Tree Planters' Notes

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Comments

Tree Planter's Notes Is Back!

Volume 52(1) is the second issue of *Tree Planters' Notes* (TPN) to be published with Dr. Robin Rose, Oregon State University, as Managing Editor. We still plan to reach our stated goal of publishing TPN twice a year. For this issue, unfortunately, we were stymied by "start-up" glitches in the editing and layout process, as well as the need to develop an adequate supply of manuscripts moving through the publication process. These problems have been addressed, and we are hopeful this will be the beginning of a regular semi-annual publication schedule.

As with the last issue, volume 51(1), we are distributing this issue at no cost to the subscribers of *Forest Nursery Notes* to make potential users of TPN aware it is being restarted. Unfortunately, we cannot directly reach all the past subscribers of TPN. Because of the lapse in publication from 2000 to 2003, the Government Printing Office removed TPN from its publication list, cancelled existing subscriptions, and erased the subscriber list from its database. We plan to distribute TPN at no cost for the next couple of issues. After that time, we will determine if there is enough interest in TPN to again offer it through paid subscriptions.

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Forest Nursery Notes
JH Stone Nursery
2006 Old Stage Road
Central Point, OR 97502-1300
FAX: 541-858-6110
E-Mail: nurseries2@aol.com

As manager of TPN, I would like to thank those who have written to express their appreciation that this publication is being restarted, as well those who have shared suggestions on improving this publication to better meet your needs. ***Please continue to give us your input, and share your expertise and information by contributing articles to TPN!***

Ron Overton
Manager of *Tree Planters' Notes*

Dedicated to technology transfer and publication of research information relating to nursery production and outplanting of native and introduced trees and shrubs for reforestation, restoration, and conservation.

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General Manager: **Dr. Ronald P. Overton**
Managing Editor: **Dr. Robin Rose**

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robin.rose@oregonstate.edu

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Although *Tree Planters' Notes* continues to move slowly forward, we are making progress in attracting new and interesting articles. This edition contains seven such articles that cover quite a bit of ground from the Pacific Northwest, Midwest, and Canada. Below is a short synopsis of the articles in this edition.

All bareroot growers are interested in organic amendments to their fields. The Davis et al. article provides a good review and education on how soil properties are affected. Their objectives were to determine the influence of organic soil amendments (chicken manure, hardwood sawdust, and compost) on soil chemistry and to assess the contribution of these amendments to the biomass production of a sorghum cover crop. Many managers are likely to greatly appreciate the data contained in this article.

Stem splitting and cankering in Pacific Northwest Douglas-fir seedlings has been an issue for quite some time. Haase et al. provide a very short but comprehensive review of the topic. Pushing seedlings to grow big over a short time span will have its problems.

Johnson and Copes follow with a paper on topworking Coastal Douglas-fir. The term topworking refers to the grafting of young scion material into tops of older, reproductively mature trees. This may be one of the first papers to report on topworking in Douglas-fir.

Jutras et al. from Quebec evaluated the effect of rooting media on seedling planting shock in black spruce. To do this, they planted three large stock types—containerized, containerized with washed root systems, and bareroot. They measured xylem water potential weekly. This is a rather unique trial and those who plant container seedlings should find the results interesting.

Stunting of Douglas-fir seedlings in their first year has long been one of those big mysteries. Linderman et al. look a the possible causes of 1+0 stunting. Is it a lack of mycorrhizae, phosphorus deficiency, or moisture stress? How about certain pathogens? What is the role of fumigation?

Tauer in Oklahoma presents a paper entitled "Performance of a wide-ranging Collection of Black Locust Seed Sources in Western Oklahoma." The results from a 1987 study showed the negative impact of hot dry summers. Those interested in this species will probably find the data useful.

One of the more traditional roles of TPN over the decades has been to publish papers about equipment. Zalesny et al. offer detailed plans on an inexpensive and reliable monitoring station design.

That wraps it up. I hope very much that you enjoy this edition of *Tree Planters' Notes*. If you want to publish a paper in TPN please contact me. See the end of this copy for the section on "Guidelines for Authors."

ROBIN ROSE
Managing Editor
Tree Planters' Notes

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Organic Matter Amendment of Fallow Forest Tree Seedling Nursery Soils Influences Soil Properties and Biomass of a Sorghum Cover Crop

REFEREED PAPER

Anthony S. Davis, Douglass F. Jacobs, and Kevyn E. Wightman

Graduate Research Assistant, Associate Professor, and Postdoctoral Researcher, respectively Hardwood Tree Improvement and Regeneration Center, Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN

Abstract

To maintain adequate soil organic matter, bareroot nurseries may add organic amendments, grow and incorporate cover crops between seedling production cycles, or both. We examined the influence of amendment of nursery soils with organic materials on both soil properties and biomass production of a sorghum (*Sorghum* spp.) cover crop. Level of organic matter, pH, cation exchange capacity, and concentrations of P, K, Ca, and Mg were all significantly influenced by application of chicken manure, sawdust, compost, or leaves. Above-ground biomass of the sorghum cover crop was highest with application of chicken manure at 8,700 kg ha $^{-1}$ (7,670 lb ac $^{-1}$) together with sawdust at 12,000 kg ha $^{-1}$ (10,580 lb ac $^{-1}$). We observed a negative influence of sawdust on sorghum biomass production, illustrating the importance of maintaining adequate C:N ratios. Our results suggest that integrating a combination of soil amendments and cover crops could potentially increase long-term organic matter levels, helping to sustain nursery soil productivity.

Introduction

The majority of hardwood seedlings produced in the central hardwood forest region of the United States are grown as bareroot stocktypes. Effective management of nursery soils can be a major influence on seedling quality. Whereas residual roots and other plant material of most agronomic crops are often incorporated into soil after harvest, bareroot forest tree seedling production results in removal of the entire plant, which can deplete soil organic matter. Organic matter influences soil chemical and physical properties, and incorporation of organic matter may benefit these properties and improve forest tree seedling growth (Rose and others 1995; Davis and others 2006).

To manage soil organic matter levels, bareroot seedling nurseries often grow annual cover crops in rotation with seedling crops (Williams and Hanks 1976; Davey 1984). While there are potential short-term benefits associated with using cover crops (Williams and Hanks 1976), their use may decrease soil organic matter over time (South and Davey 1983) because of their rapid decomposition. Therefore, most hardwood nurseries use cover crops in association with other organic amendments to supplement soil organic matter (Williams and Hanks 1976). Peat moss, tree bark, sawdust, various forms of manure, and compost all have been used as organic matter amendments in seedling nurseries (Williams and Hanks 1976; Iyer and Benson 1981; Rose and others 1995; Davis and others 2006).

It is recognized that adequate organic matter management in bareroot hardwood tree seedling nurseries is a critical component in ensuring production of high-quality seedlings. Therefore, it is likely necessary to increase soil organic matter for a longer term by coupling soil amendments with use of cover crops. Despite the importance of soil amendments and cover crops (as well as potential interactive effects) in bareroot hardwood seedling nursery production, little research has been conducted in this area. Thus, the objectives of this study were to determine the influence of organic soil amendments on soil chemistry and to assess the contribution of those amendments to biomass production of a sorghum cover crop grown as green manure in bareroot hardwood seedling nursery soils.

Materials and Methods

This study was established at the Indiana Department of Natural Resources Division of Forestry Vallonia Nursery near Vallonia, IN (38º 85 N., 86º 10 W.). An overview of cultural practices for nursery production of hardwood species in this region can be found in Jacobs (2003). The

soil in the experimental nursery beds is a Bloomfield-Alvin complex with a 1 to 6 percent slope and a loamy sand texture (Nagel 1990). Taxonomically, Bloomfield soils are sandy, mixed, mesic Psammentic Hapludalfs, and Alvin soils are coarse-loamy, mixed, mesic Typic Hapludalfs (Nagel 1990). Clay mineralogy is mixed and of Eolian deposits. Currently, this nursery uses a 1-yr corn (Zea spp.) or sorghum (*Sorghum* spp.) cover crop following a 2-yr tree crop cycle, which is then incorporated into the soil 2 to 8 mo prior to sowing the next seedling crop.

Chicken manure (CM), containing no bedding and having undergone thermophilic decomposition, was obtained from a poultry farm near the nursery. Hardwood sawdust (S) was obtained from a nearby sawmill. Compost (Cp), consisting of ground leaves, trees, and lawn trimmings from a municipal collection service, was obtained from a nearby city; materials had been composted for at least 2 yr at the time of incorporation into the study. Leaves (Lv) were obtained from the same source but had not undergone thermophilic decomposition. CM was applied by itself at a rate of 1,450 kg ha^{-1} (1,275 lb ac^{-1}) (CM4) and together with 12,000 kg ha^{-1} (10,580 lb ac^{-1}) sawdust at rates of 4,350 kg ha^{-1} (3,840 lb ac^{-1}) (CM12S) and 8,700 kg ha^{-1} (7,670 lb ac^{-1}) (CM24S). Both Cp and Lv were applied at a rate of 200 m^3 ha^{-1} (2,825 ft^3 ac^{-1}). In addition to the aforementioned treatments, an unamended control was included in the study.

This study was established as a randomized complete block design with five soil amendment treatments and the control plots, replicated three times. Each row of sorghum was a treatment, and each set of six rows formed a block. Soil amendment materials were applied to the nursery beds on 5 May 2003. On 6 May 2003, CM, S, Cp, and Lv were incorporated to an approximate uniform depth of 7.5 cm (3 in) with a disked bed former. Sorghum was sown at a uniform rate of 1.12 kg ha^{-1} (1 lb ac^{-1}) into all nursery beds following incorporation of soil amendments.

Soil samples were collected immediately following incorporation of soil amendments. A&L Great Lakes Laboratories, Inc. (Ft. Wayne, IN), analyzed soil amendments and amended soils (tables 1 and 2) according to standard analytical protocols. Percent organic matter, cation exchange capacity (CEC), soil pH, and P, K, Mg, and Ca (parts per million, ppm) were determined for the soil samples. Available P was determined according to Bray and Kurtz

Table 1. Composition of chicken manure, compost, and leaves prior to incorporation into study plots.

Property	Chicken manure	Compost Compost	Leaves
Moisture content (%)	15.68	52.25	32.01
pH	8.60	8.20	6.80
N (%)	3.93	1.39	0.83
P (%)	2.08	0.21	0.08
PO_4^3 (%)	4.78	0.48	0.19
K (%)	3.39	0.30	0.17
K_2CO_3 (%)	4.07	0.36	0.20
S (%)	0.58	0.18	0.09
Mg (%)	0.80	1.98	0.27
Ca (%)	13.31	8.24	2.27
Na (%)	0.68	0.01	0.01
Fe (%)	0.24	0.74	0.14
Al (%)	0.10	0.49	0.11
B (ppm)	45	36	32
Cu (ppm)	165	48	9
Mn (ppm)	538	433	136
Zn (ppm)	573	165	80
Soluble salt (dS m^{-1})	10.62	0.69	0.57
(dS ft^{-1})	3.24	0.21	0.17
Ash (%)	45.85	55.83	15.81
Organic matter (%)	54.15	44.17	52.18
C (%)	27.08	22.09	26.09
C:N	7:1	16:1	32:2

Table 2. Composition of sawdust before incorporation into study plots.

Property	Value
Moisture content (%)	60.0
Organic matter (%)	99.7
pH	6.7
Cation exchange capacity (meq 100 g^{-1})	1.4
Cation exchange capacity (meq oz^{-1})	0.4
P (ppm)	1.0
K (ppm)	114.0
Mg (ppm)	40.0
Ca (ppm)	150.0
C (%)	57.8
C:N	239:1

(1945), and cations were determined from extracted aliquots by atomic absorption. Total N is reported for the soil amendments.

On 3 August 2003, the aboveground portions of 20 sorghum plants were randomly selected for harvest within each treatment replication. Stems were harvested at ground level and were not collected within 0.3 m (1 ft) of the plot boundary, and roots were not sampled, given operational difficulties in separating plants from each other. Each stem was harvested, tagged, and then transported to Purdue University; there they were dried for 72 h at 80 °C (176 °F). Stems were then weighed and mean above-ground biomass per stem for each treatment was estimated.

Data were analyzed by analysis of variance (ANOVA) for a randomized complete block design to identify effects of amendment treatments in aboveground biomass. ANOVA was also used to identify treatment effects in soil physical and chemical properties. Significant differences (α=0.05) were identified by Tukey's mean separation test. SAS® software (SAS Institute, Cary, NC, USA) was used for all data analysis.

Results and Discussion

Addition of CM, S, Cp, or Lv significantly altered soil properties compared with control plots. Application of CM12S, CM24S, Cp, or Lv significantly (p<0.0001) influenced organic matter levels; the CM4 treatment was not different from control plots. Cp raised organic matter levels by 93 percent over control plots (table 3). These results concur with those of Davis and others (2006), who found that organic matter was greater when Cp was applied to nursery beds than after application of different levels of CM. The resulting differences in soil chemical properties show the influence, at least in the short-term, of the amendments used. Increased organic matter resulting from application of Lv, Cp, CM12S, and CM24S can be beneficial to hardwood seedlings, given the positive changes to soil physical and chemical properties.

