.

To determine whether the trees are dead or just under stress, look carefully at the branchlets. The branchlets of dead trees will be brittle and break off when flexed. They will be tan, rust colored, or light brown, but not red or purple. If cut in cross section and examined with a hand lens, dead branchlets will look dry, whereas live ones will be moist on the cut surface and flexible.

Q: Are fertilizer sticks beneficial for yard trees?
A: Generally, yes. As with any crop, it pays to know what the soil has and what it lacks, but homeowners rarely have their soil analyzed. For trees that are just being planted, it is better to dig the hole deeper than necessary and backfill to the bottom of the root ball with amended soil, rather than using fertilizer sticks. It is usually advantageous to amend the back fill with phosphate (because it is not mobile) and nitrogen (because it is usually low). However, the first thing a newly planted tree needs is water. It will grow roots down into the fertilized soil over time.

For established yard trees, fertilizer sticks may be a convenient way of applying a slow release fertilizer in such a way that it becomes more available to the tree and less so to weeds, grass, or other shallow rooted vegetation. Whether newly planted or established, irrigation water may not be too salty. There are many places in western South Dakota where the water may be drinkable, but it should not be used to water plants. If this is your situation, collect rainwater for supplemental irrigation of trees.

Note from the Editor: This is the first 'Ask the Experts' article. If your organization has questions it would like to ask an expert, please contact the USDA Forest Service Cooperative Forestry Programs Staff, national nursery specialists at < http:://www.rngr.fs.fed.us/contacts.html >.

Assessing the Hardiness of Aleppo Pine, Maritime Pine, and Holm Oak Seedlings by Electrolyte Leakage and Water Potential Methods

A. Royo[1], M. Fernandez[1], L. Gil[2], and J.A. Pardos[2]

Research Associates[1] and Professors[2], Departamento de Silvopascicultura, ETSI de Montes, Universidad Politeauca de Madrid, Madrid, Spain

Cold and drought hardiness of nursery stock were measured just before planting in the region of Valencia (Spain). A number of stock lots of Aleppo pine (Pinus halepensis *Mill.), maritime pine* (Pinus pinaster *Ait.), and holm oak* (Quercus ilex L.) *were assessed between December 1994 and February 1997, during 3 planting seasons. Cold hardiness was evaluated by the electrolyte leakage method and whole-plant freeze testing. Drought avoidance was estimated as the drop in predawn water potential after a period without any watering. Both parameters detected nonhardened seedling lots. The electrolyte leakage method was preferred as it was faster.* Tree Planters' Notes 50(1): 38-43; 2003.

A number of causes are involved in the failure of forest tree plantations. The plants are affected by genetic factors, by conditions of nursery cultivation, and by the environment at the plantation site (Grossnickle and Folk 1993). Sometimes, even when using the same seed source with similar plantation conditions, field performance can be quite different, reflecting differences in factors that are collectively known as seedling quality (Ritchie 1984).

In Spain, the Forest Service of the Community of Valencia, in the eastern Iberian Peninsula, is developing a reforestation program using Aleppo pine *(Pinus halepensis* Mill.), maritime pine *(P. pinaster* Ait.), and holm oak *(Quercus ilex L.).* High variability in the survival of plantations at the same time as substantial changes in nursery cultivation techniques, led to suspicions about the quality of the planting stock.

Seedlings planted in the Mediterranean climate of Spain are grown almost exclusively in containers. In the early 1990s, the polyethylene bag was abandoned in favor of newer systems (rigid containers such as Superleach®, Rootrainers®, Forest pot®, Arnabat®, Styrofoam® block, Ecopot®, and others) to prevent root deformation (Penuelas 1991). The transition was made very quickly, and proper cultivation methods were not always well developed. Additionally, a standard cultivation practice (growing medium, irrigation and fertilization practices, lifting date) was not used. Also occurring during this transition was the change from a plant produced only in state nurseries, usually close to lands to be forested, to the coexistence of private and publicly owned nurseries. In fact, in the region of Valencia, poor performance has been attributed to the stock produced in private nurseries at sea level (the elevation of the majority of the private nurseries) and outplanted in the interior mountains.

In these regions (with a Mediterranean climate), establishing plantations in autumn can be beneficial because the autumn root growth takes place on the site and because the seedling establishment period avoids the possible spring drought. However, plantations established in autumn are in danger of early frost. Thus, it is necessary to know when seedlings are hardened enough to be outplanted.

One-year-old holm oak seedlings (an evergreen species) usually set bud at the end of the growing season and probably enter a deep-rest state. By contrast, the Aleppo and maritime pines never set bud at the end of the 1st growing season and probably remain in a quiescent state, making it difficult to see any morphology changes with hardening. Consequently, this study was conducted to assess the quality of planting stock coming from different nurseries.

Freeze-induced electrolyte leakage, whole-plant freeze testing, and the drop in xylem water potential were chosen to evaluate seedling quality. Electrolyte leakage has been successfully used to assess cold hardiness in other species (Burr and others 1990). It has been operationally tested (Colombo and others 1984) and gives results quickly (Glerum 1985). Xylem water potential is just 1 measure of plant water status Qoly 1985), but tracking it has been useful in reforestation programs (Cleary and Zaerr 1980). The most common application has been monitoring the stress build-up in seedlings during lifting, grading, packing, and storage (Ritchie 1984).

Materials and Methods

Eighty-three stock lots, totaling 10,000 seedlings, from 23 private and public nurseries, were evaluated between December 1994 and February 1997. There were 44 lots of Aleppo pine, 20 of maritime pine, and 19 of holm oak.

At least 100 plants per lot were sampled randomly from the nurseries. Sampling intensity varied from 1 to 10 per 1000 seedlings. During the 1st planting season, measurements were made from December 1994 through February 1995. Over the next 2 y, the measurement periods were from November through February The sampled seedlings were brought to the lab at the same time they were sent to the field for planting. Each lot was measured once. The normal time when these seedlings are extracted and outplanted is late autumn (November 15 to December 15) and late winter (February 1 to March 15); therefore, more than 85% of the lots were analyzed during these periods. The seedlings, all grown in containers (see table 1 for height and diameter of the seedlings, container volumes, and growing densities), were 7 to 11 mo old when brought to the laboratory. Seedlings in their containers were put into perforated cardboard boxes and transported in small closed vans or trucks. Transportation was completed within 3.5 h and was arranged so that the seedlings could start to be tested within 48 hours after leaving the nursery.

Cold hardiness attributes. *A. Index of injury (I;,,). A* temperature of -8 "C (17.6 °F) was chosen to expose tissue samples to in the electrolyte leakage test. According to the methods described by Simpson (1990), the LT_{50} (temperature that kills 50% of the foliage of a seedling) recommended for cold hardiness testing of these species in midwinter is around -10 "C (14 °F). However, at the plantations, the typical minimum midwinter (January) temperature is -8.1 °C (17.4 °F) (infrequently reaching -12 "C, 10.4 "F), and during the usual planting time, the expected temperature is above -6.3 °C (20.7'F). Thus, we believe that -8 "C may be low enough (Royo 1998).

Leaves or needles (two 9-mm-diameter, 0.35-in-diameter, leaf disks, or eight 1-cm-long, 0.39-in-long, needle segments per test tube; 1 tube per seedling; 15 seedlings randomly selected from each lot) were submitted to freezing temperatures following the procedure of McKay and Mason (1991). First, the treatment tubes containing tissue samples (n=11) were placed in a freezer.

The temperature was then dropped from ambient to -8 "C at 5 "C/h (9 "F/h) and maintained for 3 h. After warming to room temperature at 10 "C/h (18 "F/h), the frozen samples, plus another 4 tubes with samples from 4 additional seedlings that were not frozen (control), were submerged in 16 ml (0.54 oz) of deionized water per tube for 24 h. Electrical conductivity of the solution was measured. Samples were then autoclaved at 110 °C (230 °F) for 10 min and electrical conductivity of the solution was measured again after 24 h. Relative electrical conductivity was calculated for each seedling; the 2 kinds of samples were Rs (frozen + autoclave) and Rc (autoclave only). Finally, the index of injury (l_{ip}), expressed as a percentage, was calculated as follows (Glerum 1985):

$$(1) \quad I_{in} = \frac{Rs - Rc}{1 - Rc} \cdot 100$$

B. Whole-plant freeze test (WPFT). To calibrate the electrolyte leakage test results to whole plant response, a browning test was done on another 15 seedlings. Seedlings in their containers, with root systems protected with Styrofoam, were exposed to the same low-temperature treatment as in the previous test. After thawing to room temperature, the seedlings were transferred to a heated greenhouse for 15 d. Each year, greenhouse temperatures were set at 27 "C (80.6 °F) during the day and 17 °C (62.6 "F) at night, and day-length was extended to 12 h (minimum photosynthetic active radiation, PAR, of 150 µmol•m^{-2}.0 provided by 400 W metal halide lamps). Nevertheless, greenhouse temperatures occasionally reached 30 °C (86 °F) during the day and 13 "C (55.4 °F) at night. The damage observed in the shoots was quantitatively estimated according to the proportion of withered leaves or needles:

Level	Foliar damage
1.	<25%
2.	26% to 50%
3.	51% to 75%
4.	75%

Table 1—*Species means and ranges of means among lots within a species for the seedling and container parameters measured for Aleppo pine* (Pinus halepensis *Mill.*, n = *44 lots), maritime pine* (P. pinaster *Ait.*, n = *20 lots), and holm oak* (Quercus ilex *L.*, n = *19 lots)*

Parameter		Aleppo pine $\bar{x} \pm s_{\bar{x}}$	Aleppo pine Range	Maritime pine $\bar{x} \pm s_{\bar{x}}$	Maritime pine Range	Holm oak $\bar{x} \pm s_{\bar{x}}$	Holm oak Range
Shoot height	(cm)	10.4 ± 0.4	19.9 - 6.3	10.1 ± 0.7	19.4 - 5.0	11.8 ± 0.6	22.7 - 6.3
	(in)	4.1 ± 0.7	7.8 - 2.5	4.0 ± 0.3	7.6 - 2.0	4.7 ± 0.2	8.9 - 2.5
Stem diameter	(mm)	2.1 ± 0.1	3.1 - 1.2	2.2 ± 0.1	3.5 - 1.4	3.8 ± 0.1	5.5 - 2.6
	(in)	0.08 ± 0.01	0.12 - 0.05	0.09 ± 0.01	0.14 - 0.06	0.15 ± 0.01	0.22 - 0.10
Cell volume	(cm^3/cell)	211 ± 6	300 - 150	209 ± 6	300 - 150	317 ± 28	810 - 200
	(in^3/cell)	12.9 ± 0.4	18.3 - 9.2	12.8 ± 0.4	18.3 - 9.2	19.3 ± 1.7	49.4 - 12.2
Cell density	(plants/m^2)	368 ± 12	600 - 200	353 ± 16	600 - 250	298 ± 12	400 - 194
	(plants/ft^2)	34.2 ± 1.1	55.7 - 18.6	32.8 ± 1.5	55.7 - 23.2	27.7 ± 1.1	37.2 - 18.0

Plant water status assessed by the drop in water potential (ΔΨ). Plants in their original containers were watered to field capacity in the afternoon upon arrival at the laboratory. The following day, predawn water potential (Ψ_1) was measured with a pressure chamber. The seedlings were then kept in a growth chamber for 15 d without watering. During the day, the chamber conditions were 22 °C (71.6 °F) air temperature, 65% relative humidity, and 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PAR at plant level during a 16-h photoperiod. At night the temperature was 16 °C (60.8 °F), with 80% relative humidity. Predawn water potential was measured again at the end of the 15 d (Ψ_{15}). Visual damage (VD) was also quantified as in the browning test. The drop in water potential was calculated as:

(2) $\Delta\Psi = \Psi_1 - \Psi_{15}$

Results

The only significant difference among species for all hardiness tests (table 2) was for initial needle water potential (Ψ_1, $P < 0.001$). The oak Ψ_1 averaged 2 to 3 times more negative than the Ψ_1 of the pines. However, after 15 d without water, the Ψ_{15} for the 3 species did not differ.

Water stress avoidance (ΔΨ) followed a bimodal frequency distribution in Aleppo pine and, to a lesser extent, in maritime pine (figure 1, left). There were 2 types of responses: a decrease in water potential less than 1.5 MPa, identifying high-avoidant lots, and a decrease greater than 2.5 MPa in less-avoidant lots, with few lots in between. There were no significant correlations among ΔΨ, container volume, root dry mass, and seedling shoot-to-root ratio (r^2 L 0.12, $P > 0.05$, data not shown). The ratio of root dry mass to container volume was not similar for all lots: it ranged from 1.3 to 3.6 g/L (0.17 to 0.48 oz/gal) for pines and 5.0 to 9.2 g/L (0.67 to 1.23 oz/gal) for holm oak.

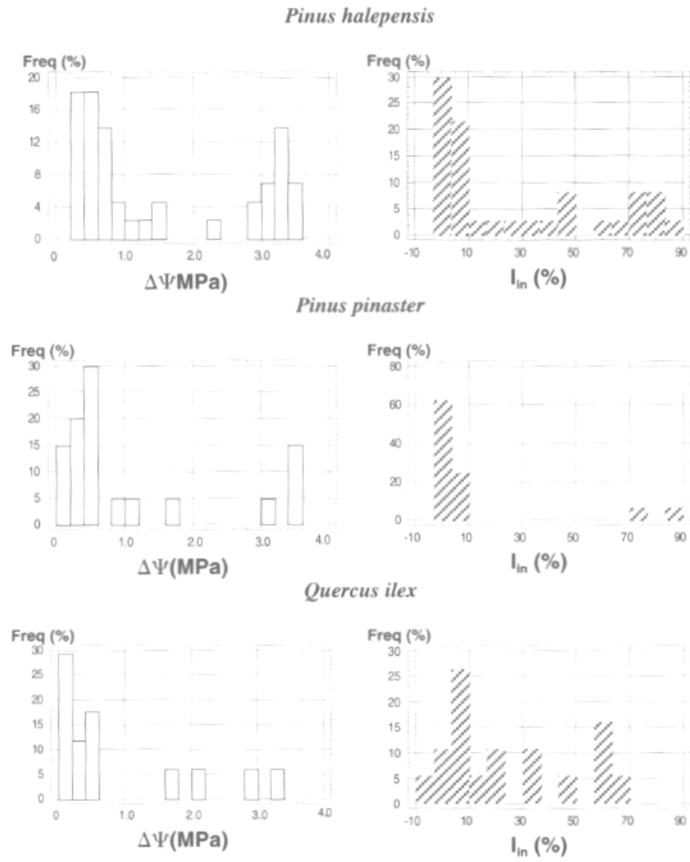


*Figure 1—Frequency distribution of the water potential drop (ΔΨ after 15 d without watering) (left) and index of injury (I_{in},-8 °C, 17.6 °F) (right) for individual stock lots of Aleppo pine (*Pinus halepensis *Mill., n = 44 lots), maritime pine (*P. pinaster *Ait., n = 20 lots), and holm oak (*Quercus ilex *L., n = 19 lots). Each lot (15 seedlings per lot) was measured once, when shipped to the field from a nursery.*

A bimodal response was also observed for I_{in} in the 3 species (figure 1, right), although with a less visible 2nd peak than for ΔΨ. This response contrasted with an unimodal distribution for other morphological and physio-

Table 2—*Species means and ranges of means among lots within a species for the hardiness parameters over all test dates for Aleppo pine (*Pinus halepensis *Mill., n = 44 lots), maritime pine (*P. pinaster *Ait., n = 20 lots), and holm oak (*Quercus ilex *L., n = 19 lots)* [a]

Parameter	Aleppo pine		Maritime pine		Holm oak	
	$\bar{x} \pm s_{\bar{x}}$	Range	$\bar{x} \pm s_{\bar{x}}$	Range	$\bar{x} \pm s_{\bar{x}}$	Range
I_{in} (%)	29.8 ± 5.4 a	96.5 - 0.0	12.1 ± 6.8 a	86.8 - 0.0	22.7 ± 6.0 a	68.4 - 0.0
WPFT rating[b]	2.2 ± 0.2 a	4.0 - 0.5	1.7 ± 0.3 a	4.0 - 0.5	1.7 ± 0.2 a	3.6 - 0.5
$-\Psi_1$ (MPa)	0.53 ± 0.03 b	0.23 - 1.06	0.38 ± 0.04 a	0.23 - 0.80	1.05 ± 0.07 c	0.68 - 2.06
$-\Psi_{15}$ (MPa)	2.04 ± 0.21 a	0.56 - 4.00	1.51 ± 0.31 a	0.43 - 4.00	1.58 ± 0.28 a	0.67 - 4.00
ΔΨ (MPa)	1.60 ± 0.02 a	4.01 - 0.27	1.13 ± 0.28 a	3.57 - 0.17	0.72 ± 0.26 a	3.30 - 0.00
Visible damage rating[b]	1.5 ± 0.2 a	4.0 - 0.5	1.1 ± 0.2 a	4.0 - 0.0	1.0 ± 0.3 a	3.0 - 0.0

[a]For each row, means followed by the same letter are not statistically different (Bonferroni, 95%).
[b]WPFT (whole-plant freeze test) and visible damage rating scale, based on the proportion of withered foliage 15 d after shoot exposure to –8 °C (17.6 °F) and 15 d without watering, respectively: 1. < 25%, 2. 26% to 50%, 3. 51% to 75%, 4. > 75%.

logical parameters measured, such as shoot height and nutrient content (data not shown).

The following results were derived from the correlation analyses between the hardiness parameters (tables 3, 4 and 5):

1. Good correlations were found between the WPFT and l_{in} (figure 2, left), and between VD and AT. The determination coefficients (r^2) were higher than 0.65 for the 3 species, and greater than 0.85 for the 2 pines.

2. h_n was highly correlated with AP in the 3 species (figure 2, right). The correlation was higher for the 2 pine species (r > 0.94, P < 0.0001) than for the holm oak (r=0.78,P<0.001).

3. There was a difference between the 2 pines and the holm oak. $'P_1$ was correlated with the WPFT and I_{in} in the 2 pines. However, there were no significant correlations for $'P_1$ in the oak.

Discussion

The studied parameters followed different patterns: a unimodal distribution for height and a bimodal distribution for cold hardiness and drought avoidance. The bimodal pattern allows the separation of 2 different groups of plants: hardy and nonhardy.

