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Rocky Mountain
Forest and Range
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Fort Collins,
Colorado 80526

General Technical
Report RM-137

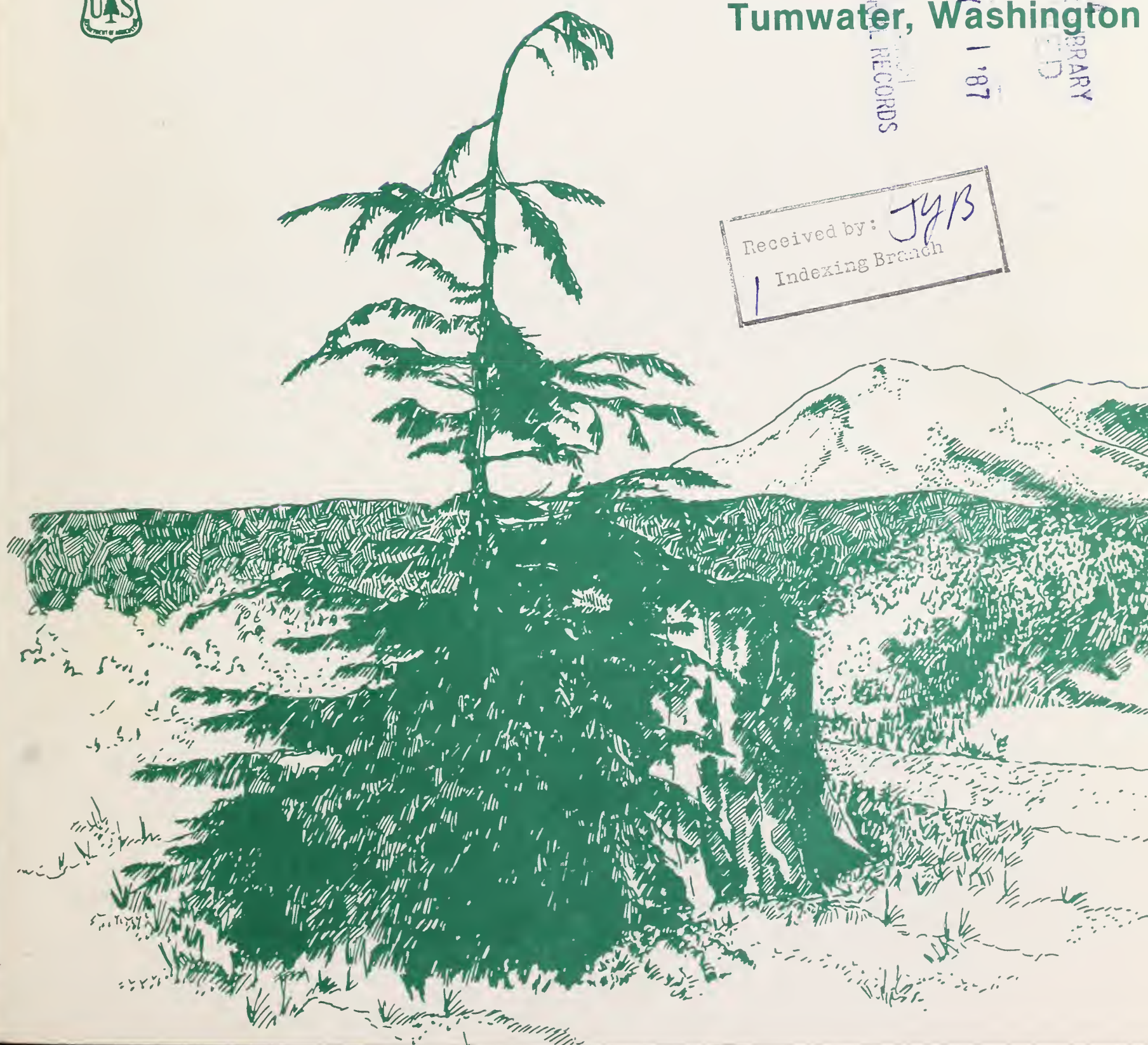


Proceedings: Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting

August 12-15, 1986
Tumwater, Washington

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Landis, Thomas D. Proceedings: Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting; 1986 August 12-15; Tumwater, WA. Gen. Tech. Rep. RM-137. Fort Collins, CO: U.S Department Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1986. 164 p.

Abstract

This proceedings is a compilation of over 30 technical articles on various phases of container and bareroot nursery management. Specific areas addressed include: seed production, cultural practices, seedling quality, nursery pests, seedling storage, and computers.

Keywords: Tree nurseries, greenhouses, tree seedlings, containerized seedlings.

Proceedings: Combined Western Forest Nursery Council and Intermountain Nursery Association Meeting

**August 12-15, 1986
Tumwater, Washington**

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**Funding for this publication was provided by
State and Private Forestry, USDA Forest Service.**

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Where Are We Headed, and What Should We Be Planning For?¹

John P. McMahon ²

INTRODUCTION

Good morning.

I want to thank you for the opportunity to be with you this morning.

As nurserymen, you play a crucial role in the reforestation process, which is essential to the future of forest management in the Northwest. I believe it is very appropriate that we get together periodically to share ideas and discuss mutual problems and opportunities. It is encouraging to see so many interested professionals from both the public and private sector involved in this forum.

THEME

I would like to propose the following theme for my remarks this morning, as well as for the balance of this four-day session. That theme is:

"Where are we headed and what should we be planning for?"

Before discussing where we are going, it is well to recognize where we are now and how we got here.

We have indeed come a long way from the low levels of forestry characteristic of the mid 60's, when direct aerial seeding was the primary means of man-influenced reforestation west of the Cascades. Public and private foresters alike recognized the need for more reliable regeneration methods, and the implications for future growth and yield, if rapid regeneration with controlled spacing could be assured following logging. At the same time, during the 1970's, regeneration requirements resulting from strengthened state forest practices acts and new federal laws increased the demand for planting stock for private, state and federal lands.

¹ Paper presented at the meeting of the Western Forest Nursery Council, Olympia, Washington, August 12, 1986.

² John P. McMahon is Vice-President, Timberlands, Weyerhaeuser Company, Tacoma, Washington.

Nursery capacity expanded through the early and mid-70's to meet this increased demand for seedlings. Private industrial landowners increased their efforts to rehabilitate poorly stocked acres and convert hardwood stands on high sites back to conifer production. The U.S. Forest Service received an extra "one-time" mandate to eliminate a sizable reforestation backlog, with the National Forest Management Act of 1976. By 1985, this resulted in more than one million acres actually treated nationwide...nearly three quarters of which occurred on the western National Forests.

The decade of the '70's was also a period of rapid change in the development of successful stock types and growing regimes. This was, and continues to be, a dynamic process. Some technology was borrowed from other parts of the world, but much local knowledge and experience had to be gained. Research has played an important role in developing that knowledge. Initially most nursery research was sponsored by larger organizations. I think it is significant that an active nursery cooperative research effort has become established here in the Northwest in the early 80's, allowing access to research results by independent nurserymen as well as private non-industrial forest landowners.

Since the early days of nursery management, we have gained a much better understanding of physiological processes as they relate to seedling performance. Research on culture, lifting, and storage has had perhaps the most significant influence on improvement in quality, and we have become much more sophisticated in how we measure seedling quality. Container systems rapidly emerged as an expected solution to bare-root problems, particularly in the higher elevations, in the mid 70's; then declined somewhat as we learned to culture for better root development, as well manage bareroot dormancy through timing of lifting and duration of storage. Although diminishing somewhat in volume, plug seedlings continue to be a very valuable special purpose stock type and are still regarded by many as a general purpose stock type. Clearly, the demand is still there for both types of seedling production systems.

Although we are consistently growing a higher quality product than ten or fifteen years ago, we still have some important opportunities ahead of us.

WHAT ARE THOSE OPPORTUNITIES AND WHAT SHOULD WE BE PLANNING FOR?

In assessing our future, we need to look at essentially two areas:

- . One is the changing nature of our **markets**.
- . The other is the set of **technical issues** we must deal with in order to meet the seedling performance expectations of the forest manager.

If we look at harvest levels in the Douglas-fir region for the next decade, private industrial harvest will trend downward to about 80 percent of today's level. Offsetting increases in non-industrial private harvest, are expected to maintain total private harvest near their mid-1980 levels. Although there are some uncertainties regarding the new National Forest Plans, it appears that there will be a reduction in Region Six harvest levels of between 10 and 20 percent from recent levels by 1990. This will have definite implications for regeneration requirements on the National Forests. In addition, the NFMA mandate to eliminate the regeneration backlog on Forest Service lands is now fulfilled. Harvest levels and regeneration requirements on state lands in Washington and Oregon will remain essentially as they are today.

Stocking levels on public and private lands have been reduced considerably over the past five years, as survival has improved and better data on the effects of stocking on long term growth and yield have become available, and we expect this trend to continue. Where we formerly planted 650 or more trees per acre, 350-500 trees per acre has become more common. That represents a very significant reduction in seedling requirements across the number of acres being planted.

In addition to changes in seedling demand, we can predict that such things as species mix and stock type mix will change as geographic distribution of planting changes, as well as customer perceptions of stock type performance.

These trends indicate a static or perhaps reduced demand for seedlings in the west for the next few years. Consequently, we should now view our challenges to be more in the technical area, as opposed to further expansion of seedling production operations.

These would include such things as:

1. Servicing each customer's special needs - "fine tune" his seedlings for more site-specific requirements.
2. Maximizing seedling yield from the increasing amounts of higher value seed becoming available from tree improvement programs.
3. Adapting growing systems to accommodate the emerging technologies of tissue culture and clonal propagation.
4. More fully exploiting existing research knowledge in day-to-day operations - accomplish technology transfer effectively.
5. And, of course, controlling costs and maintaining yields, which are key to the success of any operation, must never be taken for granted. These require continual effort.

R&D NEEDS/OUTLOOK

Research will continue to play an important role in meeting these challenges. I would broadly summarize our research needs as follows:

1. Continued emphasis on identifying cost-effective alternatives in nursery weed control.
2. Continued work in seedling pathology - specifically in dealing with Fusarium, Pythium, Phytophthora and Phoma.
3. Nursery cultural techniques to reduce the need for more expensive transplants on some sites.
4. Quality sowing - to enhance seedling yield and maximize utilization of valuable seed.
5. Increased volumes of genetically improved seed will place some unique demands on our current system in the near future:
 - a. The ability to plant more acres with improved stock earlier to capitalize on gain per unit of time will demand maximum utilization of seed.
 - b. The ability to multiply the best of this material through vegetative propagation will provide a strong economic incentive to modify and adapt cultural practices to successfully produce rooted cuttings in Douglas-fir.

There may also be some compelling reasons to propagate clonal material with special characteristics such as:

- rust-resistant white pine
- Christmas tree genotypes with desired traits
- families that have demonstrated superior performance on specific sites (GXE interaction)
- ability to propagate trees with special traits, such as high specific gravity for increased fiber yield

"THE JOB DOESN'T STOP AT THE LOADING DOCK"

I would like to leave you with one additional thought that we at Weyerhaeuser Company consider to be very important: That is, "the job doesn't stop at the loading dock."

The customer has become more **sophisticated** and **demanding**.

- . **Sophisticated:** In terms of understanding variables that affect plantation performance.
- . **Demanding:** In terms of seedling attributes that meet their needs in a cost-effective manner.

As in any other type of marketing, it is essential that we work closely with and

understand the needs of the end user if we are to fulfill our mission as nurserymen. In my own experience at Weyerhaeuser Company, I regard this close link with the field forester as one of the key factors in continual improvement in seedling quality. The results are evident in terms of significantly improved survival and growth over ten years ago. I'm sure many of you could relate similar experiences.

CLOSING REMARKS/SUMMARY

In closing, I would like to emphasize that your contributions as nurserymen are key to the future of western forest productivity. Through application of your skills and dedication to the task of producing quality seedlings, coupled with the increasingly important contribution of the western tree improvement programs, and the tools of the silviculturist, we can expect the future forest resource in the west to become increasingly productive on those acres that are intensively managed for timber production. In so doing, we can offset the inevitable loss of parts of the commercial forest land base to wilderness, NFMA restrictions, and urbanization, and thereby fulfill society's increasing demand for the full range of forest resources.

Thank you.

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Western Larch Cones and Seeds--Current Intermountain Research Station Studies¹

Raymond C. Shearer²

Abstract.--In 1985, two studies involving western larch cone and seed production were begun. The first determines the influence of spacing on seed cone production of 30- to 32-year-old larch in western Montana. The second identifies factors limiting western larch cone production in forest stands of Idaho and Montana.

INTRODUCTION

The Intermountain Research Station's Silviculture Research Work Unit located in Bozeman and Missoula, Mont., began four western larch (*Larix occidentalis*) cone and seed studies during the past 20 years. Two have been completed, two are underway. A brief review of results of two completed studies appear here; details are available in three publications cited. The remainder of this paper reports preliminary results of the two new, ongoing studies.

open. Although both indices decreased with advancing cone maturity, they did not give a clear indication of when cones were sufficiently mature to pick. Color is a poor indicator of cone maturity because of the wide range in cone colors within and among individual trees as cones mature. The study showed that cones on an individual tree open within a week, but cone opening among the trees varied considerably. Nearly all sound larch seed germinated when cone collection began by mid-August and cones were stored in well-ventilated areas for several weeks before seed extraction.

COMPLETED STUDIES

From 1964 through 1967, we studied the reliability of several factors for predicting western larch seed maturity on five larch growing at 4,000 feet on a north aspect near Missoula, Mont. (Shearer 1977). This study also determined if the period of cone collection (usually from late August through mid-September) could be extended. Embryo development (ratio of embryo length to seed cavity length) was complete in seeds from three study trees by early August and for two others by mid-August 1964. Specific gravity (about 0.75) and moisture content (about 25 percent) accurately predicted when cones would

A second study began in 1980 at four locations in western Montana to determine the extent of damage to larch cones by western spruce budworm (*Choristoneura occidentalis*) and other insects. Shearer (1984) reported 3-year results. In 1980 and 1982, about two-thirds of the larch seeds were killed by insects. Cone production failed in 1981 because few, if any, ovulate buds formed in 1980. Second- and third-stage budworm larvae killed the small, developing larch cones soon after the ovulate buds opened. Occasionally, the budworm larvae ate seeds while randomly feeding within the developing larch cones, as described earlier by Fellin and Shearer (1968). A woolly aphid and a cone maggot caused heavy losses of cones and some loss of seed (Shearer 1984). A seed chalcid and a seedbug also killed a very few seed. Only 19 and 8 percent of the seeds were filled in 1980 and 1982. Empty and aborted seed made up 45 and 16 percent of the larch seed in 1980 and 1982. Larvae fed on filled, hollow, and aborted seed of mature cones, so the actual number of each were unknown.

¹Paper presented at the Western Forest Nursery Council Meeting. [Vance Tyee Hotel, Tumwater, Wash., August 12-15, 1986.]

²Raymond C. Shearer is Principal Silviculturist, Intermountain Research Station, Forest Service, U.S. Department of Agriculture; Forestry Sciences Laboratory, Missoula, Mont.

The second study also determined the number of cones that matured on larch trees within each of the four study areas from 1980 through 1983 (Shearer 1986). A good cone crop in 1980 accounted for 80 percent of all cones counted during the 4-year study. In 1980, cones matured on 85 percent of the larch in the 12- to 14-inch diameter class but only 38 percent matured on trees in the 4- to 6-inch diameter class. Cone production also was influenced by tree size. The average number of cones per tree in 1980 increased 27 times as the diameter classes increased from 4 to 6 inches to 12 to 14 inches. In years of fair or poor cone production the average number of cones per tree was about 15 times greater in the 12- to 14-inch diameter class than in the 4- to 6-inch diameter class. More than half of the larch in the 4- to 6-inch diameter class failed to mature any cones during the study; only 7 percent of the trees in the 12- to 14-inch diameter class failed to mature cones during the same period.

ONGOING STUDIES

In 1985, two additional studies began on western larch cone and seed production:

Study 1

Young, managed stands of western larch are gradually replacing the virgin forests that have dominated the Northern Rockies. Because of the importance of knowing the cone producing capabilities of young larch, this study, Cone Production on Immature Larch as Influenced by Spacing in Western Montana, is designed to identify the effects of stand density (spacing) on the frequency and amount of seed cone production. Initial results (spring 1985) are reported by Shearer and Schmidt (in press) and summarized in this paper.

Study 2

Western larch has produced few mature cones for many years within much of the panhandle of Idaho and in some nearby Montana stands, even when excellent cone crops occurred elsewhere in western Montana. Reasons for the lack of cone production are unknown. This study, Larch Cone and Seed Potential in Northern Idaho and Western Montana--Magnitude and Causes of Cone and Seed Failure, will identify the major factors reducing larch cone and seed potential in northern Idaho and in adjacent western Montana. Early results (1985 through early July 1986) are summarized here from a paper by Shearer and Theroux (in press).

Only brief descriptions of study areas and types of data collected are presented. In-depth descriptions are contained in the study plans; short descriptions are given in the "in press" publications cited.

Study 1

Study 1 was superimposed on long-term research plots designed to evaluate the effects of spacing on the growth of young western larch. Four sets of plots were established in western Montana: two at Coram Experimental Forest near Glacier National Park; one at Cottonwood Lakes near Seeley Lake, about 93 miles south of Coram; and one at Pinkham Creek near Eureka, about 93 miles northwest of Coram. Elevations at the Coram plots averaged 3,820 feet, at Cottonwood 5,300 feet, and at Pinkham 4,870 feet. Site indices at 50 years were about 59 at Coram, 52 at Cottonwood, and 69 at Pinkham. In 1985, the average heights and ages of the sample trees were:

Coram 1	- 46 feet, 32 years
Coram 2	- 43 feet, 32 years
Cottonwood	- 30 feet, 30 years
Pinkham	- 43 feet, 30 years

Four densities were selected to study cone production at all four locations. An additional two densities were selected at the two Coram locations, resulting in 20 plots used to measure cone production. Densities and spacings were:

<u>Locations</u>	<u>Densities</u>	
	<u>Trees per acre</u>	<u>Average spacing (feet)</u>
Coram 1 and 2 only (unthinned plots)	~15,000	~2.0
All locations	1,740	6.5
All locations	680	8.0
All locations	360	11.0
All locations	200	15.0
Coram 1 and 2 only	110	20.0

Cone production is being monitored on the 10 tallest trees per plot. Binocular counts of cones in May and late August each year are made from one point for each tree.

Study 2

Study 2 identifies (1) frequency and amount of potential cone production, (2) cone development, and (3) factors reducing cones and seeds. Nine study areas were selected in northern Idaho, ranging from near New Meadows

in the south to near Bonners Ferry in the north. Two sites were chosen in western Montana, one near St. Regis and the other close to Libby. All areas are within larch forests originating after wildfires earlier this century. At each study area, 10 open-growing dominant larch were selected that met three selection criteria: (1) crown length at least 40 percent of the total tree height, (2) accessible for climbing, and (3) evidence of prior cone production. Potential cone production and actual number of mature cones were determined on the five sample trees that were judged (from binocular counts) to have the greatest cone potential. Cone development and condition were determined at each visit for cones marked on two trees of each study area. Factors reducing cone and seed production were identified at each visit to the study areas by examining the marked cones and other evidence found in the trees. Unmarked cones were collected at each visit and dissected later to determine damage to cones and seeds.

RESULTS

The results shown here are preliminary because they represent only 1 or 2 years' data from each 5-year study.

Study 1

Although seed cone production in young western larch began several years ago, most trees had relatively few if any developing cones at the time of the first measurement in May 1985. The maximum was 65 on a tree in the 15-foot average spacing.

All seed cones were produced on ascending branches or on the 1981 to 1984 terminal leaders, except within the 20-foot average spacing plots at Coram. There, half the trees produced cones on both ascending and

horizontal branches. Most seed cones at all locations were produced within the upper third of the crown. Of the trees with cones, 76 percent had cones only in the upper third of the crown, 19 percent had cones in the upper two-thirds of the crown, and 5 percent produced cones only in the central third of the crown.

In 1985, more trees produced cones at both of the moderately productive sites at Coram and at the more productive site at Pinkham than at the less productive Cottonwood site (table 1). About 19 percent of all sample trees produced cones in 1985, ranging from 0 and 2.5 percent in the unthinned and 6.5-foot spacing plots to 30 and 50 percent in the 15- and 20-foot spacing plots. These early results show that trees designated for seed production must be open grown and full crowned to produce large numbers of cones.

Table 1.--Percent of trees in May 1985 that had new developing seed cones by location and average spacing. Sample size: 10 trees per location and spacing. Adapted from Shearer and Schmidt (in press)

Location	Spacing (feet)					Unthinned
	20	15	11	8	6.5	
Coram 1	40	60	10	10	0	0
Coram 2	60	0	30	30	0	0
Cottonwood	¹ --	20	10	0	0	¹ --
Pinkham	¹ --	40	20	30	10	¹ --

¹No plot established.

Wider spacing of trees produced more seed cones (table 2). No cones were found on any of the unthinned-plot trees. Only one of the 40 sample trees in the 6.5-foot spacing produced cones---it had 18---for an average of 0.4 per sample tree. The number of developing

Table 2.--Average number and standard deviation (\pm) of new developing seed cones per tree in May 1985 by location and average spacing. Sample size: 10 trees per location and spacing. Adapted from Shearer and Schmidt (in press)

Location	Spacing (feet)					Unthinned
	20	15	11	8	6.5	
Coram 1	6 \pm 9	10 \pm 21	2 \pm 8	1 \pm 2	0	0
Coram 2	13 \pm 18	0	6 \pm 10	4 \pm 8	0	0
Cottonwood	¹ -----	<1 \pm 1	1 \pm 4	0	0	¹ --
Pinkham	¹ -----	8 \pm 17	<1 \pm 1	1 \pm 2	2 \pm 6	¹ --
Average	² 10 \pm 14	5 \pm 14	2 \pm 6	1 \pm 6	<1 \pm 3	² 0

¹No plot established.

²Coram average only.

seed cones per tree averaged 9.5 in the 20-foot spacing, 23 times greater than in the 6.5-foot spacing.

Study 2

In 1985 and 1986, cones potential (developing cones) occurred at all study sites and on nearly all study trees. There was a broad range in cone potential among these trees, both within and among stands (table 3). The four study areas with the greatest cone potential in 1985 also had the best potential in 1986.

Buds of larch seed cones open much before those of other conifer species, often when snow still covers the ground. In 1985 and 1986, seed cone buds opened in late March to early April within the four study areas between 2,500 and 3,900 feet elevation. The ovulate buds probably opened by mid-April at the five sites between 4,500 and 4,800 feet elevation, and by late April at the two study areas at 5,000 and 5,800 feet elevation. Approximate dates for bud opening are given because snow blocks most of the roads, preventing early access to the study sites.

Cone elongation quickly followed bud opening and was complete or nearly complete by early July. Cone maturity occurred in August after the embryos were fully developed within the seeds, as described previously by Shearer (1977).

Insects and frost killed nearly all potential cones in 1985 and 1986. Even the few cones that matured usually contained seeds

that were damaged by insects. As a result, almost no viable larch seed was dispersed on our study areas in northern Idaho in 1985 and even fewer are expected in 1986.

After the ovulate buds opened, frost killed all or most of the developing seed cones at all but the lower elevation sites. Although we are unsure of the threshold temperature that freezes and kills young cones, temperatures as low as 25 °F in 1986 did not kill or visibly damage the young cones at the low-elevation Twin study area. All other sites, where frost was a problem, had lower minimum temperatures (as low as 17 °F).