Application of Cp, Lv, CM12S, and CM24S raised pH significantly (p<0.0001) above control plots (table 3). Comparatively, application of a sewage sludge/wood chip compost raised nursery soil pH (Gouin and Walker 1977); Iyer and Oilschlager (1977) found a similar result for greenhouse soils amended with organic matter. Most hardwood species in the CHFR grow optimally with a soil pH of 6.0-7.2 (Ponder and Pope 2003), and therefore the aforementioned amendments would be highly beneficial in this regard. Incorporation of sawdust along with chicken manure (CM12S and CM24S) reduced CEC; the Cp treatment exhibited the highest CEC (table 3). High C:N likely resulted in lack of a positive influence of CM12S and

Table 3. Soil properties (mean ± SE) immediately following incorporation of soil amendments of control plots (Ctrl) and plots amended with leaves (Lv) at 200 m^3 ha^{-1} (2,825 ft^3 ac^{-1}); compost (Cp) at 200 m^3 ha^{-1} (2,825 ft^3 ac^{-1}); chicken manure (CM) at a rate of 1,450 kg ha^{-1} (1,275 lb ac^{-1}) (CM4); or CM at 4,350 kg ha^{-1} (3,840 lb ac^{-1}) and 8,700 kg ha^{-1} (7,670 lb ac^{-1}) each with sawdust (s) at 12,000 kg ha^{-1} (10,580 lb ac^{-1}) (CM12S and CM24S, respectively). For each property, different letters within a row indicate significant differences among treatments at =0.05.

Property	Ctrl	Lv	Cp	CM4	CM12S	CM24S
Organic matter (%)	1.23±0.03c	1.8±0.06b	2.37±0.09a	1.30±0.10c	1.67±0.04b	1.57±0.04b
pH	4.83±0.07c	6.23±0.07b	6.87±0.07a	5.35±0.30c	6.50±0.20ab	6.80±0.16ab
CEC (meq $100g^{-1}$)	5.37±0.50bc	6.63±0.07ab	8.07±0.58a	6.80±0.30ab	4.93±0.45c	5.73±0.20bc
CEC (meq oz^{-1})	1.52±0.14bc	1.88±0.02ab	2.29±0.16a	1.93±0.09ab	1.40±0.13c	1.62±0.06bc
P (ppm)	193.33±10.04c	217.00±7.64bc	229.33±3.28bc	306.50±10.50a	247.00±26.13bc	268.00±25.72ab
K (ppm)	87.00±9.54d	180.67±2.60c	199.33±3.67bc	240.00±31.00b	227.00±8.98bc	310.67±17.55a
Ca (ppm)	266.67±16.67d	750.00±0.00b	1166.67±83.33a	475.00±25.00cd	533.33±0.00bc	700.00±102.06bc
Mg (ppm)	71.67±6.67d	145.00±7.64b	185.00±10.41a	92.50±12.50cd	105.00±2.04cd	116.67±8.16bc

CM24S on CEC in the short term. As the sawdust decomposes, it is likely that soil conditions will benefit from the added organic matter.

The amount of available P (p=0.002) differed significantly between treatments and was highest when CM4 was applied (table 3). CM24S was also higher than control plots, but CM12S was not, indicating the need for proper balance between chicken manure and sawdust to avoid binding P. In contrast, K levels were significantly higher (p<0.0001) in plots that received CM24S than in any other treatment; however, all treatments resulted in higher K levels than control plots (table 3). Both Mg (p<0.0001) and Ca (p<0.0001) were highest for those treatments that received Cp (table 3), indicating it is likely a more balanced mixture. The influence of amendments on soil chemical properties clearly depends on the inherent chemical properties of the materials used, which must be accounted for in selection of organic nursery soil amendments. Our results identify potential positive and negative influences of organic matter addition on nutrient management in hardwood seedling nursery soils.

Sorghum biomass production (figure 1) differed significantly (p=0.0008) among treatments, with CM24S having the highest above-ground biomass and control plots the lowest. This illustrates the positive influence of these organic matter amendments on sorghum biomass, which could in turn help further raise nursery soil organic matter once incorporated. CM12S tended to have lower mean biomass than CM4 and CM24S, though the difference was not significant. This may have been associated with the high C:N resulting from sawdust incorporation, which could limit plant nutrient availability in the short term. In addition to raising organic matter levels, however, C:N may become more balanced as the sawdust decomposes over time. Furthermore, excessive soluble salt levels in the CM (table 1) could also negatively influence plant development (Jacobs and Timmer 2005). Addition of Cp and Lv at the rates used was not sufficient to elicit a positive growth response; therefore, higher rates of those amendments should be examined in the future.

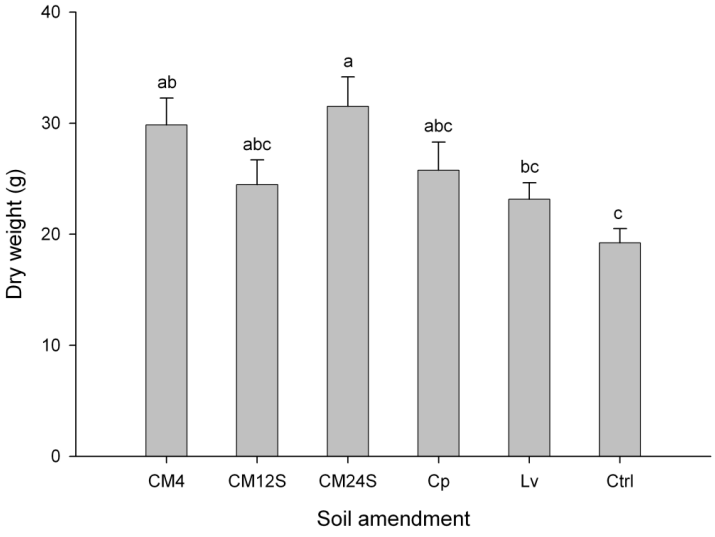

Figure 1. Influence of soil amendments on mean above-ground sorghum dry weight in control plots (Ctrl) and plots amended with chicken manure (CM) at a rate of 1,450 kg ha^{-1} (1,275 lb ac^{-1}) (CM4), CM at 4,350 kg ha^{-1} (3,840 lb ac^{-1}) and 8,700 kg ha^{-1} (7,670 lb ac^{-1}) each with sawdust (s) at 12,000 kg ha^{-1} (10,580 lb ac^{-1}) (CM12S and CM24S, respectively), compost (Cp) at 200 m^3 ha^{-1} (2,825 ft^3 ac^{-1}) and leaves (Lv) at 200 m^3 ha^{-1} (2,825 ft3 ac^{-1}). Bars represent standard errors; for each treatment, different letters represent differences significant at α=0.05.

Conclusion

Soil chemical properties in bareroot nursery beds can be improved through organic matter application. Care must be taken, however, particularly with the use of sawdust, to ensure appropriate nutrient ratios. Increased growth of sorghum indicates a likely long-term benefit, as this green manure crop will promote higher soil organic matter in the subsequent growing season. These findings indicate that a combination of soil amendments and cover crops could potentially increase nursery soil organic matter for a longer term, which could lead to improved seedling growth, decreased dependence on inorganic fertilizers, and an additional viable market for composted organic materials.

Address correspondence to: Douglass F. Jacobs, Hardwood Tree Improvement and Regeneration Center, Purdue University, Department of Forestry and Natural Resources, 715 West State Street, West Lafayette, IN 47907; email: djacobs@purdue.edu; phone: (765) 494-3608.

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Stem Splitting and Cankering in Pacific Northwest Douglas-fir Seedlings

Diane Haase, Nabil Khadduri, and Tom Landis

Associate Director, Nursery Technology Cooperative, Department of Forest Science, Oregon State University, Corvallis, OR; Nursery Scientist, Webster Nursery, Washington Department of Natural Resources, Olympia, WA; Research Nursery Specialist, Central Point, OR

Abstract

Stem splitting, most likely due to rapid seedling growth, can lead to significant nursery losses if the splits become cankered from secondary infection. This paper describes the incidence and pattern of stem splitting and cankering. In addition, we offer discussion about the causes and control of stem splitting and cankering.

Introduction

Recently, some Pacific Northwest (PNW) nurseries have experienced unacceptably high cull rates in coastal Douglas-fir (*Pseudotsuga menziesii Mirb. Franco*) seedlings because of cankered stem splits. These cankers develop when splits in the stem fail to heal over and are therefore prone to secondary infection. In bareroot nurseries, stem splitting is usually observed during the second growing season for 2-yr-old stock and is located a few centimeters above bud break. In container nurseries, stem splits can occur from a few centimeters above the growing medium to a few centimeters below the apical meristem. As seedling tissues expand with diameter growth, stem splits widen.

Cankering may be higher in bareroot nurseries because of potentially higher soil inoculum levels. An intensive integrated pest management (IPM) program is necessary to minimize inoculum for secondary infections and to encourage callusing of the splits. Generally, healed (calloused) splits are no longer visible after a couple of seasons and have no lasting effect on seedling quality and performance. Frequent fungicide application (every 2–4 wk) during periods when seedlings exhibit open splits has been likened to applying antibiotic ointment to a cut. However, many would rather prevent the wound than treat the wound.

Some nurseries must cull more than others because of these cankers. Therefore, variations in soil properties, temperature, and nursery cultural practices such as fumigation, irrigation, fertilization, and pesticide application may be contributing factors. Nutrient imbalances are suspected as a possible cause for the inability of seedlings to heal splits. In particular, discussions among nursery growers have led to speculation that the N/Ca ratio may be correlated with stem splitting. However, stem splits have been found in one PNW nursery with very high calcium levels in the irrigation water (which corresponded to high foliar Ca levels in the seedlings)(unpublished data). Another possible cause may be water relations, such as the wet-dry cycle. There are, however, few scientific data to support any of the speculations as to the cause of splitting and cankering. Correspondingly, there is no clear understanding of how to prevent its occurrence.

The general consensus is that rapid growth is the primary cause of stem splitting. It has been observed in many forest nurseries, both bareroot and container, that rapidly elongating Douglas-fir seedling stems are prone to splitting, often with multiple splits on the same seedling. Stem sinuosity (sometimes referred to as “speed wobble”) may also be evident in fast-growing seedlings. Stem splitting does not occur exclusively in the nursery. Field observations indicate that naturally regenerating seedlings exhibit stem splitting during years when precipitation is high and growing conditions are optimum. Furthermore, stem splits have been observed in the field on third-, fourth-, and fifth-yr stems of both nursery-grown and naturally regenerated seedlings (figure 1).

As nursery technology has improved over the past couple of decades, so too, have seedling growth rates. The demand for larger stocktypes with greater morphological specifications has resulted in seedlings being pushed to their utmost growth rates. Supplying normally growth-limiting factors—reducing moisture stress through frequent irrigation and providing all mineral nutrients, especially nitrogen—can generate seedling growth rates that are many

Figure 1. Example of stem splitting observed in 4th-yr growth of field seedlings.

times faster than normal. With such accelerated growth, current growing regimes may result in seedlings approaching a physiological threshold at which a greater incidence of stem splitting occurs. This is evident because the tallest seedlings tend to have the most splits, as do those from faster-growing seedlots. Stem splitting and the resulting vulnerability to cankering is very undesirable in high-value genetically improved lots. Similarly, earlier-growing, overwintered bareroot stock (such as fall-transplants and 2+0) tend to have more splits than spring-transplanted stock. The same symptoms are observed far less frequently in slower-growing interior Douglas-fir lots.

Methods

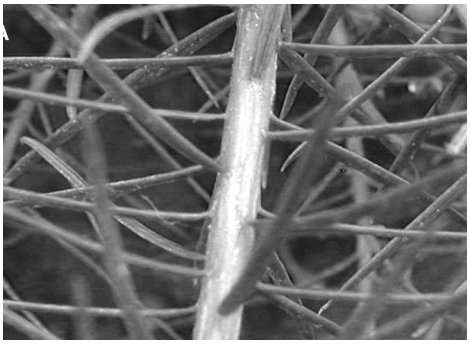
In a 2005 project, the Nursery Technology Cooperative (Department of Forest Science, Oregon State University) completed a monitoring trial to better understand the incidence and severity of stem splitting in Douglas-fir seedlings. Plug seedlings of the same seedlot from the same container nursery were transplanted in August 2004 in two different western Washington bareroot nurseries. Every 2 wk from June to August 2005, 10 plots were randomly chosen. Seedlings in the selected plots were measured for height and stem diameter. In addition, seedlings with stem splits were tallied and evaluated for number of splits, condition of splits, and location of splits. Split condition was rated as 0 for a cankered split and on a scale of 1–5 for noncankered splits (1=fresh split, ranging to 5=completely calloused) (figure 2).