Apart from outplanting, the only procedure for unequivocally evaluating damage after freezing tests is to hold the seedlings in a greenhouse or growth chamber for several weeks and then visually inspect them (Ritchie 1991). In our study, results from the whole-plans freeze test were highly correlated (r > 0.69) with those from the electrolyte leakage test. Therefore, results from the latter method can be used alone, as they are related to the true cold hardiness of the seedlings. A similar relationship occurred with AT and VD, with even higher correlation coefficients (r > 0.88). Several variables (container volume, available water, growing medium composition, phenological stage of the seedlings, seedling size, vapor pressure deficit, for example) can alter the rate of seedling dry-down and the subsequent predawn 1P reading. This may explain the lack of relationship between X'P and some of those variables.

The general stress resistance that plants show when acquiring cold hardiness (Lavender 1985; Burr 1990) would explain the high correlation found between the index of injury and X P in the 3 species. This correlation is largely affected by environmental changes throughout the annual growth cycle of seedlings (Levitt 1980; Burr 1990). Additionally, good correlations have usually been found between cold and drought hardiness and field performance (Mattsson 1997). These correlations reduce the number of tests needed for seedling quality evaluation. The measurement of cold hardiness using the electrolyte leakage method permits the estimation of hardi-

Table 3—*Linear correlations (coefficient and significance level) between measured parameters for Aleppo pine* (Pinus halepensis *Mill.). All coefficients are significant*

Parameter	I_{in}	WPFT	Ψ_1	Ψ_{15}	$\Delta\Psi$	VD
I_{in}	1					
WPFT	0.91	1				
	0.0000					
Ψ_1	-0.63	-0.63	1			
	0.0000	0.0000				
Ψ_{15}	-0.85	-0.70	0.62	1		
	0.0000	0.0000	0.0000			
$\Delta\Psi$	0.94	0.72	-0.53	-0.92	1	
	0.0000	0.0000	0.0002	0.0000		
VD	0.78	0.59	-0.57	-0.93	0.85	1
	0.0000	0.0000	0.0001	0.0000	0.0000	

Table 4—*Linear correlations (coefficient and significance level) between measured parameters for maritime pine* (Pinus pinaster *Ait.). All coefficients are significant*

Parameter	I_{in}	WPFT	Ψ_1	Ψ_{15}	$\Delta\Psi$	VD
I_{in}	1					
WPFT	0.99	1				
	0.0000					
Ψ_1	-0.78	-0.78	1			
	0.0001	0.0001				
Ψ_{15}	-0.96	-0.85	0.69	1		
	0.0000	0.0000	0.0007			
$\Delta\Psi$	0.94	0.82	-0.62	-0.99	1	
	0.0000	0.0000	0.0037	0.0000		
VD	0.73	0.73	-0.44	-0.91	0.93	1
	0.0004	0.0004	0.0490	0.0000	0.0000	

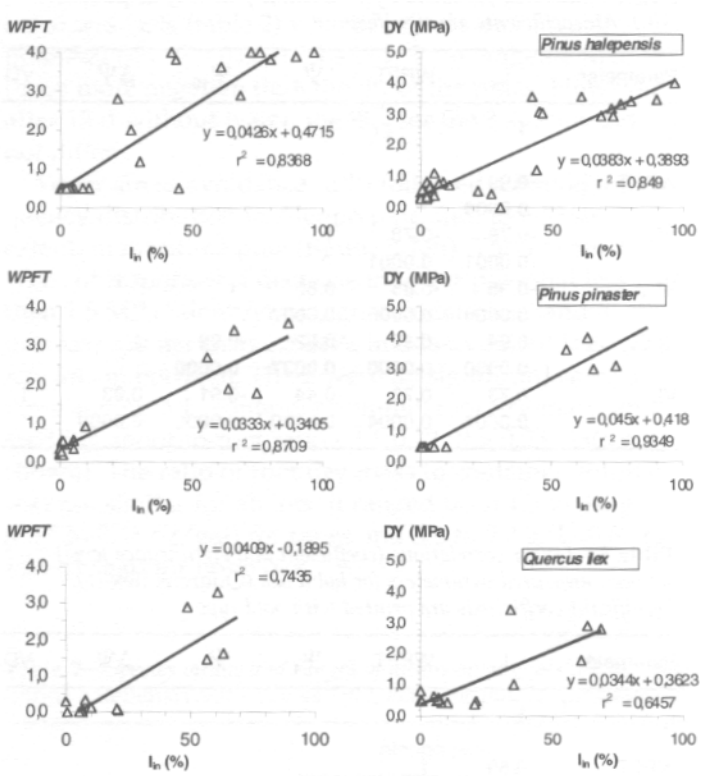
Table 5—*Linear correlations (coefficient and significance level) between measured parameters for holm oak* (Quercus ilex *L.). Significant coefficients are printed with bold type*

Parameter	I_{in}	WPFT	Ψ_1	Ψ_{15}	$\Delta\Psi$	VD
I_{in}	1					
WPFT	0.69	1				
	0.0023					
Ψ_1	0.15	-0.37	1			
	0.5526	0.0825				
Ψ_{15}	-0.77	-0.72	0.44	1		
	0.0014	0.0024	0.0768			
$\Delta\Psi$	0.78	0.69	-0.30	-0.99	1	
	0.0010	0.0042	0.2340	0.0000		
VD	0.69	0.55	-0.34	-0.88	0.88	1
	0.0061	0.0337	0.1883	0.0000	0.0000	

ness in an easier and quicker way than the whole-plant test. As long as the index of injury does not surpass 30% after freezing to -8 °C (17.6 °F) as described (figure 2), it can be assumed that plants have good drought avoidance and are ready to be planted. If water potential is used as the parameter to assess stress resistance, the DY value, following the correlation with $_{in}$, must be under 1.5 MPa.

Autumn plantations are an alternative to early spring plantations if drought periods are frequent in spring, as long as seedlings are hardened at the nursery before lifting. The relationships among seedling quality (physiological attributes, morphological parameters) and cultural and climatic conditions during the year need to be established for each nursery-species (or nursery-genotype) combination, so that lifting and outplanting schedules will be successful. The cold-hardiness test (-8 "C, 30% h_n) can be used to compare production regimes for these species to eliminate the unsuccessful regimes, especially at coastal nurseries where the chilling requirements of seedlings are not always completed.

Figure 2-Relationship between the whole-plant freeze test (WPFT) rating (based on the proportion of withered foliage 15



d after shoot exposure to -8 'C (17.6 °F): 1. < 25%, 2. = 26% to 50%, 3. 51 to 75%, 4. > 75%) and index of injury (1~,, -8 'C, 17.6 °F) (left), and between the water potential drop (DY after 15 days without watering) and index of injury (h_{am}, *-8 'C, 17.6 'F) (right) for individual stock lots of Aleppo pine* (Pinus halepensis *Mill.,* n=44*lots), maritime pine (P* pinaster *Ait., n = 20 lots) and holm oak* (Quercus ilex L., n = *19 lots). Each point represents the mean value of a stock lot (15 seedlings per lot). Each lot was measured once when shipped to the field from a nursery.*

Conclusion

Electrolyte leakage and water potential tests proved to be very useful in assessing the hardiness level of seedlings against cold and drought, respectively. The relationship between cold hardiness and drought avoidance permits inferring the status of one from the other. Electrolyte leakage was preferred as it was faster. Nevertheless, further research concerning correlation of the seedling quality test results with field performance should be carried out.

Address correspondence to: Jose A. Pardos, Departamento de Silvopascicultura, ETSI de Montes, Ciudad Universitaria s/n, 28040 Madrid, Spain. e-mail: < jpardos@montes.upm.es >.

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Damping-Off

Michelle M. Cram

Plant Pathologist, USDA Forest Service, Forest Health Protection, Athens, GA

Damping-off is a disease of germinating and newly emerged conifer and hardwood seedlings that causes decay of succulent tissue, wilting, and seedling mortality. Many species of pathogenic fungi can cause damping-off. Some of the factors influencing damping-off include pathogen populations, host susceptibility, and soil temperature, moisture, and pH. The severity of damping-off can vary from field to field and year to year depending on these factors. Managers can reduce damping-off losses in nursery beds with an integrated program of cultural and chemical practices. Tree Planters' Notes 50(1): 9-13; 2003.

Distribution and Hosts

Damping-off is one of the most common disease problems causing seedling losses in North American forest nurseries (Sutherland 1984; Cram and Fraedrich 1996). Although damping-off is often reported by nursery managers to be a slight problem (Sutherland 1984; Cram and Fraedrich 1996), under conditions favorable to disease development, damping-off can have a severe impact on seedling density and final inventory (Boyce 1961). In North America, most conifers and hardwoods are susceptible to damping-off (Filer and Peterson 1975). Some tree species are partially resistant, such as seedlings in the cypress (Cupressaceae) family (Hartley 1921); northern catalpa *(Catalpa speciosa* (Warder) Warder ex Engelm.), hackberry (Celtis occidentalis L.), green ash *(Fraxinus pennsylvanica* Marsh. var. *lanceolata* (Borkh.) Sarg.), honeylocust *(Gleditsia triacanthos L.),* and bur oak *(Quercus macrocarpa* Michx.) (Wright 1944; Filer and Peterson 1975).

Pathogens

Damping-off is caused by various pathogenic fungi that infect seedlings during germination and after emergence when the seedling tissue is succulent. Four to 6 wk after emergence, the seedlings develop woody tissue and the susceptibility to damping-off fungi quickly declines (Roth and Riker 1943c; Tint 1945). The fungi that cause damping-off vary depending on the host and location. The most common damping-off fungi are species in the genera *Pythium, Rhizoctonia, Fusarium,* and *Phytophthora* (Roth and Riker 1943a; Boyce 1961; Vaartaja 1964; Filer and Peterson 1975; Kelley and Oak 1989; Russell 1990). Other fungi that occasionally cause damping-off include *Cylindrocladium spp., Botrytis cinerea* Pers., *Sphaeropsis sapinea (Fr.)* Dyko and Sutton (Fisher 1941), *Macrophomina phaseolina* (Tassi) Goid. (Boyce 1961), *Alternaria alternata (Fr.)* Keissler, *Cladosporium cladosporioides* (Fres.) de Vries, *Penicillium expansion* Link (Huang and Kuhlman 1990), and *Phoma* spp. (Russell 1990). Many of these fungi are weak pathogens that invade the succulent tissue of germinating seedlings under environmental conditions that favor the pathogen (Boyce 1961) and reduce early seedling growth and vigor (Filer and Peterson 1975). These fungi can be present in soil and organic matter (Filer and Peterson 1975; Huang and Kuhlman 1990) and on seeds (Fisher 1941; Huang and Kuhlman 1990). Sterilized or fumigated soil can be recolonized by damping-off fungi that have been carried by wind on soil particles or by contaminated water, equipment (Vaartaja 1967), mulch, and seed.

Symptoms

Preemergence damping-off occurs when fungi infect developing radicals and kill seedlings while shoot tissues are still below ground (Filer and Peterson 1975). Random pockets of poor seedling emergence are an indication of preemergence damping-off. However, other problems can cause similar effects, including nonuniform seeding of containers or beds, poor seed development, seed decay, and removal of mulch or soil by wind and rain.

Postemergence damping-off occurs when fungi infect the succulent tissue of germinants with aboveground shoots, causing decay, wilting, and mortality (Boyce 1961). Infection occurs on the stem at or slightly below the groundline (Wright 1944; Filer and Peterson 1975) and on the roots (Hartley 1921). The infected tissue appears as a purple-to-brown lesion or as a dark water-soaked area that becomes sunken or constricted. In conifers, postemergence damping-off results in wilting and collapse of the seedling (Boyce 1961; Filer and Peterson 1975). Hardwood seedlings often remain upright as they wilt until the stem breaks off or rots away (Wright 1944).

Postemergence damping-off lesions may be confused with heat lesions (Hartley 1918). Heat lesions develop just above the groundline, are usually whitish, and are often located on 1 side of the stem in the early stage (Hartley 1918). The occurrence of heat lesion damage is scattered throughout nurseries and is dependent on pat-

***Figure 1-An** expanding patch of postemergence damping-off* (Fusarium oxysporum *Schlect. emend. Snyd. & Hans.) in black cherry* (Prunus *serotina Ehrh.) seedlings.*

terns of shade and heat buildup (Hartley 1921), while damping-off often occurs in expanding patches (figure 1).

Disease Development

Damping-off can cause significant losses in a nursery one year and minor losses the next (Hartley 1921). The susceptibility of seedlings and the activity of dampingoff fungi are affected by climatic variations, and this results in irregular losses and poor correlation of losses with soil fungal populations (Wright 1945). Other factors affecting damping-off losses include the presence of microorganisms antagonistic to pathogenic fungi (Hartley 1921; Roth and Riker 1943b; Huang and Kuhlman 1991), poor soil fumigation and rapid recolonization by damping-off fungi (Vaartaja 1967), and variation in pathogenicity within fungal species (Hartley 1921; Tint 1945; Hansen and others 1990).

The environmental conditions in which seedlings are grown usually have the greatest influence on the development of damping-off. However, the specific conditions that promote damping-off depend on the pathogens present.

Pythium. Pythium damping-off increases under high soil moisture (Wright 1957) and pH (greater than 5.8) (Roth and Riker 1943b, 1943c). The effect of temperature on *Pythium is* variable and depends on the growth rates of the host and fungus. Preemergence infection is greater when temperatures are more favorable for the fungus than for the host (Roth and Riker 1943b, Leach 1947). For example, high soil moisture combined with warm (18 to 30 °C, 64 to 86 °F) temperatures can favor damping-off by *Pythium.* However, preemergence damping-off by *Pythium* can also be very damaging at low temperatures (12 °C, 54 °F) when combined with high moisture and the absence of competitive microbes. *This Pythium* damping-off corresponds to the slow growth and emergence of the host at low temperatures (Roth and Riker 1943b).

Rhizoctonia. The conditions that promote *Rhizoctonia* damping-off differ from those that favor *Pythium* damping-off. *Rhizoctonia* damping-off losses increase with increasing soil temperatures and increasing dryness (Wright 1957) and decrease with excessive moisture (Roth and Riker 1943b). *Rhizoctonia is* less affected by pH than *Pythium* (Jackson 1940), and the activity of *Rhizoctonia* in the soil is greatly stimulated by nitrogen. In soils with high carbon-to-nitrogen ratios, the activity of *Rhizoctonia* decreases (Papavizas and Davey 1961).

Fusarium. Fusarium damping-off increases with increasing soil pH and with increased nitrogen (Tint 1945). The effects of temperature on damping-off by *Fusarium* are mixed and depend on the virulence of the fungus. Huang and Kuhlman (1990) found that highly pathogenic isolates of *F. subglutinans* Wollenw. & Reink. were less responsive to high temperature than less virulent species that significantly increased damping-off at high (30 °C, 86 °F) temperatures.

Phytophthora. In general, *Phytophthora* diseases are promoted by water-saturated soils (Duniway 1983) and increasing pH up to 8.0 (Schmitthenner and Canaday 1983). Lambert (1936) found that acidifying soil to a pH of 4.6 controlled damping-off of black locust *(Robinia pseudoacacia L.) by P. parasitica* Dast. The effects of temperature and nitrogen on *Phytophthora* diseases are variable for other crops and have not been well documented for damping-off of forest tree species in the United States.

Beneficial microorganisms. Environmental conditions can affect populations of beneficial microorganisms, as well as pathogens. For example, *Trichoderma harzianum* Rifai populations are greater in acidic soil conditions and suppress *Rhizoctonia solani* Kiihn at a soil pH of 4.3 (Huang and Kuhlman 1991). A reduction in damping-off of pine *(Pin us spp.)* seedlings by competing microorganisms also occurs with *Pythium spp.* (Hartley 1921; Roth and Riker 1943b), *Fusarium spp.* (Chakravarty and others 1990; Pedersen and others 1999), and *Cylindrocladium scoparium* Morg. (Yang and others 1995).

Management

Nursery managers can reduce damping-off by promoting fast germination and good seedling growth (Filer and Peterson 1975). Managers have a great deal of control over the factors that affect damping-off in the field, outside of the weather. Soil drainage, organic mat ter, and pH can be influenced. The timing and depth of sowing and irrigation can be controlled to improve germination. Nitrogen application can be delayed until seedlings are past the danger of damping-off. If necessary, fumigants and fungicides are available to control disease development.

Soil condition. Manipulation of the soil condition in the nursery beds can greatly affect damping-off. Soil drainage can be improved by subsoiling, crowning the beds, installing drainage tiles, and adding composted organic matter, such as composted pine bark. Organic matter affects soil texture, water-holding capacity, nutrient availability, cation exchange capacity, soil pH, and the presence and function of microorganisms. These changes are usually positive for seedling growth and survival when the origin and quality of the organic amendments are known. However, managers need to watch for N and Fe deficiencies and increases in soil pH that can occur with the addition of some organic amendments (Davey 1996). The pH of the soil can be returned to optimum (pH 5.2 to 5.7) with applications of aluminum sulfate, sulfur, or acid peat (Russell 1990). Although alkaline irrigation water can also increase soil pH over time, the water can be acidified by the addition of sulfuric or phosphoric acid if necessary (Russell 1990).

Cover crops. Cover crops are used to produce some organic matter and protect the soil from erosion and leaching (Davey 1996). They are also used as an alternate crop for disease control, but this benefit can vary with the species of cover crop. Legume cover crops often favor greater populations of damping-off fungi than grass crops (Hansen and others 1990; Russell 1990). This difference can sometimes be maintained even after fumigation (Hansen and others 1990). Fallow fields have lower populations of damping-off fungi than fields in cover crops (Russell 1990) and are comparable to fumigated fields that had been in cover crops (Hansen and others 1990).

Sowing. Usually seeds are sown when conditions are most favorable for fast and even germination. However, managers may be forced to sow seeds in an unusually warm or wet spring. This may favor fast germination but will require greater attention to watering. To avoid damping-off, soils should be irrigated to the depth of the growing roots without flooding the soil.

Fumigants. In a 1993 national survey of forest nursery managers, routine soil fumigation was used to control soil-borne disease, insects, and weeds by 86% of nurseries that produced bareroot tree seedlings (Smith and Fraedrich 1993). Fumigants that reduce the soilborne pathogens associated with damping-off include methyl bromide with chloropicrin, metam sodium (Vaartaja 1964), 100% chloropicrin, dazomet (Hansen and others 1990), and 1,3-dichloropropene (Csinos and others 2000).