Periodic cone collections from areas with surviving cones showed that insect damage began by late April. In 1985, a woolly aphid (probably a species of *Adelges*) was found on cones at Meadow, Standard, and Twin, but not at Twelve Mile or Beacon. None were found in 1986. In 1985 and in 1986, one or more cone maggot larvae (probably a species of *Hylema*) fed within many cones that survived the frost. An unidentified scale midge was found on many cones in late June, 1985.

In 1985, frost killed all cones at four of nine study areas, killed from 40 to 71 percent of the cones at three other sites, and caused no losses at the two lowest elevation sites (table 4). All of the cones at Twin were killed by insects, about 90 percent by woolly aphid, and 10 percent by cone maggot larvae. In 1986, no woolly aphids were observed on the developing cones. At Meadow in 1985, 44 and 47 percent of the cones were killed by woolly aphids and cone maggots,

Table 3.--Average number of cones per tree estimated soon after bud opening in 1985 and 1986 on 11 study areas. From Shearer and Theroux (in press)

Study area	1985				1986			
	Cones (No.)	Sx	Range	n	Cones (No.)	Sx	Range	n
Meadow	1,220	354	416-2,288	5	2,879	905	892-6,137	5
Standard	199	70	1- 432	5	24	9	3- 58	5
Twin	656	197	304-1,232	5	56	28	9- 160	5
Twelve Mile	267	110	42- 563	5	287	168	76- 957	5
Beacon	828	113	471-1,082	5	1,354	400	36-4,039	10
Cairn	¹ --				322	122	2- 688	10
Brushy Fork	¹ --				284	164	0-1,722	10
Savage	163	143	0- 736	5	111	100	0- 512	5
Ericson	981	351	121-1,937	5	1,527	343	553-2,383	5
Peter	1,270	494	366-2,795	5	1,181	357	178-2,275	5
Brush Mountain	318	180	75-1,029	5	485	228	81-1,316	5

¹Not established, no data collected.

Table 4.--Percent cone survival and mortality by cause. From Shearer and Theroux (in press)

Location	1985			1986		
	Survival	Mortality		Survival	Mortality	
		Frost	Insects		Frost	Insects
Meadow	12	0	88	0	100	0
Standard	2	40	58	0	¹ 100	0
Twin	0	0	100	² --	0	² --
Twelve Mile	10	63	27	0	100	0
Beacon	16	71	13	0	100	0
Other ³	0	100	0	0	100	0

¹Two nonplot trees had a few cones that survived the frost.

²Data not complete on July 7, 1986.

³Savage, Ericson, Peter, and Brush Mountain in 1985 and 1986; Cairn and Brushy Fork 1986 only.

the remaining 9 percent by unidentified insects. At the other three locations, the cone maggot caused most of the insect-caused mortality.

Frost killed all cones on 10 of the 11 sites in 1986, although a few cones survived on two trees at Standard (not on the study plots) (table 4). For the second year no cones were killed by frost at Twin. No insect data are available at this time.

Less than 10 percent of the seed extracted from cones collected at four sites in 1985 were sound (table 5). The average number of sound (potentially viable) seed per tree ranged from about 32 at Standard to 1,466 per tree at Meadow. Insects damaged 26 to 55 percent of the potential seed at the four locations. Empty and abnormal (often aborted) seeds made up 38 to 65 percent of the potential seed on these areas.

Table 5.--Estimated number of seeds produced per tree at four study areas in 1985 and the percent of filled, damaged, and other nonviable seed. From Shearer and Theroux (in press)

Location	Estimated seeds per tree (No.)	Filled	Insect damaged	Other nonviable
		- - - -	-Percent-	- - - -
Meadow	20,950	7	55	38
Standard	355	9	26	65
Twelve Mile	3,442	8	46	46
Beacon	13,520	3	35	62

A sample of 100 mature cones from the four study areas in 1985 averaged only 9.4 sound of 104.5 potential seeds (table 6). Insects damaged or destroyed 43.4 of these seeds, 40.1 were hollow, 9.3 were abnormal, 2.3 had malformed embryos. The cone maggot most frequently caused damage within cones, followed by the woolly aphid and the scale midge. Feeding by cone maggot larvae left spiral tunnels around the axes. The condition of the seed (sound, hollow, etc.) before damage was obscured by this feeding. An examination of only undamaged cones and of cones damaged only by cone maggot, by woolly aphid, or by scale midge, gave a better understanding of the impact of each insect on viable seed.

Table 6.--Analysis of 100 mature western larch cones from Meadow, Standard, Twelve Mile, and Beacon study areas. Data shown as average number and range and \bar{S}_x of seeds per cone and percent germination of total and potentially sound seed. From Shearer and Theroux (in press)

Condition	Average and range	\bar{S}_x
Damaged	43.4 (0-131)	3.8
Empty	40.1 (2-105)	2.4
Abnormal	9.3 (0- 67)	0.9
Malformed embryo	2.3 (0- 22)	0.4
Potentially viable	9.4 (0- 56)	1.2
Total	104.5 (52-158)	2.1
Germinated seed	7.9 (0- 56)	1.1
percent of total	7.6	
percent of potentially viable	84.2	

Cones without insects had no damaged seeds (table 7). Cones that were infested only by cone maggot larvae, however, averaged 85 (79 percent) damaged seeds; cones with only woolly aphids averaged 33 (33 percent) damaged seeds, and cones with only scale midges averaged 17 (17 percent) damaged seeds (table 7). Undamaged cones had about 14 (16 percent) seeds that were abnormal or the embryos were malformed; those with cone maggots had 5 (5 percent); those with woolly aphids 11 (11 percent); and those with scale midges 18 (18 percent). Cones with no insects had 21 (24 percent) potentially viable seed contrasting to 2 (2 percent), 5 (5 percent), and 14 (14 percent) for cones infested only by cone maggots, only by woolly aphids, and only by scale midges, respectively.

SUMMARY

In 1985, the number of seed cones generally increased as average spacing increased. Cone production was so low in 1986 that no pattern was evident. Unthinned trees had neither new nor old seed cones in 1985. The least productive site produced the fewest seed and pollen cones, while the more productive sites produced the most cones.

Frost caused the greatest reduction in cone potential by killing all cones within four of the nine stands examined in 1985 and within nine of the 11 stands examined in 1986.

One stand escaped frost-caused cone mortality both years. A cone maggot caused heavy cone mortality at the five sites least affected by frost in 1985 and was present in cones collected in 1986. A woolly aphid caused some cone mortality in 1985 but none in 1986. A cone maggot, a woolly aphid, and a scale midge caused seed mortality in mature cones in 1985. Results from 1986 were not available. In 1985, cones with no insect damage averaged 24 percent sound seed, compared to 2, 5, and 13 percent sound seed in cones damaged only by a cone maggot, woolly aphid, or scale midge, respectively.

CONTINUING RESEARCH

At least three more field seasons will be devoted to documenting cone production for both studies and causes of cone mortality in study 2. About 1989, when the fieldwork on these studies may terminate, we will begin to determine the effects of cultural treatments on cone production of western larch. This effort will interest managers of seed production areas and seed orchards. In addition, the current studies will identify other factors we should study in greater depth.

Results from our studies will help predict where natural regeneration of larch should succeed and where artificial means are necessary to ensure maintaining the species in forest stands.

Table 7.--Analysis of mature western larch cones by cause of damage. Data shown as average number and range and standard error of the mean (Sx) of seeds per cone and percent germination of total and potentially sound seed. From Shearer and Theroux (in press)

Condition	Cause of damage							
	Undamaged n=11		Woolly aphids n=7		Cone maggots n=26		Scale midges n=32	
	Avg.	Sx	Avg.	Sx	Avg.	Sx	Avg.	Sx
Damaged	0 (0)	0	33 (3- 99)	14	85 (53-131)	4	17 (0- 99)	4
Empty	52 (22- 78)	5	51 (17- 87)	10	16 (2- 46)	2	53 (17-105)	3
Abnormal	12 (2- 20)	2	9 (5- 16)	2	4 (0- 12)	1	14 (2- 67)	2
Malformed embryo	2 (0- 11)	1	2 (0- 5)	1	1 (0- 2)	T	4 (0- 22)	1
Potentially viable	21 (2- 56)	5	5 (0- 15)	2	2 (0- 11)	1	14 (0- 47)	2
Total	87 (52-112)	7	100 (82-130)	7	108 (68-144)	4	102 (58-158)	4
Germinated seed	20 (2- 56)	5	5 (0- 15)	2	2 (0- 10)	1	13 (0- 47)	2
percent of total	23		5		2		13	
percent of potentially viable	96		100		85		90	

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Tree Improvement Comes of Age in the Pacific Northwest: Implications for the Nurseryman¹

Richard F. Piesch²

Abstract.--Tree improvement programs in the Pacific Northwest have reached the stage of supplying limited, but ever increasing, quantities of genetically improved seed to nurseries for regional regeneration programs. With this seed comes opportunities as well as responsibilities for the nurseryman. This paper explores the role of the nurseryman in the capture, packaging and transfer of genetic gain potential in the integrated forest management system.

INTRODUCTION

The status of tree improvement today in the Pacific Northwest can be likened to a relay race. The tree improvement worker is nearing the end of the first lap, and is about to pass the baton onto the nurseryman. The handoff is critical, as is the race strategy. We are here today to give thought to both these elements, and to better understand how our concerted efforts will make our investment in tree improvement a winner.

In keeping with this theme, the objectives of today's presentation are threefold:

- 1) To briefly review the status of tree improvement in the region and its impact on regeneration programs.
- 2) To develop the concept of genetic gain, and its capture, packaging and transfer into an integrated forest management system.
- 3) To explore the role of the nurseryman in this system, and the opportunities he or she has to maintain or even enhance the gain potential of genetically improved planting stock.

¹Paper presented at the Western Forest Nursery Council Meeting, [Vance Tye Hotel, Tumwater, Washington, August 12-15, 1986].

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THE DEVELOPMENT AND STATUS OF TREE IMPROVEMENT IN THE REGION

Tree improvement programs, as we think of them today with selection, breeding, testing and seed production functions, started in the Pacific Northwest in the mid-1950's. By 1960, several Douglas-fir seed orchards had been established, representing both federal and private organizations. During the 1960's, few new orchards were established. However, with the 1970's came a surge of activity, such that by 1980 at least 82 orchards, representing more than one dozen species, had been established (Wheat and Bordelon, 1980). This has risen to an estimated 90 orchards today, for which Douglas-fir accounts for more than one-half. There are approximately 1700 acres of Douglas-fir orchards, or about 75% of the total orchard acres for all species.

To support this very large production activity, much effort has been placed on selection of parents from natural stands. In the Douglas-fir region alone, close to 30,000 "Parent" or "Plustree" selections have been made. Douglas-fir accounts for about 26,000 of these. More than 700 genetic tests have been established, with the primary purposes of evaluating these selections as parent trees and/or providing advanced-generation selections.

Participation in tree improvement in the Douglas-fir region is broad-based, involving at least 40 private landowners, 1 Canadian and 3 U.S. federal agencies, 3 state agencies, 1 Canadian province and 3 universities. Although a few programs are independent, the

majority are involved in IFA-PNW cooperatives (Wheat and Silen, 1982). The programs vary widely in their approaches, with different selection intensities, different approaches to seed production, and different levels of management and support. These differences in themselves have an impact on nursery practices and the management of improved seed, and will be discussed later in this paper.

THE IMPACT OF TREE IMPROVEMENT ON REGENERATION PROGRAMS

In western Oregon and Washington, more than 11,000,000 acres are covered by a tree improvement program (Cafferata, 1985), and in coastal British Columbia, more than 2,000,000 acres.³ Of this 13,000,000 total, approximately 263,000 acres are regenerated annually.

The impact of genetically improved seed on this annual planting stock requirement for some major programs are given in Table 1. Other programs not listed range from having no improved seed yet available to fully meeting their current planting stock requirements.

As Table 1 shows, nurserymen will be having a progressively higher proportion of genetically improved seed coming through their nurseries in the near future.

³Konishi, J. 1986. Personal Communication. B.C. Forest Service, Reforestation Division. Victoria, B.C. Canada

GENETIC GAIN: ITS INTEGRATION INTO A FOREST MANAGEMENT SYSTEM

To better understand what "improved" seed means to the nurseryman, we need to understand the concept of genetic gain and its integration into a forest management system. Since genetic gain comes from tree improvement, the goals of tree improvement must be defined. We can think of these goals as three interrelated functions:

- 1) To capture genetic gain potential.
- 2) To package and transfer this potential into a regeneration system.
- 3) To optimize the benefits of this potential in terms of product value, throughout the nursery, stand culture, harvest and utilization phases.

Two points need to be stressed here. First, we are dealing with gain potential. We may capture it at one stage, only to lose it at another. Thus, the onus of maintaining the gain potential transfers from the tree improvement worker to the nurseryman, to the silviculturist and to the forest land manager, much like the example of the relay race cited in the Introduction. Secondly, the word "optimize" is used rather than "maximize." Implicit in this distinction is the knowledge that economic constraints should and will play a role in seeking tree improvement benefits, a point which will be further developed later in this paper.

Table 1.--Impact of improved seed on regeneration programs for several representative organizations in the Douglas-fir region. [Acres regenerated with improved stock and percent of total annual planting stock requirements (PSR)].

Program	Current Levels		Future Projections		Year
	Acres	% PSR	Acres	% PSR	
IFA-PNW Coops (Government and Private)	18,000	12 ¹	120,000	75	1995
	80,000	50 ²	160,000	100	2000
British Columbia (Crown and Private)	9,900	29	30,000	85	1995
Weyerhaeuser	19,000	62	40,000	100	1992

¹Five-year average through 1984.

²Projected 1986 sow only. Reflects exceptional 1985 cone crop expectations.

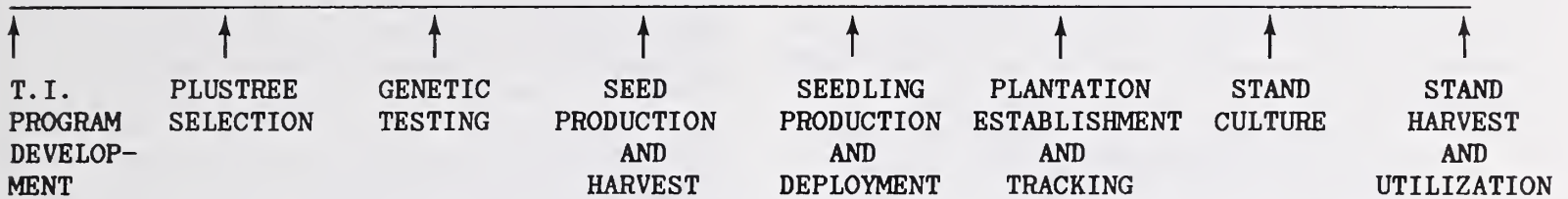


Figure 1.--Our key leverage points to capturing, maintaining or enhancing genetic gain potential.

We have many key leverage points at which we can capture, maintain and enhance genetic gain potential, from the time a tree improvement program is planned to the time the end product is utilized (Figure 1).

The first four leverage points, i.e. T.I. Program Development through Seed Production and Harvest, largely determine the amount of potential that can be captured. The last five, i.e. Seed Production and Harvest through Stand Harvest and Utilization, determine largely how much potential is maintained. The Seedling Production (Nursery) phase can also effectively enhance the potential, since the nurseryman manages populations of seeds and seedlings, and as such, can manipulate gene frequencies in a directed way. For today, we will restrict our discussions to those leverage points most directly affecting nursery management, i.e. Seed Production and Harvest, Seedling Production and Deployment, and Plantation Establishment and Tracking.

IMPACT OF SEED PRODUCTION SYSTEM ON NURSERY MANAGEMENT

Both gain potential and seed availability will impact the management of improved seed in the nursery, and both depend on the type of tree improvement program followed. Seed derived from a "Parent Tree" program (i.e. selected trees in natural stands used for seed supply) will probably become available sooner, have less gain potential and be less dependable in supply year-to-year as compared to seed derived from a seed orchard program. A clonal orchard typically will produce sooner, and with a higher gain potential, than a seedling seed orchard. A rogued orchard will have a higher gain potential than a non-rogued orchard but at the expense of total seed production at various times during the production period.

It is important to recognize here that a seed orchard is not simply a seed orchard, nor is the objective of an orchard simply to provide genetically improved seed. Rather, the orchard should strive to strike a balance between maximizing genetic gain potential and meeting planting stock requirements. The seed orchard and the seed it produces represent a very dynamic system. As the quantity of seed produced increases, so should the gain potential, due to the increasing ability to rogue inferior parents or selectively harvest from the best.

Perhaps the key leverage point at the seed orchard affecting the nursery system is seed harvest strategy. The strategy adopted for harvest sets the stage for the deployment strategy and directly affects nursery management practices. Some of the harvest options available to the orchardist include:

- whole orchard bulk mixes;
- specific mixes based on:
 - seed zone / elevation
 - tested vs. non-tested status
 - elite vs. average
- family level collections (i.e. seed from individual clones).

Whole orchard bulk mixes will result in the largest seedlot size possible, but will also have the lowest gain potential. As we progress down through the options we tend to decrease lot size (fewer parents or trees contributing per seedlot) but we also increase our ability to maximize gain potential. The orchard harvest strategy therefore will impact nursery management by determining seedlot size and gain potential, which in turn will affect nursery costs and practices.

THE ROLE OF THE NURSERYMAN IN
MAXIMIZING GAIN POTENTIAL

Family Sowing

Within the nursery system there are several key leverage points for maintaining or enhancing genetic gain potential. Among these include:

- ability to manage small lots
- potential to sow by family
- optimum utilization of improved seed
- cost control
- tracking and follow-up

Small Lot Management

The ability to deal with small lots is essential to maximizing gain potential. As discussed earlier, there is a general inverse relationship between gain potential and lot size. Thus, smaller lots can be considered opportunities rather than liabilities, as is generally the case. Two questions the nurseryman must address are (1) what constitutes the minimum sized lot that can be efficiently managed operationally? and (2) what changes in nursery technology might be possible to change this? Answers to these questions will bear on the orchard harvest strategy chosen.

Sowing by individual family represents the probable extreme case of small lot management with its associated high gain potential. In addition to this attribute, there are several other benefits from family sowings. By sowing "pure" families rather than mixtures of families, the chance for disproportionate culling could be avoided. Progeny test data have shown that some families, although excellent performers over time, start very slowly in the nursery. For example, families B and C in Table 2 ranked 40 and 39, respectively, of 45 in height at the end of the first year in the greenhouse. However, by year 8 of the field progeny test, they had risen to rank 2 and 3. Both would have been largely culled from a mixed lot after one year in the nursery, even though both proved superior performers in the field.

This example well illustrates how differential culling standards may be appropriate, particularly in those cases where subsequent field performance potential has been demonstrated. Differential culling standards here translates into improved yields, which means an increased contribution by superior families to the regeneration program.

Table 2.--Family performance rank in height over time.
Weyerhaeuser Company Twin Harbors Progeny Test.

Family	After One Year in Greenhouse	Rank							
		Year in Test							
		1	2	3	4	5	6	7	8
A	27	14	9	8	3	2	2	1	1
B	40	40	22	6	4	3	1	2	2
C	39	20	5	7	7	7	8	3	3
D	29	7	2	1	1	1	3	4	4
E	5	2	4	2	2	4	4	5	5
W	45	45	45	44	43	43	43	42	41
X	37	38	38	40	41	41	41	41	42
Y	35	39	41	42	42	42	42	43	43
Check ¹	44	44	44	43	44	44	44	44	44
Z	42	41	43	45	45	45	45	45	45

¹Check is mean of two field check seedlots.

Traits other than growth response, e.g. frost tolerance, susceptibility to herbicides, etc., also may be more observable when seeds are sown as families rather than mixes. Thus, family sowings become the key to identifying and managing unique opportunities or problems at the nursery stage.

Another benefit of family sowing is that it allows for the deployment option of family block plantations. While this option is practiced little in the Pacific Northwest, it is the main deployment strategy on large forest ownerships in the southeast United States. Limiting its use at present in the Pacific Northwest are the unknowns relative to opportunity and risk.

Optimum Utilization of Improved Seed

Perhaps the key leverage point in the nursery to maximizing genetic gain potential is the acceptance and use of a nursery system, including alternative stock types, which converts the most seed to plantable seedlings. While 100% oversow factors are not unusual in a conventional nursery program, we should not be content to lose one-half of our high cost, improved gain potential seed to nursery falldown and culling. While some level of culling will probably always be appropriate, other factors than genetic growth potential contribute to this falldown. Also, as Table 2 illustrated, genetic potential may not express itself yet in the nursery phase.

Economics of Improved Seed Utilization

In weighing the alternatives for improved seed utilization, the economics of the system must be considered. Decisions to maximize seed utilization are not "justifiable at any cost." One approach to economic evaluation is the Present Value : Cost ratio, an approach commonly used for long-term investment decisions in forestry. To determine a PV : Cost ratio, several factors must be considered and quantified.

- Incremental yields, i.e. how many more plantable trees per pound of seed are achievable.
- Incremental costs to produce this incremental yield.
- Estimated incremental gain of improved seed; which may vary by harvest strategy or level of improvement, and will be estimated by genetic test results.

- Estimated value, e.g. \$'s/acre, of incremental gain; which may vary by site class and can be estimated from economic and growth and yield models.

Once these factors have been estimated, the PV : Cost ratio can be calculated. A hypothetical example follows:

Incremental Cost Per Acre

$$= (\text{Trees per Acre}/1000) \times$$

$$(\text{Incremental Cost per K Trees}) \times$$

$$(\text{Improved Yield Factor})$$

$$= \$10$$

Incremental Value Per Acre

Case I	Improved Seedlot 1, Site I	= \$40
Case II	Improved Seedlot 1, Site II	= \$30
Case III	Improved Seedlot 2, Site I	= \$20
Case IV	Improved Seedlot 2, Site II	= \$10

PV : Cost Ratio

Case I	=	4 : 1
Case II	=	3 : 1
Case III	=	2 : 1
Case IV	=	1 : 1

The calculated PV : Cost ratios must be then compared to values considered as investment decision thresholds by your organization. PV : Cost ratios equal to or above these thresholds would suggest a sound economic decision within your organization to improve yields while accepting the increased associated costs.

Cost Control

While cost control is essential in any nursery operation, it has a special significance in maximizing genetic gain potential as it pertains to improved seed utilization. The

CONCLUSIONS

lower the cost to produce a given stock type, the more opportunity there is to increase yields within given economic constraints. Reduced costs can directly impact the PV : Cost ratio just described, thus potentially qualifying additional seedlots for the improved-yield system. For example, if the incremental cost per acre was reduced from \$10 to \$7, and the organization's threshold value for investment was 4:1, all Site II land would now qualify for Improved Seedlot 1 being grown in the improved-yield system. Genetic gain potential would be enhanced because a higher proportion of plantation acres would be impacted with improved seed.

Tracking and Follow-up

This leverage point is certainly not restricted to the nursery phase, as the genetic components of any seedlot must be trackable from the orchard through the nursery to the plantation, as well as from the plantation back to the orchard. Nurseries and plantations should be considered as extensions of the genetic testing program. Both time and number of traits measured are limited in genetic tests, and little or no testing is possible for unique and infrequent climatic events.

The nurseryman's role in this "extended testing" is vital. Not only must opportunities or problems related to improved seed be identified, but also they must be reported and followed up. Without this continual awareness by all those involved with improved stock, the genetic gain potential will most certainly be compromised.

Seed from tree improvement programs are becoming a major component of nursery sow programs in the Pacific Northwest, and within the next decade will become the exclusive component for many programs. Nurserymen are a part of the tree improvement effort and have a vital role in maintaining or enhancing the genetic gain potential of improved planting stock. Of the many opportunities for the nurseryman to impact genetic gain potential, perhaps his greatest contribution will be in optimizing the yields of improved seedlings. In so doing, he will positively effect the gene frequencies of desired traits in the integrated forest management system.