Results and Discussion

Results were as follows:
June 1: very few splits were observed at either nursery
June 18: nearly every plot had one or more seedlings with fresh splits (rated 1–3)
July 1: splits were found in all plots; the majority were mostly calloused (rated 3–5)
July 18: splits, including several fresh splits, were found in all plots; some cankering was noted
August 1: splits were found in all plots; the majority were mostly calloused (rated 3–5); some cankering was noted

These data show that the "growth spurts" occurring in May and June were accompanied by incidence of fresh splits approximately 1 mo later with some cankering evident after another 4 wk. One of the nurseries had a greater incidence of cankering and attributed that to later initiation of fungicide applications than at the other nursery.

Although there has been considerable discussion about stem splitting in the past couple of years, cankering of stem splits is not a new issue. In 1990, Hamm described upper stem canker as a disease caused by the fungi *Phoma eupyrena* and *Fusarium roseum* and noted that "cankers initially appear as sunken areas centered most often on a bark fissure, a wound on the stem that occurs natu-



(A) freshly split

(B) mostly callused

(C) cankered

Figure 2. Examples of stem splitting conditions on Douglas-fir seedlings

rally when the bark is expanding during periods of rapid growth." He noted that these fungi are common soil inhabitants and are found on healthy seedlings; they don't cause disease until finding a suitable court, such as a stem split.

As long as the demand for large seedlings remains, stem splitting is likely to continue to be a factor in Douglas-fir seedling production. Aggressive IPM can reduce the subsequent development of cankers. Ideally, future research will provide a greater understanding of the occurrence of stem splits and will result in nursery growers being better able to prevent the problem while achieving acceptable morphological specifications.

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Topworking Coastal Douglas-fir

Randy Johnson and Don Copes

Research Geneticist and Forest Genetics Team Leader (retired), USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR

Abstract

Topworking, the grafting of young scion material into tops of older, reproductively mature trees, was attempted with coastal Douglas-fir. Compared with grafting onto juvenile rootstock, grafts in the older trees had a larger percentage of scions with female flowers (27 percent vs. 5 percent, $p<0.01$) and more female flowers per scion (0.82 vs. 0.13, $p=0.16$); however, the increases were very small from a practical point of view.

Introduction

The rate of gain that can be achieved in a tree breeding program is limited by a number of factors, one being the number of years needed to breed control-pollinated families for the next cycle. Completing crosses has been more of a problem for Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] than for some other conifers. Douglas-fir seedlings rarely produce flowers as early as 2 yr following germination and produce only small quantities of seed before age 10 (Silen 1978). During the course of breeding, coastal Douglas-fir selections are typically grafted into breeding orchards where control pollination can take place starting as early as 3 yr after grafting, although crossing success at this time is sporadic. Delays in generating full-sib families increase the generation interval and reduce rate of gain.

A common method to stimulate flowering on young southern pine grafts is to graft the young scion into the tops of older trees or grafts (Bramlett and Burris 1995; Bramlett 1997). This procedure is commonly referred to as topworking. This is presently being used to reduce the breeding interval in pine tree improvement programs (e.g., Gooding and others 1999). No results from topworking Douglas-fir have been reported in the literature to date. This could be because breeders have simply not reported their attempts, or because the high levels of graft incompatibility inherent in this species have discouraged practitioners from attempting grafts onto older trees or grafts, most of which are not highly graft-compatible. The objective of this study was to examine the effectiveness of topworking in coastal Douglas-fir.

Methods and Materials

On March 7, 2001, dormant scions were collected from 11 "juvenile" 6-yr-old trees (~2 m (6.5 ft) tall) and stored at 2 °C for 2 wk. These same 11 trees were used as juvenile rootstock. Six 20-yr-old grafted trees were selected for the mature comparison (the physiological age of the trees was 50+ yr). These six trees had been used to produce graft-compatible rootstock seed and, in the past, had produced good cone crops in response to stimulation.

On March 21, 2001, scions from each of the 11 juvenile trees were grafted into the top of each of the 6 mature trees using top cleft grafts. In addition, 5 grafts were made into each of the juvenile trees, one being an autoplastic graft, i.e., grafted on to itself; the other four grafts were with scion from the other juvenile trees (table 1). One autoplastic graft was also made in each of the older grafted trees.

In April 2002, all 17 trees were bark girdled to promote flowering (see Ebel 1971 and Wheeler and others 1985 for discussions of stem girdling in Douglas-fir). A pruning saw was used to make one girdle at breast height three-quarters around the circumference of the tree. A second girdle was made on the opposite side of the stem at a distance below the first girdle approximating the tree's DBH. Procone® (gibberellic acid) was injected into the rootstock at the prescribed rate of 0.036 ml cm-2 (0.232 ml in-2) of basal area. Basal area at breast height was used for the mature rootstocks, and basal area at 0.6 m (2 ft) was used for the juvenile rootstocks. In May 2003, flower counts were made on each of the surviving grafts.

Two statistical analyses were performed. A chi-square test was used to examine whether there was difference in the number of grafts that had flowered (at least one flower).

The contingency table examined grafts on juvenile vs. mature trees and grafts with or without flowers. The second analysis examined the differences in flower counts per graft. Counts were square-root-transformed because counts are a Poisson distribution. The SAS mixed procedure was used to analyze the model:

$$\sqrt{(\text{flowers}+1)} = \text{rootstock}_i + \text{clone(rootstock)}_{ij} + \text{scion}_k + \text{rootstock} \times \text{scion}_{ik} + \text{error}_{ijk},$$

where rootstocki is the fixed effect of rootstock, i.e., tree age (contrast between juvenile and mature trees); $\text{clone(rootstock)}_{ij}$ is the random effect of *j*th rootstock or grafted interstock clone within a rootstock age category; scion_k is the random effect of the *k*th scion clone; and $\text{rootstock}\times\text{scion}_{ik}$ is the random effect of rootstock age category by *k*th scion interaction.

Results

Only two juvenile trees had female flowers on any of their grafts, and one had only one flower (table 1). None of the grafts produced pollen catkins. Five of the six mature trees had flowers on their juvenile grafts, although tree E had only one flower. Eighteen of the 66 grafts on the mature trees (27 percent) had at least one flower; only 3 of 55 grafts (5 percent) flowered on the juvenile rootstock. The chi-square value of 9.956 was statistically significant (p=0.0016).

The average number of flowers per graft was 0.26 for the juvenile rootstock (13 flowers on 49 grafts) and 0.82 for the mature rootstocks (46 flowers on 56 grafts). The probability level for this difference from the mixed model analysis was 0.1597, suggesting that this was perhaps marginally statistically significant.

All six of the older rootstock had prolific female and male flowers throughout their crowns. A branch would be covered with flowers until it reached the graft union; then flowering decreased dramatically (figure 1). Of the three autoplastic grafts found in the older trees (three were missing), all had female flowers and two had male inflorescences.

Discussion

A statistically significant increase in female flowering appears to result from topworking young Douglas-fir scions. More grafts had flowers when grafted onto the older trees, compared with younger rootstocks, and more flowers per scion were found on the older trees. The practical significance of this small increase at the age tested is questionable, however. Results in loblolly pine (*Pinus taeda*) are much more practical; studies have found 2.5–5 or more flowers per graft 1 yr after grafting (Bramlett and Burris 1997, Gooding and others 1999). Two years after grafting, Bramlett and Burris (1997) found an average of nine female flowers per graft and also found pollen catkins on some grafts. The loblolly numbers are such that a breeding program could make great strides in accomplishing a crossing program.

Table 1. Untransformed female cone counts of grafts. X represents a dead graft; M is a missing graft arising either from mortality or loss of a tag.

	Juvenile rootstock clone												Mature rootstock clone						
Scion clone	1	2	3	4	5	6	7	8	9	10	11	Mean	A	B	C	D	E	F	Mean
1	0		0		0	0				0		0	0	X	0	3	0	0	0.60
2		0	9	1	0						X	2.5	0	0	X	X	0	0	0.00
3	X	0	0					0		0		0	0	0	0	0	M	0	0.00
4	0	0		0					0	0		0	0	0	3	4	0	0	1.17
5			0		0	X	0			0		0	0	0	X	X	X	0	0.00
6	0	0				0	0		0			0	2	0	8	M	0	2	2.40
7				0	0		0	0			0	0	0	0	4	4	0	0	1.33
8			3			0	X	0			0	.75	1	0	1	1	0	0	0.50
9		0		X			0		0		0	0	0	X	X	1	0	0	0.25
10				0		0		X	0	0		0	0	0	0	1	0	2	0.50
11	0				0			0	0		0	0	0	0	1	5	1	2	1.50
Mean	0	0	2.4	0.25	0	0	0	0	0	0	0	0.26	0.27	0.00	2.13	2.38	0.11	0.55	0.82

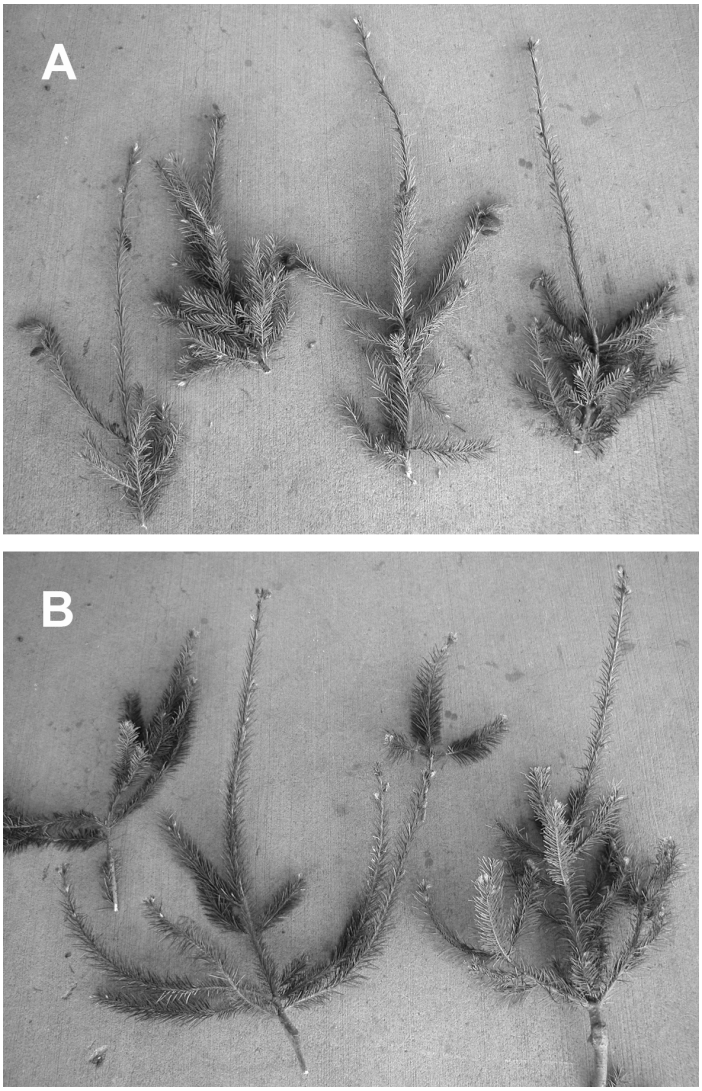

Figure 1. Grafted and ungrafted branches from the same main whorl of a mature tree: (A) ungrafted branches with flowers, (B) grafted branches without flowers

Our results with Douglas-fir suggest that very little time could be saved in completing a crossing program by topworking vs. normal breeding-orchard crossing because we did not find large numbers of female flowers and there were no pollen catkins in the topworked grafts. Better results may have been possible if we had waited an extra year before flower stimulation, since the grafts were twice as large and had considerable more branch tips where female flowers arise. Because of the cyclic nature of flowering in Douglas-fir, it was not feasible to stimulate the trees a second consecutive year; however, it should be noted that there were no flowers on any of the grafts the following year.

Acknowledgements

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Comparing Large Bareroot and Container Stock: Water Stress as Influenced by Peat and Soil Water Availability

S. Jutras, N. Thiffault, and A.D. Munson

Graduate Student, Adjunct Professor, and Professor, Centre de recherche en biologie forestière, Faculté de foresterie et de géomatique, Université Laval, Québec, Canada

Abstract

To evaluate the effect of the rooting media on seedling planting shock in black spruce [*Picea mariana* (Mill.) BSP], we planted three large seedling stock types (containerized, containerized with washed root system, and bareroot) in pans filled with sand and created two contrasting watering regimes (well-watered and limited water). We measured shoot xylem water potential (ψx) weekly on seedlings from all treatment combinations during a 10-wk period. Over the entire sampling period, and independent of the watering regime, containerized seedlings with washed-root systems showed similar water potentials to bareroot seedlings. Both types presented more negative values than intact containerized seedlings. Differences in the water status of newly outplanted large containerized and bareroot seedlings seem to result mainly from the effect of the peat-based growing medium on water availability in the rooting zone.

Introduction

In the province of Québec (Canada), vegetation control with herbicide is no longer an operational option on public forest lands (Ministère des Ressources Naturelles du Québec 1994). Alternative strategies to herbicides include planting seedlings the year following final harvest, when competing vegetation is still relatively undeveloped. Another element of this regeneration strategy includes the use of large conifer stock that can overcome competition by noncrop species (Jobidon and others 1998, 2003). However, there is still a need to evaluate the conditions for successful establishment of bareroot and containerized large transplants, as influenced by silviculture and nursery cultural practices.