Fungicides. Fungicides are used in many forest nurseries in an attempt to prevent damping-off. However, results are erratic (James 1988; Kelley and Oak 1989; Russell 1990). In general, fungicides are most effective when targeted at a specific pathogen and applied prior to disease development. Since predicting damping-off is difficult (Wright 1945), managers often rely on experience with the pathogens and conditions that cause damping-off and the fungicides, if any, that provided some control. To determine if a fungicide in use is providing control of damping-off, a few untreated plots can be established in the beds or containers. This test may have to be repeated for several years to get an accurate assessment of a fungicide. When a new chemical is to be used, it can be tested in a small area before it is applied to the entire crop.

A number of fungicides currently in use by nurseries are very specific concerning the damping-off pathogens they control. Preplant application of metalaxyl, fosetylaluminum, or etridiazole can be used to prevent damping-off by *Pythium* and *Phytophthora.* Drench applications of thiophanate-methyl may reduce damping-off by *Fusarium, Rhizoctonia, Botrytis,* and *Cylindrocladium.* Iprodione is a preplant drench for control of *Rhizoctonia* and a foliar spray for control of *Botrytis.* Broad-spectrum fungicides used to prevent damping-off include captan and a fungicide containing 15% etridiazole and 25% thiophanate-methyl. Fungicides with different modes of action should be alternated to prevent the development of resistant pathogens (Vaartaja 1964; James 1988; Russell 1990).

Seed treatments to control damping-off also provide variable results (Vaartaja 1964). Fungicides and sterilants can reduce pathogenic fungi on the seedcoat and improve germination. However, these same treatments can have phytotoxic effects depending on the species of seed, condition of the seedcoat, and application method (Vaartaja 1964; Runion and others 1991). Cleansing seed surfaces with a running water soak for 48 h is a nontoxic treatment that relies on mechanical removal of pathogens (Campbell and Landis 1990). This treatment can be used in combination with sterilants as a rinse.

Thiram is the most commonly applied seed treatment for use as a bird and small mammal repellant, as well as a fungicide for specific damping-off pathogens, such as *Fusarium* (Littke 1997), *Pythium,* and *Rhizoctonia* (Vaartaja 1964). However, thiram may delay or reduce germination of seeds of some tree species including red pine (Belcher and Carlson 1968), white spruce (Dobbs 1971), longleaf pine, and slash pine (Runion and others

1991). Few studies have determined whether the benefit of thiram as an animal repellent and fungicide exceeds its possible phytotoxic effect in the field.

Seed treatments with sodium hypochlorite (bleach) and hydrogen peroxide can reduce pathogenic fungi on the seedcoat and improve seed germination (Campbell and Landis *1990;* Barnett and Pesacreta *1993).* But these seed treatments can also reduce seed germination depending on the tree species, concentration, and duration of application (Campbell and Landis *1990;* Barnett and Pesacreta *1993).* Hydrogen dioxide *is* a surface sterilant registered as a fungicide for tree seed; however, there are no independent studies published on the efficacy of this chemical on forest tree seeds.

Summary

Damping-off is a common disease problem in forest nurseries during the 1st *4* to 6 wk after sowing. The primary fungi involved in damping-off are *Pythium, Rhizoctonia, Fusarium,* and *Phytophthora* species. Many damping-off fungi are relatively weak pathogens that require environmental conditions that favor infection. The severity of damping-off is highly dependent on whether the *soil* moisture, temperature, and pH are more beneficial to the growth of the host or the pathogen. Other factors that can affect development of the disease, aside from host susceptibility and pathogen populations, include the level of available nitrogen, presence of antagonistic microorganisms, and variation in pathogenicity within a fungal species. Managers can reduce the risk of damping-off by promoting environmental conditions for fast germination and good seedling growth. Fumigants and fungicides can also be used to reduce populations of pathogens and prevent seedling infection. Pesticides can be phytotoxic and should be used with caution.

Address correspondence **to:** Michelle Cram, USDA Forest Service, *320* Green St., Athens, GA *30602-2044;* **email:** < mcram@fs.fed.us >.

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Effect of Peat-Based Container Media on Establishment of Scots Pine, Norway Spruce, and Silver Birch Seedlings

Juha Heiskanen and Risto Rikala

Senior Research Scientists, Finnish Forest Research Institute, Suonenjoki Research Station, Suonenjoki, Finland

Growth of container seedlings grown in pure sphagnum peat and in peat mixtures containing coarse perlite and/or fine sand (25% by volume) was studied after out planting to forest sites. Relatively small differences in height growth and mortality were found among seedlings grown in the different media. Differences in postplanting success were greater among tree species and between sites than among media types. Cold soil, due to long-lasting soil frost in spring, could contribute to the increased mortality and lowered growth, especially that found in Norway spruce seedlings during the 1st growing season after planting. In practice, seedling establishment after planting cannot be expected to benefit from the addition of the constituents used here to a peat container medium in proportions less than 50%. Tree Planters' Notes 50(1): 28-33; 2003.

After outplanting, seedlings are commonly exposed to drought (Hallman and others 1978; Burdett 1990). Container seedlings are usually not as affected by water stress after outplanting as bareroot seedlings (Grossnickle and Blake 1987; Nilsson and Orlander 1995). This is due to the root system remaining undisturbed within the container. Container seedlings are commonly grown in media of low-decomposed peat and other coarse-textured materials (Landis and others 1990). Upon drying, these media may shrink in volume and have low unsaturated hydraulic conductivity and large air-filled porosity (Heiskanen 1993a,b, 1995). These factors can inhibit water uptake by seedlings after outplanting due to poor hydraulic contact between the roots and the container medium (Orlander and Due 1986; Bernier and others 1995). Moreover, soon after planting, moist peat-based media may lose large amounts of water into drier surrounding soil (Day and Skoupy 1971; Nelms and Spomer 1983; Heiskanen and Rikala 2000).

Hydraulic interactions between the container medium and the surrounding soil and the effects of these interactions on water stress and seedling establishment after outplanting are poorly understood (Hellum 1982). Water movement from the surrounding soil into peatbased container media (Heiskanen 1999), water availability to seedlings (Orlander and Due 1986; Ben-tier and others 1995), and rooting of seedlings into the soil (Heiskanen and Rikala 1998, 2000) can, to some extent, be modified by using suitable constituents in the peat medium. However, no substantial effects of growth media on the actual establishment of container seedlings after outplanting have yet been shown in practice.

The aim of this study was to test whether different peat-based container media affect establishment of container seedlings.

Materials and Methods

We studied 4 different media based on light, medium-grade, premix-fertilized sphagnum peat (Vapo E D1K2`~, Vapo Oyj., Finland) with coarse and fine constituents. Mixed with the peat (P), the coarse component was perlite (Pr, particle size 0.5-6.0 mm, 0.02-0.24 in, Nordisk Perlite Aps., Denmark) and the fine component was quartz sand (Q, particle size <0.2 mm, 0.008 in, Partek Oyj., Nilsian Kvartsi, Finland). The proportions of the components hand-mixed into the peat were determined by volume (P100, P75Pr25, P50Pr25Q25, P75Q25) (table 1). A detailed description of the properties of these media has been presented previously (Heiskanen 1995, 1999; Heiskanen and Rikala 2000).

Scots pine *(Pin us sylvestris L.),* Norway spruce *(Picea abies (L.)* Karst.), and silver birch seedlings *(Betula*

Table 1—*Mean composition by volume and bulk density of the growth media*

Medium	Peat (%)	Coarse perlite (%)	Fine sand (%)	Bulk density (g/cm^3)
P100	100	0	0	0.09
P75Pr25	75	25	0	0.11
P50Pr25Q25	50	25	25	0.49
P75Q25	75	0	25	0.45

pendula Roth) were grown from seed in a greenhouse using standard culturing procedures (Heiskanen and Rikala 2000). The container types used for the conifers and birch were hard plastic PL-81F trays (64 cells of 85 cm^3, 5.2 in^3) and PL-25 trays (25 cells of 380 cm^3, 23 i_n), respectively (Lannen Oyj., Finland). In July, the seedlings were moved to open fields, where they remained for winter storage under the snow cover. The next spring, the 1-year-old seedlings were planted onto forest sites in central Finland during the 3rd week of May. Seedling height at planting varied somewhat by medium (table 2).

Pine and spruce seedlings were planted onto 2 different planting sites located in central Finland at 62˚18'N and 27°16'E. One site was a Vaccinium type (VT), which was drier, coarser textured, and less fertile than the other site, a Myrtillus type (MT) (Cajander 1949; table 3). Both sites had been clear-cut and disc-scarified. Birch was planted on the MT site and on a tilt-plowed former field designated for afforestation (62°53'N, 28°20'E). Seedlings were planted at the intersection points of a grid 2 X 2 m (6.6 x 6.6 ft) on the VT and MT sites and on grid 1 X 1 m (3.3 X 3.3 ft) on the field site. Within sites, each species was planted alone into 6 blocks, each of which was further divided into 4 plots. Seedlings grown in different container media were randomized separately to different plots (that is, 1 container medium in each plot). VT and MT blocks measured 16 X 20 m (52.5 x 65.6 ft) each, and field blocks were 8 X 10 m (26.3 X 32.8 ft). VT and MT plots measured 8 X 10 m each; field plots were 4 X 10 m (13 X 32.8 ft). In each plot, there were 20 seedling replicates. Thus, in all, there were 480 seedlings planted per species on each site (total of 2880). Initial planting height in spring 1997, as well as height growth and mortality of the seedlings, were measured in autumn 1997 and 1998.

Soil texture on the MT site was finer than on the VT site, but the field soil had the finest texture (table 3). Thus, the field soil had higher water-retention capacity at -10 kPa matric potential (around field capacity) than the VT and MT soils did. Based on 1 measurement period (4 through 9 Aug 1998), soil-water content (`Y° by volume) below the organic horizon was, on average, 21 (range 18-24) on the VT site, 27 (25-29) on the MT site, and 26 on the field site. Thus, due to the moist measurement time, the VT soil seemed to be wetter than the field capacity. The rather low water content in relation to the water-retention capacity in the field soil was most likely due to the heavier tilt plowing compared with that done on the forest sites.

Weather conditions at the time of planting were relatively cool, and the soil was still frozen in some places. Soon after planting, the weather became warmer and precipitation was fairly low, which likely increased water stress in the seedlings. The summer after planting (1998) was clearly cooler and moister than the summer

Table 2—*Seedling height range at outplanting for 3 species grown in 4 container media*

Species	Container media[a]							
	P100		P75Pr25		P50Pr25Q25		P75Q25	
	(cm)	(in)	(cm)	(in)	(cm)	(in)	(cm)	(in)
Pine	8-14	3.1-5.5	8-14	3.1-5.5	8-14	3.1-5.5	8-14	3.1-5.5
Spruce	12-20	4.7-7.9	12-20	4.7-7.9	10-18	3.9-7.1	10-18	3.9-7.1
Birch	50-80	19.7-31.5	50-80	19.7-31.5	30-60	11.8-23.6	40-70	15.7-27.6

[a]P100=100% peat; P75Pr25=75% peat, 25% perlite; P50Pr25Q25=50% peat, 25% perlite, 25% sand; P75Q25=75% peat, 25% sand.

Table 3—*Soil texture, pH, organic matter content, bulk density, total porosity, and water retention on the study sites* ($\bar{x} \pm s$)

Site	Soil texture (mass %)							
	>0.6 mm	0.6-0.06 mm	<0.06 mm	pH	Organics (mass %)	Density (g/cm^3)	Porosity (volume %)	Water retention[a] (volume %)
VT	10.9±8.2	84.9±7.9	04.1±0.8	5.25±0.15	3.0±0.8	1.31±0.06	50.8±1.9	16.3±2.3
MT	36.7±8.1	51.8±5.8	11.5±3.1	5.09±0.19	6.5±1.7	1.09±0.01	59.0±3.4	29.3±3.8
Field	06.9±2.1	60.6±3.0	32.5±1.5	5.77±0.03	7.4±1.1	1.03±0.08	61.1±2.3	40.1±3.2

[a] Measured at -10 kPa matric potential

of 1997. Weather information was estimated from the regional data of the Finnish Meteorological Institute (table 4).

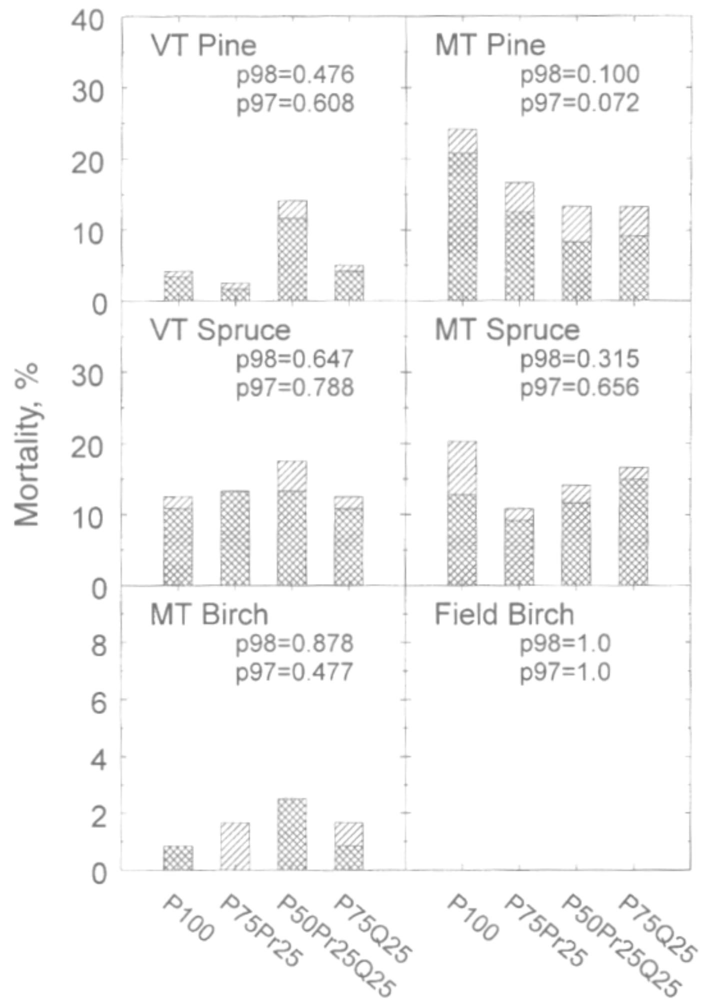
Soil texture was analyzed by dry sieving and organic matter content as loss on ignition (at 550 °C, 1022 °F). Bulk density was estimated from cylinder samples as dry mass / wet volume and total porosity as (particle density - bulk density) / particle density (Heiskanen 1993a). Water retention at -10 kPa matric potential was measured using a pressure-plate apparatus (Heiskanen 1993a). Soil-water contents were measured on 4 through 9 September 1998 using a time domain reflectometer (IMKO TRIME-FM, Germany) (Maliki and others 1992, 1996). Soil measurements were replicated 3 times (from different blocks) within species and sites.

Differences in mortality among seedlings grown in different container media were analyzed from block means (n=6) using nonparametric Kruskal-Wallis ANOVA. Differences in height growth were analyzed within sites and species using parametric ANOVA and Tukey's test, in which container media and blocks were used as fixed effects and initial planting height as a covariate.

Results

Mortality after the 1st growing season (1997) differed (P = 0.072) among pine seedlings grown in different container media on the MT site, where the seedlings grown in pure peat (P100) had the highest mortality (figure 1). On the VT site, pine mortality was highest in the P50Pr25Q25 medium, although not significantly (P = 0.608). For the other sites and species and the next year (1998), there were no differences in mortality among media (P > 0.10). In general, pine seedlings had greater mortality on the MT site than on the VT site. The mortality for spruce seedlings was, on average, higher than that for pine. Birch had very low mortality.

During the 1st and 2nd seasons after outplanting, average height growth (expressed as 1st season growth + 2nd season growth) of pine seedlings differed very little between the sites: 4.3 + 11.2 cm (1.7 + 4.4 in) on VT,



Container Media

Figure 1-Mean seedling mortality the 1st (1997, cross-hatch) and 2nd (1998, diagonal) growing seasons after outplanting on the study sites. Vaccinium type (VT) and Myrtillus type (MT) sites were discscarified, and the former field (Field) was tilt-plowed. Blocks (n=6) were used as observations. P-values for both growing seasons (p97, p98) are from Kruskal-Wallis ANOVA of mortality as a function of 4 container media (P100=100% peat; P75Pr25=75% peat and 25% perlite; P50Pr25Q25=50% peat, 25% perlite, and 25% sand; P75Q25=75% peat and 25% sand).

Table 4—*Mean monthly temperature and precipitation in the study regions*

Region	May		June		July		August		September	
	°C (°F)	mm (in)	°C (°F)	mm (in)	°C (°F)	mm (in)	°C (°F)	mm (in)	°C (°F)	mm (in)
1997										
VT + MT	6.7 (44.1)	26.5 (1.0)	16.0 (60.8)	31.0 (1.2)	18.6 (65.5)	45.5 (1.8)	17.0 (62.6)	16.5 (0.6)	9.6 (49.3)	66.5 (2.6)
Field	6.1 (43.0)	15.0 (0.6)	15.0 (59.0)	60.0 (2.4)	17.6 (63.7)	66.0 (2.6)	15.6 (60.1)	23.0 (0.9)	8.3 (46.9)	85.0 (3.3)
1998										
VT + MT	8.3 (46.9)	44.5 (1.8)	13.9 (57.0)	101.0 (4.0)	16.4 (61.5)	135 (5.3)	13.1 (55.6)	94.0 (3.7)	10.3 (50.5)	28.0 (1.1)
Field	8.0 (46.4)	57.0 (2.2)	13.8 (56.8)	120.0 (4.7)	15.7 (60.3)	159 (6.3)	12.7 (54.7)	78.0 (3.1)	10.0 (50.0)	32.0 (1.3)

and 4.6 + 11.1 cm (1.8 + 4.4 in) on MT (figure 2). During the 1st season, pine height growth differed (P < 0.0005) among container media on the MT site but not on the VT site. The pine seedlings grew best in pure peat (P100). The next summer, however, height growth in pure peat no longer differed. Spruce seedlings grew better on the VT site the 1st season, but the next season they grew better on the MT site: 3.7 + 5.7 cm (1.5 + 2.2 in) on VT, and 2.7 + 7.3 cm (1.1 + 2.9 in) on MT. During the 1st season, spruce seedlings in pure peat medium grew best on the MT site (P = 0.026), but during the following season, there were no differences among media. On the VT site, there were no differences in spruce growth among media either season. In both seasons, birch seedlings grew better on the field site: 7.9 + 33.8 cm. (3.1+13.3in)onMT,and15.1+46.7(5.9 + 18.4 in) on the field. On the field site, height growth of birch differed among media (P = 0.012) and was greater with smaller initial planting height, which occurred with seedlings that had quartz sand added to the peat container medium.