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Stratification Reduced Germination of Ponderosa Pine Seed Collected in New Mexico and Southern Colorado¹

Thomas M. Smith²

Abstract.--The 1983 seed year produced extremely low unstratified germination percentages for ponderosa pine (*Pinus ponderosa*, Rocky Mountain form) on Bureau of Indian Affairs administered lands in New Mexico and Southern Colorado. Stratification reduced this percentage in nearly every case and did not reduce the germination time.

INTRODUCTION

Cones collected on Bureau of Indian Affairs administered lands in New Mexico and Southern Colorado in the fall 1983 yielded the average amount of clean seed per bag, much larger seed, and extremely low unstratified germination. Excessive mold was noted on every sample, but seed surface fungicide treatments did not increase germination. X-rays indicated full seed.

Twenty-two samples representing all areas of collection were retested in early 1985. A germination comparison of unstratified, and stratified for 30,45,60,75 and 90 days was done at the National Tree Seed Lab in Dry Branch, Georgia and compared to unstratified, and stratified germination for 31,45 and 55 days done at Bureau of Indian Affairs Greenhouse Facility located in Albuquerque, New Mexico.

DISCUSSION AND RESULTS

The 871 half full burlap sacks of ponderosa pine cones collected from October 12, 1983 through December 8, 1983 throughout New Mexico and Southern Colorado yielded 514.8 lbs. of clean seed. The yield per bag was about average, but the approximately 11,000 seeds per pound was much better than the normal of 14,000 seeds per pound. The average unstratified germination was approximately 35 percent as

compared to the normal unstratified germination of between 85 and 90 percent.

Initial testing was performed at the National Tree Seed Lab in Dry Branch, Georgia in 1984.

Excessive mold was noted on every sample. Dipping in neither bleach nor captan at the recommended rates improved germination. There was no correlation between germination percent and date of collection.

TABLE 1, details the results from stratified and unstratified germination tests from the 1985 test at the National Tree Seed Lab.

TABLE 1, NATIONAL TREE SEED LAB
GERMINATION COMPARISON

ACCESSION NUMBER	Germination (%)					
	Stratification (days)					
	Unstratified	30	45	60	75	90
83B01	46	29	37	40	35	36
83B02	55	34	32	38	25	37
83B04	29	14	16	20	17	17
83B06	24	4	6	12	11	11
83B07	49	23	25	25	30	29
83B08	33	14	15	17	15	14
83B09	14	6	5	5	8	7
83B10	47	21	19	26	27	29
83B11	41	26	19	3	25	27
83B12	27	17	20	21	21	18
83B14	24	14	6	10	8	9
83B15	54	48	41	39	48	50
83B16	27	21	13	22	19	23
83B17	42	39	33	36	34	36
83B22	28	14	14	15	16	15
83B25	27	16	16	19	15	17
83B28	49	30	32	33	33	35
83B29	37	31	25	37	29	23
83B30	41	30	28	29	29	32

¹Paper presented at Western Forest Nursery Council Meeting [Tumwater, Washington August 11-15, 1986.]

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83B31	48	35	37	42	42	50
83B32	25	22	27	26	23	29
83B34	70	52	54	51	48	50

The report sheets indicated that the first weeks germination percentages were higher in the stratified samples than the unstratified, however by the end of the second week germination was virtually finished in all samples, stratified and unstratified. With the exception of 83B29 stratified for 60 days, germination was reduced in all cases with stratification.

TABLE 2, details the results from stratified and unstratified germination tests done at the Bureau of Indian Affairs Greenhouse Facility in Albuquerque, New Mexico.

TABLE 2, BUREAU OF INDIAN AFFAIRS
GERMINATION COMPARISON

ACCESSION NUMBER	Germination (%)			
	Unstratified	Stratified		
		31	45	55
83B01	28	10	11	12
83B02	19	8	12	11
83B04	5	3	1	6
83B06	2	4	3	4
83B07	14	5	7	7
83B08	4	1	1	3
83B09	1	1	1	1
83B10	5	2	0	6
83B11	14	6	8	11
83B12	6	3	2	3
83B14	2	1	1	3
83B15	18	18	15	18
83B16	2	1	2	4
83B17	20	15	11	15
83B22	5	2	1	1
83B25	3	1	3	5
83B28	28	15	11	13
83B29	9	10	7	6
83B30	10	10	6	8
83B31	12	9	6	10
83B32	10	7	3	7
83B34	54	37	28	28

The Bureau of Indian Affairs Greenhouse Facility in Albuquerque, New Mexico is a production greenhouse. Unstratified seed will normally begin cracking 4 days after sowing. The only equipment available for stratification is a refrigerator, which is subject to temperature fluctuations during normal use. Temperatures were maintained between 34F and 38F.

Prior to stratification the seed was soaked for 24 hours and then dipped in captan at the rate of one tablespoon per gallon. Stratification was terminated at 55 days because the seed was beginning to crack.

The reason for the large reduction in germination between the seed lab and the greenhouse can not be explained at this time.

Stratification increased germination over unstratified germination in Accession Numbers 83B04, 83B06, 83B10, 83B14, 83B25, 83B29 and stayed the same in 83B09, 83B15 and 83B30. Germination is so low in all cases, however, that the value stratification is questionable, as is the use of this seed.

CONCLUSIONS

This experiment was done in an effort to increase abnormally low germination. Stratification reduced germination in most instances and did not reduce the germination time in those samples tested here.

It should be stressed that the 1983 germination percentages were usually low, and further research on the value of stratification of ponderosa pine in the southwest should be conducted.

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Comparison of Seed Stratification Methods for Western White Pine¹

CHARLES GANSEL²

Better seed stratification is needed to break the dormancy in western white pine, to obtain more rapid and uniform germination. Four stratification methods were compared. Warm/cold stratification was superior to cold stratification methods, especially for low germinating lots.

In the past, the efficiency of the blister rust testing program at the Dorena Tree Improvement Center has been limited by the low germination percentages exhibited by some of the seedlots selected for the testing program. Germination percentage varies greatly among seedlots, ranging from 0 to almost 100 percent. Approximately 15 percent of the seedlots sown for testing purposes were in the zero to marginal range. These lots will probably not have enough surviving seedlings to provide a sufficient base for rust testing. Lack of sufficient base due to poor germination has been an ongoing problem at Dorena. Overcoming this problem would increase the efficiency of the rust testing program by an estimated 10 to 15 percent.

The low germination is not due to low viability or poor germination but to dormancy, and is expressed in large numbers of firm seeds, which do not germinate. We are looking for a method that will overcome dormancy. Dorena personnel have performed a number of small studies over the past few years aimed at developing stratification techniques which will result in higher overall germination percentages among seedlots. Such techniques have been worked out fairly successfully for sugar pine, but western white pine has been less tractable. Current research has not attacked this problem to a degree that would benefit the Dorena program. Further study is needed to upgrade stratification techniques.

BACKGROUND

The current method of stratification being used

at Dorena consists of a 48 hour soak in 1 percent hydrogen peroxide (H₂O₂) followed by 120 days chilling at 34-38°F.² This does not appear to be sufficient for some western white pine seed lots to overcome germination blocks. This problem is not limited to Dorena. A survey of other nurseries in the northwest indicated poor germination in some lots. Wind River Nursery soaks the seed for 24 hours and then puts it in cold stratification for 90 to 120 days. They have, however, gone to fall sowing for western white pine to improve stratification. J. Herbert Stone Nursery uses a 24-48 hour running water soak, followed by 100 days cold stratification in a nylon mesh bag layered in peat. Coeur d'Alene Nursery soaks the seed in a home laundry bleach (2 parts bleach to 3 parts water) for 10 minutes, then rinses them for 4 days under running water, followed by cold stratification in the refrigerator for 45 to 50 days.

Past Dorena studies indicate that a different combination of H₂O₂ concentration and length of soak may yield better results. Research by Anderson and Wilson (1966) and D.W. Taylor (personal communication) suggests that a combination of warm stratification at room temperature, followed by cold stratification, would be more effective in promoting germination than cold stratification alone.

Other factors that may affect germination are the use of infrared irradiation (Works and Boyd, 1972) and seed moisture content (Edwards, 1981). Recent work indicates that relatively small variations in moisture content of the seed during stratification may lead to significant differences in germination. Edwards (1981) has found that the optimum germination in *Abies grandis* occurs when seed is dried to 35 percent moisture content following the soak treatment. McLemore and Burnett (1968) report that dormancy was least in *Pinus taeda* seeds when stratified at a moisture content greater than 20 percent. However, the optimum moisture content for stratifying western white pine seed is as yet unknown.

¹ Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

² Dorena Tree Improvement Center, Cottage Grove, OR.

OBJECTIVE OF STUDY

The objective of this study was to compare different stratification methods for western white pine to see which would result in more rapid and uniform germination among families. Improving the uniformity of germination should lead to increased efficiency in Dorena's rust testing program. Moisture uptake was a problem that this study will address. Cold stratification vs. warm/cold stratification would be compared as well as a 1% H₂O₂ soak vs. household bleach soak followed by rinsing for four days in running water.

METHODS AND MATERIALS

Twenty families were used in this study. Five families with less than 50% germination in previous tests and five with greater than 50% germination, along with 10 families of unknown performance. All methods of stratification received a 48 hour soak except those lots which were washed for 4 days in running water. All seed had been stored in the freezer at 0°F. Fresh seed may give entirely different results. Total length of stratification for all lots was 120 days.

The following methods of stratification were compared in this study.

Method 1. Dorena operational stratification.
 A. 48 hour soak in 1% H₂O₂.
 B. Drain.
 C. Cold stratification at 34-38°F. for 120 days.

Method 2. Warm/cold stratification.
 A. 48 hour soak in 1% H₂O₂.
 B. Surface dry.
 C. 30 days warm stratification at 50°F. in growth chamber.
 D. Dry to 30-35% moisture content and then put into cold stratification at 34-38°F. for 90 days.

Method 3. University of Idaho Method.
 A. Soak seed 10 minutes in a solution containing 2 parts sodium hypochlorite (clorox) and 3 parts water.
 B. Rinse seed in flowing water for 4 days.
 C. Drain.
 D. Place seed in nylon mesh bag and layer in peat at 34-38°F. for 120 days.

Method 4. Modified University of Idaho Method.
 A. Soak 48 hours in 1% H₂O₂ solution.
 B. Drain.
 C. Place seed in nylon mesh bag and layer in peat at 34-38° for 120 days.

The seed were sown in large flats (40"X48"X12") filled with "Forestry Mix" growing media. Only sound seed were sown. Two seed were planted per spot and spots were about 4" apart. There were 2 replications of 5 planted spots per family or 20 seed sown per family per treatment method. The seed was sown on March 31, 1985, and germination was recorded periodically throughout the next 48 days.

RESULTS AND CONCLUSIONS

Results from the water uptake portion of the study are presented in Table 1.

Table 1. Water Uptake in Stratification Test

Family Tree Number	Tree Number	Weight of 20 seed (grams)	Moisture content after 48 hr. soak (percent)	Moisture content after warm strar. (percent)
1	119-01167-006	0.452	43.6	44.0
2	119-01167-007	0.358	39.1	41.5
3	119-03124-382	0.329	35.1	42.7
4	119-03124-390	0.361	34.2	32.5
5	119-06023-513	0.302	31.7	35.5
6	119-06024-612	0.393	32.3	32.3
7	119-06025-526	0.422	33.3	34.4
8	119-06124-661	0.387	32.7	36.7
9	119-06124-662	0.371	32.9	41.4
10	119-06125-538	0.246	37.7	42.0
11	119-15043-920	0.434	31.4	38.4
12	119-15045-935	0.352	34.7	39.5
13	119-17113-337	0.324	36.5	47.0
14	119-17113-340	0.312	37.5	40.5
15	119-17115-715	0.395	33.6	36.8
16	119-17115-816	0.287	36.9	46.2
17	119-18035-393	0.437	27.0	36.7
18	119-18034-397	0.412	29.4	35.3
19	119-20046-025	0.466	35.6	45.9
20	119-20046-044	0.543	33.9	34.6

It appears that water uptake was not a problem in this study. The moisture content of the seed in storage was approximately 6%. Moisture content of the seed after the 48 hour soak ranged from 27.0 to 43.6%. The moisture content in all lots appears to be adequate for germination, as the lot with the least moisture content germinated about as well as the lot with the most moisture (85 vs. 90% respectively).

Results of germination from the four stratification methods are presented in Tables 2 - 5.

Table 2. Rate and Proportion of Germination of Seed Following Stratification by Method 1: The Dorena Operational Procedure.

Family Number	Date:	4/19	4/25	5/6
	Day No.	20	30	41
	Number of emergent seedlings per 20 planted seed.			
1		12	13	18
2		9	10	10
3		11	14	17
4		16	16	18
5		0	0	2
6		12	13	13
7		2	3	4
8		4	5	9
9		10	11	16
10		1	2	6
11		15	16	19
12		18	19	19
13		10	13	16
14		3	3	5
15		10	12	15
16		13	15	16
17		13	14	17
18		17	17	18
19		15	15	15
20		20	20	20
OVERALL %		53	58	68

Table 4. Rate and Proportion of Germination of Seed Following Stratification by Method 3: University of Idaho Method.

Family Number	Date:	4/19	4/25	5/6
	Day No.	20	30	41
	Number of emergent seedlings per 20 planted seeds.			
1		11	13	15
2		11	11	12
3		9	14	16
4		15	15	15
5		0	1	6
6		12	16	18
7		5	6	7
8		8	9	9
9		9	11	12
10		7	11	12
11		11	14	18
12		19	19	19
13		12	13	16
14		5	5	10
15		11	16	20
16		14	18	19
17		13	15	19
18		17	19	19
19		20	20	20
20		20	20	20
OVERALL %		57	67	76

Table 3. Rate and Proportion of Germination of Seed Following Stratification by Method 2: Warm/Cold Stratification.

Family Number	Date:	4/19	4/25	5/6
	Day No.	20	30	41
	Number of emergent seedlings per 20 planted seed.			
1		13	14	17
2		11	14	15
3		15	17	19
4		18	19	20
5		0	1	16
6		14	15	15
7		12	17	19
8		12	17	20
9		13	16	18
10		5	8	18
11		8	16	17
12		14	16	18
13		13	17	18
14		14	17	20
15		9	12	19
16		3	10	20
17		9	15	19
18		11	17	19
19		16	17	17
20		12	18	20
OVERALL %		56	73	91

Table 5. Rate and Proportion of Germination of Seed Following Stratification by Method 4: Modified University of Idaho Stratification.

Family Number	Date:	4/19	4/25	5/6
	Day No.	20	30	41
	Number of emergent seedlings per 20 planted seeds.			
1		9	10	15
2		7	8	10
3		7	9	14
4		13	13	15
5		0	1	2
6		10	11	13
7		4	7	8
8		8	8	8
9		11	14	15
10		7	8	11
11		14	15	17
12		20	20	20
13		13	14	17
14		3	3	6
15		15	18	18
16		17	17	20
17		11	12	17
18		16	17	19
19		17	17	18
20		20	20	20
OVERALL %		56	61	71

Germination at 41 days appears to be the best time for comparison. Little change was noted after that time and seed which had germinated by that time would be useful in the rust test. Overall germination for Methods 1-4 are 68, 91, 76, and 71 respectively. The Warm/Cold Stratification Method does stand out above the rest.

The important issue at Dorena is "how well do the poorest lots do with Method 2, and does it have any adverse effect on the best germinating lots". The 5 best germinating lots are compared with the 5 poorest germinating lots. Results are presented in Table 6.

Table 6. Comparison of Germination in Best and Poorest Families.

Five Best Germinating Families

Family Number	Stratification Method (Number of Germinates at 41 Days)			
	1	2	3	4
4	18	20	15	15
11	19	17	18	17
12	19	18	18	20
18	18	19	19	19
20	20	20	20	20
Percent	94	94	90	91

Five Poorest Germinating Families

5	2	16	6	2
7	4	19	7	8
8	9	20	9	8
10	6	18	12	11
14	5	20	10	6
Percent	26	93	44	35

There appears to be very little difference in germination in the best germinating lots, regardless of stratification method used. Method 2 does not appear to have an adverse effect on lots which are easy to germinate. When stratification methods were compared for the 5 poorest germinating lots, Dorena's method had only 26% germination. These lots would probably be lost in rust test, as they would have insufficient base for a valid test. The warm/cold stratification method brought these lots up to the same germination percentage as the best germinating seed lots (93%). The germination using the modified University of Idaho method (35%) was 9% better than the Dorena method (26% germination). The germination by the University of Idaho method (44%) was 9% better than the modified Idaho method (35% germination). The largest improvement in germination was obtained by use of the warm/cold stratification methods on the poorest

germinating lots. This 67% increase in germination over Dorena's operational method is highly significant.

These results indicate that significant improvement can be made in seed germination by using warm/cold stratification method. We now have a good method to use for stratification of western white pine seed, but additional fine tuning may yield further improvements.

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ACKNOWLEDGEMENT

I wish to express my gratitude to the personnel at the Dorena Tree Improvement Center for making this study possible. A special thanks to Bob Weaver for doing the field work and measurements and to Kim Bates-Mahlein for the laboratory portion of the study.

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Excised Embryo Test for Western White Pine¹

William G. Johnson²

Abstract.--The excised embryo test provides accurate estimates of viability for Western White Pine (Pinus monticola) seed in 10 days.

INTRODUCTION

Western White Pine (Pinus monticola) seed is dormant and needs three months stratification and one month incubation for laboratory germination testing. Often the seed dormancy is still not overcome and the germination test is substantially below the germination in the nursery beds. A quick viability test should be used for deep dormancy species. The excised embryo test has been used on tree seed to determine viability since 1934 (Heit 1955) and has a close correlation with actual germination.

THE EXCISED EMBRYO TEST

The excised embryo test is quick, seven to ten days, and accurate. It works well on Western White Pine (Pinus monticola). The test is performed on 200 seed per lot as follows:

1. Surface sterilize the seed.
 2. Cut 1 mm off the radicle end of the seed.
 3. Soak the seed in water 18 hours.
 4. Cut the seed on both sides of the embryo.
 5. Pry open the seed to expose the embryo.
 6. Remove the embryo with a needle.
 7. Incubate the embryo nine days at 20°C.
- Live embryos will spread open the cotyledons and green up. Dead embryos will deteriorate.

¹ Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

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Nursery and Field Evaluation of Compost-Grown Coniferous Seedlings¹

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INTRODUCTION

An essential part of forest tree nursery culture is the use of organic amendments. Organic matter maintains soil characteristics like low bulk density, high water and nutrient holding capacities, improved soil structure and optimal environments for beneficial rhizosphere microorganisms (nitrifying bacteria, mycorrhizae, etc., Davey and Krause, 1980). Common organic amendments include green manure from cover crops, sawdust and peatmoss. Unfortunately, all have a high carbon to nitrogen ratio, may cause net nutrient immobilization and may release phytotoxic compounds. Sawdust and peatmoss availability are limited and used in other markets. Cover cropping requires additional nursery acreage. Composted material derived from manure, sawdust or spent mushroom compost results in less immobilization and little or no phytotoxic effects while still providing the desired organic input (Bledsoe 1981). Municipal sewage is an abundantly available organic nutrient source and has been favorably utilized in coniferous seedling production (Berry, 1985; Bledsoe and Zasoski, 1981). Addition of sludge provides supra-optimal nitrogen levels and will increase heavy metal levels in soils and plants (Bledsoe, 1981). However, the use of both sludge and sawdust, which have been composted together, combines the beneficial characteristics of each and mitigates the less desirable properties. The purpose of this experiment was to investigate the potential use of a sawdust-sludge compost in forest tree nurseries.

METHODS

Nursery

Nursery beds at the USFS Wind River nursery, Carson, WA were amended with compost (3:1 fir-hemlock sawdust: municipal sewage sludge from METRO, Seattle, WA). Additional characteristics of the compost, density 0.2 g/cm³, 0.5% N, are found in Bledsoe (1981).

Each of 12 nursery beds (330') were randomly selected for a particular compost treatment-tree species combination. The four compost treatments were 0, 2, 4 and 6 inch (0, 270, 528, and 805 cu. yds./acre, equivalent to 0, 513, 1000, and 1530 m³/ha). The 3 tree species were Douglas-fir (*Pseudotsuga menziesii*), noble fir (*Abies procera*) and ponderosa pine (*Pinus ponderosa*). Compost was disced into the soil and seeds were sown in spring 1982. Seedlings were raised according to standard nursery procedures. In fall 1983, the 2-0 nursery stock was lifted and stored at 3°C until spring 1984 when they were outplanted at three sites.

Field

Douglas-fir was planted with hoedads on the southeast side of Mt. St. Helens in the blast zone on a 3000' elevation site (35% slope) which had been salvage-logged. Planting occurred 4 years after the May 18, 1980 eruption. Tefra, 12-20 inches deep, covered the surface. Roots of planted seedlings did not extend into mineral soil.

Noble fir was planted near Estacada, Ore. at an elevation of 3800' and slope of approximately 20%. The site had been logged in 1980, slash was hand piled and burned. Considerable brush covered the area. Seedlings were planted with hoedads in mineral soil.

Ponderosa pine seedlings were planted east of the Cascade crest at 3400' elevation, near Leavenworth, WA. The area had been tractor logged for mixed ponderosa pine and Douglas-fir and broadcast burned in fall 1983. Slopes were approximately 45%. Seedlings were planted with power augers in mineral soil.

The experimental design for all 3 sites was a randomized complete block. Each row consisted of seedlings from a single treatment with 4 treatments in each block. Rows and seedlings within rows were spaced 8' apart. The design was arranged as follows:

Site	Rows/ block	Blocks	Trees/ Row	Total
Mt. St. Helens	4	5	30	600
Estacada	4	12	12	576
Leavenworth	4	6	24	576

¹This research was supported by grants from the Municipality of Metropolitan Seattle and the U.S. Forest Service, Portland, Oregon.

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Measurements and Analyses

Twenty-four seedlings from each compost treatment were measured for height, diameter and dry weight after 1 and 2 years in the nursery. Nutrient (N, P, K) and heavy metal (Zn, Cu, Pb, Ni, Cd) concentrations in roots were measured after 1 year on 4 pooled samples of 24 seedlings. Data were analyzed using a fixed-effects one-way ANOVA model for ponderosa pine, Douglas-fir and noble fir, respectively.

Field measurements of initial seedling height and diameter were made after planting in the spring of 1984. Seedling survival, height, and diameter were taken in the fall of 1984 and 1985. In these cases, a fixed-effect two-way ANOVA model was used for data analysis; compost treatment and blocks were the two factors used.

RESULTS AND DISCUSSION

Nursery: Growth

In general, Douglas-fir 1-0 seedlings were tallest while ponderosa pine had the greatest biomass (Table 1). Ponderosa pine seedlings responded favorably to compost application, with significant treatment effects on height and dry weight. Noble fir and Douglas-fir did not show any significant effects of compost treatment on growth parameters. Root collar diameter data are not presented since there were no significant treatment effects. Mean diameters were 2.4, 1.9 and 2.8 cm for Douglas-fir, noble fir and ponderosa pine respectively. Growth data from year 2 nursery phase are not presented since treatment effects for 2-0 seedlings in the

nursery were similar to results from the outplanting phase.

When seedlings were lifted, average seedling shoot and root dry weights (g) were: Douglas-fir 3.6, 1.7; noble fir 2.5, 1.5; ponderosa pine 7.1, 1.7. Compost-grown seedlings were generally similar to control seedlings in height, diameter, shoot and root weights. However, compost-grown Douglas-fir and noble fir were 5-30% shorter than control seedlings. Compost-grown seedlings also had slightly higher root/shoot ratios than controls.