Recent field experiments indicate that large container-grown seedlings of black spruce [*Picea mariana* (Mill.) BSP] experience more pronounced water stress than do bareroot seedlings during their first growing season on harsh-competition sites of eastern Québec (Thiffault and others 2003). The generally observed poor first-year root-soil contact for containerized seedlings (Burdett 1990) was hypothesized to be responsible for the results observed. Örlander and Due (1986a, b) report that the most important resistance to water flow in the soil–plant pathway for seedlings of containerized Scots pine (*Pinus sylvestris* L.) is in the peat soil surrounding the roots. Low soil hydraulic conductivity of peat-based growing medium under low soil water content conditions and its subsequent effect on containerized seedling water stress are also reported by Bernier (1992) and Bernier and others (1995). No study, however, has investigated, under a semicontrolled environment, the water relations of the different types of large stock seedling actually outplanted in Québec in order to understand how different soil water availability conditions may affect their capacity to absorb water.

We designed this study to test the following hypotheses: (1) the peat-based growing medium is responsible for the differences in water stress experienced by newly planted large containerized and bareroot seedlings; (2) significant differences in the water status of large containerized and bareroot stock are more important under low soil water content than when soil water is readily available.

Material and Methods

Seedling description. We obtained large containerized (initial height = 35 to 45 cm, 13.8 inches to 17.7 in) and bareroot (initial height = 40 to 60 cm, 15.7 to 23.6 in) black spruce seedlings from the Saint-Modeste governmental nursery (Québec) in late fall of 1998. Large con-

tainerized seedlings (CO) were produced over 2 yr (2+0) in 350–cc, 25-cavity airslit containers developed by the Ministère des Ressources naturelles du Québec (Gingras and Richard 1999). Bareroot seedlings (BR) were grown outside over 4 yr (2+2). We ovendried a sub-sample of each stock type at 65±2 ˚C for 48 h to determine initial dry biomass. We produced a third stock type, "washed container" (WCO), by randomly selecting half of the containerized seedlings, immersing their root systems in water, and gently washing. The objective of this operation was to remove all of the growing medium (peat–vermiculite, 3:1 v:v), while minimizing disturbance to the root system.

Experimental design and measurements. We filled plastic pans of 90 dm^3 with fine sand and grouped them 2 × 2 to form four experimental blocks that were distributed in a greenhouse at Université Laval (46˚46'51" N., 71˚16'46" W.). We planted two seedlings of each stock type (BR, CO, and WCO) side by side in each of the eight pans, the stock type position being randomized at the pan level. To induce bud break and favor root growth, we watered all pans every 2 d for 1 mo. Seedlings received a water-soluble fertilizer (20N–20P–20K, 1 g L^{-1}, 5 L pan^{-1}) 2 wk after plantation. Meanwhile, we gradually increased photoperiod (from 8 h to 16 h), day-time air temperature (15 to 25˚C), and night-time air temperature (10 to 18˚C). Air relative humidity was not controlled and varied from 25 to 45 percent. Thirty days after planting, each pan within each experimental block was randomly assigned to receive one of the following qualitative watering treatments: (1) well-watered conditions (WR1) or (2) limiting soil water (WR2). We created the WR1 treatment by abundant watering of the pan every 2 d. We induced the WR2 treatment) by abundant watering every 4 wk.

As soon as watering treatments commenced, we evaluated seedling shoot xylem water potential (ψx) between 11 a.m. and 1 p.m. weekly for 10 consecutive wk. We preferred midday to predawn measurements because they more closely reflect acclimation of newly planted seedlings to site condition (Bernier 1993). At each sampling period, we measured 24 seedlings (3 stock types × 2 watering regimes × 4 blocks) with a portable pressure chamber (PMS Instruments, Corvallis, OR), following the recommendations of Ritchie and Hinckley (1975). The experimental design was a split-split-plot in time, with the watering regime treatment (WR) applied to the main plot, stock type (ST) considered as the subplot unit, and time (T) as the sub-subplot level.

Statistical analysis. We determined the significance of the effects of watering regime, stock type, time, and all possible interactions on ψx by analysis of variance for repeated measurements (ANOVAR), using the MIXED procedure of the SAS 8.01 software (SAS Institute Inc., Cary, NC). In the case of a significant p-value ($p \leq 0.05$) for the treatment or interaction, we used a Fisher's protected LSD test (Steel and others 1997) to separate treatment means. Before analysis, we square-root transformed all data to satisfy the normality and homoscedasticity postulates. For clarity and convenience, we present back-transformed means.

Results and Discussion

The qualitative watering regime treatments were effective in creating contrasting soil conditions, as shown by the significant WR × T effect on seedling ψx (table 1). Detailed analysis of this interaction revealed that seedlings in the low water availability treatment took 4 wk to present significantly lower ψx than seedlings under well-watered conditions (figure 1). After having been rehydrated at the fourth week, the WR2 seedlings recovered a similar water status to the WR1 seedlings for 1 wk, and then presented more negative ψx values until week 9.

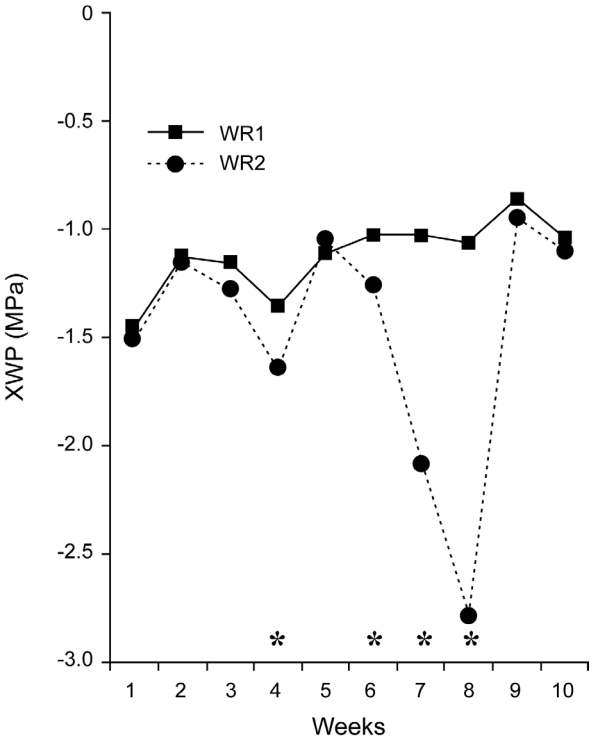

Figure 1. Effect of the watering regime on the weekly φx of black spruce seedlings. WR1: well-watered condition (watered every 2 d); WR2: limiting soil water(watered immediately after the φx measurements of week 4 and 8). A significant watering regime effect on x for a particular week ($p \leq 0.05$) is indicated with an asterisk. Standard error of the mean for the plotted data is ± 0.07 MPa.

Stock type had a statistically significant effect on shoot ψx, and this effect was independent from the watering regime or sampling date (table 1). Lack of a significant interaction between stock type and the watering regime negates the second research hypothesis; the difference between the stock types must be interpreted independently from soil water availability. Multiple comparisons of treatment means showed that WCO and BR seedlings had similar ψx, and that both stock types experienced a slightly more pronounced water stress (more negative ψx value) than CO seedlings (table 2).

Nursery managers can do little to regulate air temperature and humidity above the nursery seedbeds (Lavender 1984). During production, bareroot seedlings are exposed to more demanding climatic conditions than are containerized seedlings produced in tunnels. The water potential below which stomatal conductance falls steeply varies in relation to the environmental and physiological history of the shoots (Beadle and others 1978). Thus, the cultural regime under which a seedling is produced can influence seedling capacity to control water loss once outplanted on a forest site. In the present experiment, WCO seedlings behaved like BR in terms of water potential (table 2). It can be concluded that both stock types (CO and BR) presented similar stomatal control of water loss, since the sole elimination of the peat barrier to water flow resulted in a similar water status. This result is different from those of Blake and Sutton (1987), who report that black spruce bareroot seedlings have greater responsiveness of stomatal conductance to xylem water potential than containerized seedlings. Seedlings used in their study, however, were much smaller that those used in this experiment, with average total dry weight of 7 g and 1 g for the bareroot and the container stock, respectively. Seedlings produced under different cultural regimes can be expected to differ in their physiological status at time of planting (Grossnickle 2000). Thus, comparison between studies may be precarious.

The containerized and bareroot seedlings we used presented morphologically different root systems with similar initial shoot:root biomass ratios (table 3). Thus, our results support the previous observation that initial size of the root system does not relate well to its capacity to conduct water after planting (Krasowski and Owens 2000). Instead, quality of the root system, in terms of vigor and fibrosity, may be of crucial importance (Lamhamedi and others 1998) to positively influence the feedback loop relating seedling root growth, water status, gas exchange, and photosynthesis (Burdett 1990).

It can be concluded from our greenhouse experiment that (1) differences between large containerized and bareroot black spruce seedling water status were induced by the peat surrounding the root system of the container-grown seedling; and (2) peat growing medium effect on containerized seedling water status was independent from soil water availability.

Address correspondence to: N. Thiffault, Ministère des Ressources Naturelles et de la Faune, Direction de la recherche forestière, 2700 Einstein, Québec, QC, G1P 3W8, Canada. E-mail: nelson.thiffault@mrnf.gouv.qc.ca. Phone: + 418 643 7994

Table 1. Source of variation (fixed), degrees of freedom (d_f), and p-values for xylem water potential of the three stock types of black spruce seedlings, submitted to two watering regimes during 10 wk.

Source of variation (fixed)	d_f	p
Watering Regime (WR)	1	0.003
Stock Type (ST)	2	0.016
WR × ST	2	0.198
Time (T)	9	<0.001
WR × T	9	<0.001
ST × T	18	0.445
WR × ST × T	18	0.323

Table 2. Effect of stock type on the xylem water potential (ψx) of large black spruce seedlings.

Stock type	ψx (-MPa)
Containerized 350 cc (CO)	1.21a
Containerized 350 cc with washed root system (WCO)	1.30b
Bareroot (BR)	1.31b
Analysis was performed on square-root transformed data, but back-transformed means are presented for clarity and convenience. Means followed by the same letter are not significantly different according to the Fisher's protected LSD test (p > 0.05).	

Table 3. Initial dry biomass (g) of large containerized and bareroot seedlings.

	Bareroot	Containerized 350 cc
Shoot dry biomass (g)	32.0±7.5a	7.0±0.5b
Root dry biomass (g)	10.5±1.6a	3.1±0.7b
Shoot:Root Biomass Ratio	3.0±0.3a	2.4±0.8a
Data are expressed as mean±sd. For each variable, stock type means followed by the same letter are not significantly different at p=0.05.		

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Investigations of the Cause of First-Year Stunting of Douglas-fir Seedlings in Bareroot Conifer Nurseries

R.G. Linderman, K.W. Russell, and Y. Tanaka

Research Plant Pathologist, USDA-Agricultural Research Service, Horticultural Crops Research Laboratory, Corvallis, OR; Plant Pathologist, formerly Washington State Department of Natural Resources, Forest Health, Olympia, WA; Forest Nursery Ecologist, deceased, formerly Weyerhaeuser Company, Western Forestry Research Center, Centralia, WA

Abstract

We investigated several possible causes of 1-0 stunt in Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] in two fumigated bareroot nurseries. The results suggest that (1) delayed development of a root system contributes to seedling nutrient stress; (2) lack of ectomycorrhizae did not cause stunt; (3) root diseases were not involved; and (4) some soil microorganisms on root surfaces may have produced toxins that prevented nutrient-absorbing hair root development. We conclude that some combination of factors limits root system development, leading to nutrient deficiency, bud set, and stunting.

Introduction

Stunting of first-year conifer seedlings (1-0 stunt) in bare-root seedling nurseries in the Pacific Northwest (PNW) has been a concern for many years. Stunted seedlings cease growth early in the growing season. They thus fail to reach commercial size and are a potential loss to the nursery. The pattern of stunted trees is often a mosaic (Landis 2001) in which areas within beds have stunted trees next to areas where trees are not stunted (figure 1). Frequently, however, individual trees are stunted immediately adjacent to trees that are not (figure 2). The cause of this abnormal growth pattern has been hypothesized to be either a phosphorus (P) deficiency or lack of mycorrhizae that could help seedlings acquire P more effectively. In many cases, adding higher rates of preplant P fertilizer has solved the problem. Sometimes, however, the fertilizer is not thoroughly or uniformly mixed into the planting bed, and P is not mobile enough in soil to even out the P level and availability (Landis 2001). Thus, some trees could become stunted because of localized P deficiency and prematurely set bud for the season. Because mycorrhizal fungi are eliminated by soil fumigation in many nurseries, mycorrhizae may not be in place in time to improve P uptake by young seedlings.