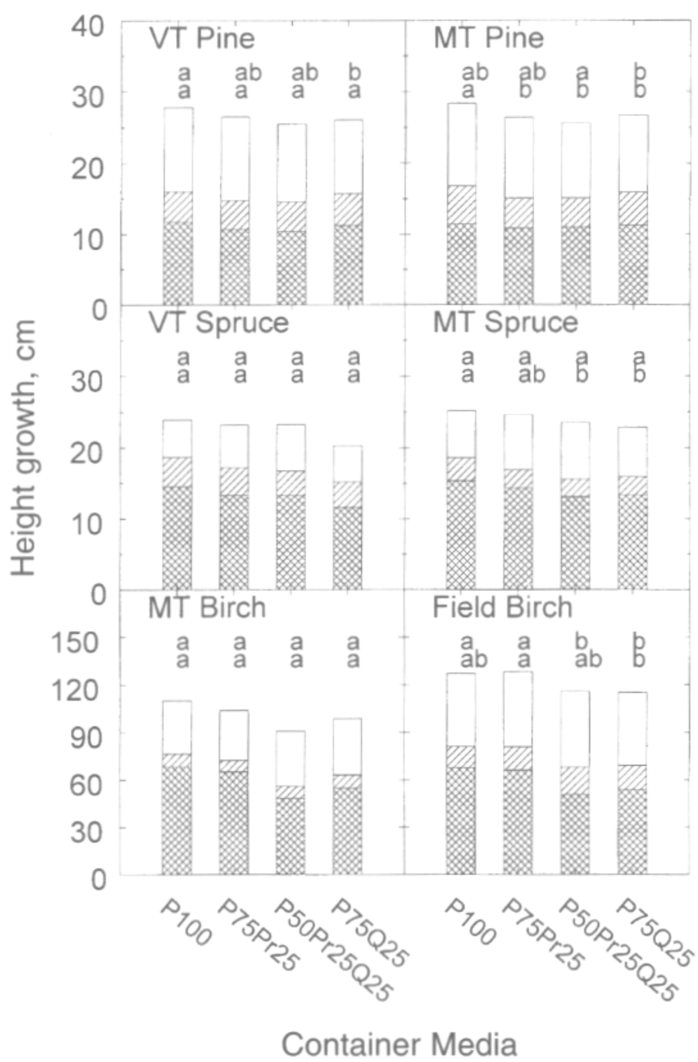


Figure *2-Mean seedling planting height (lowest partition), 1styear-growth (1997, middle partition), and 2nd-year-growth (1998, top partition) for 3 species by growth medium. Media compositions were: P100=100% peat; P75Pr25=75% peat and 25% perlite; P50Pr25Q25=50% peat, 25% perlite, and 25% sand; and P75Q25=75% peat and 25% sand. Study sites were a Vaccinium type (VT), a Myrtillus type (MT), and a former field (Field). Different letters among growth media denote different growth rates (Takey, P < 0.05, planting height used as a covariate, dead seedlings excluded). The lower row of letters indicates the 1st season (1997), the upper row, the 2nd season (1998).*

Discussion

Relatively small differences in height growth and mortality were found among seedlings grown in the different peat-based growth media used. On the other hand, the postplanting success of tree species seemed to differ somewhat between the sites. Pine seedlings had lower mortality on the VT site than on the MT site, which was flatter and wetter and had later soil frost after planting than the VT site did. Therefore, the increased mortality on the MT site might have been caused by low soil-water availability and by drying before the seedlings were able to grow roots into the surrounding soil after planting. In addition, the increased mortality of pine seedlings grown in pure peat on the MT site was probably contributed to by poor hydraulic contact with the surrounding soil (Heiskanen and Rikala 1998; Heiskanen 1999; Heiskanen and Rikala 2000).

The mortality of spruce seedlings was almost equally high on both outplanting sites, although the VT site was, in general, drier during the growing season and was not a typical site for spruce. In comparison with pine, this high mortality for spruce on the drier VT site may have been due to the weaker drought tolerance of spruce during the rather dry 1st summer. Birch seedlings had very low mortality, which indicates sufficient water uptake. This may have been because birch seedlings were leafless at the time of planting, and did not need as much water for transpiration immediately after planting. Thus, soil frost and dryness did not cause water stress or weak root growth since the roots of birch seedlings begin to grow only after the onset of bud burst and leaf growth (Abod and Webster 1991; Rikala 1996). The higher growth rate on the field site was presumed to be due to the higher soil fertility.

In principle, water flow between the surrounding soil and the container medium is affected by the coarseness of the soil and of the container medium, as well as by the hydraulic gradient (that is, the difference in dryness between medium and soil) (Heiskanen 1999; Heiskanen and Rikala 2000). Thus, to improve the water uptake of seedlings after outplanting, it may seem reasonable to modify a peat container medium with additives. In general, however, the water potential in boreal forest soils is commonly close to the field capacity (about -10 kPa matric potential), although in some years it may reach the wilting point (about -1500 kPa) after summer droughts (Heiskanen 1988; Norden 1989). Therefore, in practice, boreal forest soils can be expected to provide sufficient water for seedling uptake, especially when seedlings are outplanted in springtime. On the other hand, in spring, low soil temperatures may retard water uptake by seedlings (Lopushinsky and Max 1990; Ryyppo and others 1998), but this apparently cannot be affected much by modification of peat container media. Modification of peat container media with suitable additives may, however, be more effective with summer planting, when forest soils are warmer and drier.

Conclusions

Addition of the sand and perlite constituents used here to peat container media in proportions of 25% or 50% did not lead to any clear benefit for height growth or establishment of seedlings on the studied sites after early spring planting. However, under different weather and soil conditions, more distinctive effects may result with different additions of constituents to the peat medium or with different container types.

Address correspondence to: Dr. Juha Heiskanen, Finnish Forest Research Institute, Suonenjoki Research Station, FTN-77600 Suonenjoki, Finland; **e-mail:** < juha.heiskanen@metla.fi >.

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Effect of Soil Temperature on Rooting and Early Establishment of Balsam Poplar Cuttings

Simon M. Landhausser

Research Assistant Professor, University of Alberta, Department of Renewable Resources, Edmonton, Alberta, Canada

Low soil temperatures are the primary limiting factor when using non rooted balsam poplar (Populus balsamifera *L.) stem cuttings for reforestation of highly productive, nutrient rich, cold, wet boreal sites that have severe grass competition problems. This study investigated the effect of soil temperature on the establishment and early growth of dormant balsam poplar hardwood stem cuttings. During a 6-wk experimental period, nonrooted cuttings were subjected to 3 soil temperatures-5, 15, and 25 °C (41, 59, and 77 °F). The soil temperatures were maintained by submerging water-tight pots into temperature controlled water baths. Cuttings exposed to a soil temperature of 5 °C did not produce any roots by the end of the 6-wk experiment. At 5 °C, cuttings had 80% survival and less top growth compared to cuttings grown at soil temperatures of 15 and 25 °C. At 15 and 25 °C, survival was 100%, and all cuttings produced roots. The cuttings grown at 25 °C had the highest biomass of aboveground and belowground plant components. The strong sensitivity of root development in dormant stem cuttings of balsam poplar to low soil temperatures will have a large impact on the use o f nonrooted cuttings for reforestation on cool, wet sites.* Tree Planters' Notes 50(1): 34-37; 2003.

Valley-bottoms, floodplains, and seepage slopes are some of the most productive forest sites of the boreal forest. In late successional stages, these sites are commonly dominated by white spruce *(Picea glauca* (Moench) Voss). However, after harvesting, these sites can become too wet for successful conifer regeneration due to high water tables. Marsh reed grass *(Calamagrostis canadensis* (Michx.) Beauv.) is a fierce competitor with tree species and can dominate these sites after harvesting (Eis 1981; Landhausser and Lieffers 1998). Complete loss of conifer plantations can result. When marsh reed grass dominates a site, the accumulation of a heavy thatch can lead to delayed spring thawing of the soil and lower (by about 6 °C, 11 °F) midsummer soil temperatures (Hogg and Lieffers 1991).

At an early to mid successional stage, balsam poplar *(Populus balsamifera L.)* is commonly found on these productive, moist-to-wet (sub-hygric) soils (Zasada and Phipps 1990; Peterson and others 1996). The establishment of balsam poplar on these cool, grass-dominated sites could prove advantageous, not only by shading out marsh reed grass, but also by creating a nurse crop for white spruce.

Balsam poplar reproduces asexually very well through stem cuttings due the presence of preformed root primordia. The use of nonrooted stem cuttings in the field could provide an inexpensive and potentially effective alternative to the planting of rooted cuttings or seedlings. However, there are many factors influencing the success of root initiation and growth in cuttings. The selection and position of cuttings are important, since cuttings of last year's growth from young trees tend to root more easily than cuttings from older plants (Nordine 1984), and lower portions of the cutting tend to produce more root primordia (Bloomberg 1959; Smith and Wareing 1974). In addition, carbohydrate status, as a function of the diameter and length of the cutting, is considered very important in the success of rooting (Nanda and Anand 1970; Tschaplinski and Blake 1989; Rossi 1991). Storage (Fege and Phipps 1984), date of collection (Phipps and Netzer 1981; Fege and Phipps 1984), and the treatment before rooting-such as soaking (Hansen and Netzer 1993) and application of rooting hormones or fungicides (Nordine 1984)-are also important factors influencing rooting success of cuttings. However, since soil temperature is likely the major limiting factor in the establishment of nonrooted stem cuttings on these grass-dominated sites, the objective of this study was to investigate the rooting potential of balsam poplar stem cuttings when exposed to different soil temperatures.

Methods

In February 1999, 1-m-long whips of balsam poplar shoots collected from randomly selected clones were cut in the Slave Lake area, Alberta, Canada, wrapped in plastic, and stored in a freezer at -10 °C (14 °F). After 6 wk of storage, 90 cuttings, each 20 cm (8 in) long with similar diameters averaging 6.3 mm (0.25 in) (s = 0.63 mm, 0.025 in) and a terminal bud, were made from the most recent year's growth. The cuttings were soaked in water for 3 days at 2 °C (35.6 °F), and then 2 cuttings (subsamples) per whip were planted 10-cm-deep into a pot (15-cm diameter x 12-cm depth, 5.9 X 4.7 in) filled with sand. Cuttings were subsequently grown at 3 soil temperatures (5, 15, and 25 °C; 41, 59, and 77 °F); with 15 replicates for each soil temperature treatment.

To control soil temperature, the pots were submerged into 9 water baths (3 for each temperature) consisting of water-tight insulated polyethylene boxes (150 L, 39.6 gal). A similar design was used successfully by Landhausser and Lieffers (1994). Soil temperature treatments were maintained by regulating the water temperature with thermostats in the baths and circulating the water at 13 L/min (3.4 gal/min). Five pots were placed in each bath (15 per test temperature). To prevent water logging, the pots had false bottoms that allowed for free drainage of water into the bottom of the pot. A hose was inserted into this drainage area to suction out excess soil water. The space between the pots in the baths was covered with a white polystyrene board, and the soil surface in the pots was covered with perlite to a depth of 2 cm (0.79 in) for insulation.

The growth chamber conditions during the 6-wk period were 18 h light and 6 h dark with a day air temperature of 18 °C (64.4 °F) and night temperature of 16 °C (60.8 °F). The relative humidity was maintained at 70%. Photosynthetic flux density was 400 μmol.m-2.s ⁱ at 20 cm (8 in) above the soil surface. The light flux density at different water bath positions in the growth chamber was not different (P = 0.11). The pots were watered to field capacity when necessary, and after bud flush they were fertilized weekly with 0.1 L of a 2 g/L (0.105 qt, 0.07 oz/qt) solution of a commercial fertilizer (N:P:K 20:20:20) with chelated micronutrients. The pots were moved weekly to different water bath positions to minimize positional effects.

After 6 wk, the experiment was terminated. Survival and root development were determined on all 90 cuttings. A cutting was considered dead when no green leaves were present. Necrotic shoots with some partially green leaves were still considered alive. Height growth; leaf area; and stem, leaf, and root dry weights were determined on a random sample of 10 cuttings for each soil temperature.

The design of this experiment was completely randomized with soil temperature as the single fixed factor. After log transformation of total leaf area and dry weight of roots, all response variables met the assumption of normal distribution and homogeneity of variances. To test for treatment effects, analysis of variance with least significant difference multiple comparisons were performed with PROC GLM (SAS 1988). The significance levels were set at x=0.05.

Results

All balsam poplar cuttings broke bud within 7 d of planting. Cuttings in the 25 °C (77 °F) soil flushed about 2 d earlier than those at 5 °C (41 "F). At the end of the 6wk experiment, survival of cuttings was 100% in soil temperatures of 15 (59 "F) and 25 °C. At 5 °C the survival rate was 80%. Stem cuttings at 15 and 25 °C produced roots, while root development was completely absent at a soil temperature of 5 °C. Average root dry weight was doubled at 25 °C (0.309g) when compared with plants growing at 15 °C (0.144 g, P=0.0001) (figure 1). Total dry weight (including stem cutting) of balsam poplar cuttings grown at a soil temperature of 5 °C was 2.28 g compared to 3.17 and 5.97 g at 15 and 25 °C, respectively. The average dry weights of the new shoots at 5, 15, and 25 °C were 0.286, 1.09, and 3.84 g, respectively; about 10-fold larger than the root mass (figure 1). This resulted in generally low root:shoot ratios for cuttings exposed to the 3 soil temperatures. However, the root:shoot ratio of cuttings grown at 15 °C (r/s=0.128) was greater than that of cuttings grown at 25 °C (r/s=0.079) (P<0.05) (figure 1).

Although the terminal buds of all cuttings exposed to a soil temperature of 5 °C flushed, the shoots did not elongate and the leaves became necrotic and partially abscised. At a soil temperature of 25 °C, the cuttings had the tallest new shoots with an average of 20.1 cm (7.9 in), compared to 10.2 (4.0 in) and 2.2 cm (0.9 in) at 15 °C and 5 °C, respectively (P=0.0001). Cuttings grown at 25 °C had a greater number of leaves with 36, compared to 19 and 7 leaves per plant at 15 and 5 °C, respectively (P = 0.0001). The average leaf size was also significantly different for the 3 soil temperatures. The average area per leaf was smallest at the coldest soil: 2.7 cm² (0.42 in²) at 5 °C, 6.1 cm² (0.95 in²) at 15 °C, and 15.3 cm² (2.37 in²)

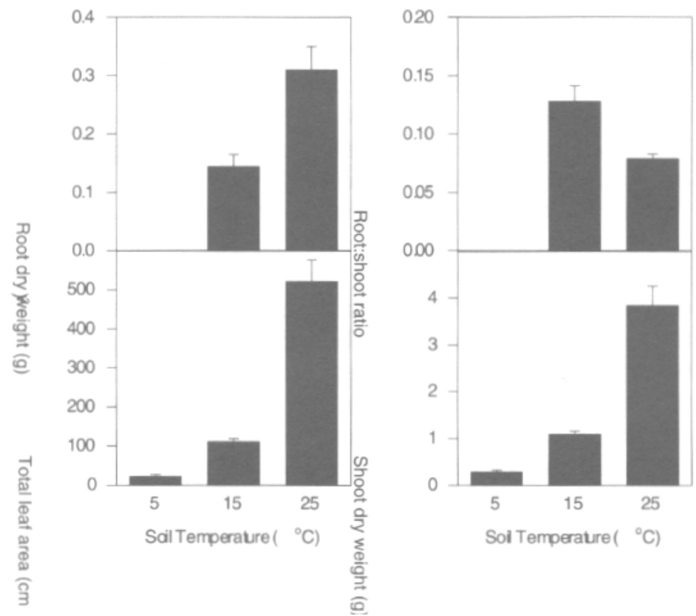

***Figure** 1-Aboveground and belowground responses of non rooted balsam poplar (Populus balsamifera L.) cuttings subjected to soil temperatures of 5, 15, and 25 °C (41, 59, 77 °F) (x ± s_x).*

at 25 °C (P = 0.0001). These differences in leaf size and number resulted in a total leaf area of 521 cm^2 (81 in) per plant grown at 25 °C, which was $4x_2$ higher than the total leaf area of plants at 15 °C (111 cm^2, 17.2 in^2), and 23x higher than plants grown at 5 °C (23 cm^2, 3.6 in^2, P = 0.0001) (figure 1). Similarly, leaf dry weights were 0.159, 0.756, and 2.765 g for the 3 soil temperatures of 5,15, 25 °C, respectively (P = 0.0001).

Discussion

Low soil temperature strongly affected the development of roots and shoots from balsam poplar cuttings; a soil temperature of 5 °C (41 °F) resulted in 20% mortality (no green leaves), a complete lack of root development, and poor leaf and shoot development after 6 wk. In a related study (Landhausser, unpublished data), rooted balsam poplar stem cuttings (container stock) suffered high mortality (72%) with no new root growth after 6 wk at 5 °C, while no mortality and abundant new root growth were observed at 20 °C (68 °F). Cool soil temperatures are very common early in the growing season in boreal forests (Bonan 1992), and these low soil temperatures can be maintained by an insulating mat of slowly decomposing marsh reed grass litter (Hogg and Lieffers 1991). For the western boreal forest of Alberta, Hogg, and Lieffers (1991) found that on open cut blocks (logged sites), the maximum soil temperature at a depth of 5 cm (1.97 in) in mid-August reached 19 °C (66.2 °F) without grass, while only 13 °C (55.4 °F) under the grass cover.

The lack of root development at cool soil temperatures will directly affect the feasibility of using nonrooted balsam poplar stem cuttings for reforestation purposes on sites that are already occupied by the grass. The importance of warm (20 to 30 °C, 68 to 86 °F) soil temperatures for the development of roots in cuttings is recognized (Loach 1988; Ford-Logan 1994).

The results of this study indicate that cuttings should be planted in late spring or early summer of the growing season immediately after timber harvesting to give the cuttings a headstart before grass occupies the site. In the 1st growing season after harvesting, soil temperatures will likely be the highest on these sites, creating the most favorable conditions for root development. The use of longer whips than tested here could also give balsam poplar a height advantage over early establishing grass and shrubs. Longer whips might also be more effective since they have been more successful in the development and establishment of new roots and leaf area due to higher carbohydrate reserves (Nanda and Anand 1970; Tschaplinski and Blake 1989). By inserting a larger portion of the cutting into the ground, the development of roots along a larger section of the cutting could result in more access to moisture (Rossi 1991), producing more favorable root:shoot ratios than found in the present study.