Nursery: Nutrients and Metals

Nutrient concentrations in 1-0 seedlings did not differ among species with 2 exceptions. Potassium levels in noble fir roots were high (1.3%) as were N levels in pine shoots (2.3%). Potassium levels were not altered by compost treatment so these data were not included. Average K concentrations were 0.64%, 1.0%, 0.62% for Douglas-fir, noble fir and ponderosa pine, respectively. The average root and shoot concentrations for all species combined were 1.5% and 1.9% (N), .26% and .24% (P). A significant increase in N and P due to compost application was observed for Douglas-fir and noble fir (Table 2). This enhancement in root and foliar P and in foliar N was not observed in pine.

Root heavy metal levels, averaged over all species, were 4.7 ppm for Zn, 6.0 ppm for Cu, 8.1 ppm for Pb, 3.4 ppm Ni and 1.0 ppm for Cd. Cadmium and Zn values were as much as 6 times greater in compost-treated seedlings but only the Cd values were significant (Table 3).

Table 1.--Height and biomass of conifer seedlings grown in compost-amended nursery beds for one year. Values are means of 24 samples. Values for each row followed by the same letter are not significantly different (alpha = .05)

Species	COMPOST TREATMENT				
	0"	2"	4"	6"	MEAN
Douglas-fir					
Height, cm	15. b	18. a	16. b	17. b	16.
Shoot, g DW	0.78 a	0.81 a	0.72 a	0.88 a	0.80
Root, g DW	0.39 a	0.32 a	0.31 a	0.35 a	0.34
Root/Shoot	0.51 a	0.41 b	0.44 b	0.42 b	0.44
Noble fir					
Height, cm	9.4 a	9.4 a	9.9 a	9.3 a	9.5
Shoot, g DW	0.31 a	0.36 a	0.37 a	0.31 a	0.34
Root, g DW	0.18 a	0.22 a	0.23 a	0.20 a	0.21
Root/Shoot	0.56 b	0.62 a	0.65 a	0.68 a	0.63
Ponderosa pine					
Height, cm	13. b	14. a	14. a	15. a	14.
Shoot, g DW	0.98 b	1.3 a	1.3 a	1.2 a	1.2
Root, g DW	0.45 b	0.61 a	0.56 a	0.61 a	0.56
Root/Shoot	0.49 a	0.48 a	0.43 a	0.50 a	0.48

Table 2. Percent nutrient concentrations in roots and shoots of seedlings grown in compost-amended nursery beds for one year. Values are means of four tissue analyses which were pooled samples from 24 seedlings. For root and shoot data, values for each row followed by the same letter are not significantly different (alpha = .05).

Species	Compost Treatment, Roots				Compost Treatment, Shoots				
	0"	2"	4"	6"	0"	2"	4"	6"	
	- % -				- % -				
Douglas-fir	N	1.4 a	1.6 a	1.6 a	1.5 a	1.5 c	1.7 ab	1.8 a	1.5 b
	P	0.22 c	0.31 a	0.26 b	0.25 b	0.17 c	0.24 a	0.21 b	0.19 b
Noble fir	N	1.3 b	1.5 a	1.5 a	1.5 a	1.4 b	1.9 a	1.9 a	1.7 a
	P	0.19 b	0.25 a	0.25 a	0.25 a	0.20 b	0.27 a	0.26 a	0.25 a
Ponderosa pine	N	1.3 c	1.6 ab	1.8 a	1.5 b	2.1 a	2.2 a	2.3 a	2.4 a
	P	0.27 a	0.27 a	0.28 a	0.28 a	0.27 a	0.27 a	0.27 a	0.26 a

Table 3. Heavy metal content in ppm in roots of seedlings grown in compost-amended nursery beds for one year. Values are means of four tissue analyses which were pooled samples from 24 seedlings. Trace levels: Zn <.001, Ni <.01, Cd<.025 ppm. Values for each row followed by the same letter are not significantly different (alpha = .05).

Species	Compost Treatment				
	0"	2"	4"	6"	MEAN
	- ppm -				
Douglas-fir					
Zinc	T	0.88 a	1.8 a	3.2 a	2.0
Copper	5.0 a	5.7 a	5.8 a	4.4 b	5.2
Lead	4.4 a	6.2 a	5.2 a	4.4 a	5.0
Nickel	3.5 a	1.6 b	T	1.7 b	2.3
Cadmium	T	0.25 b	0.31 b	0.63 a	0.40
Noble fir					
Zinc	1.2 a	8.6 a	5.9 a	5.6 a	5.3
Copper	3.7 d	5.7 c	6.8 b	7.9 a	6.0
Lead	5.7 a	6.6 a	8.1 a	8.5 a	7.2
Nickel	2.2 a	1.6 a	T	1.7 a	1.9
Cadmium	0.56 b	0.63 b	1.8 a	2.1 a	1.3
Ponderosa Pine					
Zinc	4.8 a	11. a	5.1 a	T	6.8
Copper	7.2 a	6.1 a	7.3 a	7.0 a	6.9
Lead	12. a	11. a	9.1 a	16. a	12.
Nickel	6.0 a	5.9 a	5.8 a	6.7 a	6.1
Cadmium	0.50c	0.13 c	1.3 b	3.5 a	1.4

Other metals (Cu, Pb, Ni) did not accumulate above levels found in the control treatment, with one exception. In noble fir, copper levels steadily increased with increasing compost application rate.

There is little information on heavy metal levels in coniferous seedlings (Bledsoe and Zasoski 1981; Burton et al. 1984, 1986). Burton et al. 1984 found that root growth of Sitka spruce was inhibited at root concentrations >61 ppm Cd and 228 ppm Pb. Rolfe & Bazzaz (1975) measured inhibition of loblolly pine photosynthesis at similar tissue levels. The values for growth inhibition reported by Burton et al. (1984) were greater than 10 times the Cd and Pb concentrations measured in this study (Table 3). Wind River Nursery could accept more composted sludge before toxic levels of these two elements are reached.

Field

After one season's growth in the field, average survival ranged from 97% for Douglas-fir to 93% for noble fir and 88% for Ponderosa pine. For Douglas-fir, field survival of seedlings grown in compost-treated nursery beds was similar to control seedlings, except at the heaviest (6") application rate. Here, year 1 and year 2 survival was reduced from 93% (yr 1) to 84% (yr 2, Table 4). For noble fir, survival for compost-grown trees was slightly reduced in year 1, but this effect was not present by year 2. For ponderosa pine, survival effects were complex and seemingly unrelated to compost application rates. Survival was significantly reduced by the 2" and 6" treatments, but, inexplicably, survival in the control and 4" treatment was similar.

Douglas-fir height data show that growth in year 1 was much greater than growth in year 2.

Table 4. Two year height and survival data for 2-0 seedlings outplanted in spring 1984 on three sites in Washington and Oregon. Seedlings were previously grown at the Wind River nursery in beds amended with 0, 2, 4 or 6 inches of compost. Values for each row followed by the same letter are not significantly different ($\alpha = .05$).

Species, Site	Compost Treatments			
	0"	2"	4"	6"
Douglas-fir, Mt. St. Helens WA				
Height, cm				
Spring 1984	25.2a	20.4b	24.4b	21.9b
Fall 1984	28.7a	24.0b	28.6a	23.9b
Fall 1985	29.5a	25.8b	29.1a	25.0b
Total Inc. %	17.5b	27.0a	19.5ab	14.7b
Survival, %				
Fall 1984	97.9a	99.3a	99.3a	93.4b
Fall 1985	98.0a	95.9a	96.9a	84.2b
Noble fir, Estacada OR				
Height, cm				
Spring 1984	22.1a	13.7b	14.7b	14.5b
Fall 1984	24.3a	15.9b	16.4b	16.5b
Fall 1985	26.5a	18.1b	18.5b	18.8b
Total Inc. %	20.6b	34.6a	26.9a	29.7a
Survival, %				
Fall 1984	99.2a	90.9b	87.2b	93.3b
Fall 1985	95.4a	90.2a	85.9a	87.3a
Ponderosa pine, Leavenworth WA				
Height, cm				
Spring 1984	17.1a	18.3a	17.7a	16.7a
Fall 1984	23.3a	20.7b	21.5b	19.3c
Fall 1985	30.9a	27.4b	27.9b	25.8b
Total Inc. %	81.7a	49.7b	58.3b	54.5b
Survival, %				
Fall 1984	97.5a	71.5c	100.0a	81.3b
Fall 1985	93.5a	49.6c	83.8a	66.0b

Reduced second year growth may have been due to low nutrient availability in the tephra. Height increase for the 2 inch treatment was significantly greater than the control treatment.

For noble fir, seedling heights were significantly lower in composted treatments, due to differences developed in the nursery. Percent height increase in compost treatments was significantly greater than controls, suggesting that compost-treated seedlings grew well in the field.

Ponderosa pine seedlings initially were identical in height, but later composted seedlings were shorter than controls. This trend was carried through the 1985 season. By the end of 1985, height increase in the control exceed 80%, whereas composted seedlings only grew 50%. Thus pine may not be suited for compost applications.

CONCLUSIONS

This study indicates that although initial growth of compost-treated nursery seedlings is improved, probably due to increased nutrient availability, subsequent nursery growth seems to be reduced. Nutrient immobilization in the high C:N compost may cause reduced growth. This process is no different than processes which occur after incorporation of traditional organic amendments such as peat, sawdust or cover crops. Despite the suspected immobilization effects of compost applications, especially on noble fir and ponderosa pine, the use of compost as an organic amendment appears promising. This is especially true for Douglas-fir which responded well to compost application as compared to controls. The optimal compost application rate for nursery phase seedlings appears to be either the 2" or 4" treatment. Six inch treatments produced consistently smaller seedlings than did the other compost treatments.

Use of sludge or composted sawdust/sludge mixtures should be applied with caution, since this study showed increased cadmium and zinc concentrations in roots of compost-grown trees. Addition of toxic heavy metals should be monitored, because these metals will accumulate in nursery soils. Fortunately, these environmentally hazardous materials often remain in the soil in close association with the applied organic compounds (Zasoski 1981). The problem with this soil retention is the possible build-up of these compounds to toxic levels. Lake et al. (1984) listed annual loading rates of Cd in Scandinavia - 22 g/ha, in the U.K. - 167 g/ha and in the U.S. - 1250 g/ha. Rather than discussing annual application rates, Bicklehaupt (1980) referred to cumulative levels for several different heavy metals. Cadmium levels should not exceed 20 kg/ha, while zinc levels should not exceed 1000 kg/ha for soils with high cation exchange capacities. In soils with lower cation exchange capacities, such as sandy soils or soils

sandy soils or soils low in organics, these maximum levels are cut by a factor of 4. It therefore appears evident that use of sludge or composted sludge compounds in forest nurseries for organic inputs will require careful monitoring of soil and tissue levels so that toxic levels and seedling growth inhibition do not occur.

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First-Year Field Performance of Douglas-fir Seedlings in Relation to Nursery Characteristics¹

Steven K. Omi, Glenn T. Howe, and Mary L. Duryea²

Abstract.--First-year field performance of 48 Douglas-fir seedling samples from six nurseries and nine seed sources was analyzed in relation to nursery measurements of seedling morphology, phenology, and vigor. Height at lifting accounted for 84 percent of the variation in first-year field height, while root dry weight and stem diameter at lifting had the highest correlations with first-year height growth ($r^2 = 0.43$ for both). A combination of phenological, morphological, and physiological characteristics yielded the best predictions of field performance (e.g., root dry weight at lifting combined with two vigor-test measurements accounted for 63 percent of the variation in first-year height growth). All correlations of nursery characteristics with first-year field survival were nonsignificant. First-year height growth and frequency of multiple leaders in the field were negatively related ($r^2 = 0.16$).

INTRODUCTION

High-quality seedlings are necessary for successful reforestation. Because morphological characteristics of seedlings are easy to measure, most nurseries grade their seedlings according to those criteria (Ritchie 1984, Thompson 1985). Recently, however, the physiological condition of a seedling has been emphasized as an important determinant of its ability to survive and grow in the field (Duryea 1984, Ritchie 1984, Duryea 1985), and

nurseries and reforestation organizations are examining more closely the use of physiological qualities (e.g., root growth potential, frost hardiness, stress response, or vigor) as well as traditional morphological measurements in assessing field performance potential.

The objective of this study was to investigate the relationships of Douglas-fir (*Pseudotsuga menziesii*) first-year field performance to nursery measurements of seedling phenology, morphology, and vigor.

¹ Paper presented at the Western Forest Nursery Council Meeting [Tumwater, Wash., August 12-15, 1986]. Manuscript 2147 of the Forest Research Laboratory, Oregon State University, Corvallis.

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MATERIALS AND METHODS

Data for this study were originally gathered during an investigation of top-pruning effects on the morphology, physiology, and field performance of Douglas-fir (Duryea and Omi, unpublished). In 1983, two-year-old bareroot seedlings were selected at six nurseries in central California, Oregon, and southwestern Washington (fig. 1). Four plots (averaging 3.7 x 1.2 m) of unpruned seedlings were selected from each of two seed sources at each nursery. Seed zones ranged in elevation from 305 to 1219 m (table 1). Because one seed source was common to four of the nurseries, nine seed sources were represented in the study. Forty-eight samples were used for comparing seedling characteristics to field

performance (12 nursery and seed source combinations x 4 plots).

MEASUREMENTS

Phenology

Nursery flushing date was defined as the date during the second growing season when 50 percent of the seedlings had initiated growth (needles emerging through bud scales). Approximately six weeks after this date, 20 seedlings per plot were flagged and numbered. The terminal bud of each was rated as growing (flushed) or not actively growing (budset), and was monitored by nursery personnel approximately once a week for 14 weeks and then once every two weeks until late fall. The two phenological measurements derived for each seedling were budset date (Julian date of final budset) and weeks to budset (number of weeks from flushing date to final budset). This second measurement, therefore, assesses growing-season length.

Morphology

Seedlings were lifted during January and February 1984 (table 1) and graded. In contrast to some operational grading procedures, seedlings with multiple leaders were retained if they met all other standards. After grading, seedlings were root-pruned to 25 cm, and approximately 20 seedlings per plot were measured for shoot height, stem diameter, number of branches, terminal bud length, and shoot and root dry weights. Shoot:root ratios were calculated from these dry weights.

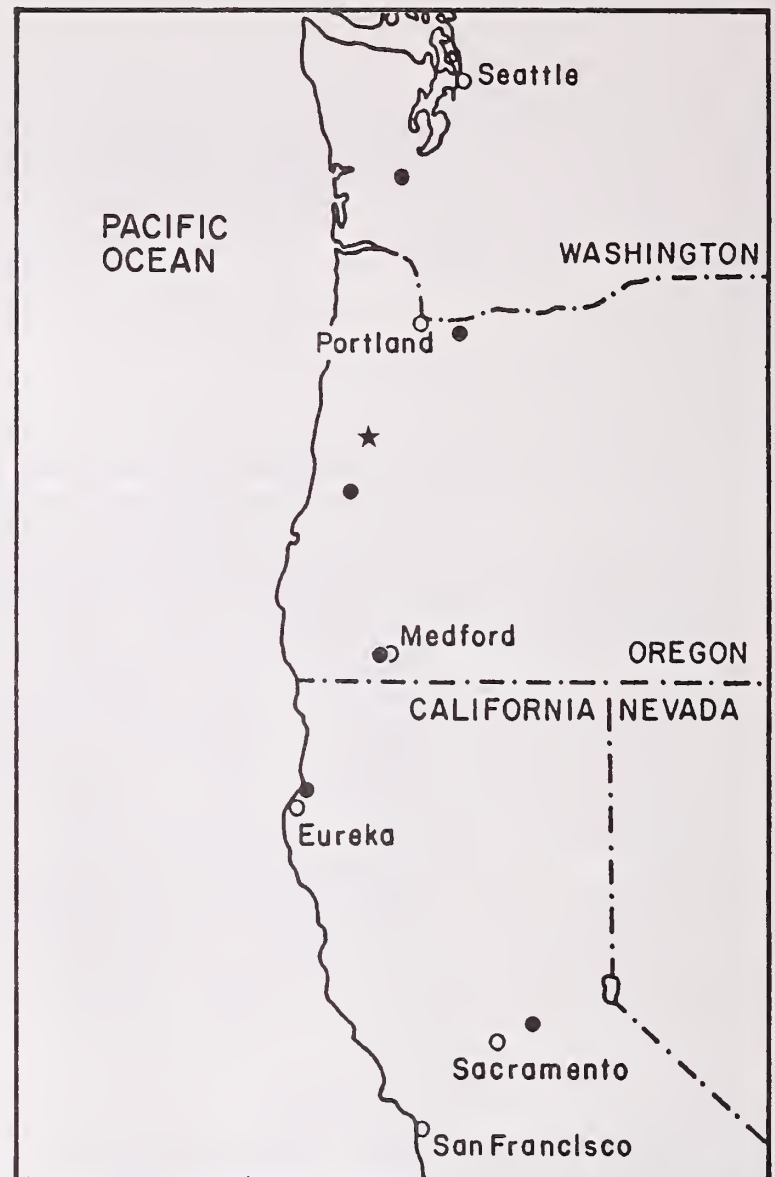


Figure 1. Locations of nurseries (•) and planting site (★).

Table 1. Nursery and seed zone characteristics and lifting and planting dates for the twelve nursery and seed source combinations.

Nursery ¹	Seed zone	Elevation in ft (m)	Owner of stock	Seedbed density	Lifting date	Planting dates
				in seedlings per ft ² (m ²)		
1	030	1000 (305)	Washington Dept. of Natural Resources	22 (237)	2/7/84	3/14/84 - 3/27/84
	430	1000 (305)		24 (258)	1/10/84	3/14/84 - 3/27/84
2	270	1500 (457)	International Paper Co.	22 (237)	2/14/84	3/28/84 - 4/11/84
	461	3500 (1067)		20 (215)	2/14/84	3/14/84 - 3/27/84
3	270	2000 (610)	Medford District, BLM	30 (323)	1/17/84	3/28/84 - 4/11/84
	062	1500 (457)		22 (237)	1/17/84	3/14/84 - 3/27/84
4	270	2500 (762)	Medford District, BLM	34 (366)	1/11/84	3/28/84 - 4/11/84
	492	3500 (1067)		26 (280)	1/11/84	3/14/84 - 3/27/84
5	270	2000 (610)	Medford District, BLM	21 (226)	1/31/84	3/28/84 - 4/11/84
	072	1000 (305)		22 (237)	1/31/84	3/14/84 - 3/27/84
6	525	4000 (1219)	Tahoe National Forest	34 (366)	1/24/84	3/14/84 - 3/27/84
	524	2500 (762)		48 (517)	1/24/84	3/14/84 - 3/27/84

¹ See figure 1 for nursery locations.

OSU Vigor Test

A separate sample of 20 shippable seedlings per plot was used for seedling quality evaluation in the OSU vigor test (McCreary and Duryea 1985). Seedlings were randomly divided into two groups of 10. One group was given a 15-minute stress treatment (root exposure at 30°C and 30% relative humidity), and the other was left unstressed (McCreary and Duryea 1985). Two-month greenhouse survival and the number of seedlings that had broken bud after one month were recorded for both groups.

Field Performance

Seedlings were planted on one site at the OSU McDonald Forest in Corvallis, Oregon (fig. 1) over a one-month period in spring 1984 (table 1). Seedlings from each nursery sample were planted as two randomly assigned 10-tree row plots at 1.2 x 1.2 m spacing (960 seedlings total). Vexar® tubes were placed over all seedlings immediately after planting.

In the fall of 1984 (one season after planting), survival, total height, 2+0 height, and stem condition (multiple or dominant leader) were recorded for each tree. First-year height growth was determined by subtracting 2+0 height from first-year height.

Data Analyses

Sample means for all field traits were calculated by averaging over the two 10-tree row plots (20 seedlings). Coefficients of simple determination (r^2) were computed on nursery and field means for all samples ($N = 48$). In addition, a stepwise regression procedure (SAS Institute, Inc. 1985) was used to develop relationships between the independent (i.e., nursery phenology and morphology, OSU vigor test) and dependent (i.e., field performance) variables, and for these a coefficient of multiple determination (R^2) was calculated. To remain in the model, independent variables had to cause a reduction in the sums of squares of the dependent variable at the 0.05 level of significance. Before analysis, all proportions were transformed to arcsine square-root values (Steel and Torrie 1980).

RESULTS

First-year Field Survival

Correlations of all independent variables with first-year field survival were nonsignificant ($P > 0.05$, table 2). Uniformly high survival among all samples made it difficult to detect significant relationships. Mean survival was 90 percent (s.e. = 1%) and ranged from 70 to 100 percent. Because survival

varied little among sample means, no adequate regression model could be derived.

First-year Height

First-year height was significantly correlated ($P < 0.01$) with several independent variables (table 2). Coefficients of determination ranged from 0.14 (budbreak of unstressed seedlings) to 0.84 (height at lifting); budset date and weeks to budset were also significantly correlated with first-year height ($r^2 = 0.35$ and 0.64 , respectively). Average first-year height was 43 cm (range 29 to 62 cm, s.e. = 1.34 cm).

The best regression equation for predicting first-year height included height at lifting, shoot:root ratio, and weeks to budset, and accounted for 90 percent of the variation in first-year height. However, variation in height at lifting alone could account for 84 percent of the variation in first-year height.

First-year Height Growth

Nine of the 14 independent variables were significantly correlated with first-year height growth (table 2); root weight and stem diameter at lifting had the highest correlations ($r^2 = 0.43$ for both; fig. 2). Again, weeks to budset had a higher correlation ($r^2 = 0.18$, $P < 0.01$) than budset date ($r^2 = 0.02$, $P > 0.05$).

The best regression equation for predicting first-year height growth accounted for 78 percent of the variation and included root weight, stem diameter, survival and budbreak of unstressed seedlings (OSU vigor test), shoot weight, weeks to budset, and frequency of multiple leaders at lifting. Root weight combined with unstressed vigor-test survival and budbreak accounted for 63 percent of this variation; stem diameter in the same combination accounted for 57 percent.

Because weeks to budset only accounted for an additional three percent of the variation in first-year height growth when entered into the model, we deleted this variable to explore the relationships among the others; and, because the remaining variables could be classified as either physiological (OSU vigor test) or morphological, we investigated each class of independent variables separately. When only morphological variables were considered, the best regression equation involved root weight alone and accounted for 43 percent of the variation in height growth. When only physiological traits were analyzed, both budbreak and survival of unstressed seedlings contributed significantly to reducing the sums of squares ($R^2 = 0.32$).

First-year height and height growth were positively correlated ($r^2 = 0.26$, $P < 0.01$). First-year height growth averaged 7 cm (s.e. = 0.3 cm) and ranged from 3 to 12 cm.

Frequency of Multiple Tops After One Year

After one year in the field, only four independent variables were significantly correlated with the proportion of multiple-leader seedlings (table 2); first-year height growth and multiple-leader frequency in the field were negatively related ($r^2 = 0.16$, $P < 0.01$). Mean frequency of seedlings with multiple leaders in the field was 21 percent (s.e. = 2%) and ranged from 0 to 61 percent.

The best predictive regression equation included the proportion of multiple-leader seedlings at lifting, weeks to budset, and height at lifting, and accounted for 46 percent of the observed variation in multiple-leader frequency in the field.

DISCUSSION

Significant correlations between nursery characteristics and field performance suggest that a variety of phenological, morphological,

and physiological nursery characteristics could be used for predicting seedling quality for the samples in this study. Several of these relationships previously have been confirmed. Thompson (1985) indicated that morphological characteristics such as seedling height, stem diameter, dry weight, and bud length are significantly correlated with the field performance of many conifer species. McCreary and Duryea (1985) reported significant correlations between the OSU vigor test and field performance.