Nutrient deficiency in conifer seedlings during the first 2 mo of growth, resulting from lack of mycorrhizae, low levels of available soil P, or both, could stop shoot growth and cause terminal bud set in the middle of the growing season. This stunting of seedlings during the first growing season (figure 1) occurs, but the cause has not been thoroughly

Figure 1. Mosaic stunting pattern of Douglas-fir seedlings in a bare-root nursery showing a mixture of stunted and normal seedlings.

Figure 2. (A) Stunted (S) first-year Douglas-fir seedlings, grown in nursery soil fumigated with methyl bromide/chloropicrin, adjacent to unstunted seedlings (NS).

investigated to determine whether lack of mycorrhizae (Trappe and Strand 1969), P deficiency, root disease, some other cause, or a combination of factors, is involved.

Soil fumigation has been practiced for many years as a means of combating weed, insect, and disease problems. In the PNW, fumigation is generally done in late summer to early fall when conditions are optimum, rather than in spring, when conditions are generally too cold and wet. This practice results in a lengthy fall-winter fallow period before spring sowing in early May, during which soils can become colonized by both deleterious and beneficial microbes. Root pathogens of Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], such as species of *Pythium* and *Fusarium* (Hansen and others 1990), may readily invade the fumigated soil, either as mycelium growing from below the fumigation layer or as spores in soil carried by moving water, wind, or machinery. At the time of sowing, pathogens of Douglas-fir, such as *F. oxysporum* Schlect., also may be introduced to the fumigated beds as seedborne inoculum (Graham and Linderman 1983; Hoefnagels and Linderman 1999). Species of *Fusarium* and *Pythium* commonly encountered in plate counts of soil from PNW nurseries are F. *oxysporum*, F. *roseum* (LK.), P. *debaryanum* Auct. non R. Hesse, P. *ultimum* Trow, and P. *sylvaticum* W. A. Campbell and J. W. Hendrix (K. W. Russell, unpublished data).

While soil fumigation is an effective means of combating soilborne pests and pathogens, the concomitant reduction or elimination of beneficial mycorrhizal fungi is a concern (Campagna and White 1969; Henderson and Stone 1970; Carpenter and Boyd 1980; Kough and others 1985; Linderman 1987; Riffle 1980) because mycorrhizae aid seedlings in acquisition of water and nutrients, especially immobile nutrients such as P, copper and zinc. Commercial bareroot nurseries in the PNW rely on natural recolonization of fumigated beds by mycorrhizal fungi via vegetative growth of residual mycelium up through the fumigation layer, or by airborne spores from fruiting bodies elsewhere in the nursery or surrounding areas.

We observed that first-year (1-0) stunting occurs at greater frequency in unfumigated areas of fumigated nurseries. This observation suggested that a biotic agent may be involved. If deleterious microorganisms are involved, and fumigation seems to eliminate these agents temporarily, then one must assume that they reestablish during the period between fall fumigation and planting in the spring or, possibly, are introduced at seeding as seed contaminants. Furthermore, if mycorrhizal establishment were to prevent stunting by improving seedling nutrient uptake capacity, that symbiotic relationship would have to be fully functional before mid-July of the first growing season when the stunt syndrome appears.

The purpose of this study, therefore, was to examine possible causes of 1-0 stunt on Douglas-fir, including the time of development of feeder roots on seedlings, the time of development of ectomycorrhizae that could aid in nutrient uptake, and the possible role of deleterious microbes, including root rot pathogens, that could reduce nutrient uptake by seedlings. An earlier report described some of the results (Tanaka and others 1986).

Materials and Methods

Treatments, plot design, and soil assays. Fumigation treatments were applied at two Washington nurseries (designated A and B) in a randomized block design with three plot replications per treatment. For comparative purposes, soils were fumigated or not with methyl bromide/chloropicrin or dazomet (Basamid). Treatments were conducted at both nurseries in early September 1985, as follows:

Treatment 1: Fumigation with methyl bromide/chloropicrin (MBC) (2:1) at 404 kg ha^{-1} (360 lb ac^{-1}) rate; plots were covered with a polyethylene tarpaulin, which was removed after 2 d at Nursery B and 1 mo at Nursery A (normal operational practice). MBC was injected at the 15 cm (5.9 in) depth and tarped.

Treatment 2: Fumigation with dazomet (DAZ) at 393 kg ha^{-1} (350 lb ac^{-1}). Dazomet fumigation was done by rototilling the granules into the top 15 cm (5.9 in) of soil and sealing by irrigation but without tarping.

Treatment 3: Unfumigated control (C). Each plot consisted of three 4-m (13.1-ft) long sections of 1.3-m (4.3-ft) wide seedling beds included in an approximately 7 × 7 m^2 (23 x 23 ft^2) area.

Soil samples were collected from the three replicate plots for each treatment at 6 and 8 mo (presow), and 10 mo (postsow) after fumigation, the last sampling being just before expected onset of stunt symptoms. Three 2.5-cm (0.98-in) diameter core soil samples from each plot were separately pooled from 0-30 cm (11.8-in) depth. The core

sampler was flamed between plots to prevent cross contamination. Combined samples weighing approximately 500 g were screened (1 cm/0.39 in) to eliminate large particles and debris, and refrigerated until plated, usually within 3 d.

Standard soil dilution plating techniques on selective media were used to determine populations of *Pythium* and *Fusarium* species. The *Pythium*-selective cornmeal, antibiotic medium was a modification of that used by Mircetich (1971). The only change made was to substitute 250 mg of ampicillin sodium salt (Sigma Chemical Co., St. Louis, MO) for the 300 mg of vancomycin hydrochloride antibiotic. The *Fusarium*-selective medium was that developed by Komada (1975).

Soils for *Pythium* dilution plating first were screened through a 4-mm (0.16-in) sieve; then 5.0 g was mixed into 100 ml of 0.5 percent water agar, swirled sufficiently to suspend the soil, and allowed to stand for 30 s to settle the larger particles. One milliliter of the suspension was ladled onto each of five Petri plates containing 25 ml of selective medium and carefully spread with a sterile spoon, taking care to keep the suspension away from the plate edge. After incubating in the dark at 20 °C for 60–72 hours, inoculated plates were washed with running tap water to remove the surface water agar and soil to facilitate counting of colonies. *Pythium* species were not differentiated, and populations were expressed as propagules g^{-1} moist soil.

Fusarium populations were assayed as in the *Pythium* assays, except that the soil was suspended in a 0.3 percent water agar. Plates were incubated for 5 d at 22–24 °C in natural light, and colonies were counted as described by Komada (1975).

Seedling sampling and assays. Seed was sown by machine at both nurseries in early May 1986. Measurements of growth and mycorrhizal colonization were made on 10 seedlings from each replicate plot on July 15, 1986. Seedlings were carefully washed to remove adherent soil, bagged, and shipped on ice to the Horticultural Crops Research Laboratory in Corvallis, OR, where each was examined for presence of ectomycorrhizae. We determined total number of short roots per seedling, percentage of short roots with mycorrhizae per seedling (as indicated by the presence of a fungal mantle), and number of seedlings with any mycorrhizae. Measurements were made on photocopy images of each root system, and number of short roots was determined from the photocopies.

During the 1986 growing season, incidence of 1-0 stunting within the trial plots also was determined on the basis of the percent of stunted seedlings within a 0.557-m^2 (6-ft^2) area of bed. Based on previous years' observations, a seedling was considered stunted if it was less than 7 cm (1.5 in) tall from ground to apical bud.

In a supplemental experiment, soil was collected from areas in Nursery A where stunted seedlings occurred. Soils were sent to the Horticultural Crops Research Laboratory in Corvallis, OR, pasteurized with air-steam (60 °C, 30 min) or not pasteurized, and used to fill pine cell (55 cm^3/3.356 in^3) Leach tubes (Steuve and Sons, Corvallis, OR). The stunt soils, pasteurized or not, were seeded with Douglas-fir, and seedlings were grown under greenhouse conditions without additional fertilizer beyond the residual in the soil collected from the nursery. Soil was washed from seedling roots after 2-mo growth, and roots were observed under a dissecting microscope.

All data were analyzed statistically as means of replicate plots with analysis of variance (Steel and Torrie 1960). When differences between treatments were significant at the 5 percent level of probability, means were compared with Duncan's new multiple range test. Percentages were analyzed after arcsin transformation.

Results

Plant responses. *First year stunting*. The incidence of first-year stunting was very low at both nurseries in the blocks used for this study. The highest level for any treatment was in the unfumigated controls, being 0.14 percent for Nursery A and 2.5 percent for Nursery B (table 1). In general, seedlings grown in soil fumigated with MBC or DAZ were significantly larger (root weight and shoot height) at the end of the growing season than were those grown in unfumigated soil.

Root development. In general, MBC (and, to a lesser extent, DAZ) fumigation increased the root mass and length and the number of short feeder roots (table 1). At the end of the growing season, the number of short roots was greater on seedlings grown at Nursery B than Nursery A. Careful removal of stunted and unstunted trees from Nursery A and visual examination showed a striking difference in the size of the root systems, as well as in the adherence of soil to the roots. With stunted seedling roots, the soil fell off easily, leaving largely bare roots; in contrast, soil ad-

hered to the roots of unstunted seedlings (figure 3). Washing the soil off the unstunted seedlings revealed abundant hair roots to which the soil had adhered; hair roots were mostly missing from the stunted seedlings. Seedlings from Nursery B were not examined in this manner.

Mycorrhiza formation. Examination of short roots for mycorrhizae on seedlings in Nursery A on July 15, 1986, revealed that more mycorrhizae generally occurred on seedlings from the DAZ fumigated plots than on those from the MBC-fumigated or unfumigated control plots (table 1). The occurrence of seedlings with mycorrhizae was scattered and on relatively few seedlings. In Nursery B, seedlings in plots fumigated with either MBC or DAZ also had more mycorrhizae than in the unfumigated control, comparable to Nursery A. Over all treatments, 16–57 percent of the seedlings at Nursery A and 16–50 percent at Nursery B had some mycorrhizae at the end of the growing season. The percentage of short roots with mycorrhizae at that sampling time, however, was only 1–9 percent at Nursery A and 5–17 percent at Nursery B, with control treatments generally having a lower level of mycorrhizae than fumigation treatments. Thus, less than half of the seedlings had any ectomycorrhizae; the incidence on short roots of those that did was very low on both stunted and unstunted seedlings.

Root rot pathogen population dynamics. Population counts of *Fusarium* and *Pythium* were determined for samples taken, at the same times from both nurseries, from the top 30 cm (11.8 in) of soil (table 2). The data clearly show the effectiveness of MBC fumigation in reducing *Fusarium* and *Pythium* populations. Dazomet was statistically as effective in reducing *Fusarium* populations as MBC at all sampling dates in Nursery A, but generally did not reduce them to the extent of the MBC treatments. The same trend was found for *Fusarium* at Nursery B.

Figure 3. Left: stunted (right) and unstunted (left) seedlings after washing. Right: stunted (left) and unstunted (right) seedlings just after removal from nursery soil. Seedlings were immediately adjacent in the nursery bed; note the difference in the soil adherence to the two root systems.

Table 1. Effects of soil fumigation with methyl bromide/chloropicrin (MBC) or dazomet (DAZ) compared to with untreated controls (C) on development of shoots, roots, and mycorrhizae (MR) in relation to the incidence of stunting on Douglas-fir seedlings grown at two Pacific Northwest bare-root nurseries, as measured on July 15 following seeding in May 1986.

Treatment	Shoot height (cm)	Root weight (mg)	Root length (cm)	No. short roots/ seedling	Short roots with MR(%)	Seedling roots with MR(%)	Stunting (%)
				Nursery A			
MBC	17.8a [x]	185a	89a	155a	1b	23 [y]	0b
DAZ	13.8b	134b	63b	109b	9a	57	0b
C	13.1c	105c	66b	112b	2b	16	0.14a
				Nursery B			
MBC	13.3a	211a	112a	264a	17a	50	0b
DAZ	12.1b	181b	103a	189b	12b	43	0.8b
C	11.5c	137c	84b	178b	5c	16	2.5a

[x]Data are means of means of 3 replicate plots per treatment, 10 seedlings per plot. Means in a column followed by the same letter are not significantly different ($p<0.05$; Duncan's new multiple range test).

[y]Data are means of 3 replicate plots, each derived from the average of 10–15 seedlings sampled

Table 2. Effects of soil fumigation with methyl bromide/chloropicrin (MBC) or dazomet (DAZ) compared with untreated controls (C) on populations of *Fusarium* and *Pythium* in the top 30 cm of soils assayed 6 and 8 m (presow) and 10 mo (postsow) after fumigation and prior to the expected onset of Douglas-fir seedling stunting in Pacific Northwest nurseries A and B.

	SAMPLE (TIME) AFTER FUMIGATION IN MONTHS											
	Fusarium						Pythium					
	6 (March)		8 (May)		10 (July)		6 (March)		8 (May)		10 (July)	
TREATMENT	A	B	A	B	A	B	A	B	A	B	A	B
MBC	20b	7b	0b	0b	0b	20b	0b	2b	45b	0b	1b	4b
DAZ	247b	13b	133b	13b	0b	133ab	8b	0b	53b	7b	4b	3b
C	3100a	300a	687a	553a	13a	180a	117a	80a	277a	97a	36a	56a

Data presented are mean numbers of propagules/g moist soil taken from three replicate plots. Data in columns followed by the same letter are not significantly different ($p<0.05$; Duncan's new multiple range test).