The promotion of balsam poplar as a companion in mixed wood ecosystems is desirable because it can function as a nurse crop for the shade-tolerant white spruce. Additionally, the early establishment of balsam poplar can benefit sites by suppressing the grass and other competitors due to shading. This is especially true for productive, cool, wet sites that are prone to rising water tables and severe grass and shrub competition after harvesting (Lieffers and Stadt 1994; Peterson and others 1996). Balsam poplar is well adapted to growing on wet floodplains and seepage slopes (Zasada and Phipps 1990) while white spruce cannot tolerate these wet locations with severe grass competition (Eis 1981; Grossnickle 1987).

Conclusions

The rooting of balsam poplar stem cuttings was strongly influenced by soil temperature. To successfully establish stem cuttings, soil temperatures greater than 5 °C (41 °F) are necessary to permit adequate leaf and root development. Soil temperature can be considered the major limiting factor on cool, wet sites for the planting of nonrooted cuttings in the boreal forest. These results will impact the planting time of nonrooted cuttings for reforestation purposes on these problem sites. The results of this study are limited to the effect of soil temperature on the rooting ability of nonrooted balsam poplar stem cuttings. However, other factors, such as the length of the cutting and the planting time in relation to reducing the effects of competition, need to be addressed in future studies. In addition, the selection of clones more tolerant to low soil temperatures might be considered.

Address correspondence to: Dr. Simon M. Landhausser, Department of Renewable Resources, 4-42 Earth Sciences Building, University of Alberta, Edmonton, Alberta, T6G 2E3, Canada; e-mail: < Simon. Land hausser@ualberta.ca >.

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Estimating Merchantable Seedlings in Nursery Seedbeds

Cuauhtemoc Saenz-Romero, Trent L. Marty, and Raymond P. Guries

Professor, Universidad Michoacana de San Nicolks de Hidalgo, Instituto de Investigaciones sobre los Recursos Naturales, Morelia, Michoacan, Mexico, Forest Tree Improvement Specialist, Wisconsin Department of Natural Resources, Bureau of Forestry, Madison, WI, and Professor, University of Wisconsin-Madison, Department of Forest Ecology and Management, Madison, WI

We determined the sample size needed to accurately estimate the number of merchantable seedlings per seedbed in forest tree nurseries in Wisconsin. Analysis of highly variable seedling stocking within some seedbeds indicates that it is better to use more, small, closely spaced samples distributed throughout a seedbed, rather than a few, large, widely spaced samples distributed across a seedbed. We suggest a new sampling design using 4-ft-long (1.22-m-long) row segments distributed throughout the seedbed, where the number of samples (row segments) can be adjusted proportionally to the heterogeneity of seedling density within the seedbed. Our approach is broadly applicable to other bareroot nurseries. Tree Planters' Notes 50(1): 23-27; 2003.

Estimating the number of merchantable seedlings prior to lifting is an important activity for any bareroot forest tree nursery. An accurate inventory is needed to balance the available nursery stock with customer orders. If the inventory is underestimated, customer orders must be canceled; if it is overestimated, surplus stock must be maintained for another year or be destroyed. In either instance, additional costs are incurred.

Current inventory procedures at State forest nurseries in Wisconsin proved reliable for seedbeds that were relatively uniform in seedling density. However, inconsistencies between the seedbed inventory and the number of seedlings actually lifted and shipped occurred when the seedbed density was highly variable. Such seedbed heterogeneity was attributed to the combined effects of variable seed germination, abiotic factors (wind erosion, hail damage, flooding, and mechanical damage during cultivation), and biotic factors (animal predation and localized disease and insect losses). Highly variable seedbeds required more sampling than seedbeds with uniform seedling density, but intensive sampling was too expensive. Thus, the dilemma was to find a sampling design that provided the necessary accuracy at a relatively low cost.

A simple strategy was designed and implemented to improve current inventory practices for estimating seedling numbers in a forest tree nursery operated by the Wisconsin Department of Natural Resources. We wanted to know the sample sizes needed to estimate seedling inventories in nursery seedbeds at given levels of precision and the appropriate distribution of samples across the seedbeds. We used data from an existing inventory to estimate the sample size needed. Then we tested a new sampling design on a highly variable seedbed.

Methodology

Like many bareroot nurseries, the Wilson State Forest Nursery (Boscobel, Wisconsin) produces tree seedlings in 4-ft-wide (1.22-m-wide) seedbeds several hundred feet long (figure 1a). Each seedbed contains 30 to fifty 12-ft-long (3.66-m-long) "beds"; these subdivisions are established solely for administrative purposes. Conifers are sown in 7 rows per seedbed, while hardwoods are sown in 5 rows per seedbed. Inventories are completed each summer when seedlings are 1 or 2 y old.

The current method of inventorying 2-0 conifer seedbeds (regardless of total seedbed length) consisted of counting the number of seedlings in 7 samples, 1 sample for each of the 7 rows (figure 1b). The samples were 12-ft-long segments of individual rows, distributed along an imaginary diagonal across the seedbed. Past sampling indicated that random placement of the samples usually provided better estimates, but the systematic placement of samples along a diagonal became (perhaps incorrectly) a standard method to simplify sampling. Hardwood seedlings *were* sampled in the same fashion as conifers, except that only 5 samples per seedbed were taken.

Data from a large existing inventory were used to provide preliminary estimates of the number of samples *(n)* needed for each of the 63 seedbeds at the nursery. We used the following model (Cochran 1977):

$$(1)\quad n = n_0 \,/\, [1 + (n_0 / N)]$$

where

$$(2)\quad n_0 = [(t_{\alpha/2,\, n-1} \cdot s)/(r \cdot \bar{x})]^2$$

And n= number of 12 ft long samples needed for a particular seedbed, ***N*** = total number of 12-ft-long row sections in the seedbed, ***t*** = tabulated value of Student t-test with x/2 ordinate (x=0.10), *n-1* degrees of freedom, s =

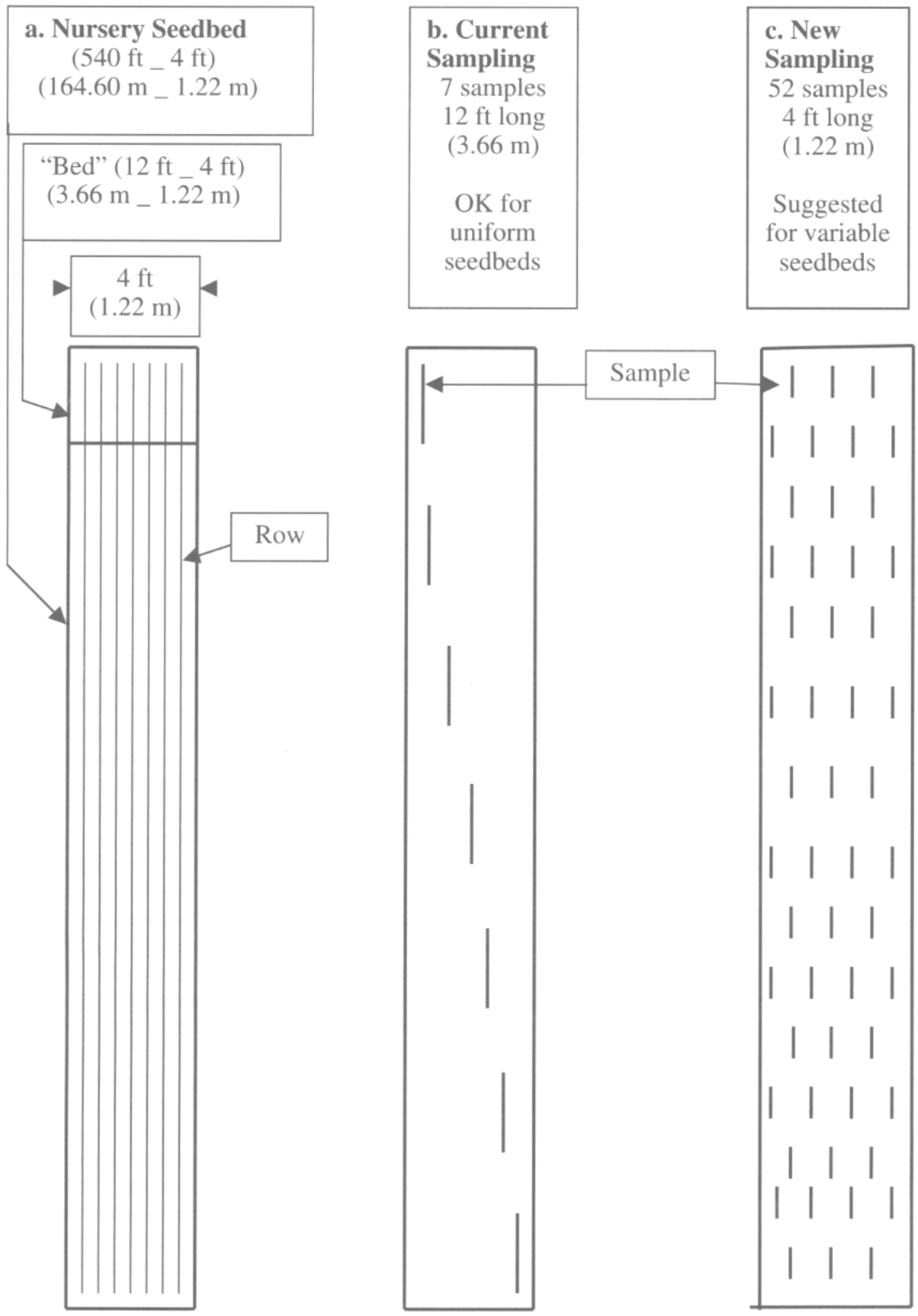

Figure 1—*Layout of (a) a conifer nursery seedbed, (b) the current sampling design used for seedling inventories, and (c) our proposed sampling design. The seedbed is not shown to scale.*

standard deviation of the sample, r = desired half width of the relative error (for example, an *r = 0.1 is* interpreted as ± 10% of the mean number of seedlings per sample), and x = mean number of seedlings per sample. An example showing the use of formulae (1) and (2) is provided in box 1.

Since large differences in seedling densities often existed among and within seedbeds, we divided the 63 seedbeds into 3 arbitrary groups based on their coefficients of variation (CV = (s / x) 100). These were identified as "best-case" (20 low-variability seedbeds, with 0 < CV <_ 20), "typical-case" (22 medium-variability seedbeds, with 20 < CV <_ 35), and "worst-case" (21 high-variability seedbeds, with 35 < CV) seedbed groups. Then we calculated the average sample size needed to provide estimates for each group of seedbeds by averaging estimated sample sizes for seedbeds within groups.

We also examined the distribution of the variability within a highly variable 2-0 red pine *(Pines resinosa* Ait.) seedbed (CV = 83) from our worst-case seedbed group. To estimate the variability among beds within a seedbed, we recorded the number of seedlings from 12ft-long samples in all 7 rows for 15 alternating beds. To estimate the variability within rows in beds, we subdivided the 12-ft-long row segments (105) into 4-ft-long segments or subsamples (315). We estimated variance components using ANOVA and VARCOMP procedures of the Statistical Analysis System (SAS 1988). The variability among 4-ft-long row segments nested within 12ft-long row segments became the error term in the analysis of variance.

Results and Discussion

The estimated sample size needed for seedbeds in the best-case group *(n= 9)* was similar to the sample size (ii = 7) currently employed with 12-ft-long (3.66-m-long) row segments along a diagonal (figure 1b). However, for the typical- *(n* = 28) and the worst-case *(n* = 75) situations, the minimum sample size needed to provide an accurate estimate of seedlings in highly variable seedbeds was well above current sampling practices. It is easy to understand why large discrepancies often existed between typical- or worst-case seedbed inventories and merchantable seedlings. Only 84 row-ft (7 samples x 12 ft) (25.6 row-m, 7 samples x 3.66 m) per seedbed had been sampled, but 336 row-ft (102.5 rowm) (28 samples x 12 ft) or *900* row-ft (274.5 row-m) (75 samples x 12 ft) would be needed for the typical- or worst-case scenarios, respectively.

Results from a highly variable (worst-case) seedbed indicated that most observed variation was distributed among beds (63% of the total variance; table 1).

Variation among rows within beds and among 4-ft-long (1.22-m-long) segments within 12-ft-long segments was essentially the same, accounting for 17% and 20% of the total variance, respectively. The relatively small variability among row segments and within row segments suggested that the size of each sample could be reduced here. This savings in time and effort would allow managers to survey a larger number of beds to account for heterogeneity in typical- and worst-case seedbeds. Thus, a sampling design using a larger number of smaller, more closely spaced samples distributed across more beds provided a better alternative for highly variable seedbeds.

Based on these results, we designed a new procedure to sample more beds using smaller sampling units. The new sampling design used fifty-two 4-ft-long row segments distributed in sets of 3 or 4 samples for each of 15 beds within a seedbed (figure 1c). Trials using this procedure produced estimates of the average number of seedlings per 4-ft-long row segment that were well within the 90% confidence interval obtained using very intensive sampling (table 2). In other words, adequate estimates of seedling numbers were achieved by measuring 208 row-ft (63.44 row-m) (52 samples x 4 ft) using the new design, rather than 336 row-ft (28 samples x 12 ft) or 900 row-ft (75 samples x 12 ft) required with the old design, for the typical- and worst-case scenarios, respectively.

We suggest the use of the proposed sampling proce-

Table 1—*Summary analysis of variance for a highly variable "worst-case" 2-0 red pine (*Pinus resinosa *Ait.) seedbed at the Wilson State Forest Nursery in Wisconsin*

Source of variation	Degrees of freedom	Mean square	% of total variance	*F* test
Beds	14	1438	63	19.8[a]
Rows (beds)	90	73	17	3.4[a]
Segments (row [bed])	210	21	20	

[a] Significant at the $P < 0.001$ level.

Table 2—*Average numbers of seedlings per 4-ft-long (1.22-m-long) row segments, and 1 standard error, based on initial intensive sampling of 63 seedbeds, in contrast to the proposed sampling design*

Estimator	Intensive sampling	Proposed sampling design	
		1st test	2nd test
Number of samples	315	52	52
Mean number of seedlings[a]	11.08 ± 0.92	11.30 ± 2.23	10.53 ± 2.41
Standard error	0.56	1.38	1.47

[a] 90% confidence interval.

dure for highly variable seedbeds. The number of samples can be adjusted proportionally to the seedbed variability for each inventoried seedbed. Sample means and standard deviations necessary to estimate the appropriate sample size (formulae 1 and 2) can be taken from existing inventories available at the nursery or from pilot samplings.

Further research is needed to test alternative procedures that might further reduce sampling time and effort without decreasing the quality of the inventory estimates (such as shorter sample segments, for example, 1-ft-long, 30.48-cm-long, row segments). Simulations to determine the optimal distribution of sampled row segments are also needed to better characterize variability among beds and within beds.

Conclusions

Highly variable nursery seedbeds require sample sizes proportional to their variability to provide accurate estimates of the number of merchantable seedlings. A large number of small samples (for example, 4-ft-long, 1.22-m-long, row segments) was preferable to a small number of large samples (for example, 12-ft-long, 3.66m-long, row segments) where considerable heterogeneity in seedling density existed. This appeared to be especially useful when most of the observed heterogeneity was among beds rather than within beds. The sample size needed to provide precise estimates of seedbed stocking is easily estimated using data from preexisting inventories or from pilot samplings.

Address correspondence to: Raymond P. Guries, University of Wisconsin-Madison, Department of Forest Ecology and Management, 1630 Linden Drive, Madison, WI 53706; **e-mail:** < rpguries@facstaff.wisc.edu >.

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Box 1—*Estimation of sample size.*

The sample size (n) needed to provide an estimate of the actual number of seedlings in a nursery seedbed depends upon the precision required and the variability within the seedbed. The formula for calculating 'n' is given by (Cochran 1977):

(1) $n = n_0 / [1 + (n_0 / N)]$

(2) $n_0 = [(t_{\propto/2,\, n-1} \cdot s) / (r \cdot \bar{x})]^2$

For this example, we used inventory data from seven 12-ft-long (3.66-m-long) row segments of a highly variable "worst-case" seedbed. The average number ($\bar{x}$) of seedlings in a 12-ft-long row was 123.4 and the standard deviation (s) was 50.5. The total number of 12-ft-long row segments (N) for that particular seedbed was 7 rows x 40 "beds" = 280. The degrees of freedom appropriate for estimating Student t-test was 7 - 1= 6. To be confident that 90 times in 100 the sample estimate was within a specified relative error (or error range) surrounding the population mean ($\propto = 0.10$), we consulted tabled values of Student t-test (for example, Steel and Torrie 1997). We chose a value (in this case, 1.943) that represented the $\propto$ probability (a "2-tailed" test) that the estimate would be within the relative error. A value of $r = 0.1$ was used, which provided a 20% width for the relative error (± 10% of the mean). Our experience suggested that this margin of error was acceptable because the inventory still met customer orders. To estimate the number of (12-ft-long) samples needed to be within the specified relative error containing the "true" population mean with 90% probability, we substituted into formula (2): $n_0 = [(t_{/2,\, n-1} \cdot s) / (r \cdot \bar{x})]^2 = [(1.943 \cdot 50.5) / (0.1 \cdot 123.4)]^2 = 63.23$

The formula $n = n_0 / [1 + (n_0 / N)]$ is a correction for finite population size. Substituting n_0 and N into formula (1): $n = n_0 / [1 + (n_0 / N)] = 63.23 / [1 + (63.23 / 280)] = 51.58$

Rounding the result, we concluded that a total of fifty-two 12-ft-long segments was an acceptable sample size for estimation of merchantable seedlings in that particular seedbed.

Installing a Practical Research Project and Interpreting Research Results

R. Kasten Dumroese and David L. Wenny

Research Plant Physiologist, USDA Forest Service, Southern Research Station, Moscow, ID and Professor/Director, Forest Research Nursery, Department of Forest Resources, University of Idaho, Moscow, ID

The basic concepts of the scientific method and research process are reviewed. An example from a bareroot nursery demonstrates how a practical research project can be done at any type of nursery, meshing sound statistical principles with the limitations of busy nursery managers. Tree Planters' Notes 50(1): 18-22; 2003.

Although they may not realize it, most growers already do nursery research. Have you ever done the following: (1) contemplated a problem at your nursery, (2) had an idea how that problem might be corrected after reading an article or discussing it with a colleague, (3) put in trials to test your guess, and (4) decided if your idea solved the problem? If so, you have done scientific research. Depending on how the research is done, the process can provide accurate and useful information, or it can yield conclusions that are meaningless. Our objective is to help growers design projects that yield meaningful results. Once you can design a good experiment, you can also tell if published research results are generated by a well-designed experiment and are worthy of consideration.