In our study, morphological variables were consistently the best predictors of field performance. Although the best regression model for predicting first-year height included other variables, height at lifting accounted for 84 percent of the variation. Similarly, combining root weight or stem diameter with OSU vigor test measurements yielded significant regression equations for first-year height growth. However, of the important seedling-quality indicators in this study, stem diameter appeared to be one of the most practical because of its ease of measurement.

Height at lifting was not significantly related to first-year height growth ($r^2 = 0.05$). Because it is reasonable to expect

Table 2. Coefficients of determination (r^2) relating first-year field performance with nursery budset and with morphology and OSU vigor test at lifting.

Nursery variable	First-year field performance			
	Survival (%)	Height (cm)	Height growth (cm)	Multiple leader (%)
Weeks to budset	0.04	0.64**	0.18**	0.01
Morphology at lifting				
Root weight (gm)	0	0.26**	0.43**	0
Shoot weight (gm)	0	0.59**	0.25**	0.02
Total weight (gm)	0	0.50**	0.32**	0
Height (cm)	0.05	0.84**	0.05	0.10*
Stem diameter (mm)	0	0.42**	0.43**	0
Number of branches	0.01	0.21**	0.01	0.06
Terminal bud length (mm)	0.01	0.18**	0.13*	0.04
Shoot:root ratio	0	0.20**	0.08*	0.23**
Multiple leader (%)	0	0.03	0	0.21**
OSU vigor test at lifting				
Unstressed seedlings				
Survival (%)	0.06	0.05	0.10*	0.07
Budbreak (%)	0	0.14**	0.08*	0.02
Stressed seedlings				
Survival (%)	0.01	0.02	0.03	0.19**
Budbreak (%)	0.01	0.08*	0	0.08

* Significant at $P < 0.05$

** Significant at $P < 0.01$

that future growth potential is more closely related to first-year height growth than to height at lifting, the latter seemed relatively unimportant for assessing the field growth potential of seedlings in this study. If superior first-year height growth translates into growth superiority in later years, the seedling traits most important to consider for long-term performance are those which, either alone or in combination, best predict first-year height growth.

Although weeks to budset (length of growing season) was correlated with first year height ($r^2 = 0.64$) and height growth ($r^2 = 0.18$), it may not be useful as an indicator of seedling quality because of the time required for measurement. In addition, when combined with the other independent variables in the best models, weeks to budset only accounted for 2 to 3 percent of the variation in first-year height and height growth. However, weeks to budset was consistently a better predictor of field performance than budset date, probably because budset date is strongly influenced by the nursery environment. The nurseries in this study were geographically distant; seedlings in nurseries farther north

would naturally have earlier budset dates because of climate and cultural practices that induce earlier seedling dormancy. Weeks to budset is less influenced by differences in nursery environment because it is essentially a measure of growing season length, and, although growing season length also varies somewhat among nurseries, the predictive ability of this variable appeared to be better than that of budset date.

As with phenological characteristics, OSU vigor test variables require more time for measurement than do morphological characteristics; and, in contrast to previous reports (McCreary and Duryea 1985), we found poor relationships between OSU vigor test variables and field performance. This may be due to confounding effects of planting dates and storage intervals for the twelve nursery and seed source combinations; the time interval between stress tests and actual planting date must be minimized (McCreary and Duryea 1985), and that interval ranged from one to three months in this study. Another possible explanation is the lack of variability in vigor-test means. For example, average growth-room survival of unstressed seedlings was consist-

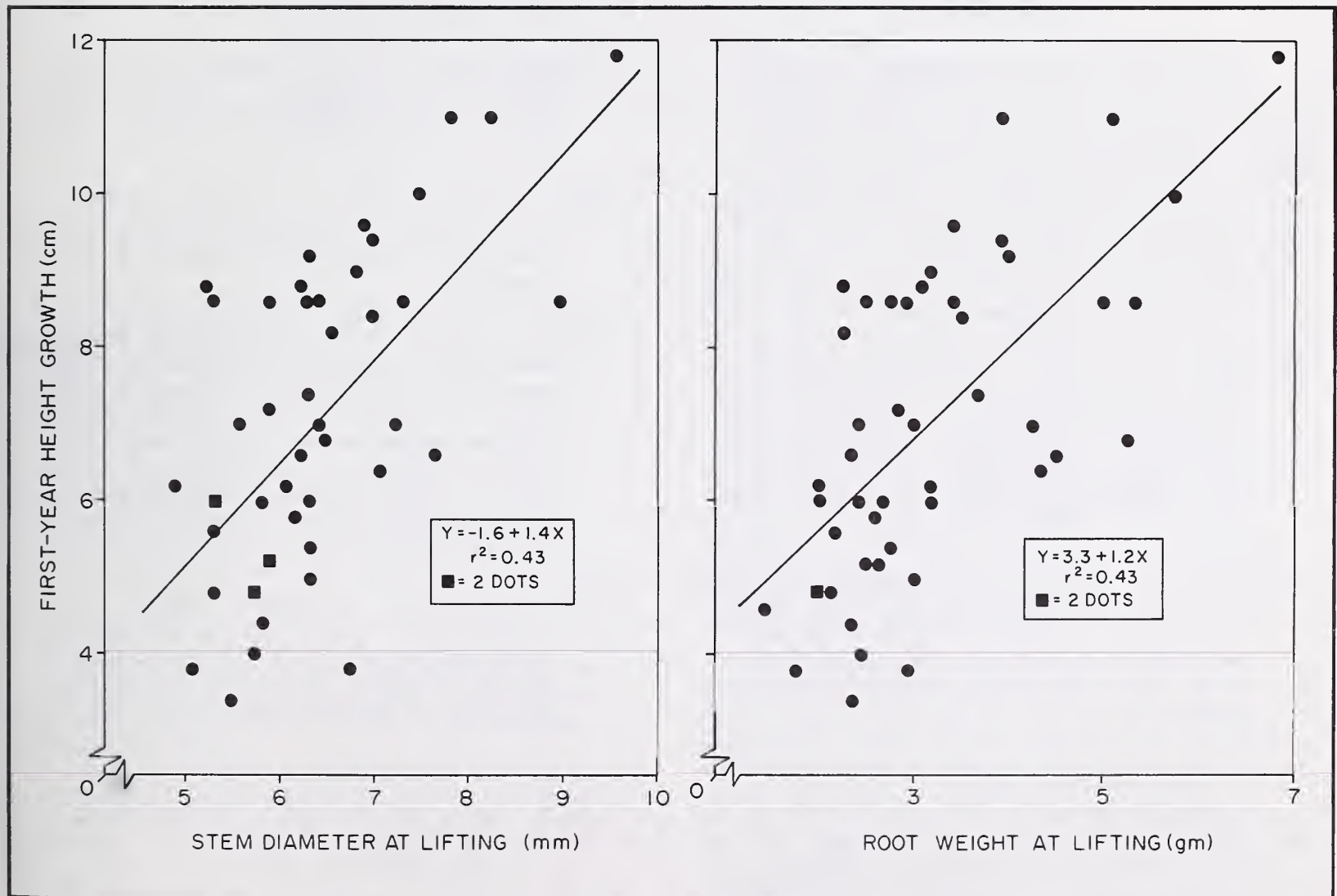


Figure 2. Relationship of first-year height growth to stem diameter and root weight at lifting.

ently high (average 97%, range 50 to 100%), which made it difficult to develop strong relationships with the dependent variables (McCreary and Duryea 1985).

The significance of multiple leaders as an indicator of seedling quality is largely unknown. Reports in the literature suggest that apical dominance is apparent in multiple-leader seedlings after two growing seasons in the field (Lanquist 1966, Dierauf 1976, Webb and Reese 1984). Three years after outplanting, survival of white spruce (*Picea glauca*), black spruce (*Picea mariana*), and jack pine (*Pinus banksiana*) differed little between trees with single leaders and those with multiple leaders at lifting (Webb and Reese 1984). Webb and Reese (1984) also indicated that multiple-leader trees may have field height growth similar to that of single-leader trees. In our study, the nursery multiple-leader condition was positively correlated, and first-year height growth was negatively correlated, with the occurrence of multiple leaders after the first growing season in the field. The long-term retention of multiple leaders and its effect on field performance remain to be investigated.

ACKNOWLEDGMENTS

We wish to thank the members of the Nursery Technology Cooperative for assistance in study layout, measurement, and site maintenance. We appreciate the support of the OSU Forest Research Laboratory and Department of Forest Science, Robin Rose and Doug McCreary (our reviewers), Mayvin Sinclair (our typist), and Dave Merrill (our editor).

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Winter Sowing for Production of 1-0 Douglas-fir Planting Stock¹

James L. Jenkinson and James A. Nelson²

Abstract.--Effects of early sowing on emergence and growth of Douglas-fir were examined in the Humboldt Nursery on California's north coast. In a 1979 study, seeds from coastal and inland regions of western Oregon and northern California were chilled 30 or 90 days at 1°C and sown in March and May. Chilling seeds for 90 days resulted in greater speed and amount of seedling emergence in cool soil (March) and greater speed of emergence in warm soil (May). March sowing captured at least six additional weeks early in the potential growing season and resulted in 1-0 seedlings that were large enough to outplant. Top dry weight was increased by 63 to 106 percent and root dry weight after pruning, by 24 to 82 percent, depending on seed source. In a 1985 study, seeds of coastal and inland sources were chilled 90 days and sown in January, February, March, April, and May. Sizes of the resulting 1-0 seedlings defined sowing windows that were wide open in February and closed in late April. Relative stem volumes in the February through May sowings were 7.5, 4.2, 2.9, and 1.0, and the cull percentages, 14, 21, 38, and 82, respectively. Humboldt Nursery can efficiently produce 1-0 Douglas-fir for the Pacific slope by sowing fully chilled seeds in winter and early spring.

INTRODUCTION

Planting 1-0 seedlings of Pacific Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) is an attractive option for reforestation programs in the Pacific slope regions of western Oregon and northern California. Advantages for forest management include shorter lead times and greater silvicultural flexibility for regenerating harvested stands and forests burned by wildfire. Advantages for nursery management include more frequent cover cropping or fallow years and ripping or chisel plowing to improve soil aeration

and drainage. Compared with 2-0 seedlings, 1-0 seedlings take less water, fertilizer, weeding, and inventory effort, require neither undercutting nor vertical pruning of roots in the nursery, and cost less to lift, grade, pack, store, ship, and plant. They are more easily lifted and separated without mechanical damage to the roots, and standard root pruning removes less of the lifted root system. Up to three times as many 1-0 as 2-0 seedlings can fit in the standard packing bag, tripling the capacity of premium cold storage. Because 1-0 seedlings are easier to plant with proper root placement and easier to protect against depredation by animals, their use may enhance early plantation establishment.

¹ Paper presented at combined meeting of the Western Forest Nursery Council and Intermountain Nurseryman's Association. [Olympia, Washington, August 12-14, 1986].

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The biological basis for growing 1-0 Douglas-fir partly rests on knowledge of the physiological ecology of conifer seeds and seedlings. Seeds of most conifers in the wild, including those of Douglas-fir on the Pacific slope, are shed in autumn, undergo moist overwinter chilling, and germinate in early spring. Research on Douglas-fir, sugar pine (*Pinus lambertiana* Dougl.), ponderosa pine (*P. ponderosa* Dougl. ex Laws.), loblolly pine (*P. taeda* L.), lodgepole pine (*P. contorta* Dougl.), Engelmann spruce (*Picea engelmannii* [Parry]

Engelm.), and Fraser fir (Abies fraseri [Pursh] Poir.) has shown that prolonged chilling may enable rapid germination, seedling emergence, and early growth in cool conditions (Adkins and others 1984, Allen 1960, Danielson and Tanaka 1978, Dunlap and Barnett 1982, Jenkinson and others 1982, McLemore 1969, Sorensen 1978, Tanaka and others 1986). Moreover, cool soils may restrict the lethal activity of damping-off and Fusarium root disease (Bloomberg 1973, Filer and Peterson 1975, Jenkinson and others 1982, Smith 1975) and promote the early mycorrhizal development and protection of young seedling roots (Parke and others 1983, Sinclair 1974, Sinclair and others 1982, Sylvia 1983).

Nursery and field experience with three widespread pines in California encouraged our work on Douglas-fir. By sowing in May, nurseries in the western Sierra Nevada readily produce successful 1-0 seedlings of ponderosa and Jeffrey pines (Pinus jeffreyi Grev. & Balf.) for many different seed sources (Jenkinson 1980). In these same nurseries, the traditional May sowings always take 2 years to grow acceptable crops of sugar pine. A recent April sowing of sugar pine at the Placerville Nursery nevertheless produced successful 1-0 seedlings for a number of different seed sources in the North Coast Range and Sierra Nevada (U.S. Dep. Agric., Forest Service 1982). In the nearby Institute of Forest Genetics nursery, February and March sowings of sugar pine from an elevational transect of the western Sierra consistently produced large and healthy 1-0 seedlings, whereas seedlings in May sowings were highly susceptible to Fusarium disease and too small to outplant (Jenkinson and others 1982).

Situated on the Pacific Coast near McKinleyville, the Humboldt Nursery is historically free of winter snow and frozen soil, but traditionally has sown in May to avoid the rainy season. Seedlings of all conifers in these late spring sowings require 2 years to reach acceptable planting sizes. By contrast, trial sowings of Douglas-fir in March and April have commonly produced 1-0 seedlings that were big enough to outplant. No other treatment was needed.

To evaluate the survival and growth potential of its 1-0 Douglas-fir, Humboldt Nursery and its clientele established a series of field tests in the Oregon Coast and Cascade Ranges, the Klamath Mountains, and the North Coast Range of California. Seedlings were planted in spring on cleared sites in the seed zone of origin for a total of 11 different seed sources. Results were encouraging. For seedlings dug within the seed source lifting window (Jenkinson and Nelson 1978), field survival averaged 81 to 99 percent, depending on planting site, and tree heights often doubled in the first and second years (Jenkinson 1984; Jenkinson and Nelson 1983, 1985; Turpin and others 1985).

It seems evident that by sowing early,

bareroot nurseries in California might easily produce 1-0 planting stock for sugar pine and Douglas-fir. Yet responsible nursery people hesitate to shift from the traditional sowing schedules, and for valid reasons (Owston and Stein 1974). Seed treatment and soil preparations for early sowing will necessarily invade the nursery lifting season, and the usual winter and spring rains will typically obstruct any calendar for seedling harvest, nursery bed formation, and early sowing. In such circumstances, work plans must be highly flexible if harvest and sowing schedules are to be coordinated effectively. The greatest deterrent to sowing early is the occasional torrential rain that can cause severe soil erosion, destroy newly sown beds, and force another sowing with summer imminent.

This paper reports two studies of early sowing in the Humboldt Nursery and offers guides for the production of large, 1-0 planting stock for Pacific Douglas-fir. In 1979, we explored the effects of seed chilling period and nursery sowing date on the speed and amount of seed germination, seedling emergence and growth for seed sources from coastal and inland regions of western Oregon and northern California. Seedlings from this study were successfully tested for field survival and growth (Jenkinson and Nelson 1983). In 1985, we investigated the nursery sowing windows--that is, the earliest and latest safe times to sow coastal and inland seed sources for the production of 1-0 stock--and explored ways to control erosion in the seed beds. Field tests of seedlings from this study are in progress.

MATERIALS AND METHODS

For the 1979 study, seed sources were chosen in the Oregon Coast Range and western Cascade Range, and in the North Coast Range and eastern Klamath Mountains of California (table 1). These sources represent the diversity of coastal and inland regions supplied with planting stock from Humboldt Nursery.

Seed Germination Test

Seeds were soaked 36 hours in aerated water at 22°C (72°F), chilled 0, 20, 40, or 60 days at 1°C (34°F) to bracket Humboldt's traditional 30 days, and germinated at 22°C on moist filter paper in 11-cm Petri dishes. Each dish contained 100 seeds of a particular source and chilling treatment, and each combination was replicated four times. Filter papers were kept moist with a dilute suspension of captan fungicide. Germinated seeds were counted and removed at 7, 14, and 21 days. A seed was considered germinated once the radicle had extended 2 mm beyond the seedcoat and showed positive geotropic response.

The effects of seed source and chilling period on germination were assessed by analysis of variance using BMD P2V (Jennrich and others 1981).

Table 1. Seed sources used to investigate early spring and winter sowing for the production of 1-0 Douglas-fir at Humboldt Nursery

Forest region and seed source code	Ranger District or Resource Unit	Tree seed zone ²	Seed parent elevations (ft) ³
March and May sowings, 1979			
Oregon Coast Range AL 252.15	Alesea	252	1000-1500
Cascade Range, western MK 472.30	McKenzie	472	2500-3000
North Coast Range KR 390.20	King Range ¹	390	1500-2000
Klamath Mtns, eastern OK 321.30	Oak Knoll	321	2500-3000
January through May sowings, 1985			
North Coast Range GQ 091.25	Gasquet	091	2000-2500
Klamath Mtns, central SA 311.40	Salmon River	311	3500-4000

¹ Bureau of Land Management.

² U.S. Dep. of Agric., Forest Service 1969, 1973.

³ 1 m = 3.28 ft.

Seedling Emergence and Growth Test

Seeds were soaked 36 hours in aerated water at 22°C, chilled 30 or 90 days at 1°C, and sown in the nursery on March 14 and May 15. Adjacent beds were prepared by the standard chisel plow and power harrow method in early March. Monoammonium phosphate (11-48-0) and potassium sulfate (0-0-52) were incorporated into the soil during bed preparation, according to traditional practice (200 lb and 50 lb material/acre, respectively). To facilitate plot installation and cultural treatments, one bed was necessarily assigned the March sowing and the other, the May sowing. A Love-Oyjord seeder was used to sow the seeds at a depth of 3 to 6 mm and in the standard 8-row pattern, to provide 30 seedlings per square foot (325 per m²).

The design of the test consisted of five replications of a randomized complete block of split plots. The bed pair was divided into five blocks of seed source plots. The blocks were 80 ft long, the source plots, 20 ft, and the treatment plots, 10 ft (1 ft = 30.5 cm). The source plots were split across the beds for chilling treatment and between the beds for sowing

dates. The five replications extended 400 ft, sampling most of the width of the nursery block or soil management unit.

Water was applied by impact sprinklers, as needed to moisten the soil surface during emergence, and once or twice weekly to irrigate the soil profile through the growing season. The seedlings were not fertilized.

To track seedling emergence, four sample plots were randomly located in seed rows 2 to 7 of the middle 5 ft of each chilling treatment plot. Each sample plot consisted of 1 ft of seed row and was permanently marked with parallin stakes. New germinants were counted three times weekly after emergence began, and less frequently as emergence neared completion. A germinant was counted after its hypocotyl penetrated the bed surface.

In December, seedlings were dug from the sample plots, combined by treatment plot, carefully washed free of soil, root-pruned 23 cm (9 in) below the cotyledon node, and graded to eliminate any damaged individuals. Ten randomly selected seedlings per treatment plot were evaluated for shoot height above the cotyledon

node, stem diameter 1 cm below the node, and oven dry weights (65°C or 140°F) of the top and roots separated at the node.

The effects of seed source and chilling period on seedling emergence were assessed for the March and May sowings separately, by analysis of variance BMD P8V (Jennrich and Sampson 1981). The data were analyzed as a split plot design, with seed sources and chilling periods considered fixed and the blocks, random.

The effects of seed source, chilling period, and sowing date on seedling growth were also assessed by BMD P8V. The data were analyzed as a split-split plot design with seed sources, chilling periods, and sowing dates considered fixed and the blocks, random.

Determining Nursery Sowing Windows

For the 1985 study, seed sources representing coastal and inland regions were chosen in the North Coast Range and the central Klamath Mountains of California (table 1).

Seeds were soaked 24 hours in aerated water at 22°C, chilled 90 days at 1°C, and sown in the nursery on January 15, February 19, March 21, April 23, and May 17. One full bed was prepared by the chisel plow and power harrow method in early January, when soil conditions were favorable. Triple super phosphate (0-48-0) and potassium sulfate (0-0-52) were incorporated into the soil during bed preparation (440 lb and 200 lb material/acre, respectively). The shaped bed was protected against erosion by covering the soil surface with a 1/4-inch-mesh net made of polypropylene. The net was removed as the plots were sown. A Love-Oyjord seeder again was used to sow the seeds at a depth of 3 to 6 mm and in the standard 8-row pattern, to provide 30 seedlings per square foot (325 per m²).

The design of the test consisted of three replications of a randomized complete block of split plots. Sowing date was split for seed source and seed source was split for a check and three erosion control methods, that is, a woven tissue paper mat, hydromulch (Landis and others 1984), and a 30-percent shade polypropylene cloth stretched 20 cm (8 in) above the soil surface. The sowing-date plots were 40 ft long, the source plots, 20 ft, and the treatment plots, 5 ft (1 ft = 30.5 cm). The three replications extended 600 ft, sampling the full width of the nursery block or soil management unit.

Water was applied by impact sprinklers, as needed to keep the soil surface moist during emergence and twice a week to irrigate the soil profile as seedlings grew and summer progressed. Seedlings of each sowing were fertilized with nitrogen within 2 months of emergence (100 lb N/acre). The soil surface was scarified between seedling rows and top-dressed with granular ammonium phosphate sulfate (NPS 16-20-13, 625 lb

material/acre). Time of application varied with the sowing date, which largely determined time of emergence.

Initial emergence was recorded for each sowing. Seedling height was measured in July, August, September, and October, and stem diameter, in October. A standard nursery inventory frame (0.5 by 4 ft or 15 x 122 cm long) was set across the bed in each of two randomly located positions per plot. Seedlings within the frame were counted and measured separately for rows 1 to 4 and 5 to 8.

Effects of seed source, sowing date, and erosion control on seedling growth and stocking were assessed by analysis of variance BMD P8V (Jennrich and Sampson 1981). The data were analyzed as a split-split plot design with seed sources, sowing dates, and erosion control considered fixed and the blocks, random.

For each source, coefficients of determination were calculated to assess the relations of seedling height and stem volume to sowing date and time of emergence (Ryan and others 1981). The frequency distributions of stem diameter were determined for each sowing, using BMD P5D (Chasen 1981).

RESULTS

Seed sources from both coastal and inland regions required prolonged chilling and early sowing to produce 1-0 seedlings efficiently.

Seed Chilling and Germination

In the 1979 study, germination was significantly affected by seed source and chilling period (0, 20, 40, or 60 days) and their interaction after 7, 14, and 21 days at room temperature (table 2).

Both the speed and amount of germination were greatest with 60 days of chilling for three of the four sources tested (fig. 1, table 3). The 20-day chill sacrificed speed in every source and enabled complete germination of only the North Coast, or King Range, source. After 7 days, germination was highest with the 60-day chill for sources from the Oregon Coast Range (AL), Cascade Range (MK), and Klamath Mountains (OK), and with the 40- and 60-day chills for the King Range (KR). After 21 days, germination was highest with the 60-day chill for source MK, nearly as high with the 40- as the 60-day chill for sources AL and OK, and about equally high with the 20-, 40-, and 60-day chills for source KR.

Seedling Emergence in March and May Sowings

Emergence was significantly affected by the seed source and chilling period (30 versus 90

Table 2. Significance of effects of seed source and chilling period on the cumulative germination of Douglas-fir seeds ¹

Source of variation	Degrees freedom	Variance (mean square) for germination (percent), by day		
		7	14	21
Seed source, S	3	1453.9**	491.2**	380.1**
Chilling period, T	3	19444.1**	21978.9**	15367.6**
ST	9	529.8**	433.3**	469.4**
Error	48	37.8	28.9	29.8

¹ Seeds from coastal and inland regions in Oregon and California were chilled for 0, 20, 40, or 60 days.