Fusarium population fluctuations at both nurseries only occurred to any extent in the C treatment in the March to May samples taken before sowing in the spring. populations were consistently greater at Nursery A than at Nursery B until the July sampling, when populations were inexplicably greater in B than A.

Pythium populations were effectively reduced by either fumigation treatment at both nurseries and remained low throughout the study (table 2). In the unfumigated control (C), the populations began to increase in March, peaked by the May sampling, and then declined in the July sample; the effect was more pronounced at Nursery A than B. A similar trend occurred in the May samplings from the MBC and DAZ treatments, but to a much lesser extent than in C.

In the supplemental experiment comparing pasteurized and unpasteurized stunt soil, pasteurization appeared to reduce the incidence of seedling stunting. Even seedlings grown in pasteurized soil however, did not grow well and were generally stunted and chlorotic, indicating nutrient deficiency in the small tubes. Nevertheless, seedlings grown in pasteurized stunt soil had more hair roots, similar to the unstunted seedlings observed in the bareroot nursery (figure 3). Roots of seedlings grown in the unpasteurized stunt soil exhibited the lack of hair roots as seen in nursery A. No data on seedling growth or hair root development were taken, however. Also, no microbial isolations were performed to determine what possible deleterious microbes might have been involved.

Discussion

Several possible causes were investigated to explain stunting of conifer seedlings that can occur during the first year of growth in PNW bareroot nurseries. The first was that there was a delay in the development of feeder roots. Our growth data on seedling roots indicated that there were fewer short feeder roots on stunted than on unstunted seedlings at the time of stunt onset, which could have reduced nutrient uptake during a critical time of seedling growth. Nutrient deficiency at that time would lead to growth cessation and bud set. There was also a lack of hair roots on stunted seedlings, compared with unstunted seedlings, which also would help in nutrient uptake to sustain growth following exhaustion of seed reserves.

The second possible cause of first-year stunting that was investigated, that fumigation had eliminated mycorrhizae that could aid nutrient uptake and seedling growth, was not confirmed by our study. Mycorrhizae were at low levels before and during the time when stunting usually appears (mid-July), yet very little stunt occurred in our fumigated study plots. In other sites in previous years, as in this study, stunted seedlings had no fewer mycorrhizae than nearby (often immediately adjacent) unstunted seedlings (figure 2). Furthermore, the incidence of stunt in this study was highest in the unfumigated plots, as we had observed in previous years. However, early formation of mycorrhizae might have prevented stunting. In some cases, lack of mycorrhizae can reduce seedling growth (Campagna and White 1969; Trappe and Strand 1969; Ridge and Theodorou 1972; Sinclair and others 1975; Riffle 1980; Hung and others 1982; Kough and others 1985; Linderman 1987), especially under nutrient-limiting conditions. Inoculation of such soils with mycorrhizal fungi can often correct growth

problems by increasing the nutrient-capturing capacity of seedlings.

The third cause that we investigated was that root pathogens might damage the root system enough to impair nutrient uptake. The hypothesis that root rot caused stunting would be supported by our observations that stunting was greater in unfumigated control soil, where deleterious microbes might have occurred, than in fumigated soil. However, stunt has occurred in soil previously fumigated with MBC in the fall. If some deleterious microbes caused the stunt, they must have reinvaded the soil after fall fumigation and before spring sowing or been introduced on the seed (Graham and Linderman 1983; Hoefnagels and Linderman, 1999). It is possible that such microbes affect seedlings at sublethal levels, as has been shown by Sinclair and others (1975). At the time of stunt occurrence, we saw no signs of infection by pathogens causing root rot, so we discounted them as the cause of stunt. We did, however, isolate at the end of the season and found that the roots of most seedlings in both nurseries, regardless of soil treatment or occurrence of stunt, were heavily infected with species of *Fusarium* and *Pythium*, although root rot was not obvious (data not presented). One could, however, hypothesize the presence of deleterious microbes on the root surface that functioned under cool wet conditions, such as some species of *Pythium* or bacteria, producing toxic substances that inhibited feeder root or hair root development. Our observations that rhizosphere soil adhered more readily to unstunted seedlings than to stunted (figure 3) indicated that there were differences in hair root development and probably rhizosphere microbial activity, even between adjacent stunted and unstunted seedlings.

In the supplementary study, growing seedlings in pasteurized stunt soil, we observed a slight reduction of the stunting effect. Pasteurization of soil eliminates most deleterious microbes. Seedlings grown in pasteurized stunt soil also developed abundant hair roots to which soil adhered; roots of seedlings grown in unpasteurized stunt soil were devoid of hair roots. These observations were similar to those made in the nurseries. Unfortunately, no attempt was made to isolate the hypothetically responsible microbes that air-steam pasteurization would have eliminated. Their potential to deleteriously affect seedling root development therefore could not be determined. Reports by Suslow and Schroth (1982), Nehl and others (1997), and Li and others (2002) indicate that specific deleterious rhizobacteria can suppress root hair development. We can only speculate, however, that such bacteria were present and involved in the 1-0 stunt phenomenon. Future research would shed more light on this hypothesis.

Conclusions and Application

Stunted conifer seedlings occur, often forming a mosaic pattern, in many PNW bareroot nurseries during the first growing season. Lack of ectomycorrhizae under nutrient stress conditions, presence of root pathogens, or both have been hypothesized to explain the mid-season cessation of top growth. We examined stunting in two nurseries in relation to fumigation, root development and formation of ectomycorrhizae, and population dynamics of potential *Fusarium* and *Pythium* root pathogens or other deleterious microbes. We found that (1) root growth on stunted seedlings, compared to unstunted seedlings, was retarded with fewer short roots and less hair root development; (2) seedlings exhibit stunting symptoms before ectomycorrhizae become significantly established, and unstunted seedlings generally had no more ectomycorrhizae than stunted, leading to the conclusion that lack of mycorrhizae in fumigated nursery soils does not cause this type of first-year stunting; (3) there were no apparent signs of root rot disease, and (4) elimination of potentially deleterious microbes by soil pasteurization with aerated steam appeared to correct the stunt problem. We therefore hypothesize that some microbial causal agent or agents of stunt reinvade fumigated soil during the winter fallow period or on contaminated seed and colonize the roots of some young seedlings, subtly affecting the developing roots. Their distribution may be scattered and not associated with previous sites where stunting had occurred. Their capacity to induce stunting may be closely linked with soil conditions in the immediate vicinity of individual seedlings, since adjacent seedlings within a few centimeters frequently are not stunted. Analysis of the fertility and microbial composition in the rhizosphere soil of adjacent stunted and unstunted seedlings could provide insight as to the identity of causal agents and the nutrient elements that limit shoot growth when root system function is reduced. For some nurseries, increasing soil P levels has decreased or eliminated the 1-0 stunt phenomenon (W. Littke, personal communication), making P deficiency less likely, even if root development is delayed or inhibited.

Address correspondence to: R.G. Linderman, USDA-ARS, Horticultural Crops Research Laboratory, Corvallis, OR, 97331; email: lindermr@science.oregonstate.edu; Tel. 541-738-4062. Fax. 541-738-4025

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Performance of a Wide-ranging Collection of Black Locust Seed Sources in Western Oklahoma

C.G. Tauer

Professor, Department of Forestry, Oklahoma State University, Stillwater, OK

Abstract

Results of a 1987 black locust (*Robinia pseudoacacia* L.) seed source planting in western Oklahoma are reported. The 116 families showed considerable variation in growth. Survival to age 5 remained above 90 percent for all but nine families. Between ages 5 and 10, 40 percent of the surviving trees suffered stem dieback, probably due to hot, dry summers. Consequently, if one is selecting for use in harsh environments, testing should be long term. Correlations of growth with latitude and longitude were found, but they accounted for 10 percent or less of the variation. Greatest variation was among families, and family selection for utilization or improvement is suggested.

Introduction

Black locust (*Robinia pseudoacacia* L.) is recognized as one of the most versatile tree species in North America, and perhaps also in Europe, if not the world. It has been utilized for firewood, fuelwood, posts, poles, lumber, wood fiber, bioenergy, site stabilization, land reclamation, forage and honey production. It is drought-resistant, tolerates poor soils, fixes nitrogen, and has shown wide site adaptability. It produces a high-energy, stable wood that is decay resistant.

The original range of black locust was confined to the Appalachian, Ozark, and Ouachita Mountains. It has since been planted widely and has become naturalized throughout the United States, southern Canada, and parts of Europe and Asia (Hardin and others 2001). Black locust is reportedly one of the most widely planted hardwoods worldwide (Genys and Harman 1990), yet little information on seed source and family adaptability is available.

A few early survivability reports in Oklahoma (Afanasiev 1947, 1948) did point to the general adaptability of black locust. Some breeding work in Hungary (Keresztesi 1980) demonstrated the potential for improvement in the species. Seed source studies in Georgia (Kennedy 1983), Michigan (Mebrahtu and Hanover 1989), and Maryland (Genys and Harman 1990) all reported considerable variation among sources and families for many traits, but no geographic trends. Bongarten and others (1992) reported that black locust shows considerable potential under short rotation intensive culture management. All these seed source studies reported 1- to 3-yr data, and much remains to be learned about this species.

In this study, black locust seed sources were tested in western Oklahoma to examine growth trends and evaluate utilization of the species in the relatively harsh southern Great Plains. The study was planted in 1987, and 10-yr data are reported.

Materials and Methods

Open-pollinated black locust seeds were collected from four trees in each of 15 natural or naturalized stands across Oklahoma and one in northwest Arkansas. In addition, seeds from 151 open-pollinated families from the eastern United States and southeast Canada were provided by the Michigan Cooperative Tree Improvement Program, Michigan State University. Some of the Michigan collection consisted of two or more families from a stand; others represented single families from a collection location. Seeds of all 215 trees were acid scarified for approximately 1 h as described by Bonner and others (1974). Seed were stored wet overnight and sown in the nursery the following day, in early June 1986. No germination tests were conducted. Sowing density was 27 seed per ft^2 (0.09 m^2), and nursery practices were standard for hardwood seedlings. One hundred seed of each family were planted. Seedlings were lifted as 1-0 stock for field planting.

Seedlings were planted near Canton, Oklahoma, on an alluvial soil near the North Canadian River. The soil is a Canadian fine sandy loam. Average annual precipitation is approximately 26 in (66 cm), mean maximum July

temperature is 96 °F (70 °C), and mean minimum January temperature, 25 °F (-4 °C). Competition was controlled by mowing.

The planting design was a randomized complete block, with three-tree-row family plots and five replicates. Spacing was 8 × 8 ft (2.4 ×2.4 m), and the planting was surrounded by one border row of mixed leftover seedlings.

Number of seed germinated in the nursery was determined approximately 2 mo after planting the seed. In the field planting, survival and height were recorded at plantation age 1, 5 and 10 yr, and diameter at breast height was measured at age 5 and 10. The number of multiple stems was counted at age 10, and, because considerable dieback had occurred between ages 5 and 10, the number of stems showing main stem death was also recorded. These data were subjected to an analysis of variance with the SAS program GLM (SAS, Cary, NC).

To look for possible geographic trends in growth related to collection location, simple correlations of family means for growth and survival with latitude and longitude were calculated, as well as age/age correlations. Family and single-tree heritabilities were estimated using formulas suggested by Wright (1976), excluding the site component. These estimates were made using expected mean squares estimates from the SAS program "Variance Components Estimation Procedure."

Results

Average germination for seed planted from the 215 open-pollinated-families was 15 percent, ranging from 0 to 66 percent. Seedling survival after 1 yr in the nursery was 28 percent, ranging from 0 to 42 percent. The reason for poor seedling survival is unknown. A minimum of 15 seedlings per family was required for field planting; thus, only 116 of the 215 families are represented in the field planting.

First-year plantation survival (table 1) was 97 percent; plantation mean height was 4.3 ft (1.3 m). Only three families had survival below 90 percent. Height growth was considerably more variable, ranging from 0.8 to 8.3 ft

Table 1. Black locust plantation family and stand means and range.

				FAMILY		STAND	
TRAIT		*N*	—	*Minimum*	*Maximum*	*Minimum*	*Maximum*
SURVIVAL (%)							
Yr 1		1658	97	67	100	67	100
Yr 5		1658	92	40	100	40	100
Yr 10*		1658	60	0	100	07	100
HEIGHT							
Yr 1	(ft)	1614	4.28	0.82	8.29	2.16	5.64
	(m)		1.30	0.25	2.53	0.66	1.72
Yr 5	(ft)	1527	13.32	1.50	20.60	7.07	14.90
	(m)		4.06	0.46	6.28	2.15	4.54
Yr 10	(ft)	989	20.35	0.80	32.00	11.80	27.30
	(m)		6.20	0.24	9.75	3.59	8.32
DIAMETER							
Yr 5	(in)	1498	1.59	0.24	3.27	0.91	2.18
	(cm)		4.04	0.61	8.31	2.35	5.54
Yr 10	(in)	989	2.91	0.51	6.89	1.34	4.13
	(cm)		7.39	1.29	17.50	3.40	10.49
AGE 10							
% multiple stems		988	26.6	0.00	100	0.00	100
% dieback		988	29.9	0.00	100	0.00	100

* % = number without dieback Yr 10/number alive Yr 5

(0.25 to 2.53 m). Stand data are also presented in table 1. The 116 families represented 54 stand locations, but 29 of these stands are represented by a single seed source. The other stands included 2 to 13 families. Stand range in survival was the same as the family range because the poorest family was a single-family stand.