What Is Research?

Science is the possession of knowledge attained through study or practice. Research is the systematic search for new knowledge. Scientific research, simply stated, "is the testing (systematic, controlled, empirical, and critical investigation) of ideas (hypothetical propositions about presumed relations among natural phenomena) generated by intuition" (Stock 1985). Scientific research is carried out using the scientific method, which has 5 distinct steps (table 1). The process begins with observation, which can be practical experience, a literature review, or conversations with other nursery managers. It is followed by problem definition: specific questions are asked that you hope to answer. Third, the hypothesis is formulated and methods are selected for testing the hypothesis, based on the defined objectives. The 4th step, testing the hypothesis, involves collection, analysis, and interpretation of data. And finally, the hypothesis is accepted, rejected, or modified (Stock 1985).

Table 1—*Steps in the scientific method*

Steps	Example
1. A natural phenomenon is observed.	Ships sailing from port gradually disappear from sight, with the tops of the masts being the last part seen.
2. The problem is defined.	If the world is flat, why do ships gradually disappear from bottom to top?
3. A hypothesis (a guess) is made.	The world is not flat, but round.
4. A test is conducted.	Sail west from port and see if you return to where you started without falling off the end.
5. A theory is formulated.	The world is round.

When sufficient investigation is completed, a theory may be formulated. Theories are general explanations of natural events that are useful to understand, predict, and control natural phenomena. When installing practical research projects at our nurseries, we are probably not concerned with developing broad, sweeping theories of the universe. But we are interested, for example, in whether or not it is cost effective, in terms of improved growth, to double the amount of magnesium (Mg) we apply to 1+0 black cherry *(Prunus serotina* Ehrh.). To illustrate how an experiment is designed, we offer an example to answer this question using the steps of the scientific method. The same approach can be applied to any number of similar questions. Experiments are designed the same way whether you grow bareroot or container seedlings.

Following the Scientific Method-An Example

Observation. After a usually competent employee accidentally applies twice (2X) the normal amount of Mg to a barroxot bed of 1+0 black cherry, those seedlings appear taller than an adjacent bed. After measuring 100 random seedlings from each bed, we note that those receiving 2x Mg are 12 in (30 cm) taller. What can we conclude from this? Not much. This is an observational study: the study lacked control over which seedlings were in each treatment (1 x or 2x Mg). Are growth differences due to the 2X Mg? Possibly, but growth might be affected by seed source, soil conditions, or because the 1 x Mg bed was weeded 3 wk after the 2x Mg bed. Seed source, soil conditions, and weeds *confound* the issue of whether or not it is solely the Mg fertilizer. We cannot be certain about the treatment effects, only that 2x Mg is associated with increased growth. However, when talking with other nursery managers, they also report observing that extra Mg increases growth. Then we read about Mg nutrition. Based on our personal observations, discussion with colleagues, and reading papers (see box 1 at end of paper), we think seedling growth benefits from increasing the Mg fertilization rate.

Problem definition. Our problem statement is based on what we have seen and heard: our 1+0 black cherry seedlings may not be getting enough Mg fertilizer.

Stating the hypothesis. From the problem definition, we *could* state the following hypothesis: doubling Mg fertilizer increases growth of 1+0 black cherry. How would we test this hypothesis? As broad as this statement is, we would have to test all 1+0 black cherry seedlings, in all nurseries, on all possible nursery soil types, and all possible seed sources. And we would have to test several growing seasons to make sure weather did not affect the results! Often the hardest part of the research process is defining a concise, achievable objective. Another hypothesis more succinctly states our best guess: doubling the amount of Mg applied to 1+0 black cherry grown in fields 6 and 14 at our nursery increases seedling height. We then formulate the null (no effect) hypothesis: heights of 1+0 black cherry seedlings grown in fields 6 and 14 at our nursery that are fertilized with 1 x and 2X Mg *are the same.* The goal of our experiment is to determine which of these statements is true.

Testing. Randomly assigning seedlings to treatments is the most important part of the design of the experiment. Randomization ensures that, other than the treatment, systematic differences between or among groups of seedlings are lacking, allowing us to conclude the 2X Mg treatment is causing the observed result (increases in seedling height) in the experiment (Ganio 1997).

The 1 x Mg application serves as our "control" because this is the usual fertilization rate. Without a control for comparison, we cannot be sure our treatment has an effect. *One of the most common mistakes in installing a practical research study is failure to have an adequate control.* Our hypothesis is rather broad in that we think this will work for 1+0 black cherry, implying all possible seed sources of black cherry we might ever grow at the nursery. It is not realistic to include every possible seed source, but at least 3 should be included in the test. If only 1 seed source is used, and it happens to have a genetic trait that yields a growth response to Mg, we might conclude that 2x Mg is beneficial to all seed sources of black cherry when in fact it only favors that particular seed source. As stated in our hypothesis, we also want to check the effects of Mg in the 2 fields (6 and 14) in which we grow black cherry. We assume that soil in field 6 is fairly uniform and soil in field 14 is also fairly uniform, although the soils are not the same.

To determine that the Mg level is affecting growth, we must design the experiment so that the Mg level is not confounded. A location where the entire test plot has similar conditions is needed so that the only variable is the treatment (Columbo 1999). We *could* put 1 x Mg on all the black cherry in field 6 and 2X Mg on seedlings in field 14, but this is the incorrect approach because differences in soil conditions between the 2 fields would confound the Mg level. In other words, it would be impossible to determine if growth differences were due to Mg levels or soil conditions. Similarly, if Illinois seed sources were grown in field 6 while field 14 had Iowa seed sources, we would not be able to tell if any growth effects were due to Mg levels or the genetic differences between seed sources. Again, the experiment would be confounded.

To avoid confounding, researchers generally design experiments into blocks determined by the potentially confounding factors. In our test, these factors are the fields and the seed sources. Each field - seed source combination is a block, and each block receives both levels of Mg. Each field (2) - seed source (3) - Mg level (2) combination (we have 12; 2 X 3 X 2 = 12) is a plot. Plots must be replicated and their differences assessed to conclude with certainty whether the treatment and control seedlings are actually different. Growth differences between the I X and 2x Mg rates must be larger than the growth differences among replicates of the plots for the Mg rates to be considered different. A minimum of 3 replicates of each plot is encouraged; 4 to 6 are better.

If the 12 plots are each replicated 4 times, we have 48 distinct experimental units. The next step is lining these out in the fields. Think in terms of dividing the fields into grids with an equal number of plants in each grid (Columbo 1999). In a perfect study, the seed source - Mg level combinations would be randomly assigned across each field throughout the grid (figure 1). By so doing, portions of several beds would have multiple seed source - Mg level combinations, allowing us to compare seedling growth among seed sources and Mg levels with the same precision. In real life, however, this

Rep 1	Rep 2	Rep 3	Rep 4
1×-A	1×-C	2×-A	2×-B
2×-B	2×-A	1×-C	2×-C
2×-A	1×-B	1×-A	2×-A
1×-C	1×-A	2×-C	1×-B
1×-B	2×-C	2×-B	1×-A
2×-C	2×-B	1×-B	1×-C

Figure 1-The completely randomized layout of 24 plots that would be installed in each of the 2 fields having dissimilar soils. The 6 combinations of magnesium *level (1 X, 2 X) - seed source (A, B, C) are randomly assigned within each bed (column).*

A	B	C	
2×	1×	1×	
1×	2×	2×	Rep 1
1×	2×	2×	
2×	1×	1×	Rep 2
1×	2×	2×	
2×	1×	1×	Rep 3
2×	2×	1×	
1×	1×	2×	Rep 4

Figure 2-In this layout, magnesium levels (1 X, 2X) are randomly replicated 4 times within a bed of each seed source (A, B, C).

Seed A

	6-ft (1.8-m) buffer at end of bed (untreated seedlings)	
2×	8-ft (2.4-m) plot with 2× Mg	Replicate 1
	3-ft (0.9-m) buffer (untreated seedlings)	
1×	8-ft (2.4-m) plot with 1× Mg	
	3-ft (0.9-m) buffer (untreated seedlings)	
1×	8-ft (2.4-m) plot with 1× Mg	Truncated portion of Replicate 2

***Figure** 3-Spacing and location of the first 3 plots for seed source A shown in figure 2 (modified from Sandquist and others 1981).*

would make lifting while maintaining seed source integrity difficult. Since soil conditions within each field are similar, and because we are less interested in comparing growth among the seed sources than Mg levels, we can manipulate the design. Although not statistically perfect, we can plant each of the 3 seed sources, 1 seed source per bed, and lay out the remaining 8 experimental units (2 levels of Mg X 4 replicates) in each bed (figure 2). If we plant 100 bed-ft (30.5 m) of each seed source, each experimental unit could be 12.5 ft (3.8 m) long (divide 100 by 8). However, we should avoid using the ends (1st and last 6 ft, 1.8 m) of each bed because of the variability in seedbed density caused by starting and stopping the seed drill. That leaves 88 ft (26.8 m). We should also have a buffer (3 ft, 0.9 m) between treatments to adjust the fertilizer application rate of the equipment. That leaves 67 ft (20.4 m), or about 8 ft (2.4 m) per experimental unit.

After sowing the black cherry, we measure the beds as shown in figure 3. The first 6 ft (1.8 m) is avoided, then an 8-ft-long plot, a 3-ft-long buffer, an 8-ft-long plot (2.4 m, 0.9 m, 2.4 m) and so on is measured. We then randomly assigned the Mg levels to each plot. The process is repeated for each of the remaining 2 seed sources in field 6. We move the equipment to field 14 and repeat the process with the same 3 seed sources, 2 Mg levels, and 4 replicates.

When the Mg is applied, appropriate plots are fertilized with 1 *X* and 2x rates. Buffer strips between plots serve as the transition zone between fertilizer levels. Codes can be used to identify the plots to hide treatment identities and help reduce any bias that might occur during data collection and evaluation (Columbo 1999). *It is essential to make a detailed map of the layout in both fields, add the codes to the map, and store it in a safe place.*

From the time of sowing until the end of the growing season, cultural treatments to the experiment are implemented concurrently. That is, if you add ammonium sulfate, add it to all of the plots at the same application rate. Root prune or apply pesticides to all plots on the same day. The more uniformly cultural practices are applied, the more likely it will be that treatment effects are measured.

Measuring seedlings. At the end of the growing season, seedlings heights must be measured to determine if indeed Mg level affected height growth. In the perfect experiment, the number of seedlings to measure is determined by statistical methods. Often, the perfect statistical answer is tempered by real-world considera tions of time and money. Assuming seeds were sown to achieve 5 seedlings/ft= ($54/m^2$), each plot has about 160 trees. Measuring seedlings around the outer edges of the plots should be avoided because of "the edge effect" where seedling growth can be influenced by lower density, higher soil compaction in the wheel ruts, more light, and so on. With 7 rows in a bed, we can avoid measuring seedlings in the 2 outside rows and for at least 1 ft (30 cm) on each end of the plot (figure 4). That leaves about 70 seedlings in the center of each plot to measure for a total of 3360 seedlings in all the plots in both fields (2 Mg levels x 3 seed sources x 4 replicates x 2 fields x 70 seedlings = 3360). That is a lot of seedlings. Sub-sampling each plot by systematically measuring every 5th seedling in each row (5 per row x 3 interior rows = 15 seedlings per plot) would result in

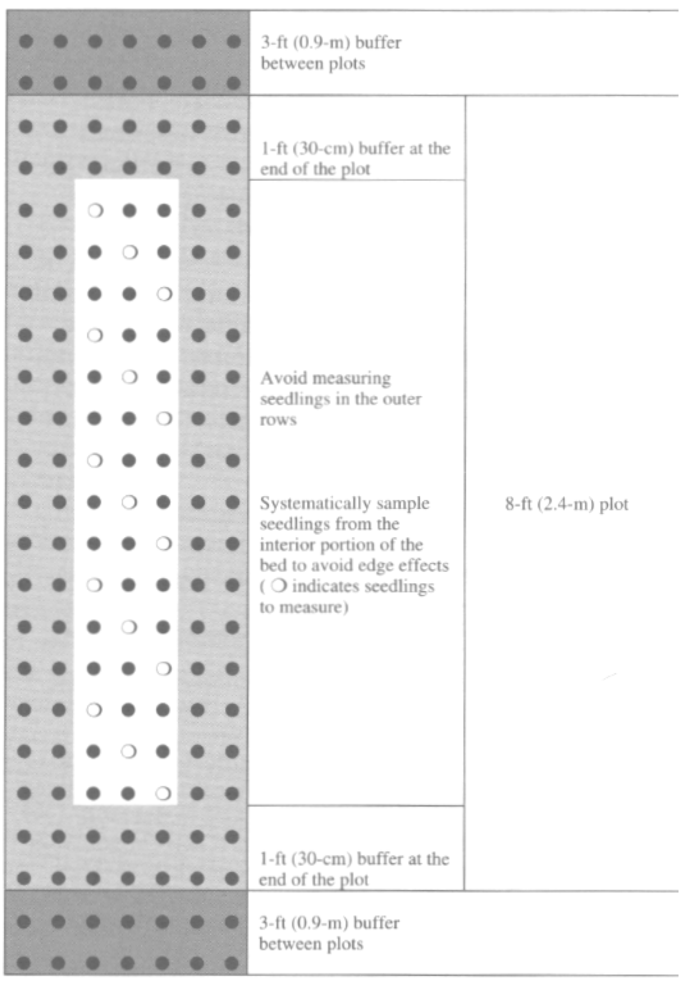

Figure *4-Measuring seedlings within a plot. To reduce the variability of measured seedlings, avoid measuring seedlings on the edges of the treatment plot. Depending on the number of remaining seedlings in the plot, a systematic sampling of seedlings might be most efficient in terms of labor.*

measuring a more realistic 720 seedlings. Have the same person collect data from each Mg level at the same time to reduce unwanted variability (Columbo 1999).

Statistics: accepting, rejecting, or modifying the hypothesis. Statistics do 2 things: estimate population parameters and test hypotheses about those parameters. In our example, we can use statistics to estimate the heights of the seedling populations that received 1x or 2X Mg, and then use those estimates to decide if the null hypothesis is correct (that seedlings have the same height regardless of Mg rate). Statistics do not prove anything: statistics only compute the probability of something happening and leave it to us to draw conclusions from that probability (Freese 1980). Usually the researcher selects the probability to use for testing the null hypothesis, often the 0.05 level of probability. If statistics show that the probability of the null hypothesis occurring is < 0.05, then the difference between treatments has less than 1-in-20 odds of occurring by chance; or stated the other way, in 19 out of 20 instances, the difference can be expected to be due to the treatment. In our experiment, if the probability of the null hypothesis (seedlings in 1 X and 2X Mg are the same height) being true is < 0.05, we can infer the alternate hypothesis is true (seedlings in 1 x and 2X Mg are not the same height).

Nursery managers have several options for complete analysis of their data. Several powerful statistical software packages are available, and some spreadsheet programs have statistical options. But without an understanding of the process by which the computer is generating the results, it is difficult to know if the answer is correct. An analysis of variance or t-test can be done by hand, and hand calculations are explained well in Freese (1980). However, we should not overlook another option. When our experiment is designed well, like the design of our hypothetical Mg experiment, we have a powerful tool to partition the variation in the data to the different sources (fields, seed sources, Mg fertilizer levels) and to evaluate the effects of any of the combinations of these factors. Such an experiment is likely to garner assistance from USDA Forest Service nursery specialists, statisticians, and editors of technology transfer publications who will realize the value of the work and can help you with data analysis.

If a basic evaluation of the data is all that is necessary, an easy way to compare treatments is to compare arithmetic means. Means are the average value of all the measured values in our experimental units. Calculators can generate means, along with the standard deviation and confidence interval. The standard deviation characterizes the dispersion of individuals around the mean. It indicates whether most of the individuals in a population are close to the mean or spread out. If the means are normally distributed, 67% of all individuals will be within ±1 standard deviation of the mean, 95% will be within ±2 standard deviations, and *99%* within ±2.6 standard deviations. A confidence interval provides a range of values inside which the true mean of the population resides. It is an indication of the reliability of the mean. Usually the upper and lower values that define the interval are set at a *95%* or *99%*, level. In other words, if you choose a 95% confidence interval (0.05 level of probability), unless a 1-in-20-chance event has occurred, the population mean is within the specified interval (Freese 1980). A very wide interval indicates a lot of variability in the measurements taken. Collecting more samples from the treatment plots may, or may not, yield a better estimate of the mean, which would be indicated by a narrower confidence interval.

Is it significant? For most growers, the statistical significance of the comparison of means is reduced to 1 simple question: *what is important to me, the grower?* Sometimes treatments can be significantly different from a statistical perspective, but not biologically or economically significant, so not meaningful to us. If 2X Mg treated black cherry were 2 in (5 cm) taller than the 1 x Mg treatment, and that was statistically different, would it be important to you as a grower? What if they were 6 in (15 cm) taller? Or 12 in (30 cm) taller? What if the treatment indeed made them taller, but less sturdy? Or if the treatment increased height but made them more susceptible to insects? As growers, we must interpret the statistical analysis of our data from both the qualitative and quantitative aspects.

Summary

Define your problem and subsequent hypothesis concisely, with very specific objectives of what you want to evaluate. Use blocking to eliminate confounding. Randomly assign seedlings to treatments. Include a control treatment. Treat all seedlings the same, except for the treatment itself, to reduce the chance of confounding. Although powerful statistical packages can be useful, for most growers, a comparison of means between or among treatment populations is probably sufficient enough to determine whether or not the treatment is biologically and economically significant. Growers with well-planned experiments should consider seeking assistance with statistics. Growers should share their results by publishing.

Address correspondence to: Kas Dumroese, USDA Forest Service Southern Research Station, 1221 South Main Street, Moscow, ID 83843; **e-mail:** < kdumroese@fs.fed.us >.

Box 1—*Reading scientific papers.*

Armson (1993) points out several things to consider when reading scientific papers: (1) just because a paper appears in a journal that requires peer review, do not assume the information is correct; (2) do not assume that previous research is cited correctly; (3) do not jump to conclusions. If you only read the abstract or conclusions with the purpose of deciding whether or not the authors agree with your point of view, bias may enter the decision. Papers must be read thoroughly, critically, and with an open mind. Check the references for titles of similar work and read them too.