** Statistically significant at the 1 percent level.

days) in both the March and May sowings, and by their interaction in the March sowing (table 4).

For the March sowing, emergence began on March 29, 15 days after sowing, and was essentially completed by May 7, 54 days after sowing (fig. 2, table 5). The 90-day chill resulted in faster and greater emergence than did the 30-day chill. At 28 days, emergence for the 90-day chill was greater by factors of 4.3, 2.0, 1.4, and 1.7 in sources AL, MK, KR, and OK, respectively. The 90-day chill, compared to the 30-day, increased total emergence by an absolute 46 percent in source AL, 16 percent in source MK, and 29 percent in source OK.

For the May sowing, emergence began on May 25, 10 days after sowing, and was finished by June 14, 30 days after sowing. The 90-day chill again resulted in faster emergence but did not increase total emergence. At 15 days, emergence for the 90-day chill exceeded that for the 30-day by factors of 4.2, 1.8, 1.6, and 1.4 in sources AL, MK, KR, and OK, respectively.

Seedling Growth in March and May Sowings

Sowing date significantly affected seedling height, stem diameter, top dry weight and root dry weight after pruning, but not top/root ratio (table 6). The seed source significantly affected seedling height, stem diameter, top weight and top/root ratio, but not root weight. The chilling

period significantly affected seedling height, but no other size trait.

Seedling height and top dry weight decreased with increase in source latitude and distance inland from the Pacific Coast (table 7). The coastal sources, AL and KR, were taller than their inland counterparts, MK and OK, and the California

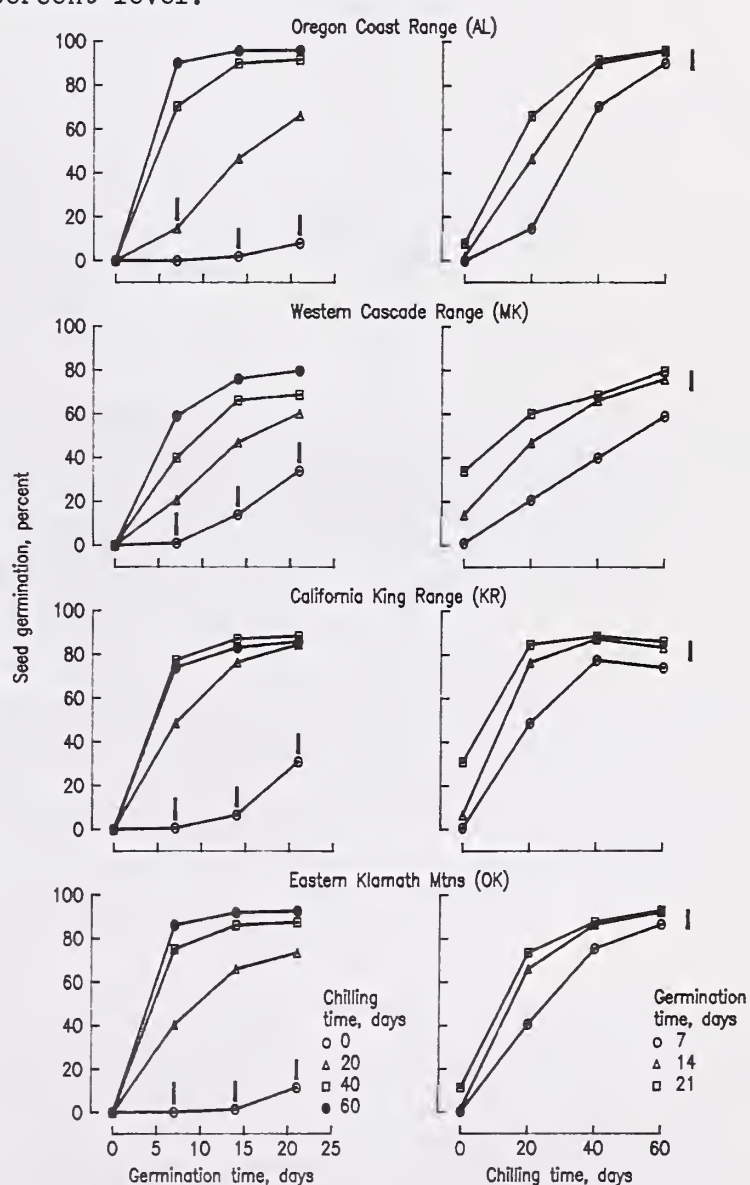


Figure 1. Seed source and chilling period significantly affected germination of Douglas-fir seed. Curves are for chilling periods of 0, 20, 40, and 60 days at 1°C (left panel) and germination periods of 7, 14, and 21 days at 22°C (right panel). Bars indicate least significant difference at the 5 percent level.

Table 3. Effects of seed source and chilling period on the cumulative germination of Douglas-fir seeds

Seed source and germination time (days)	Germination (percent), by chilling period (days) ¹				LSD ²
	0	20	40	60	
Oregon Coast					
Range (AL)					
7	0.0	14.7	70.5	90.2	8.8
14	2.0	46.7	90.0	95.7	7.7
21	8.0	66.2	91.7	96.0	7.8
Cascade Range, western (MK)					
7	1.0	20.7	40.0	59.0	8.8
14	14.0	47.0	66.2	76.0	7.7
21	34.0	60.2	68.7	79.7	7.8
North Coast Range (KR)					
7	0.7	48.7	77.5	74.0	8.8
14	6.7	76.5	87.2	83.2	7.7
21	31.0	84.7	88.5	86.0	7.8
Klamath Mtns, eastern (OK)					
7	0.2	40.5	75.2	86.2	8.8
14	1.5	66.0	86.2	92.0	7.7
21	11.5	73.5	87.5	92.7	7.8

¹ Values are the means of four replications of 100 seeds each.

² Least significant difference at the 5 percent level.

Table 4. Significance of effects of seed source and chilling period on seedling emergence in March and May sowings of Douglas-fir in Humboldt Nursery (1979) ¹

Source of variation	Error term	Degrees freedom	Variance (mean square) for emergence (percent)					
			March sowing, by day			May sowing, by day		
			28	37	44	15	21	28
Seed source, S	SB	3	250.8**	142.5	102.3	1391.6**	1867.8**	1729.3**
Chilling period, T	TB	1	1452.0**	1404.2*	1113.0*	1322.5**	1081.6**	483.0*
Block, B	2	4	68.6	28.9	34.6	101.1	297.5	182.9
ST	STB	3	58.1	156.2*	158.3*	118.5	126.5	230.6
SB	STB	12	39.3	82.5	76.3	41.5	107.6	104.9
TB	STB	4	54.7	124.9*	138.2*	29.6	9.0	39.2
STB		12	29.1	37.8	40.8	55.6	120.3	210.1

¹ Seeds from coastal and inland regions in Oregon and California were chilled for 30 or 90 days.

² SB + TB - STB for March dates; STB for May dates. F-Tests with the Satterthwaite approximation using only the variance components with positive method of moments estimates.

*, ** Statistically significant at the 5, 1 percent levels.

sources, KR and OK, were taller than their Oregon counterparts, AL and MK.

Seedlings from the March sowing were taller and stouter and had greater top and root dry weights than seedlings from the May sowing (fig. 3). Seedlings of sources AL, MK, KR, and OK were respectively 21, 27, 24, and 35 percent taller and had 26, 31, 31, and 44 percent greater stem diameter. They had 63, 68, 92, and 106 percent greater top weight, and 24, 45, 82, and 61 percent more root weight. Increases in top/root ratio were not significant.

Nursery Sowing Windows

In the 1985 study, several problems related to sowing time and seedling emergence required solution. The January sowing was necessarily dropped from the analyses because a flock of juncos partially harvested the plots soon after emergence began. Depredation of the February and later sowings was forestalled by spraying the newly sown plots with a bird repellent containing the fungicide thiram.

The nursery soil was crusted by February and needed scarification to shatter the crust and enable a uniform sowing depth and density. Thus the February, March, April, and May sowings were done after first raking the plots with steel tines.

The woven paper mat treatment was discontinued after it badly entangled emerging seedlings in the February sowing. In every sowing, the shade cloth in the shade cloth treatment was permanently removed after emergence was well underway, to permit drying of the soil surface to inhibit damping-off disease.

Seedling height, stem diameter, and stocking in October were significantly affected by sowing date and replication (table 8). In addition, seedling stocking was significantly affected by seed source and erosion control. All traits were significantly affected by various interactions. Results of the analyses of seedling height and stocking in July, August, and September (not presented) were mostly like those in October, at the close of the growing season.

Seedling Growth.--Throughout the growing season, seedlings of both the coastal and inland seed sources were consistently taller with earlier sowing (table 9). At the end of the growing season, stem height and diameter for the coastal seedlings were 106 and 82 percent greater in the February than in the May sowing, and for the inland seedlings, 115 and 95 percent greater.

In July, the inland seedlings were taller than the coastal seedlings and they remained so through August for all sowing dates. In September, inland seedlings were still slightly taller in the March, April, and May sowings, but coastal seedlings were

Table 5. Effects of seed source and chilling period on seedling emergence in March and May sowings of Douglas-fir in Humboldt Nursery (1979) ¹

Seed source and chilling period (days)	Emergence (percent)															
	March sowing, by day							May sowing, by day								
	21	23	26	28	30	37	44	54	11	15	17	21	23	25	28	30
Oregon Coast Range (AL)																
30	1.9	2.8	6.9	13.0	24.1	37.5	49.1	53.7	0.0	6.3	16.8	70.2	82.1	89.5	98.6	100.0
90	4.6	14.8	33.3	56.5	69.0	88.4	95.8	100.0	0.0	26.4	46.8	85.6	90.8	93.3	97.9	100.0
Cascade Range, western (MK)																
30	6.4	9.6	28.8	30.4	43.3	64.1	76.3	84.0	0.0	8.7	25.5	66.4	80.5	88.6	96.0	100.0
90	12.2	21.8	38.5	59.6	75.0	91.7	97.4	100.0	0.0	16.1	35.5	73.7	79.6	88.2	98.4	100.0
North Coast Range (KR)																
30	13.0	21.2	43.5	56.5	67.4	89.7	97.8	100.0	0.7	31.7	53.0	82.2	90.7	92.2	98.6	100.0
90	20.0	33.7	60.0	77.7	83.4	97.7	99.4	100.0	3.0	51.1	70.2	89.8	93.8	96.0	98.4	100.0
Klamath Mtns, eastern (OK)																
30	13.6	23.8	30.2	42.6	49.0	60.9	66.3	70.8	0.8	41.5	63.1	86.4	91.9	95.8	98.3	100.0
90	28.2	44.6	62.4	72.8	82.2	94.1	99.5	100.0	9.5	57.3	69.7	91.2	93.8	96.7	98.5	100.0

¹ Values are expressed as percent of maximum for the seed source.

taller in the February sowing. In October, coastal seedlings were taller and stouter than inland seedlings, regardless of the sowing date (table 9).

For seedlings of both sources, the seasonal pattern of height growth varied with sowing date (fig. 4). Through September, growth rates were higher in the February than in the May sowing. From September to October, growth rates decreased in the February sowing and increased in the May sowing. Intermediate patterns were found in the intervening March and April sowings.

Seedling Stocking.--Seedling stocking decreased with earlier sowing and the rate of reduction was greater for the coastal than for the inland seed source (fig. 5, table 9). Averaged over all sample dates, stocking for coastal seedlings in the February, March, and April sowings was 63, 71, and 87 percent of that in the May sowing, and for inland seedlings, 83, 89, and 92 percent. These differential trends in stocking explain the highly significant interaction of seed source and sowing date (table 8).

Erosion Control.--Use of hydromulch and shade cloth improved stocking for seedlings of the coastal but not inland seed source (table 10). Stocking for coastal seedlings in the hydromulch and shade cloth plots respectively was 24 and 41 percent greater than in the check plots, and for inland seedlings, zero and 5 percent. The interaction of seed source and erosion control was significant in the inventories for July and August, but not September and October.

Humboldt Nursery received an average number of heavy rainstorms in the January-March period of 1985 (fig. 6). Each of four storms delivered 2 inches (5.1 cm) or more within 48 hours. The January sowing got all of these rains and the February and March sowings, two of them. The seed beds were saturated each time, but there was no visible evidence of soil erosion nor of any washing of seed or germinants, even in the check plots.

DISCUSSION

Whatever the seed source, the size of 1-0 seedlings in Humboldt Nursery largely depends on how early the seed is sown. Sowing early captures valuable weeks and months at the front end of the growing season, even though the prevailing cool soil conditions slow germination and prolong emergence. In 1979 at Humboldt, the usual cool soil of early spring stretched emergence of the March sowing to the first of May, and the typically warm soil of late spring enabled complete emergence of the May sowing by the middle of June. But by the time emergence was complete in the May sowing, most seedlings in the March sowing had been elongating roots and expanding shoots for more than 6 weeks.

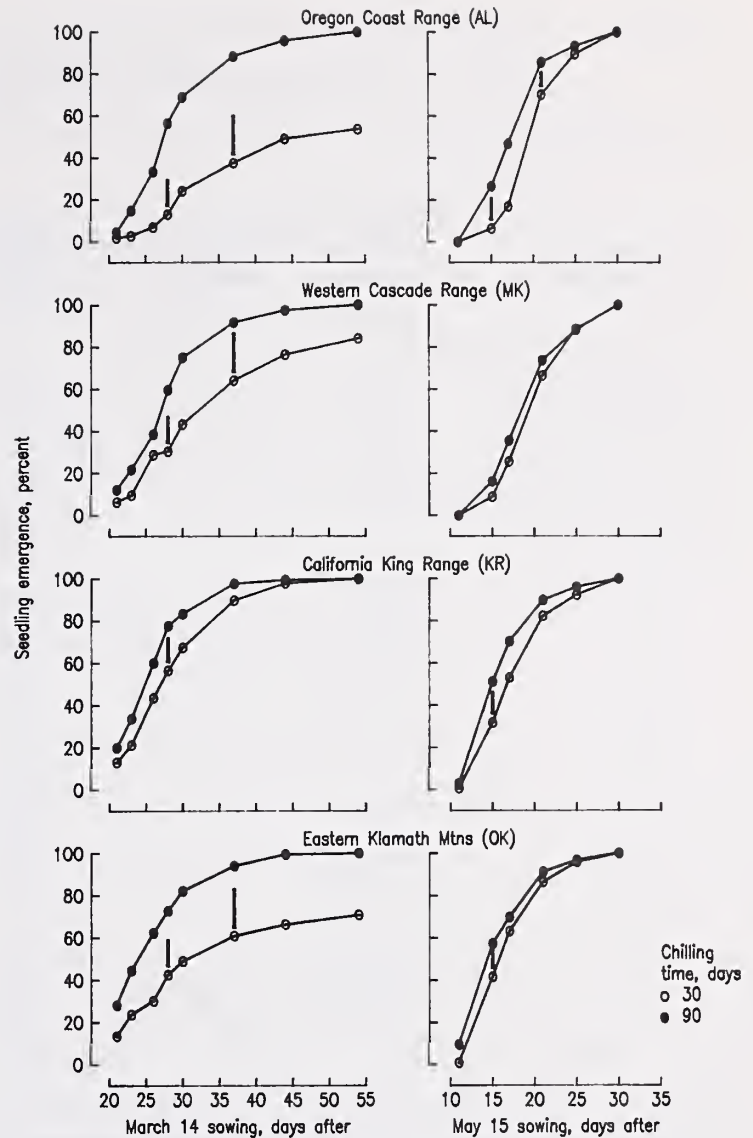


Figure 2. Seed source, chilling period, and sowing date markedly affected emergence of Douglas-fir in Humboldt Nursery. Curves are for chilling periods of 30 and 90 days for sowings on March 14 (left panel) and May 15 (right panel). Bars indicate least significant difference at the 5 percent level.

Similar patterns of emergence and growth held at Humboldt in 1985. Emergence of the January sowing started in the middle of February and emergence of the February sowing was just underway when the March sowing was installed. Germinants in the March, April, and May sowings began to emerge within 18, 9, and 6 days of seeding, respectively. By early April, all seedlings in the January sowing were expanding shoots, and all seedlings in the February sowing had shed their seedcoats. The winter sowings were clearly up and growing more than 3 weeks before emergence began in the April sowing and 6 weeks before it began in the May sowing.

Emergence and Growth in Cool Conditions

Full benefit of early sowing can only be achieved by a seed treatment that effectively substitutes for overwinter chilling in the wild. To insure maximum rates and amounts of emergence in the cool soils that prevail in winter and early

Table 6. Significance of effects of seed source, chilling period, and sowing date on the growth of 1-0 Douglas-fir in Humboldt Nursery (1979) ¹

Source of variation	Error term	Degrees freedom	Variance (mean square) for...				
			Seedling height (cm)	Stem diam (mm)	Top weight (g)	Root weight (g)	Top/root ratio
Sowing date, D	DB	1	235.709**	12.8480**	13.0411**	3.2321**	0.4961
Seed source, S	SB	3	104.367**	2.9942*	1.7454**	.0401	1.9338**
Chilling period, T	TB	1	8.179*	.0130	.1280	.0054	.0858
Block, B	2	4	3.232	.0615	.1104	.0352	.2488
DS	DSB	3	2.412	.1224	.3370	.1141	.0801
DT	DTB	1	2.513	.0106	.0442	.0353	.1514
ST	STB	3	1.704	.1178	.1639	.0369	.0307
DB	3	4	.652	.2568	.1375	.0252	.1197
SB	4	12	4.025	.5519	.1177	.0611	.1089
TB	5	4	.816	.0782	.0244	.0308	.0389
DST	DSTB	3	1.438	.0971	.0580	.0389	.0126
DSB	DSTB	12	5.126	.1609	.1440	.0463	.0688
DTB	DSTB	4	1.177	.1809	.0220	.0626	.0827
STB	DSTB	12	2.505	.0757	.0733	.0163	.0607
DSTB		12	1.368	.0852	.0976	.0458	.0243

¹ Seeds from coastal and inland regions in Oregon and California were chilled for 30 or 90 days and sown in March and May.

² DB + SB + TB - DSB - DTB - STB + DSTB (See table 6A for denominators)

³ DSB + DTB - DSTB. ⁴ DSB + STB - DSTB. ⁵ DTB + STB - DSTB.

*, ** Statistically significant at the 5, 1 percent levels.

Table 6A. Denominators for F-Tests for Table 6.¹

Source of variation	Seedling height	Stem diam	Top weight	Root weight	Top/root ratio
B	DSB+STB-DSTB	DB+SB-DSB	DSB	SB+DTB-DSTB	SB+DTB-DSTB
DB	DSB	DTB+DSB-DSTB	DSB	DTB+DSB-DSTB	DTB+DSB-DSTB
SB	DSB+STB-DSTB	DSB	DSB	DSB	DSB+Stb-DSTB
TB	STB	DTB	DSTB	DTB	DTB+STB-DSTB

¹F-tests with the Satterthwaite approximation using only the variance components with positive method of moments estimated

Table 7. Effects of seed source and sowing date on the growth of 1-0 Douglas-fir in Humboldt Nursery (1979)

Seed source and sowing date ¹	Seedling height (cm)	Stem diam (mm)	Top weight (g)	Root weight (g)	Top/root ratio
Oregon Coast Range (AL)					
March 14	16.0	2.82	1.58	1.14	1.44
May 15	13.2	2.24	0.97	0.92	1.13
Cascade Range, western (MK)					
March 14	13.6	3.36	1.48	1.19	1.27
May 15	10.7	2.57	0.88	0.82	1.16
North Coast Range (KR)					
March 14	19.5	3.80	2.40	1.29	1.91
May 15	15.7	2.89	1.25	0.71	1.90
Klamath Mtns, eastern (OK)					
March 14	16.2	3.02	1.69	1.14	1.51
May 15	12.0	2.09	0.82	0.71	1.31

¹ Within source, values of all traits except top/root ratio were significantly greater for the March sowing. See table 6.

spring, stored seeds must be properly soaked and then chilled for at least 60 and preferably 90 days before sowing. Sources like those from the Oregon Coast Range, Cascade Range, and Klamath Mountains (AL, MK, OK), which typify much of the Pacific slope forests of Douglas-fir in Oregon and California, will require 60 to 90 days of chilling for most rapid and complete germination and emergence (fig. 1, 2). Although certain sources like that of California's north coast King Range (KR) may germinate completely with a 20-day chill and show maximum emergence with a 30-day chill, they will germinate and emerge most rapidly with prolonged chilling.

Early growth in cool conditions may be just as essential for the health of 1-0 Douglas-fir as it is for 1-0 sugar pine (Jenkinson and others 1982). For coastal and inland seed sources, seedlings in our February, March, and April sowings mostly escaped disease, had abundant mycorrhizae and associated mycelium (*Laccaria laccata* and *Thelephora terrestris* are common in Humboldt Nursery), and grew uniformly. By contrast, seedlings in our May sowings had incipient problems with *Fusarium* or other damping-off fungi (Kliejunas and Allison 1982) and exhibited stunting in the classic mosaic pattern

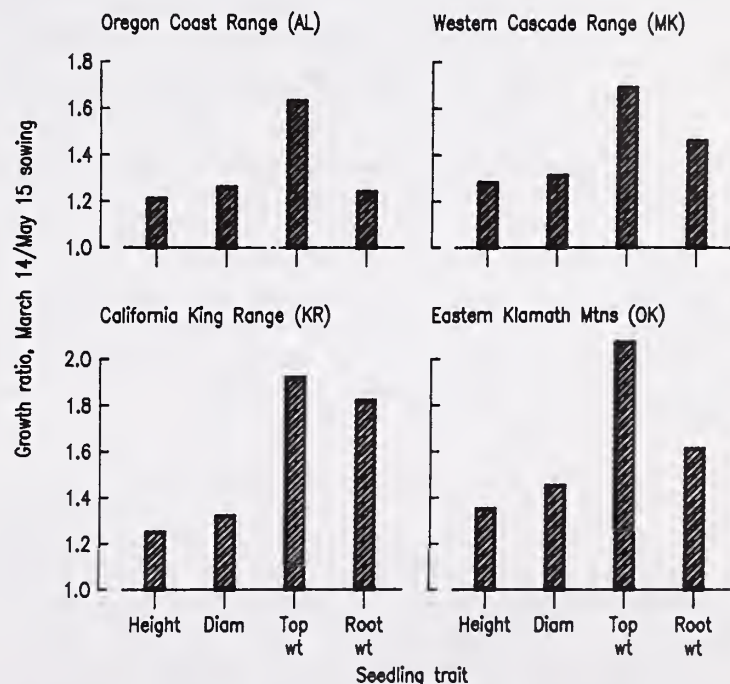


Figure 3. Sowing in early spring compared to late spring resulted in substantial gains in the size and dry weight of 1-0 Douglas-fir in Humboldt Nursery.

Table 8. Significance of effects of seed source, sowing date, and soil erosion control on the growth and stocking of 1-0 Douglas-fir in Humboldt Nursery (1985) ¹

Source of variation	Error term	Degrees freedom	Variance (mean square) for		
			Seedling height (cm)	Stem diam (mm)	Seedlings per ft ²
Sowing date, D	DB	3	1511.28**	32.670**	741.1**
Seed source, S	SB	1	349.80	2.000	803.3*
Erosion control, T	TB	2	1.58	.241	759.8*
Block, B	P	2	262.50**	7.094**	176.3*
DS	DSB	3	5.28	.058	185.1**
DT	DTB	6	26.91**	.097	199.9
ST	STB	2	31.72	.029	149.0
DB	P	6	9.27*	.152	72.9
SB	P	2	37.74**	1.214**	12.9
TB	P	4	34.87**	.731**	62.5
DST	DSTB	6	13.17*	.862*	179.8
DSB	P	6	18.77**	.207	15.7
DTB	P	12	5.26	.230	142.0**
STB	P	4	10.78*	.233	132.6*
DSTB	P	12	4.14	.201	159.8**
P(DSTB)		216	4.15	.162	48.1

¹ Seeds from coastal and inland regions in northern California were chilled for 90 days and sown in February, March, April, and May.