Fifth-year survival was still high, with a plantation mean of 92 percent. At this age, 9 more families had dropped below 90 percent survival, for a total of 12. Only 3 of these families were below 80 percent survival, and these were the families below 90 percent survival at age 1. Variability in height among families had increased considerably, with a plantation mean height of 13.3 ft (4.06 m), but a range of 1.5–20.6 ft (0.46–6.28 m). The stand height ranged from 7.1 to 14.9 ft (2.15 to 4.54 m), but, except for the two slowest growing stands (the same two with the lowest survival), all stands averaged between 11 and 15 ft (3.3 to 4.6 m) in height. Plantation mean DBH at age 5 was 1.6 in (4.04 cm), with a range of 0.2–3.3 in (0.61–8.31 cm) for families and 0.9–2.2 in (2.35–5.54 cm) for stands. Only trees >4.5 ft (1.37 m) in height are included in the diameter data.

A large number of families suffered from main stem dieback sometime between age 5 and 10. Since most of the trees showing dieback had lower stem or basal sprouts, they were not counted as dead. Therefore, to better reflect the performance of families not exhibiting dieback, age 10 survival was calculated as the number of trees alive at age 5 not showing dieback at age 10. Thus, as shown in table 1, only 60 percent of the trees alive at age 5 did not exhibit dieback by age 10. The family range was 0–100 percent, and the stand range, 7–100 percent.

Trees showing main stem dieback were not included in the age 10 height and diameter data summaries. Age 10 family mean heights ranged from 0.8 ft (suggesting that some trees suffering from dieback were inadvertently measured) to 32.0 ft (0.24 to 9.74 m), while stand means ranged from 11.8 to 27.3 ft (3.59 to 8.32 m). Stem diameter at age 10 for family means ranged from 0.5 to 6.9 in (1.39 to 17.50 cm); stand means were 1.3–4.1 in (3.40–10.49 cm).

Age/age correlations of growth traits (table 2) were high for age 1 with age 5, but were much reduced for age 10 with age 1 and 5 because of the age 5 dieback. Consistent, relatively small, yet generally significant negative correlations were found between most traits and latitude. A generally consistent but, again, relatively small positive correlation was found for correlations of growth traits with longitude.

At age 10, 26 percent of the remaining trees had multiple stems. Number of stems showed a small but significant correlation with longitude ($r = -0.30$) and latitude ($r = 0.27$). Number of stems was also positively correlated with height and diameter at age 1 and age 5, but this was lost at age 10, no doubt due to dieback.

Analysis of variance for growth traits and family and individual tree heritabilities were estimated (table 3), although these estimates are upwardly biased because a single planting is represented. Except for age 1 family in stand survival, family in stand and stand differences were significant for all survival, height, and diameter measurements, as well as percent dieback at age 10. The number of stems was not significant.

Discussion

Seed germination and seedling survival in the nursery were highly variable among families. Germination rates were no doubt highly influenced by the acid scarification. Olson (1974) reported that predetermined optimum acid soaking times can vary from 10 to 120 min by seed lot. Since we treated all lots similarly, germination data were probably not representative of the true viability of the families, and therefore germination data were not included in further analysis.

Initial survival and growth of virtually all the families in the field were excellent. There was no difference in survival between family and stand means at age 1 because the three poorest performing families (the only families below 90 percent survival) were single-family stands, and many stands and families showed 100 percent survival. Unlike survival, there was considerable variation in height growth by the end of 1 yr in the field, with the best families exceeding 8 ft (2.4 m). As expected, first-year stand height showed less variability than did family height. At age 5, both survival and growth were still excellent for the plantation as a whole, with considerable variability in growth, suggesting that a breeding program to improve growth in black locust would be quite effective. Since survival was still >90 percent, little need to improve survival

was suggested. There were, however, several families which exhibited both slow growth and poor survival and were clearly not well adapted to the Oklahoma conditions. These families became more obvious at age 10.

By age 10, a considerable amount of main stem dieback had occurred. This dieback was probably due to one or several exceptionally hot, dry summers. Consequently, initial planting survivability was no longer of concern; rather, families surviving dieback on harsh sites such as the test site would be more important. For black locust planted in harsh environments, such as western Oklahoma, these 10-yr survival data are perhaps the most valuable. It would seem logical to select those families showing little or no age 10 dieback for such sites.

Obviously, black locust possesses a vast amount of variability in growth at both the stand and family levels. There, is however, a very limited apparent geographic pattern or trend among sources to suggest a starting point for a selection and improvement program. The small correlations

Table 3. Analysis of variance p values and heritability (h^2) estimates.

	GLM–ANOVA P VALUES (TYPE III)			HERITABILITIES	
Trait	**Stand**	**Family (Stand)**	**Rep × F(S)**	**h^2 Family**	**h^2 Tree**
Survival					
Age 1	0.0001	0.8964	0.3500	0.32	0.12
Age 5	0.0001	0.0001	0.0001	0.58	0.41
Height					
Age 1	0.0001	0.0001	0.0001	0.59	0.47
Age 5	0.0001	0.0001	0.0001	0.69	0.63
Age 10	0.0001	0.0001	0.0001	0.58	0.47
Diameter					
Age 5	0.0001	0.0001	0.0001	0.67	0.60
Age 10	0.0001	0.0028	0.0027	0.58	0.40
% Stems	0.1634	0.1310	0.2447	0.32	0.13
% Dieback	0.0001	0.0001	0.0081	0.69	0.60

Table 2. Simple correlation coefficients among family means[a] and with latitude and longitude.

	SURVIVAL	HEIGHT			DIAMETER		PERCENT	PERCENT
	Age 1	Age 1	Age 5	Age 10	Age 5	Age 10	Multiple stems	Dieback
HEIGHT								
Age 1	0.2906[b] 0.0019[c]							
Age 5	0.2924 0.0014	0.6795 0.0001						
Age 10	-0.0217 0.8181	0.2819 0.0023	0.3950 0.0001					
DIAMETER								
Age 5	0.1784 0.0554	0.6647 0.0001	0.8059 0.0001	0.4776 0.0001				
Age 10	0.0268 0.7761	0.2992 0.0012	0.3454 0.0002	0.7925 0.0001	0.5932 0.0001			
% Multiple stems	0.2875 0.0018	0.1897 0.0422	0.3842 0.0001	0.1526 0.1034	0.2525 0.0065	0.1023 0.2765		
% Dieback	0.0457 0.6265	0.0934 0.3186	-0.0667 0.4769	-0.0878 0.3507	-0.1959 0.0350	-0.0212 0.8225	0.1176 0.2107	
Latitude	-0.1319 0.1582	-0.1051 0.2617	-0.1675 0.0723	-0.1751 0.0613	-0.1952 0.0358	-0.2488 0.0073	-0.3016 0.0011	-0.2062 0.0264
Longitude	0.0843 0.2681	0.0871 0.3526	0.2361 0.0107	0.2141 0.0216	0.2890 0.0017	0.3386 0.0002	0.2763 0.0028	-0.0111 0.9063

[a]The number of families = 116 at ages 1 and 5 and 115 at age 10.

[b]Pearson correlation coefficients

[c]Prob >_R_ under Ho: Rho = 0--i.e., the probability that the correlation is not different from 0.

with latitude detected suggests the typical relationship of northern sources growing more slowly, but these correlations account for less than 10 percent of the total variation and are no doubt of limited importance. The correlations with longitude may reflect the original range of black locust, a range split between east and west of the Mississippi River Valley. If origin were known for all sources, the correlation might be greater, as might correlations with latitude. Again, these correlations represent at most about 11 percent or less of the total variation observed and, since native and naturalized stands can no longer be distinguished even in the native range of the species, the correlations are of limited practical value. Good-performing stands and families tend to be scattered among both the native range and naturalized areas, and it seems practical to recommend testing to identify good sources for use in any particular area.

The positive correlation of multiple stem number with growth traits suggests a relationship of fast growth to poor form, which may be a concern, depending on intended use of a planting.

Both family and individual tree heritabilities tend to be quite high for all traits except number of stems. First-year survival heritabilities were also relatively low, probably because survival was uniformly high. Generally high heritabilities suggest that an improvement program would be effective. The low heritability of stem number may alleviate any concern about the possible relationship of stem number to growth.

Conclusions

These 1, 5-, and 10-yr growth data generally agree with earlier reports on black locust at ages 1 to 3 (Kennedy 1983; Mebrahtu and Hanover 1989; Genys and Harman 1990). That is, there is a considerable amount of genetic variation available in black locust, but there are no important or strong geographic trends. Consequently, selection of "best sources or families" for any particular region will require testing of many sources or families on the sites of interest to determine which sources and families are best for those sites. For example, if selecting the best stands, defined as growth of 20 ft (6 m) in height or better with less than 10 percent dieback at age 10, one stand from each of Oklahoma, Arkansas, Kentucky and Tennessee would be included. With the same criteria, at the family level, 16 families would be selected: 7 from Oklahoma, 2 from Kentucky and Maryland, and 1 each from Tennessee, Arkansas, Michigan, and New Brunswick and Ontario, Canada. Relaxing the dieback criteria to 20 percent, 9 sources from 5 States would be included; at the family level, 29 families, 13 of them from Oklahoma and Arkansas, fit the criteria, coming from 11 States or provinces. Obviously, for finding good sources or starting an improvement program for black locust in Oklahoma, Oklahoma and Arkansas sources would be appropriate. Family selection could be quite effective.

These results suggest the opportunity to greatly improve black locust through selection and breeding. As suggested by Surles and others (1989), a breeding program should focus on family-level selection, as stand selection alone has limited potential for gain.

Address correspondence to: Chuck Tauer, Rm 008C, Department of Forestry, Oklahoma State University, Stillwater, OK 74078; email: chuck.tauer@okstate.edu

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An Inexpensive and Reliable Monitoring Station Design for Use with Lightweight, Compact Data Loggers

Ronald S. Zalesny, Jr., Adam H. Wiese, Edmund O. Bauer, William L. Headlee, Jr.*,
Richard B. Hall, A. Assibi Mahama, and Jill A. Zalesny

Research Plant Geneticist, Forestry Technician, Biological Laboratory Technician (retired), Forestry Technician, USDA Forest Service, Northern Research Station, Forestry Sciences Laboratory, Rhinelander, WI; Wallace Endowed Professor, Iowa State University, Department of Natural Resource Ecology and Management, Ames, IA; Research Associate, Iowa State University, Department of Agronomy, Ames, IA; Doctoral Graduate Research Assistant, Iowa State University, Department of Natural Resource Ecology and Management, Ames, IA

**Current Affiliation: Agricultural Inspector, Arizona Department of Agriculture, Plant Services Division, Lake Havasu City, AZ*

Abstract

We designed, constructed, and field-tested an inexpensive and reliable monitoring station that can be used with lightweight, compact data loggers. We feel this design, improved three times over 6 yr, could benefit anyone in nursery or field settings interested in acquiring environmental data. We provide step-by-step instructions on the construction of the monitoring station, with the cost of materials at less than $20 per station (not including the data loggers).

Introduction

Maximum temperatures greater than 120 °F (48.89 °C) at the soil surface in canopy gaps with a diameter of 150 ft (45.72 m) have been reported (Nauertz and others 1997). Such extreme weather conditions require researchers to invest substantial amounts of time, money, and other resources in protecting their weather-monitoring equipment from damaging environmental conditions. For example, temperature and moisture extremes within any given 24-h period can cause problems due to expansion and contraction of metal wires and other components, leading to faulty connections and eventual loss of data. Also, direct solar radiation causes breakdown of weather-monitoring equipment and its protective coverings over time.

We routinely acquire environmental data on our poplar (*Populus* spp.) progeny tests, rooting trials, and other studies so that trends can be interpreted and development explained (Hansen 1986; Wan and others 1999; Zasada and others 2001). Similarly, researchers from many fields of study in the plant sciences assess the correlation between growth and environmental parameters such as air and soil temperature, soil moisture, relative humidity, and related variables (Luomajoki 1995; Landhäusser and others 2001; Lu and others 2001). Older devices used to collect environmental data are cheaper than newer equipment, but are more cumbersome, less reliable, and less precise. In contrast, some current equipment supports rapid, reliable, and precise data acquisition, but at great cost. In addition, some new devices are complicated to program and operate, requiring a greater training investment than older devices. Also, substantial costs are incurred from securing the instrumentation in the field over extended periods of time. The cost of the monitoring station often is a major investment relative to other research supplies. Yet the price of a monitoring station may not be positively correlated with ease of use, reliability in the field, and durability during periods of inclement weather. Therefore, our objective was to design, construct, and field test a monitoring station that was less cumbersome and more reliable than older stations, while less expensive and less complicated than other new equipment.