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Monitor Tree Seedling Temperature Inexpensively With the Thermochron iButton® Data Logger

David S. Gasvoda, Richard W. Tinus, and Karen E. Burr

Engineer, USDA Forest Service, Missoula Technology Development Center, Missoula,MT, Former Plant Physiologist, USDA Forest Service, Southern Research Station, Flagstaff, AZ; and Horticulturist, USDA Forest Service, Coeur d'Alene Tree Nursery, Coeur d'Alene, ID

Monitoring the storage and shipping environments of planting stock is inexpensive with the $10 button-size temperature-recording device called an iButton®. Setting data collection parameters and downloading data are easy and require only a $15 iButton receptor that plugs into a COM port and uses free software. Tree Planters' Notes 50(1): 14-17; 2003.

Tracking tree seedling temperature from the nursery to the planting site can be the key to evaluating possible physiological causes of seedling mortality after outplanting. Seedlings enter and leave nursery storage with easily documented levels of cold hardiness, root growth potential, and general stress tolerance (Burr 1990; Ritchie and Tanaka 1990). The temperatures and the durations to which seedlings are exposed to them after leaving the nursery can dramatically alter these physiological quality attributes. This may occur directly by impacting tissue viability, or indirectly by affecting respiration, transpiration, and plant water relations. To determine how the environment may have interacted with seedling physiology and affected outplanting survival and performance, the environment must be measured. This can be accomplished easily and inexpensively with the Thermochron iButton® data logger manufactured by Dallas Semiconductor Corporation[1] .

Thermochron iButton Hardware and Software

The Thermochron iButton is a digital temperature recorder within a small (17.35 mm diameter x 6.76 mm thick, 0.68 in x 0.27 in), durable, water-proof, stainless steel case (figure 1). It interfaces with a computer by inserting into a receptor (Blue Dot Receptor, Serial Port, part number DS1402D-DRS, $5) with an RJ-11 (telephone) connector, that in turn inserts into a standard 1Wire® 9-pin COM port adapter (Universal Serial Port Adapter, part number DS9097U-009, $10), that then plugs into the serial port of the computer. These items can be purchased as a starter kit (part number DS1921K)

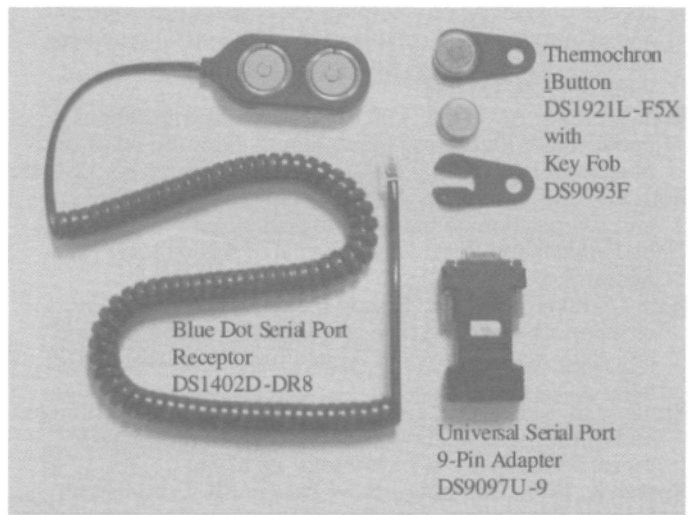

***Figure** 1-The Thermochron iButton' with hardware to interface to an IBM®-compatible computer using a Windows® platform.*

for $25. Additional Thermochron iButtons (part number DS1921L-F52), each with a unique 64-bit identification number, can be purchased for $10.34. Accessories are available to attach iButtons to almost anything (for example, a plastic flanged key fob, part number DS9093F, $0.80, figure 1). The self-extracting and installing "iButton Viewer" software, which is necessary to program Thermochron iButtons and review data, requires a Win32® platform, such as Windows 2000, 98, 95, or ND® (Microsoft Corporation), and is available without charge by downloading from the Dallas Semiconductor Web site:
< http://www.ibutton.com >. Any of these hardware items can be ordered there as well.

The digital thermometer measures temperatures from -40 to +85 °C (-40 to +185 °F) in 1 °C (1.8 °F) increments with an accuracy of ±1 °C (±1.8 °F). A real-time, clock calendar is Y2K compliant and accurate to ±2 min/mo within a 0 to 40 °C (32 to 104 °F) range. The recording interval selected can range from 1 to 255 min in 1-min intervals, with a starting offset of 0 min to 46 days. At each recording interval, the Thermochron iButton logs

__1 Dallas Semiconductor Corporation, 4401 South Beltwood Parkway, Dallas, Texas 75244-3292__
Tel: 972-371-6824 Fax: 972-371-3715 **e-mail:** < **http://www.ibutton.com/dsl921k.htrnl** >

the date, time, and temperature; updates a frequency histogram of temperature values; and, if requested, updates the date, time, and duration of up to 24 temperature events outside a range of selected alarm trip points. Recording stops or over-writes oldest data (selectable) after 2048 time-stamped temperature values are logged. The histogram feature is a long-term monitoring approach. The histogram has 63 data bins of 2 °C (3.6 °F) resolution with a maximum capacity of 65535 temperatures per bin. The lifespan of the nonreplaceable power source in the device is about I million measurements or 10 y, which ever comes 1st. The data sets are exportable as text (.txt) files for import into other software packages to enhance graphic presentation. Text files cannot be imported back into the iButton Viewer software.

Getting Started

A quick trip to the Web site will download the iButton Viewer software. Select "iButton-TMEX Runtime Environment Install for 32-Bit [Windows 98,95,NT] (Version 3.12) (Y2K Update)" near the bottom of the page. Save the file (tm312 32.exe) to disk (your hard drive). The space required is about 1.5 MB. Execute the file (double left-mouse click) to install it on your computer. The default install location is C:\Program Files\Dallas Semiconductor. Then start the iButton Viewer from the pull-up Windows menus: Start > Programs > iButton-TMEX. The iButton Viewer Help file installed at the same location provides information on using the device successfully.

The iButton Viewer main window displays the identification number of the serial port interface (ending in 09) and the identification numbers of the 1 or 2 Thermochron iButtons in the Blue Dot receptor (ending in 21). Determine which number goes with which Thermochron iButton by removing one and watching which number disappears. Click the Thermochron iButton number to select it. Then click the "click here for viewer" box in the lower right corner of the window and select "Thermochron Viewer." The Thermochron Viewer window has 3 tabs. Select the "wizard" tab to program a "mission." The process is straightforward and takes only a minute. Successive windows will prompt to set the Thermochron time from the computer clock, set the start delay period and sample rate, and to specify whether to over-write the first 2048 measurements. Alarm options are also set here. Selecting to view data in Fahrenheit or Celsius is accomplished at the top task bar of the iButton Viewer window in a pull-down menu under Options. Data can be converted from one scale to the other at any time.

Viewing and Exporting Data

Stored data can be viewed and saved during or after a mission by selecting "mission results," the 2nd of the 3 tabs at the Thermochron Viewer window. Three types of data are present: Temperature Alarms, Log, and Histogram. The Temperature Alarms window presents the starting and ending date and time of the occurrence of temperatures outside the high and low alarm limits. The Log window displays the date, time, and temperature of the 2048 time-stamped measurements. The Histogram window lists the 63 histogram bins and the count of the data in each bin. Viewing options available here also affect the export format of the data. They include changing the date and time to the number of minutes since the start of the mission, and various ways to describe histogram bins, such as by bin number, by the range of temperatures within the bin, or by the starting temperature of the bin. A viewing option available at the top taskbar pull-down Option menu, "show F/C on temperatures," adds or removes "°F" or "°C" from the Log and Histogram data. Removing the units can make graphing the data in another software package easier because the numerical temperature and the alphanumeric unit are assigned to the same commadelimited data field when the data are exported.

The Log and Histogram data sets are graphed at the Mission Results window quickly by just the push of a button. This option makes it easy to scan the data for any deviations from expected temperatures that may be of concern. Although there are no edit or print options for these graphs within the iButton Viewer software, editing and printing can be accomplished by exporting the data.

Data can be exported to a text file with a .txt extension by clicking the "export" button in the Mission Results window. Mission status information is exported in a tab-delimited sentence structure, and the actual logged data follows in a comma-delimited format. To open the text file from within Microsoft Excel®, for example, use the Text Import Wizard. Select "delimited,"both "tab" and "comma," and "general" as each question is asked. Once in the spreadsheet, a chart can be designed to suit your needs. A 2nd method for transferring the data to another program is available. Copying data to a clipboard, exiting out of the iButton Viewer software, opening a 2nd software package, such as Microsoft Word`', and clicking on the paste icon will import the data to a new file with a doc extension. This is a quick way to get a hard copy of the raw data. The iButton Viewer software "copy export data to clipboard" option is in the "file" pull-down menu at the top taskbar.

Viewing Mission Status

The "status" tab is the 3rd of the 3 tabs at the Thermochron Viewer window. Thermochron iButtons can be snapped into the Blue Dot receptacle and checked on at any time without disrupting a mission. Information provided includes current and starting date and time, whether the mission is in progress, the sample rate, whether over-writing of data has occurred, the start delay, and the number of samples taken in the current mission and in total over all missions. All this information is included at the top of the file with each export.

The option to stop the current mission is the last item on the Options pull-down menu in the top task bar. The data recorded remain stored when the mission is stopped, and continue to be stored until the Thermochron iButton is reprogrammed. Confirm a successful export of the data prior to reprogramming if you wish to save the data.

Sample Data

A sample data set was recorded by placing a Thermochron iButton in a shipment of trees sent from the Colorado State Forest Service Nursery, Fort Collins, CO, to the USDA Forest Service Rocky Mountain Research Station, in Flagstaff, AZ. Twenty-three seedlings, in the nursery's standard heavy paper shipping bag, left the nursery on 2000 May 22 at 12:00 PM in a van from the private mail carrier typically used by the nursery to deliver trees. Temperature measurements were logged every 30 min until 2 h after arrival at the Station in Flagstaff at 12:00 PM on 2000 May 25. The data were exported to Microsoft Excel, and the iButton Viewer software Log and Histogram graphs were recreated (figure 2).

The seedlings left nursery storage at 3.5 °C (38 °F) at Time = 0 h (figure 2a) and quickly rose to 34 °C (93 °F) the afternoon of May 22nd. This was, of course, much too warm for packaged dormant tree seedlings. Tree temperature dropped to about room temperature (21 °C, 70 °F) during the 1st and subsequent nights, but continued to approach 30 °C (86 °F) or 35 °C (95 °F) each afternoon. At noon on May 25th (Time = 72 h), the package entered the temperature-controlled Flagstaff office complex and returned to room temperature. The histogram of the frequencies of various temperatures in 2 °C (3.6 °F) intervals provides an indication of the relative amount of time spent at the various temperatures (figure 2b). About half the total trip time was spent at temperatures greater than or equal to 26 °C (79 °F). Nurseries shipping trees through the mail can easily conduct similar tests to assess the insulative value of their packaging materials and the temperature stresses encountered en route.

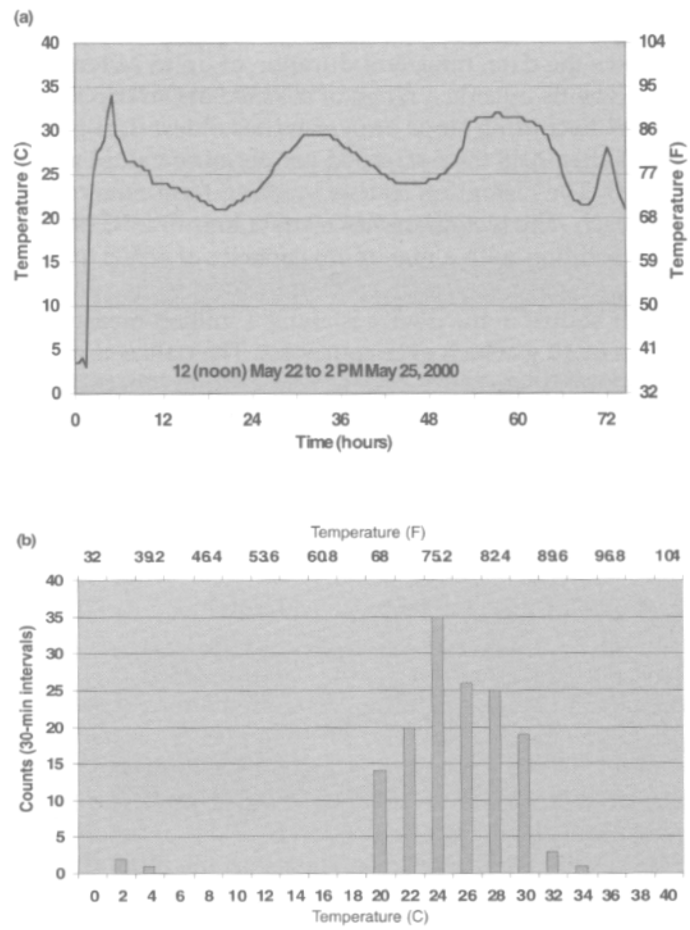

Figure 2-(a) An Excel® re-creation of the iButton Viewer® software Log graph of time-stamped data. Temperatures were measured in a shipment of trees en route from the Colorado State Forest Service Nursery, Fort Collins, CO (leaving at 12 PM on 2000 May 22), to the Rocky Mountain Station, in Flagstaff, AZ (arriving at 12 PM on 2000 May 25). (b) An Excel recreation of the iButton Viewer software Histogram graph of the same time-stamped data. Bars represent the frequency of temperatures measured at 30-min intervals in transit from Fort Collins, CO, to Flagstaff, AZ, from 2000 May 22 to 2000 May 25.

Summary

The Thermochron iButton, manufactured by Dallas Semiconductor, has the features we were looking for in a recording device for monitoring tree temperature from nursery production to outplanting: reliability; weather resistance; a wide, measurable temperature range; ease of use; and minimal expense. This device should be very useful to both producers and receivers of tree seedlings for determining the likelihood that temperature exposure has impacted tree survival and performance.

Address correspondence to: David S. Gasvoda, USDA Forest Service, Missoula Technology and Development Center, Fort Missoula, Bldg. 1, Missoula, MT 59804

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Disclaimer

The mention of commercial products is solely for the information of the reader. Endorsement is not intended by the Forest Service or the U.S. Department of Agriculture.

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Survival and Growth of Selected White Spruce Container Stock Types in Interior Alaska

Jeff S. Graham and Tricia L. Wurtz

Alaska Department of Natural Resources, Division of Forestry, Palmer, AK, and USDA Forest Service, Boreal Ecology Cooperative Research Unit, Fairbanks, AK

Survival and growth of white spruce (Picea glauca *(Moench) Voss) seedlings raised as 4 different-sized container stock types were followed on 5 harvested sites in the Cache Creek drainage of interior Alaska. Stock types evaluated were 1-0 Ray Leach Pine Cells® (65 cm^3, 4 in^3) and 1-0 Styroblock® sizes 313B (65 cm3, 4 in3), 415B (98 cm3, 6 in3), and 415D (164 cm^3, 10 in^3). After 5 y, survival and height growth were mixed. Ray Leach Pine Cells had a significantly higher rate of survival than seedlings grown in Styroblock 313B containers, but there were no differences among the survival of Ray Leach and the other 2 Styroblock sizes, nor among the Styroblock sizes themselves. Survival of all 4 stock types varied dramatically among sites. Although this experiment was not designed to evaluate site factors, lowest survival rates (25% to 40%) may have been related to the bluejoint grass* (Calamagrostis canadensis *(Michx.) Beauv.) and fireweed* (Epilobium angustifolium *L.) cover found in 2 of the sites, and highest survival (90%) may have been related to the slight topographic elevation of 1 site. Seedlings grown in Styroblock containers were substantially taller at planting than those grown in Ray Leach containers; this difference was maintained after 5 y. Stem diameter did not differ significantly among stock types, either at planting or after 5 y. Our results reiterate that seedling out planting performance is a complex f unction of many factors, including stock type, competing vegetation, and microsite, and suggest that more research on the performance of different stock types in Alaska is needed before standard stock types can be identified for various site conditions.* Tree Planters' Notes 50(1): 44-49; 2003.

Over the last 10 y, the timber harvest on State lands of interior Alaska has averaged approximately 400 ha (Clautice, personal communication, see "Notes"), with some additional harvesting occurring on Alaska Native Corporation and other private lands. Clearcutting is the most common harvest method used for white spruce *(Picea glauca* (Moench) Voss) in this region. Because seed production in white spruce varies greatly from year to year (Zasada and Viereck 1970; Rupp 1998), prompt natural regeneration requires that forest management activities be timed to coincide with good seed years (Zasada 1980). Although spot seeding and natural regeneration have been used successfully (Densmore and others 1999), planting seedlings has become a common regeneration method. In recent years, an average of 350,000 white spruce seedlings has been planted annually on 300 ha (about 750 acres) in the Fairbanks area (Lee, personal communication, see "Notes").

The 1st white spruce plantations in Alaska were established in the late 1970s with all planting stock produced at a single nursery. In the early 1990s, some Alaskan forest managers began to purchase seedlings outside Alaska from nurseries with an increased selection of containers. The applicability of stock type trials from other regions was uncertain and information on outplanting performance under Alaskan conditions was needed. Cole and others (1999) found that plug+1 white spruce seedlings had slightly higher survival and were taller than container-grown seedlings 5 y after outplanting in south-central Alaska. Our study was conducted in interior Alaska using seedlings produced in different container sizes: Ray Leach Pine Cells® and 3 Styroblock® sizes.

Methods

White spruce seedlings from a single, local seed source were produced at 2 nurseries from spring through summer 1992 (table 1). The State forest nursery at Eagle River, AK, used Ray Leach Pine Cells (Landis and others 1990), and Pelton Reforestation at Maple Ridge, British Columbia, used Styroblock 313B, 415B, and 415D containers (Scagel and others 1993). Seedlings were shipped from the nurseries and held in a shade house for less than 2 w prior to planting.