*, ** Statistically significant at the 5, 1 percent levels.

that is symptomatic of poor or spotty mycorrhizal development (Molina and Trappe 1984).

Early sowing obviously has specific advantages. In fact, the disease and stunting problems that have plagued past seedling crops in the Humboldt Nursery might largely be avoided by simply shifting to a sowing schedule that captures the natural germination environment.

Growth Gains with Early Sowing

Any assessment of the amount of growth gained by sowing early is determined partly by the trait measured and partly by the seed source examined (fig. 3). Thus, gains of 20 to 35 percent in seedling height were accompanied by gains of 30 to 45 percent in stem diameter, 65 to 110 percent in top dry weight, and 25 to 85 percent in root dry weight after pruning. Growth gains for inland sources MK and OK were much alike while those for coastal sources AL and KR differed. Top weight showed the greatest gain in all sources, and root

weight kept pace in one coastal source (KR) but trailed notably in the other (AL).

Seed Source Lifting Windows

Early sowing may be essential if seed source lifting windows for 1-0 seedlings at Humboldt Nursery are to correspond approximately to those already determined for the standard 2-0 seedlings (Jenkinson 1984). Winter and early spring sowings (February, March) may capture enough of the potential growing season to allow 1-0 seedlings to approach dormancy in early autumn. The seasonal course of height growth in Humboldt Nursery suggests a sigmoid pattern in the winter sowings (February) and an exponential pattern in the late spring sowings (May). Exponential patterns seemed to characterize even the early and midspring sowings of the coastal GQ source, but not of the inland SA source (fig. 4). In early autumn, however, growth of both sources was slowing in the February sowing and accelerating in the May sowing. Such divergent rates suggest

Table 9. Effects of seed source and sowing date on the seasonal growth and stocking of 1-0 Douglas-fir in Humboldt Nursery (1985)

Seed source and sowing date	Seedling height (cm)				Stem diam (mm)	Seedlings per ft ²
	Jul 22	Aug 19	Sep 16	Oct 21		
North Coast Range (GQ)						
Feb 19	6.82	11.12	17.48	22.47	3.49	18.6
Mar 21	4.85	8.39	12.70	18.20	2.94	21.7
Apr 23	4.32	7.13	11.32	16.49	2.65	25.9
May 17	2.88	4.62	6.24	10.92	1.92	29.3
Klamath Mtns, central (SA)						
Feb 19	7.72	12.68	16.92	19.50	3.40	24.6
Mar 21	5.08	8.88	13.00	16.42	2.77	27.8
Apr 23	4.41	7.36	11.35	14.28	2.42	27.2
May 17	3.37	4.83	6.41	9.07	1.74	29.2

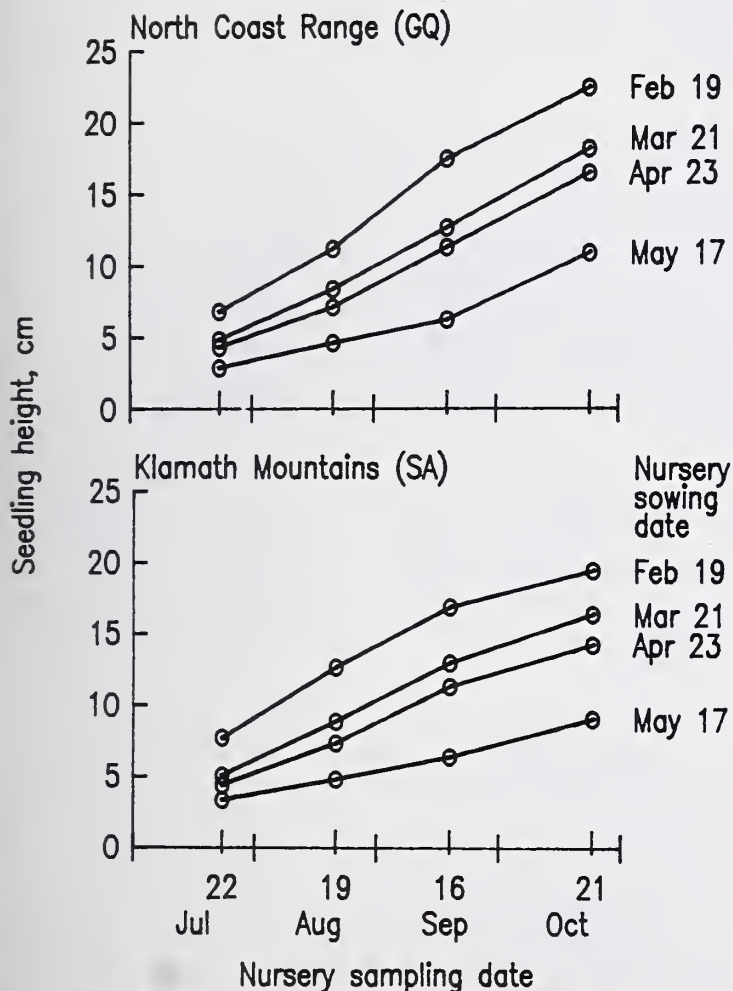


Figure 4. Sowing in winter compared to late in spring resulted in sigmoid rather than exponential patterns in the seasonal height growth of 1-0 Douglas-fir in Humboldt Nursery.

physiological states that respectively enhance and delay the autumn development of seedling dormancy, cold hardiness, and readiness for cold storage.

Winter sowing probably is essential if every source lifting window is to open at the same time for 1-0 as for 2-0 seedlings. Field survivals of 1-0 seedlings from April sowings have shown lifting windows that open later than those of 2-0 seedlings for nearby seed zones (Turpin and others 1985). And survivals of 1-0 seedlings from March sowings have shown windows that open as soon as, shortly after, or later than those of 2-0 seedlings planted in the same or nearby zones (Jenkinson 1984). Winter sowings are thus indicated if 1-0 seedlings are to achieve the physiological conditioning that is necessary to allow lifting and cold storage on the first safe date for 2-0 seedlings.

Seedling Size

Besides their physiological condition and storability, the size of 1-0 seedlings is a vital concern. No nursery wants to lift, and no forester wants to plant, thin-stemmed or whippy seedlings. Field experience suggests that 1-0 planting stock should be culled to a stem diameter of about 2.5 mm. In our March sowings, most seedlings of every seed source exceeded that standard. In 1979, stem diameters for sources AL, MK, KR, and OK averaged 2.8, 3.3, 3.8, and 3.0 mm, respectively, compared to 2.2, 2.6, 2.9, and 2.1 mm for the May sowing (table 7). In 1985, stem diameters for sources GQ and SA averaged 2.9 and

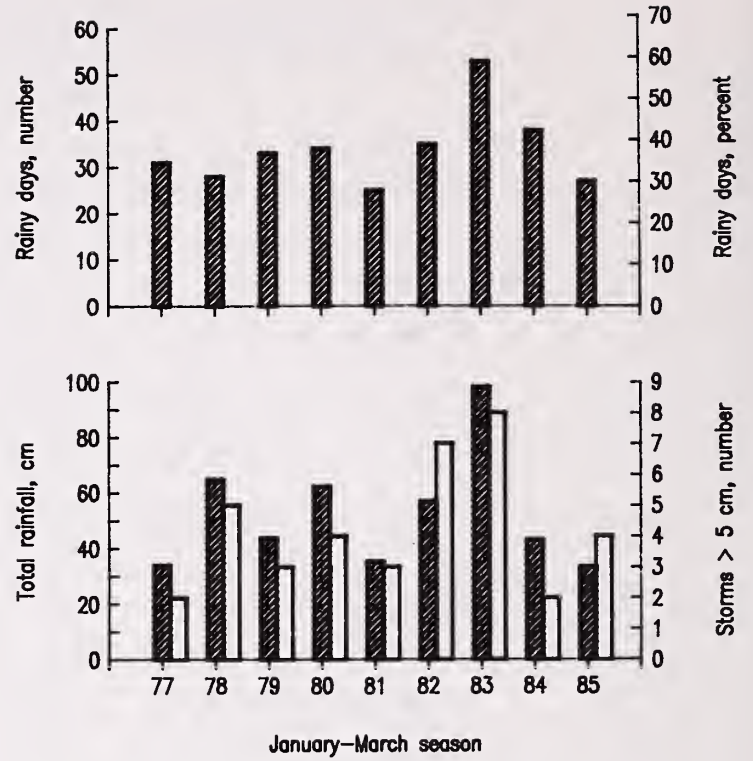
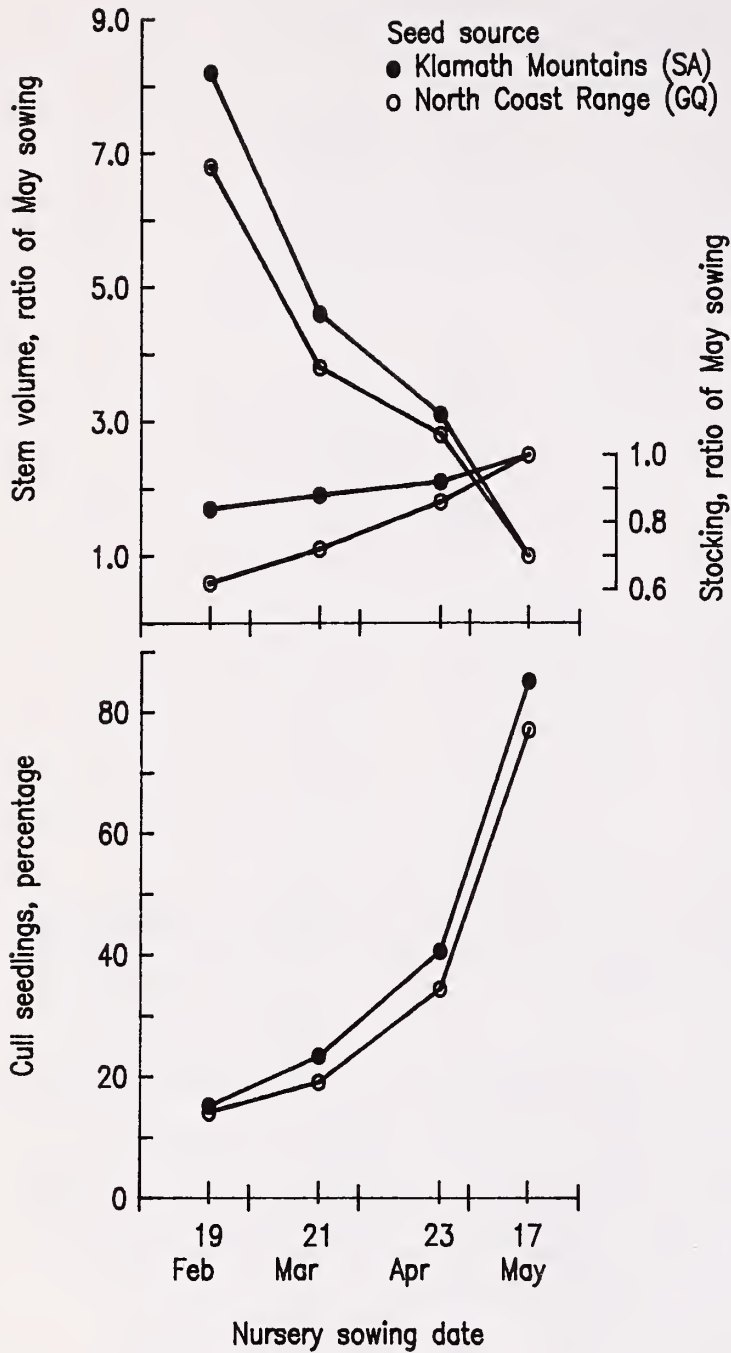


Figure 6. Weather patterns in January through March at Humboldt Nursery usually bring two to five heavy rainstorms and 50 to 65 clear days. The wettest period on record (1983) had eight heavy storms and 36 clear days.

Figure 5. Sowing in winter compared to late in spring lowered seedling stocking by 18 or 34 percent, depending on seed source, but increased stem volumes seven- to eightfold and reduced cull percentages more than fivefold for 1-0 Douglas-fir in Humboldt Nursery.

Table 10. Effects of seed source and soil erosion control on the stocking of 1-0 Douglas-fir in Humboldt Nursery (1985)

Seed source	Seedlings per ft ² , by erosion control method ¹			Mean ²
	None	Hydromulch	Shade cloth	
North Coast Range (GQ)	19.4	24.1	27.4	23.6 b
Klamath Mtns, central (SA)	27.5	27.6	29.0	28.0 a
Mean ²	23.4 b	25.8 ab	28.2 a	

¹ Values are grand means of inventories in July, August, September, and October.

² Means followed by different letters differ significantly at the 5 percent level.

2.8 mm, compared to 1.9 and 1.7 in the May sowing (table 9). Even modest increases in stem thickness mean substantial gains in the total dry matter of root-pruned seedlings, for example, 44, 57, 88, and 85 percent respectively in sources AL, MK, KR, and OK.

Early spring sowings (March) in Humboldt Nursery can produce large 1-0 seedlings that have wide seed source lifting windows and high potentials for plantation establishment (Jenkinson and Nelson 1983). Our 1985 test suggests that winter sowings may prove to be even better, however, because seedlings of both coastal and inland sources were about 75 percent larger in the February than in the March sowing (fig. 5).

Nursery Sowing Windows

With an improved capability for winter sowing, Humboldt Nursery might safely sow in January to produce 1-0 planting stock. The potential sowing window may span up to 3 months, from midwinter to midspring. The number of seedlings produced per hundred viable seeds will determine when the window opens, and the size of the seedlings produced will determine when the window closes. The last safe sowing date will usually fall in early April, assuming that 75 percent of the seedlings must have a minimum stem diameter of 2.5 mm (fig. 5).

The first safe sowing date will depend on the effects of early sowing and soil erosion control on seedling stocking. Sowing in February reduced the stocking of inland seedlings by one-sixth, and of coastal seedlings, by one-third, compared to sowing in May (fig. 5). Erosion control substantially improved stocking for the coastal source but not the inland source, with shade cloth increasing stocking by 41 percent in source GQ but by only 5 percent in source SA (table 10). Thus, any choice of a first safe date may have to balance the tradeoffs of lower stocking and larger seedlings that accompany earlier sowing. The date chosen should be one for which the possible reduction in stocking is slightly less than an accepted cull percentage, assuming that most seedlings in the earliest sowing will be large enough to outplant.

The greater effects of early sowing and erosion control on the stocking of coastal seedlings may be explained by the significantly smaller seeds of coastal sources. Air dry seeds were 23 percent smaller for the North Coast Range than for the central Klamath Mountains source (12.2 mg/seed, or 37,100 seeds/lb against 15.0 mg/seed, or 30,200 seeds/lb). Sowing depth is critical for the successful germination and emergence of Douglas-fir (Minore 1985), and the precise sowing and uniform maintenance of smaller seeds at 3 mm below the surface may be more difficult and less likely under winter conditions.

The smaller size of the coastal seeds may also explain why the coastal seedlings were

consistently smaller than inland seedlings during the summer (table 9). By late autumn, however, coastal seedlings were larger than inland seedlings, reflecting their adaptation to length of growing season at seed origin.

CONCLUSION

Early spring and winter sowings of Douglas-fir over two separate years at the Humboldt Nursery have consistently resulted in plantable 1-0 seedlings for diverse seed sources in coastal and inland regions of western Oregon and northern California. We conclude that Humboldt Nursery can readily produce 1-0 Douglas-fir planting stock for most forest sites on the Pacific slope. To produce 1-0 stock efficiently, we recommend three practices:

- o Chill seeds at least 60 to 90 days to insure rapid and complete emergence in cool soil conditions.
- o Sow in winter and early spring to utilize all or most of the potential growing season.
- o Protect newly sown beds with hydromulch or shade cloth to control soil erosion and limit seed losses.

Studies are being repeated to determine the stability of nursery sowing windows for 1-0 stock and to firmly establish procedures that can preclude soil and seed losses. With the proper sowing schedule, seed source lifting windows can be as wide for 1-0 as for the highest quality 2-0 stock. Continued aggressive field evaluation of 1-0 stock is warranted because of its potential payoff in high survival and growth for less than the costs of 2-0 stock.

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Weed Control: Alternatives to Herbicides¹

Edward Olson²

Abstract. In 1984 Federal use of herbicides was banned in Oregon and Washington. The purpose of this presentation is to outline the impact and response to the loss of herbicide useage at one USDA nursery, and to provide a brief look at the arsenal of tools and equipment used to keep unwanted vegetation at bay.

INTRODUCTION & BACKGROUND OF THE HERBICIDE BAN

On March 1, 1984, U.S. District Court Judge James Burns issued an injunction to the Forest Service in Washington and to both the Bureau of Land Management and the Forest Service in Oregon, enjoining them from applying herbicides in any of their vegetation management programs including nurseries, re-search projects, noxious weeds and individual tree treatments until the agencies could develop adequate NEPA documents, including worst case analysis.

Federal nurseries in the region were directed to defer the use of all herbicides by the end of March 84. Due to the wording of our pesticide use proposal which identified the herbicidal properties of soil fumigation as a positive tool in the control of unwanted vegetation, it was felt that the court could have interpreted the use of Methyl Bromide to be an application of an herbicide. Therefore, the decision was made by the nursery superintendent to discontinue the use of fumigation at Wind River Nursery.

At Wind River two consecutive bareroot crops totaling roughly 32 million seedlings were sown on unfumigated ground. In 1985 a resubmission of our use proposal identifying the fumigation targets of most significance as soil borne diseases, insects and other pests resulted in the approval to resume the use of soil fumigation. In 1985 we were able to fumigate approximately 1 acre of bedhouse area, and in the spring of 1986 we fumigated roughly 40 acres for spring bareroot sowing. We are still unable to apply any herbicides

at Wind River.

At this time the herbicide ban on Federal lands in Oregon and Washington is still in effect. A herbicide Risk Assessment has been prepared by the Washington Office and it will be used in the preparation of several Environmental Impact Statements. As we understand the situation, Federal Nurseries and possibly the noxious weed programs are to be covered under separate EIS's that are being prepared by the Washington Office. At this time it appears that there will be a formal legal request for relief made in the fall of 1987. Much work remains to be done and it could be several years before we know the outcome of the litigation.

THE PREVIOUS STANDARD HERBICIDE PROGRAM AT WIND RIVER NURSERY

Prior to the injunction, herbicide useage at Wind River had been kept to moderate levels. Our annual program on the 1-0 crop consisted of one application of Stoddard's Solvent just prior to seedling germination (@25 gallon/acre), followed by one or two summertime applications of Dymid or Dacthal (@ 8 lbs/acre and 12 lbs/acre respectively). The 2-0 crop received only one shot of Dacthal or Dymid in the spring. Roundup had been used along the fences and in areas where the use of equipment was difficult. Fumigation had been done on areas for bareroot sowing, having a positive impact on subsequent weed populations. All other weed control was done either by manual or mechanical methods except that in 1981 we began using Chinese Weeder Geese. The philosophy of the weeding program at the time was to keep the seedling beds as clean as possible in order to eliminate competition for light, moisture and nutrients, and to keep weed seed contamination from adjacent areas to a minimum.

¹ Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1985.

² Forester, [Wind River Nursery, Carson, Washington.]

THE POST INJUNCTION WEED CONTROL PROGRAM

The herbicide injunction arrived at a time when Federal nurseries were experiencing personnel and budget limitations. We could see that we needed new tricks to keep from being inundated with weeds. One of our first attempts in 1984 was to enter into personal services contracts with individuals willing to submit an hourly wage bid for their own personal labor. We simply took the lowest bidders until we had a crew of sufficient size. This worked well except that we received pressure from the National Federation of Federal Employees and the Washington Office of the Forest Service to discontinue the use of this type of labor force after only one year.

In 1985 and again this year we have had a program in cooperation with the Washington State Parks and Recreation Commission called the Youth Development and Conservation Corps. This program employs youths 14 thru 21 years of age at below minimum wage levels. In addition to their salary the enrollees receive work experience and conservation education. This program has been very successful so far, but, even with 40 enrollees we are unable to maintain the nursery fields as inexpensively and as cleanly as they had been prior to the ban. Nowadays, we must often be satisfied to weed only those weeds that are starting to bloom or are developing seed and move on to other priority areas.

Over the years we have developed or purchased a wide variety of hand tools. Some of the more common ones are shown in these slides. A variety of mechanical equipment including the Turner Rear Mounted Flail Mower, the Fobro Brush Hoe, the Rotary Cultivator, the Roter, Rototillers, various Weed Eaters, Troy Built tillers, the Bush Hog and even a Flame Thrower have been used for weed control.

We have had limited success with Biological Control. Of the various agents tried, we have had the most success with the weeder geese which was a presentation given at a previous meeting. Also, the county has released Cynabar larva in the general area in an attempt to combat the tansy ragwort. These larva also feed on groundsel, one of our biggest problem species. Although there are now large populations of Cynabar at Wind River, their impact on the groundsel has been minimal. Finally, manipulation of irrigation water is sometimes used during periods of peak seed dispersal to reduce their germination. We would be interested in hearing

from anyone who has experimented with other forms of biological control.

COSTS

The injunction in early 1984 caught us by surprise. Our cost data from the years when there were few restrictions on herbicides was not detailed enough for a highly accurate breakdown of the weed control aspect of our program. However, we began keeping track of the situation on a more detailed basis early that spring and were able to compare the total cost of the previous program with the cost of operating under the injunction. It was determined that the total additional cost to our nursery was roughly \$106,000 in 1984. Based on a production of around 20MM at that time, this raised our production costs by about \$5.30 per thousand. This figure included the cost to our clients of the additional seed required to offset the expected (and experienced) increase in cull %, but did not include the cost to them of replenishing their seed inventory. Also, the competition for light, nutrients, water and space may have resulted in some less vigorous seedlings being shipped. In theory, if only 5% of the total production (or @ 1MM seedlings) failed to survive after outplanting as a result of the injunction, the additional cost of replanting could be as high as \$700,000, based on a planting cost of \$350 per acre @ 500 trees per acre. The increased production costs combined with the additional reforestation costs could result in a total additional cost of up to \$20 per acre to our clients.

IN SUMMARY

We sincerely hope that the legal effort to gain relief from the current herbicide injunction will bring us back to a more realistic program of weed control by the spring of 1988. However, weed seed buildup in areas that we had had under control in the past will provide us with difficulties for years to come. In the meantime we are trying to stay ahead of the blooming weeds.

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Seedling Monitoring During the 1-0 Growing Season¹

David Steinfeld²

Abstract.--Describes a method for measuring seedling growth characteristics and environmental factors in a conifer tree nursery during the first growing season and how this data can be used for culturing seedlings.

INTRODUCTION

Knowing how well the seedlings at your nursery are performing at any given time is essential for good nursery management. The systematic 1-0 monitoring plan presented in this paper is one way of obtaining that information.

than 40 feet away. A report is made upon completion of the walkthrough that addresses such things as stunted or chlorotic seedlings, poor germinating lots, insect and disease damage and plugged sprinkler heads. If any observations show up in a pattern, they are plotted on a map of the nursery. These maps are later used to correct the problems before sowing another crop in the same area. Field reports are circulated to appropriate nursery personnel to keep them abreast of the current condition of the stock.

PROCEDURES

The procedure for monitoring 1-0 seedlings at J. Herbert Stone Nursery is designed to evaluate (1) seedling growth and environmental factors at individual plots (intensive monitoring) and (2) the overall condition of the stock across the entire field (extensive monitoring). The intensive and extensive monitoring are performed together at weekly intervals.