Field Observations and Design Improvements

A prototype of our monitoring station was designed at the Forestry Sciences Laboratory in Rhinelander, WI, during the spring of 1998. The prototype consisted of data loggers mounted on a wooden post with a plexiglass shield for shade and protection from other elements. We tested the prototype at the Hugo Sauer Nursery in Rhinelander dur-

ing the 1998 growing season. Two major problems were apparent: the plexiglass shield was too small to provide adequate protection, and the post became unstable as it began to rot.

The original design was revised during the fall of 1998. Four monitoring stations of the revised design were used with data loggers recording air temperature at 3 ft (91.44 cm) above the soil surface, soil temperature at a depth of 8 in (20.32 cm), and relative humidity in a field study at two sites in central and northern Minnesota during 1999 (Zalesny and others 2004). The remaining two monitoring stations were installed at the Hugo Sauer Nursery during the growing seasons of 1999 and 2000. The lightweight monitoring stations were easy to build and were constructed at a fraction of the cost of commercial stations. The monitoring stations were reliable throughout the growing season, which led to minimal loss of data from the data loggers and minimal resources invested in maintenance of the monitoring stations. The monitoring stations had to be removed from the field at the end of each growing season, however, because of increased impact of moisture on the wooden posts.

During the spring of 2001, we modified the monitoring station design, adding a piece of polyvinyl chloride (PVC) pipe that was inserted into the ground. We speculated that we could leave the PVC in the ground during winter months without damage, and we were correct. The shade framework post was inserted into the PVC and secured with two bolts the next spring, and the monitoring station and its data loggers were still operational.

The final design, which is explained in detail below, was field-tested during the 2001 and 2002 growing seasons. Two stations with data loggers were installed at each of three sites across Iowa and Minnesota as part of three field studies of *Populus* (Zalesny 2003; Zalesny and others 2003; 2005ab). The PVC remained in the field throughout the year, while the shade framework was removed during the winter. Overall, there were no structural problems with the monitoring stations across the 2 yr and three sites. We lost less than 1 percent of the potential data because of malfunction of the data loggers themselves; no data were lost because of a faulty monitoring station. Maintenance of the stations was negligible, despite strong winds, severe temperatures, wet soils, and extreme solar radiation.

The total cost of the materials to construct the final monitoring station was less than $20 (not including the data loggers). We feel this design, improved three times over 6 yr, could benefit anyone in nursery or field settings interested in acquisition of environmental data. Provided below are step-by-step instructions on the construction of the final monitoring station.

Monitoring Station Construction

Materials and Equipment. Figure 1 is a photograph of an assembled monitoring station. The materials and equipment needed to construct a monitoring station according to our specifications for use with most lightweight, weatherproof compact data loggers are as follows (figure 2): one piece of lumber, 2-in × 2-in × 8-ft (5.08-cm × 5.08-cm × 2.44-m) (A, B); 2.25-in (5.715-cm) wood screws (C); one piece of plexiglass 0.125 in (0.3175 cm) thick (D); 1.25-

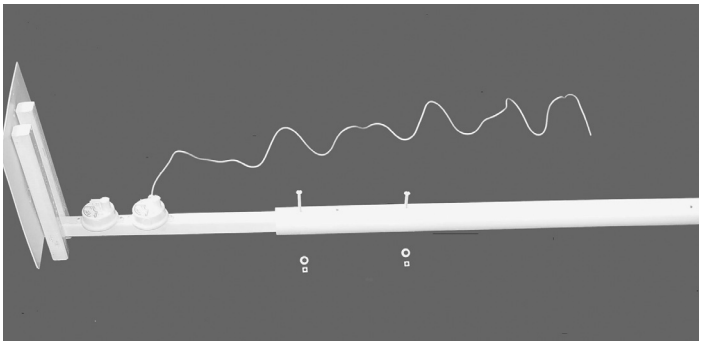

Figure 1. Monitoring station for use with lightweight, compact data loggers.

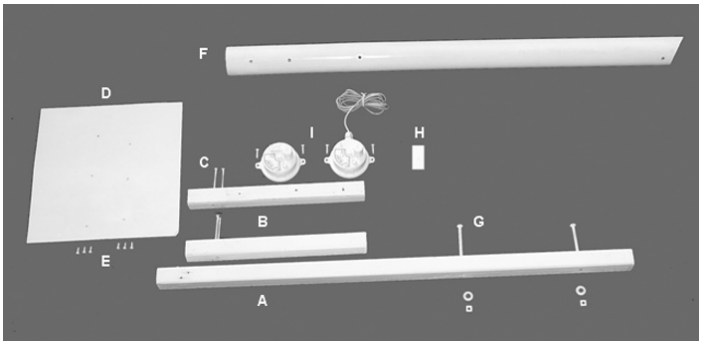

Figure 2. Materials needed to construct the monitoring station: one piece of lumber 2-in × 2-in × 8-ft (5.08-cm × 5.08-cm × 2.44-m) (A, B); 2.25-in (5.715-cm) wood screws (C); one piece of plexiglass, 0.125 in (0.3175 cm) thick (D); wood screws, 1.25-in (3.175-cm) (E); 39 in (99.06 cm) of 2-in (5.08-cm) polyvinyl chloride pipe (PVC), usually sold in 10-ft (3.05-m) sections (F); two bolts, 3 in (7.62-cm) long × 0.25-in (0.635-cm) diameter, with washers and nuts (G); a wedge. used as a spacer between the lumber and the PVC to add rigidity (H). HOBO® H8 Pro Series data loggers (I) are shown; however, other data loggers will work.

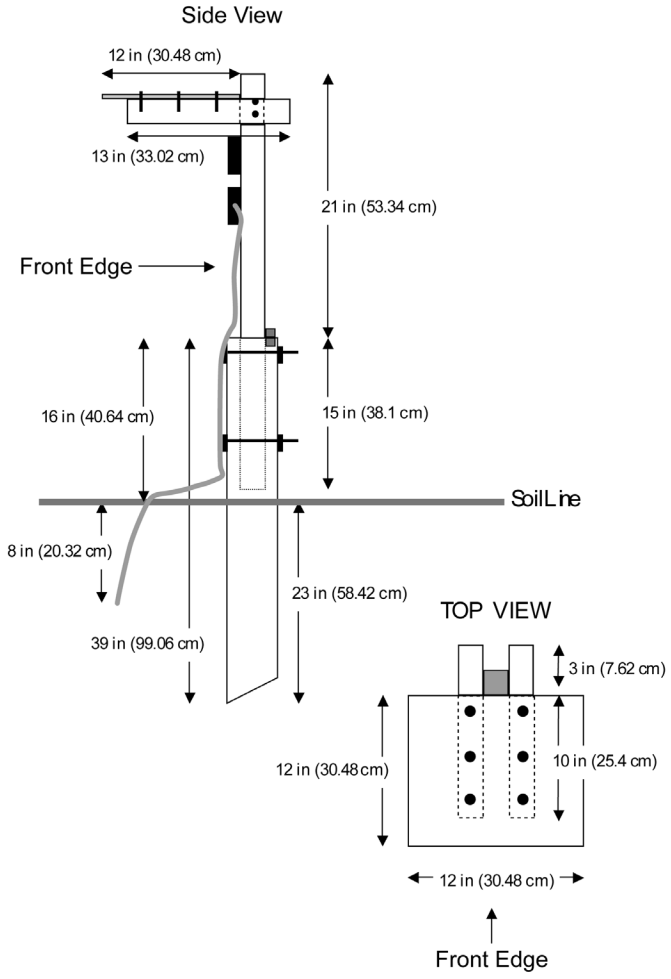

Figure 3. Specifications for assembly of the monitoring station.

in (3.175-cm) wood screws (E); 39 in (99.06 cm) of 2-in (5.08-cm) polyvinyl chloride pipe (PVC), usually sold in 10-ft (3.05-m) sections (F); two bolts, 3-in (7.62-cm) long × 0.25-in (0.635-cm) diameter, with washers and nuts (G); a wedge used as a spacer between the 2-in × 2-in (5.08-cm × 5.08-cm) lumber and the PVC to add rigidity (H); one can of white spray paint, a drill, drill bits, a compound miter saw, wrenches, a tape measure, and C-clamps.

Assembly. Figure 3 gives design specifications.

Step 1. Cut the piece of lumber into one section 36 in (91.44 cm) long (figure 2, A) and two sections 13 in (33.02 cm) long (figure 2, B) with the compound miter saw. After cutting the lumber, paint all of the components and allow to dry.

Step 2. Mark 10 in (25.4 cm) from the end of the two 13-in pieces of lumber. Use the 2.25-in (5.715-cm) wood screws (C) to attach the 13-in (33.02-cm) pieces of lumber to the 36-in (91.44-cm) piece of lumber, 1.5 in (3.81 cm) from the top. Be sure the 10-in (25.4-cm) mark is flush with the front edge of the 36-in (91.44-cm) piece of lumber. *Note:* it is advised to drill pilot holes before attempting to fasten the pieces together in order to prevent the wood from splitting.

Step 3. Cut the plexiglass into a 12- × 12-in (30.48- × 30.48-cm) square (D). Paint the plexiglass and let stand until dry. Mark 3.75 in (9.525 cm) from both sides. These marks should line up with the outside edges of the two 13-in (33.02-cm) pieces of lumber that were attached in *step 2.* Using the C-clamps, clamp the plexiglass to the horizontal 13-in (33.02-cm) pieces of lumber and drill six pilot holes, three holes for each 13-in (33.02-cm) piece. Attach the plexiglass to the horizontal pieces of lumber with 1.25-in (3.175-cm) wood screws (E). Caution: overtightening may fracture the plexiglass .

Step 4. Make a 45° cut 39 in (99.06 cm) down from either end of the piece of PVC (F). This measurement is to the long point of the angle.

Step 5. Mark 16 in (40.64 cm) down from the square end of the 39-in (99.06-cm) piece of PVC. This line is the soil surface mark. Measure from the bottom of the 36-in (91.44-cm) piece of lumber and make a mark at 15 in (38.1 cm). The difference of 1 in (2.54 cm) will keep the wood post off the ground and aid in extending the life of the monitoring station.

Step 6. Insert the 36-in (91.44-cm) piece of lumber into the PVC to the 15-in (38.1-cm) mark made in *step 5.* Drill two holes through the PVC and the lumber, one hole 3 in (7.62 cm) down from the square end of the PVC and one hole up 3 in (7.62 cm) from the soil surface mark on the PVC. *Note:* be sure the hole is the same size or slightly larger than the bolts (G).

Field Installation. Refer to figure 3 for design specifications.

Step 1. Drive the PVC into the ground to a maximum depth of 23 in (58.42 cm) using a sledge hammer or other appropriate tool, depending on soil conditions. *Note:* put a block of wood on top of the PVC in order to prevent splitting the PVC when pounding.

Step 2. Insert the 36-in (91.44-cm) piece of lumber into the PVC and line up the holes made in step 6 above. Insert the bolts and washers and fasten the nuts with the appropri-

ate wrenches. Insert the wedge (H) before tightening. The wedge, which can be made from any material available, adds rigidity to the shade framework. Use the remaining paint to touch up any part of the shade framework that was scratched during construction or transportation to the field.

Step 3. Secure the data loggers to the shade framework just below the plexiglass with the screws. *Note:* secure the data loggers as close as possible to the underside of the plexiglass to aid in the protection of your equipment from solar radiation. If using a data logger with a soil probe, insert the probe into the ground at least 12 in (30.48 cm) from the PVC to avoid overestimates of soil temperature when the PVC heats up.

Address correspondence to: Ronald S. Zalesny Jr., USDA Forest Service, Northern Research Station, Forestry Sciences Laboratory, 5985 Highway K, Rhinelander, WI 54501 Voice: (715) 362-1132, Fax: (715) 362-1166, E-mail: rzalesny@fs.fed.us

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Disclaimer

We used HOBO® H8 Pro Series data loggers (Onset Corporation, Bourne, MA) because they met our research needs. Use of specific data loggers is left to the discretion of the researcher. Endorsement is not intended by the Forest Service, United States Department of Agriculture, or Iowa State University.

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Send the manuscript to Dr. Robin Rose at:
robin.rose@oregonstate.edu

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College of Forestry
Oregon State University
Richardson Hall
Corvallis, OR 97330
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Article in proceedings:	Smith, A.B.; Brown, E.F.; and Jones, C.D. 1999. Tree planting in Oregon. In: Roberts, G.H.; Jones, C.D., eds. 22nd Annual Meeting of the Northern Tree Planters Association; 1998 August 11; Seattle, WA. General Technical Report PNW-444. Portland, OR: USDA Forest Service, Pacific Northwest Research Station: 120-122.
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