Study plots were located on 5 different operational cutting sites, all located within 2 km (1.24 mi) of each other in the Cache Creek drainage (lat 64°50'N, long 148°17'W), about 24 km (15 mi) west of Fairbanks. Sites all occurred on a gentle south- to southwest-facing slope or on the bench on top of the slope; they varied in size and shape. The mean annual temperature at Fairbanks, the nearest recording station, is -3.2 °C (26.2 °F) and mean annual precipitation is 26.5 cm (10.4 in). Before harvesting, the sites supported a mature, productive "closed white spruce forest" (Viereck and others 1992) with paper birch *(Betula papyrifera* Marsh) and occasional quaking aspen *(Populus tremuloides* Michx.). Common understory plants were mountain alder *(Alnus crispa* (Ait.) Pursh), lingonberry *(Vaccinium vitis-idaea L.),* fire-

Table 1—*Container specifications and size of white spruce (*Picea glauca *(Moench) Voss) seedling stock types at planting*

Stock type[a]	Container depth (cm)	Container depth (in)	Container volume (cm^3)	Container volume (in^3)	Cell spacing (cm)	Cell spacing (in)	Shoot height $\bar{x} \pm s_{\bar{x}}$ (cm)	Shoot height $\bar{x} \pm s_{\bar{x}}$ (in)	Stem diameter $\bar{x} \pm s_{\bar{x}}$ (mm)	Root:shoot ratio
Ray Leach Pine	16	6.3	65	4	3.0	1.18	14.1 (0.5)	5.6 (0.20)	2.2 (0.05)	0.66
Styro. 313B	13	5.1	65	4	3.4	1.34	16.6 (0.6)	6.5 (0.24)	3.1 (0.1)	0.90
Styro. 415B	14	5.5	98	6	4.2	1.65	15.5 (0.8)	6.1 (0.32)	3.5 (0.1)	0.52
Styro. 415D	15	5.9	164	10	5.0	1.97	18.5 (0.9)	7.3 (0.35)	3.6 (0.08)	0.62

[a]Ray Leach Pine Cells®; Styroblock® 313B, 415B, 415D.

weed *(Epilobium angustifolium L.),* bluejoint grass *(Calamagrostis canadensis* (Michx.) Beauv.), squashberry, *(Viburnum edule* (Michx.) Raf.), and prickly rose *(Rosa acicularis* Lindl.) (USDA NRCS 2001). Soils in this area are moderately deep, well-drained, silty loams, with a parent material of micaceous loess underlain by Birch Creek schist (Rieger and others 1963).

The sites had been clearcut less than a year before planting and had received single-disk trencher scarification treatment approximately a month before planting. The seedlings were hand-planted on sides of trenches beginning in late July 1992. The layout was a randomized block design with different cutting sites as blocks; 60 seedlings per stock type were planted per block. The height and diameter of a separate sample of seedlings was measured at planting; then these seedlings were oven-dried, clipped at the root collar, and weighed to determine root:shoot ratio. All planted seedlings were measured for height and groundline diameter after 2, 3, and 5 growing seasons. Seedling survival was tallied at each measurement.

Mean heights, diameters, and survival percentages were subjected to analysis of variance, and means were separated using Tukey's procedure. Survival percentages were normalized prior to analysis with the arcsine transformation (Zar 1984).

During the 3rd growing season of the study, the vegetation associated with the planted seedlings was assessed. Three seedlings of each stock type were randomly selected in each site, for a total of 60 seedlings. Circular 1-m^2 (10.76-ft^2) plots were established around the stem of each seedling, and the percent cover of each plant species was visually estimated.

Results

After 5 years, considerable mortality had occurred (table 2). Larger initial seedling or container size did not increase field survival. Rather, survival of the stock type that was smallest at planting, seedlings from Ray Leach Pine Cells, was highest but not significantly greater than the largest seedlings grown in 415D Styroblocks. In the most striking result of the study, survival of all 4 stock types varied dramatically by study site (figure 1). For example, survival of 415D seedlings varied from 25% to 85% and that of Ray Leach varied from 43% to 90%, depending on study unit (table 2).

At planting, seedling diameter more closely reflected container volume and cell spacing than did seedling height (table 1). After 5 y, there were no significant differences in diameter among any of the stock types examined in this study. The Ray Leach Pine Cell seedlings were shortest at planting and remained significantly shorter than the 313B and 415B Styroblock types after 5 y (table 3). However, height did not differ significantly among the 3 Styroblock stock types (figure 2).

Eighteen species or groups of associated vegetation were tallied in the 5 study sites (table 4). Of those, fireweed and bluejoint grass were the most frequently encountered; these 2 species also accounted for the most cover. Although all 5 sites supported similar amounts of total cover (all species combined), the 2 sites in the western end of the study area (Sites 1 and 2) had the most fireweed and bluejoint grass (table 5). After 5 y, seedling survival in Sites 1 and 2 was clearly the lowest (figure 1).

Table 2—*Percent survival of white spruce (*Picea glauca *(Moench) Voss stock types 5 y after outplanting near Fairbanks, AK*

Site	Stock type[a] RLPine	313B	415B	415D
1	43	27	25	25
2	54	29	42	32
3	65	36	60	76
4	65	52	67	61
5	90	69	78	85
All sites[b]	70 (8.4) a	47 (8.7) b	62 (8.8) ab	62 (12.9) ab

[a]RLPine = Ray Leach Pine Cells®; others are Styroblock®
[b]Means, $\bar{x} \pm s_{\bar{x}}$, followed by the same letter are not significantly different (Tukey's test, $P \leq 0.05$).

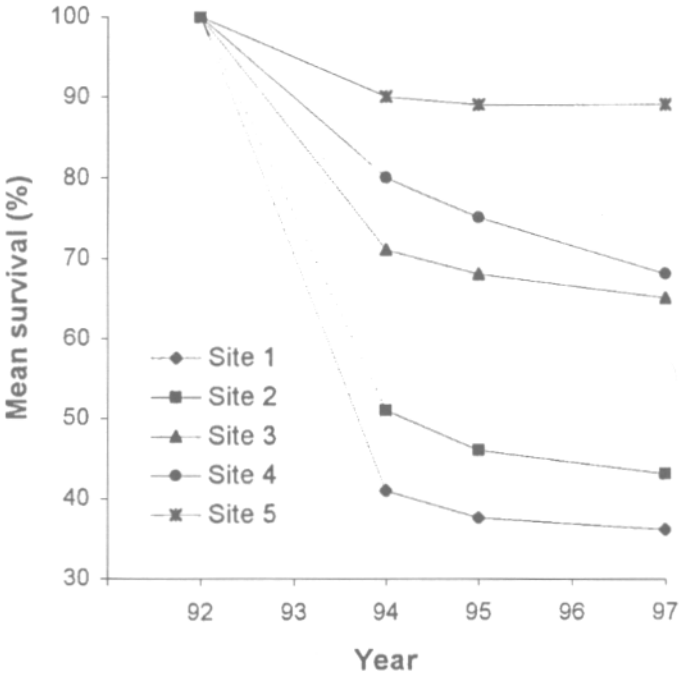

Figure 1—*Mean survival of all white spruce (*Picea glauca *(Moench) Voss) seedlings on 5 planting sites near Fairbanks, AK*

Discussion

Whether summarized by stock type or by site, seedling survival in the present study was low compared to that of other plantations in interior Alaska. Styroblock 415D seedlings planted in 1993 on an upland ,site near the Cache Creek drainage had 5-y survival ranging from 80% to 88% (Wurtz 2000), while Ray Leach Pine Cell seedlings planted on a nearby floodplain site in 1983 had 5-y survival greater than 96% (Youngblood and Zasada 1991). In south-central Alaska, Cole and others (1999) reported the average survival of a number of white spruce stock types to be greater than 74% under a variety of site preparation treatments.

The 5-y height of Ray Leach Pine Cell seedlings in the present study is comparable to similar seedlings planted on other Alaska sites (Youngblood and Zasada 1991; Cole and others 1999). However, Styroblock 415D seedling size (table 3) is somewhat less than reported by Wurtz (2000) for 5-y size of Styroblock 415D seedlings on a nearby site (94 to 96 cm, 37.0 to 37.8 in, average height; 14 to 16 mm, 0.55 to 0.63 in, average diameter). In northwestern Alberta, the height of container-grown white spruce seedlings at 5 y ranged from 25 to 46 cm (9.8 to 18.1 in) (Walker 1987). In northern British Columbia the seedlings ranged from 35 to 122 cm (13.8 to 48.0 in) (Van Eerden 1978; McMinn 1982). In general, the growth rate of planted white spruce seedlings in the

Table 3—*Height and diameter, $\bar{x} \pm s_{\bar{x}}$, of white spruce (*Picea glauca *(Moench) Voss) stock types 5 y after outplanting near Fairbanks, AK*

	Stock type											
	Ray Leach Pine Cells®			Styroblock® 313B			Styroblock 415B			Styroblock 415D		
	Height		Diameter	Height		Diameter	Height		Diameter	Height		Diameter
Site	(cm)	(in)	(mm)	(cm)	(in)	(mm)	(cm)	(in)	(mm)	(cm)	(in)	(mm)
1	55.3 (3.8	21.8 (1.5)	8.2 (0.6)	77.4 (6.3)	30.5 (2.5)	12.8 (1.1)	73.5 (4.3)	28.9 (1.7)	11.1 (0.6)	60.1 (6.6)	23.7 (2.6)	9.3 (1.1)
2	44.2 (3.3)	17.4 (1.3)	7.8 (0.5)	65.5 (5.7)	25.8 (2.2)	10.4 (1.1)	59.1 (4.3)	23.3 (1.7)	8.6 (0.6)	50.8 (4.4)	20.0 (1.7)	7.7 (0.5)
3	55.1 (3.0)	21.7 (1.2)	7.6 (0.3)	67.8 (5.2)	26.7 (2.1)	9.6 (0.7)	83.4 (4.2)	32.8 (1.7)	11.7 (0.5)	79.7 (4.1)	31.4 (1.6)	15.0 (3.7)
4	62.1 (3.8)	24.4 (1.5)	9.6 (0.5)	75.5 (6.0)	29.7 (2.4)	11.3 (0.9)	76.1 (3.0)	30.0 (1.2)	10.7 (0.5)	69.4 (3.8)	27.3 (1.5)	10.2 (0.6)
5	61.5 (2.6)	24.2 (1.0)	8.9 (0.3)	68.7 (3.4)	27.0 (1.3)	10.3 (0.3)	64.4 (3.0)	25.4 (1.2)	9.7 (0.4)	82.3 (3.7)	32.4 (1.5)	11.2 (0.5)
All sites[a]	55.6 (3.2)a	21.9 (1.3)	8.4 (0.3)y	71.0 (2.3)b	28.0 (0.9)	10.9 (0.5)y	71.3 (4.3)b	28.1 (1.7)	10.3 (0.5)y	68.4 (5.9)ab	26.9 (2.3)	10.7 (1.2)y

[a]Values followed by different letters (height, a, b; diameter, y, z) are significantly different (Tukey's test, $P \leq 0.05$).

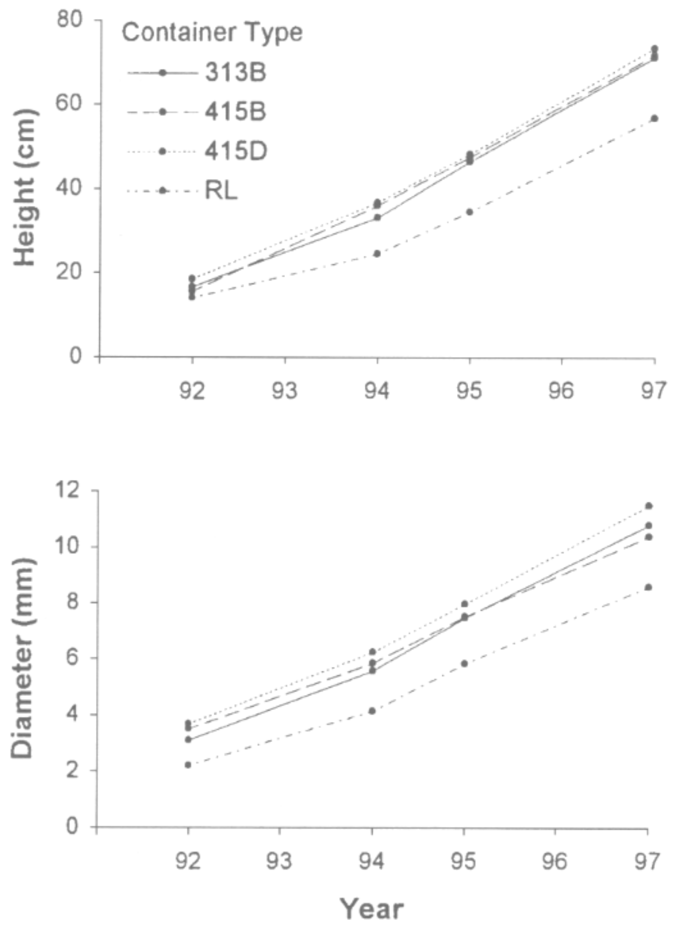

*Figure 2—Mean height and diameter of different stock types of white spruce (*Picea glauca *(Moench) Voss) over the 1st 5 y after planting near Fairbanks, AK (RL=Ray Leach Pine Cells®; others are Styroblock®).*

Table 4—*Species found associated with planted white spruce (*Picea glauca *(Moench) Voss) on each of 5 sites near Fairbanks, AK, 3 y after clearcut harvesting (USDA NRCS 2001)*

Common name	Scientific name
mountain alder	*Alnus crispa* (Ait.) *Pursh*
bluejoint grass	*Calamagrostis canadensis* (Michx.) *Beauv.*
bunchberry dogwood	*Cornus canadensis* L.
fireweed	*Epilobium angustifolium* L.
field horsetail	*Equisetum arvense* L.
northern bedstraw	*Galium boreale* L.
twinflower	*Linnaea borealis* L.
tall bluebells	*Mertensia paniculata* (Ait.) G. Don
white spruce	*Picea glauca* (Moench) Voss
quaking aspen	*Populus tremuloides* (Michx.)
prickly rose	*Rosa acicularis* Lindl.
red raspberry	*Rubus idaeus L. var. strigosus* (Michx.) Maxim
willow	*Salix* spp.
russet buffaloberry	*Shepherdia canadensis* (L.) Nutt.
common dandelion	*Taraxacum officinale* G. H. Weber ex Wiggers
lingonberry	*Vaccinium vitis-idaea* L.
squashberry	*Viburnum edule* (Michx.) Raf.
violet	*Viola* spp.

Table 5—*Percent cover ($\bar{x} \pm s_{\bar{x}}$) of fireweed (*Epilobium angustifolium *L.), bluejoint grass (*Calamagrostis canadensis *Michx.), and total of all species 3 y after clearcut harvesting in 5 sites near Fairbanks, AK*

Site	Cover (%)		
	fireweed	bluejoint	Total
1	42.0 (7.3)	22.6 (6.2)	76.6 (5.4)
2	26.3 (6.7)	34.1 (9.9)	75.4 (5.9)
3	11.2 (5.8)	5.8 (3.1)	75.8 (4.6)
4	15.4 (0.9)	0.9 (0.5)	62.9 (5.7)
5	18.0 (4.0)	7.4 (3.3)	69.1 (6.9)

Cache Creek drainage appears typical despite the somewhat low survival.

Comparisons of white spruce stock types have been conducted across Canada, with most reports comparing bareroot with container-grown seedlings (Dobbs 1976; Vyse 1981; Burdett and others 1984; Ball and Kolabinski 1986). The results of these studies have been mixed, possibly due to differences in planting sites and stock type condition at the time of planting. Comparisons among container-grown seedlings have been more consistent. In general, seedlings grown in larger containers have been larger at planting and have survived and grown better than seedlings from smaller containers (Van Eerden 1978; McMinn 1982; Walker 1987; Sutherland and Day 1988; Thompson and McMinn 1989; Simpson 1991).

Although this study was not designed to compare site factors statistically, we believe that observed differ ences may be associated with site factors, and seedling survival seemed to be more closely related to site factors than to stock type. Although the 5 study sites were located along a single, continuous hillside, and were harvested, scarified, and planted at the same time, they varied in the composition of their associated vegetation. Sites I and 2 had far more cover of fireweed and bluejoint grass, 2 species that compete aggressively with newly planted seedlings (Lieffers and Stadt 1994). The study sites did not receive any brush control; competition and overtopping were present. Seedling survival was much lower in those 2 sites than in the other sites used in this study, regardless of stock type. No one stock type demonstrated any particular ability to survive competition from those 2 species. Interestingly, relative survival was largely consistent across the range of conditions presented, with Ray Leach seedlings surviving best on sites with heavy bluejoint grass as well as in sites with little competition.

Seedling survival of all 4 stock types was markedly higher in Site 5 than in the other 4 sites. Because there were no differences in associated vegetation among Sites 3, 4, and 5, the high survival in Site 5 cannot be attributed solely to a lack of competition from bluejoint and fireweed. Because we did not collect soil or microclimatic data, we can only speculate that the difference may have been due to elevation. Site 5 was about 30 m higher in elevation than the other study sites, located on a bench on top of the slope. This position likely allowed more solar radiation, and had warmer soils than the other study sites (Slaughter and Viereck *1986).*

For white spruce seedlings, increasing container volume and cell spacing have resulted in increased field growth (Van Eerden *1978;* McMinn *1982;* Walker *1987;* Sutherland and Day *1988;* Thompson and McMinn *1989).* However, in this study, seedling height at 5 y was not significantly different among the Styroblocks, despite an apparent height advantage for the 415D Styroblock seedlings at planting. Similarly, Simpson *(1991)* found that height growth in the field was not strongly affected by nursery spacing. As with survival, 5-y height and height growth were significantly affected by site (PS 0.05).

In Canada, white spruce survival generally improves with larger container size (Sutherland and Day *1988),* but larger size did not enhance survival in the present study. Geographic differences in survival may be related to climate; interior Alaska typically has an early summer drought when soil frost depth is still shallow (Slaughter and Viereck *1986).* Smaller stock types may tolerate these conditions better than larger stock types.

The practical implication of our results is that one cannot reliably predict what the response of a stock type will be on any given site. Yet, stock type selection involves many factors, including cost and predicted planting site competition (Scagel and others *1993).* Larger seedlings generally cost more than smaller seedlings (Landis and others *1990),* but nursery pricing may be determined by more than greenhouse space alone. In the present study, larger stock types maintained superior height but not superior diameter nor survival. If planting density remains unchanged, then plantation establishment costs would likely be increased by using larger stock. The economic gain from improved growth by planting larger stock types was not evaluated. However, based on these limited data, the use of midsize or smaller stock types in interior Alaska appears justified.

Our results reiterate that seedling outplanting performance is a complex function of many factors, including stock type, competing vegetation, and microsite, and suggest that more research on the performance of different stock types in Alaska is needed.

Address correspondence to: Jeff S. Graham, Alaska Department of Natural Resources, Division of Forestry, 101 Airport Road, Palmer, AK *99645, USA.* ***e-mail:*** < Jeff_Graham@dnr.state.ak.us >

Notes: Personal communications with the following individuals are cited and unreferenced.

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