Intensive Monitoring

The purpose of intensive monitoring is to record site factors and seedling growth trends at individual plots throughout the growing area. The plots are installed before seedling emergence. They are randomly located on the course of travel for the extensive monitoring in such a manner that all field conditions are monitored. Presently, we are monitoring approximately one plot per acre.

Extensive Monitoring

The purpose of extensive monitoring is to observe the entire growing area for overall condition of the crop and to identify any problems. This is accomplished by planning a course of travel so that seedlings in the entire growing area are observed from no more

Data Collection

Mortality. A four by one half foot permanent sampling area is marked at each plot using plastic "popscicle stick" markers in each row of seedlings. Dead and alive seedlings within this area are counted weekly. After each count, dead seedlings are removed from the sampling area. Mortality is expressed as a percent of dead seedlings for the week of collection over the total seedling count for that sampling area at the end of the season (dead plus live count).

¹Paper presented at the Western Forest Nursery Council Meeting, Olympia, Washington, August 12-15, 1986.

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Lygus Damage. In the same sampling area, all seedlings with Lygus damage in the top inch of the terminal leader are counted. Lygus is expressed as percent damaged over total seedlings in the plot for that week.

Bud Set. All seedlings in the sampling area are observed for bud set. This is expressed as percent budset over total seedlings.

Seedling Height. Plastic rings are placed at the base of ten seedlings at each plot. Height is determined by measuring from the base of the tagged seedling to the growing tip of the terminal leader. Height can be expressed as either total mean height or mean incremental growth for that week.

Surface Soluble Salts. Salts rising to the surface due to capillary action is a problem at this nursery. We believe that the high salts have lead to mortality and stunting of several species of seedlings. Monitoring the surface salt levels helps us determine when to irrigate to bring the soluble salt levels down to acceptable levels for plant growth and survival.

Soil within 1/2 inches of the surface is collected from undisturbed areas outside of the sampling points. Electrical conductivity is measured at our facilities using a "quick test" for electric conductance (Wilde 1979).

Soil Moisture. At each plot, a permanent soil tensiometer is placed at 5 inches and read at least twice a week. Soil moisture as determined by the gravimetric method is collected occasionally at each plot.

Other Data Collected. Later in the summer, several of these plots are used as sampling areas for predawn plant moisture stress readings. Also, each of these plots are within 40 feet of a permanent soil nutrient sampling point. These soil sampling points are areas where soils are collected in the fall before sowing and sent to a lab for a complete soil nutrient analysis.

Use of Intensive Monitoring Data For Nursery Management

Plotting growth, site factors, and cultural manipulations over time will show annual growth

trends in relation to cultural and site factors. With several years of growth trend data, a manager can develop an idea of what to expect from the current 1-0 crop and what measures, if any, to take to produce the desired seedling for that year.

For example, the 1-0 crop in our 1985 field was several inches higher than desired. Using the 1985 data, we were able in 1986 to produce a shorter seedling by scheduling the last irrigation to be several weeks earlier than the last irrigation in 1985. This would not have been possible if we had not known the growth trends for the previous years irrigation schedule.

Understanding how site conditions affect seedling growth can lead to a better manipulation of the seedling environment to produce the desired seedling. Using two years of data, we have been able to characterize the moisture regimes for the optimum growth of several species. This has lead to a better irrigation schedule for all of our stock.

Evaluating site conditions and seedling growth can also clarify specific nursery problems. We have been able to determine when and to what extent Lygus is damaging certain species. This understanding has lead us to better control of this insect.

DISCUSSION

1-0 monitoring does not take the place of an inventory, nor should the data be used for calculating survival factors. The sample size is too small. There is some question as to whether we are collecting enough data to give us a clear picture of trends. We intend to pursue this question. Nevertheless, our initial intention of monitoring was to make sure that the entire field was observed weekly in a relatively unbiased fashion. We feel that this monitoring system meets this objective at the least expense.

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Growing Seedlings on a Production Scale in a Shadehouse¹

Thomas M. Smith²

Abstract.--In Albuquerque, New Mexico five (5) crops (approximately 400,000 seedlings) of ponderosa pine (*Pinus ponderosa*, Rocky Mountain form) were grown in single 30'X96' greenhouse from January 1985 to December 1985.

INTRODUCTION

On January 3 & 4, 1985 crop number one was sown using Acoma, New Mexico, and Zuni, New Mexico seed sources. Crop number one was moved to the shadehouse on May 3, 1985. Crop number two was sown on May 6 & 7, 1985 using a Zuni, New Mexico seed source, and moved to a shadehouse on June 7, 1985. Crop number three was also a Zuni, New Mexico source sown on June 10 & 11, 1985, and moved to a shadehouse on July 10, 1985. Crop number four was a Jicarilla, New Mexico seed source sown on July 15 & 16, 1985, and moved to the shadehouse on September 6, 1985. Crop number five, a Santa Clara, New Mexico seed source was sown on September 9 & 10, 1985 and moved to the shadehouse on December 23, 1985.

All seedlings were ponderosa pine (*Pinus ponderosa*, Rocky Mountain form). Spencer-LeMaire Tinus (21.5 cubic inches) Roottrainers were used. Each crop was approximately 80,000 seedlings. The Bureau of Indian Affairs (BIA) greenhouse located in Albuquerque, New Mexico was used.

DISCUSSION AND RESULTS

The Bureau of Indian Affairs greenhouse in Albuquerque, New Mexico is a 30'X96' doublepoly Nexus style greenhouse. The growth fertilizer was Peters 20-20-20, and Peters 9-45-15 was used after flushing and stressing, Peters STEM was added to every fertilizer application for trace

¹Paper presented at Western Forest Nursery Council Meeting [Tumwater, Washington August 11-15, 1986.]

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elements. None of the seed was stratified.

Crop number one was sown on January 3 & 4, 1985 and grown using the usual procedure for the BIA facility in Albuquerque, New Mexico. Table 1 details the procedure.

TABLE 1, Normal Water & Fertilizer Program

Wk	Stage of Crop	Boom Passes	Time	Fertilizer (20-20-20+STEM)
1	Germination	2	Daily am & pm	None
2	Germination	2	Daily am & pm	None
3	Juvenile	5	M-W-F am	M-W ½ lb #3 Pass
4	Juvenile	5	M-W-F am	M-W 1 lb #3 Pass
5	Juvenile	5	M-W-F am	M-W 1½ lb #3 Pass
6*	Exponential	5	M-W-F am	M-W 2 lb #3 Pass

*Remains the same until flushing and stressing then 2 lbs 9-45-15+STEM substituted for 20-20-20.

The crop was moved to the shadehouse on May 3, 1985, and outplanted in August and September, 1985 when soil moisture was adequate.

On May 6 & 7, 1985, crop number two was sown and moved to the shadehouse on June 7, 1985. The crop had been thinned and transplanted and was about to begin the exponential growth stage by that time. The greenhouse water and fertilizer schedule was maintained until the crop was flushed on September 23, 1985.

Crop number three was sown June 10 & 11, 1985 and moved to the shadehouse on July 10, 1985. As with crop number two this allowed time for thinning, transplanting and the beginning of the exponential growth stage. This crop was also maintained on the exponential water and fertilizer schedule until September 23 flushing.

Crop number four was sown on July 15 & 16, 1985 and kept in the greenhouse until September

1985. This was to allow additional development under greenhouse conditions prior to the onset of winter. This crop was also flushed on September 23, 1985.

Flushing on September 23 was done to allow natural hardening off to occur in the shadehouse. Watering was cut back to twice per week and fertilizer with 2 lbs 9-45-15+STEM.

Crop number five was sown on September 9 & 10, 1985 and moved to the shadehouse on December 23, 1985. The house was flushed on November 15 and the hardening off procedure was begun at that time.

Throughout this accelerated program only two environmental problems occurred.

Spring cottonwood seed drop created a large thinning problem in the shadehouse. Crop number two had 1 pine seedling and from 5-10 cottonwood seedlings. Only crop number two was affected. Shadecloth over the shadehouse roof during seed fall, should reduce this problem in the future.

After flushing the shadehouse, for Albuquerque, it rained quite frequently. There were several small stressings instead of one long one. The seedlings developed all the usual signs of stressing.

Root tip elongation was first noted on March 3, 1986. Shoot elongation was first noted on April 1, 1986 for May, June and July crops, elongation for September crop began on April 14, 1986. Shoot elongation tends to be later when a crop is forced into dormancy in a greenhouse, in Albuquerque.

CONCLUSIONS

The accelerated growth schedule using the greenhouse in Albuquerque, New Mexico as a germinator worked very well on a production scale. The seedlings developed to a stage enabled them to overwinter under shadehouse conditions. Further research regarding field survival needs to be done.

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Some Effects of Cold Storage on Seedling Physiology¹

Gary A. Ritchie^{2,3}

Abstract.--When tree seedlings are lifted from the nursery in winter and placed into cold storage they are no longer exposed to the natural environmental factors which provide energy for growth and information for phenological development. This affects many important physiological variables which influence seedling quality. This paper summarizes several years of storage physiology research on Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) conducted by Weyerhaeuser Company.

Stored carbohydrates are depleted, dormancy release is slowed, and cold hardiness is gradually lost in cold storage. Root growth potential may increase, decrease or remain constant depending on lift date, storage duration and species. Effects of cold storage on seedling water relations have not been adequately investigated.

INTRODUCTION

Cold or frozen storage of planting stock enables nurserymen and foresters to bridge the gap between fall or winter lifting and spring planting. Because of this it has become an invaluable tool in forest regeneration operations in the Pacific Northwest.

In the natural outdoor environment tree seedlings are exposed to strong diurnal fluctuations in air and soil temperature, light intensity and duration, soil and atmospheric water status, and other factors. Over the millenia tree species have adapted to use these factors as sources of both energy for growth and information for driving phenological development (Campbell 1978).

When seedlings are lifted from the nursery or greenhouse and placed into cold, dark storage they no longer experience these environmental changes. Rather, temperature

remains low and constant, light is absent, and humidity is very high.

This paper will consider some important physiological processes and variables and outline the manner in which they respond to the cold storage environment. It is based almost entirely on our research and experience with coastal Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings at Weyerhaeuser. When available and pertinent, data from other conifers are also cited. The focus of the review is on seedling quality.

PHYSIOLOGICAL VARIABLES AFFECTED

Enumerable physiological processes and variables affect seedling physiological quality. Among those which are strongly affected by cold storage are: (1) carbohydrate reserves, (2) bud dormancy status, (3) root growth potential, (4) cold hardiness, and (5) water relations.

Carbohydrate Reserves

Nearly all plant food reserves are stored in the form of starch and sugars. These are produced ultimately by photosynthesis and are consumed by respiration to sustain plant growth and metabolism. Both photosynthesis and respiration are strongly temperature-dependent and photosynthesis requires light.

¹Paper presented at the Western Forest Nursery Council Meeting, [Tumwater, Washington, August 12-15, 1986].

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³The author thanks Dr. Nicholas Wheeler for reviewing and Ms. Joan Ruthford for preparing this manuscript.

Cold storage impacts photosynthesis and respiration in two ways. First, absence of light stops photosynthesis; second, low temperature decreases the rate of respiration. The net effect is that seedlings burn up their supply of reserve carbohydrates in storage - but they do so very slowly. In an experiment with 2+0 Douglas-fir, total non-structural carbohydrate (TNC) concentrations in January were highest in foliage (Ritchie 1982). During the first two months of storage foliar TNC was respired more rapidly than stem or root TNC (fig. 1.). During the following 10 months a near-linear decrease in TNC occurred in all tissues - the result being that during one year the seedlings had consumed roughly half their food reserves. Storage temperature also affects the rate of loss of food reserves. Douglas-fir seedlings stored at -2°C contained about 2.5 mg/g more TNC after 6 months than did those stored at $+2^{\circ}\text{C}$ (Ritchie, unpublished data).

It would be valuable to know how much food reserve is necessary to ensure survival and adequate early growth but this information is

Total nonstructural carbohydrate
($\text{mg}\cdot\text{g}^{-1}$ dry matter)

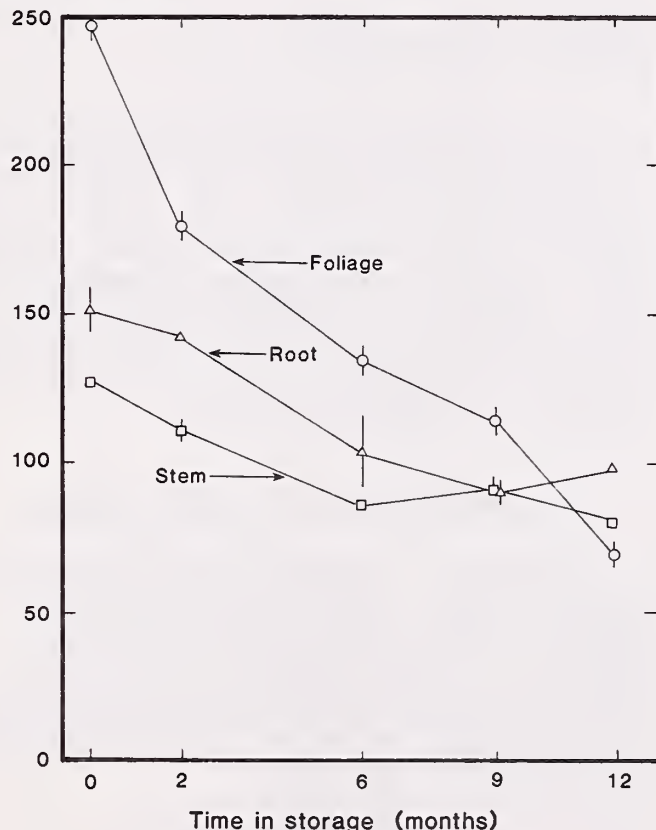


Figure 1.--Changes in total nonstructural carbohydrate concentrations in foliage, stems, and roots of 2+0 Douglas-fir seedlings lifted January 27, 1978 and stored at -1°C . Vertical bars = ± 1 standard error. Reproduced with permission from *Canadian Journal of Forest Research* 12(4): 908, 1982.

not yet available. As a first approximation, 10 to 12 mg/g might be a reasonable estimate.

Bud Dormancy Status

By late fall (October) in the coastal Pacific Northwest, conifer seedlings normally will have reached the peak of dormancy (Lavender 1985). As winter progresses, continual exposure to temperatures below about 6°C (chilling) acts to release dormancy. By March dormancy release is complete and seedlings will break bud and begin growing upon exposure to warm, spring-like conditions.

This progress through dormancy to dormancy release can be visualized by plotting a "Dormancy Release Index" (DRI) curve over the accumulation of hours of chilling temperatures. DRI for Douglas-fir is calculated as the number of days to terminal budbreak of seedlings held in a warm, forcing environment (DBB) divided into 10 (Ritchie 1984). As dormancy release progresses through winter the DRI value approaches unity. This relationship is shown for 2+0 Douglas-fir seedlings of four seed zones in figure 2.

Dormancy Release Index

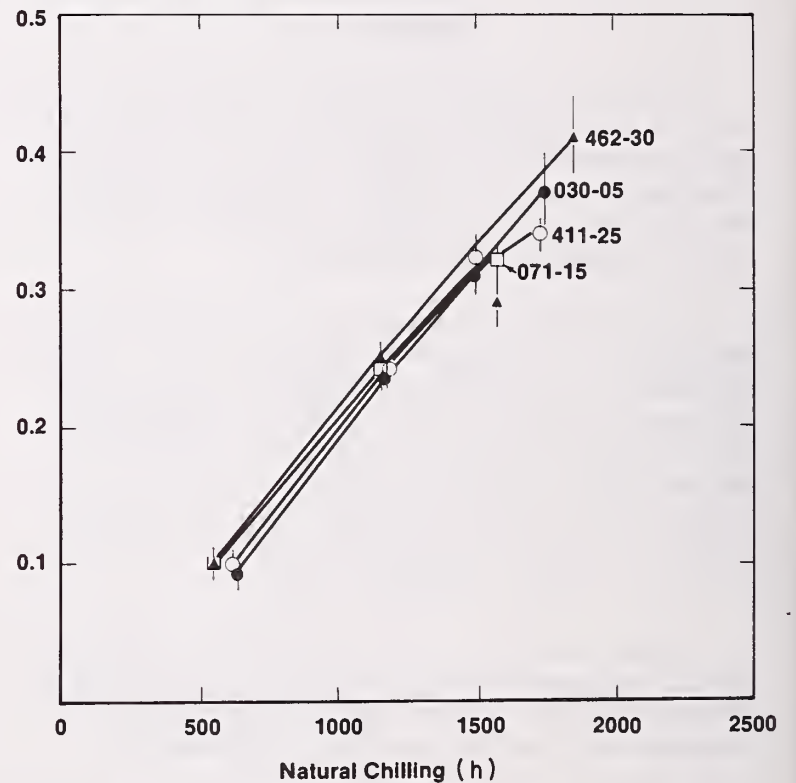


Figure 2.--Dormancy release index in 2+0 Douglas-fir seedlings as a function of natural (nursery) chilling. Data are for the winter of 1979-1980. Each point is a mean (\pm standard error) of 15 seedlings held in a forcing environment. A chilling hour is defined as one during which the air temperature is below 6°C . Reproduced with permission from *Canadian Journal of Forest Research* 14(2): 188, 1984.

When seedlings are lifted from the nursery and placed into cold storage several things occur which affect this relationship. First, seedlings are exposed no longer to daily fluctuating light and temperature; and second, they are held at a temperature which is apparently not very efficient at releasing dormancy. The net effect is that dormancy release does occur - but at a much reduced rate.

In the experiment illustrated in figure 3 we lifted Douglas-fir seedlings on four dates during winter and determined their DRI value. These are plotted as circles on the figure. We then held back samples of these seedlings for storage at -1°C for two [\square] and six [Δ] months, then removed them and again determined the DRI values. In each case, seedlings were far more dormant following storage than they would have been had they been allowed to remain in the nursery beds. Similar experiments were performed with lodgepole pine (*Pinus contorta* Dougl.) and interior spruce (*Picea glauca-engelmannii* complex) with similar results (Ritchie et al. 1985) suggesting that this may be a relatively common response in many conifers.

The practical implication of this phenomenon is that one can lift stock in fall or winter when it is dormant and hold it in a dormant condition well into spring for spring planting. It is primarily because of this

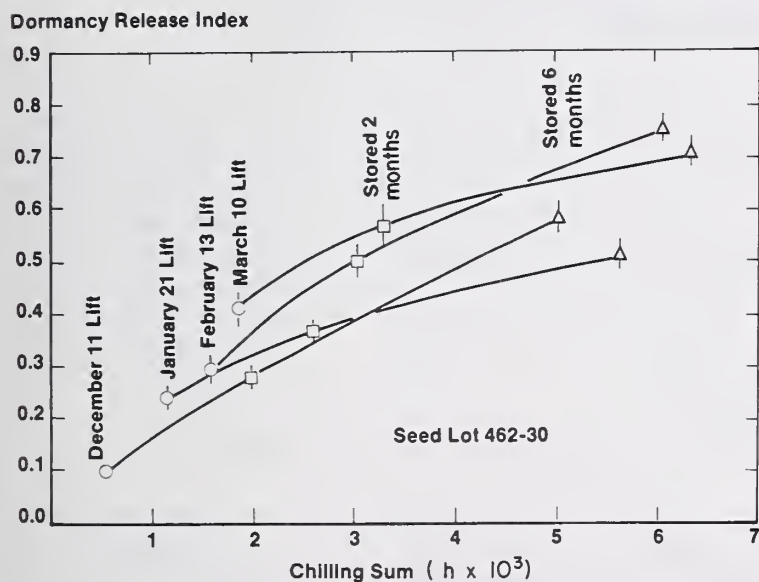


Figure 3.--Dormancy release index in 2+0 Douglas-fir seedlings from a western Oregon Cascade seed zone during winter of 1979-1980. Seedlings were lifted at four times during winter and stored at -1°C for 2 or 6 months. Chilling sum is the sum of nursery chilling plus hours held in storage. Reproduced with permission from *Canadian Journal of Forest Research* 14(2): 188, 1984.

relationship that cold storage works as well as it does.

Root Growth Potential

Root growth potential (RGP) is not a physiological process *per se*. However, it integrates many important physiological processes in the seedling and, for this reason, has become a popular and useful indicator of seedling vigor. The rationale is that if there is any problem with the seedling physiologically it should show up as a decrease in the seedling's ability to produce roots.

RGP is strongly affected by cold storage. In 2+0 Douglas-fir a very clear pattern has emerged over several seasons of testing. RGP is low in fall and early winter, increases and peaks in December and January, then decreases in February to a low in March. With respect to cold storage: two-month storage is nearly always beneficial - the greatest benefit being gained with fall and early-winter lifted stock, while six-month storage is rarely beneficial - especially when stock is lifted in late winter or spring.

This relationship is apparently not universal, however. In a study with lodgepole pine and interior spruce (Ritchie et al. 1985) quite different patterns were observed (fig. 4). The reasons for these differences are not

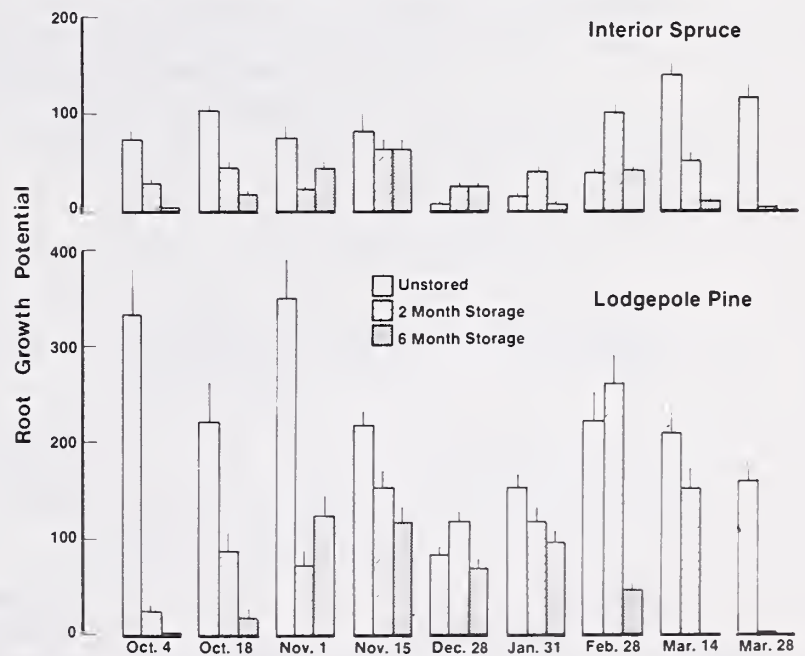


Figure 4.--Root growth potential (number of new roots per seedling) of 2+0 lodgepole pine and interior spruce seedlings lifted throughout winter from a central British Columbia nursery. Seedlings were tested immediately after lifting and after 2 and 6 months in -1°C storage. Each value is a mean (standard error) of 20 seedlings. Reproduced with permission from *Canadian Journal of Forest Research* 15(4): 639, 1985.

known and until the underlying mechanisms driving RGP are understood it will probably be necessary to develop this information for each species and, perhaps, each nursery as well.

Cold Hardiness

A seedling's ability to endure sub-freezing temperatures varies dramatically over the course of the year. In summer exposures to -5°C are sufficient to kill Douglas-fir seedlings. But in mid-winter these same seedlings can easily withstand temperatures below -20°C . With hardier northern species such as white spruce (*Picea glauca* (Moench.) Voss) and lodgepole pine, midwinter hardiness can approach -80°C .

Hardiness develops in fall in response first to shortening photoperiod then to increasing exposure to cold nights (Glerum 1985). As nights become increasingly colder, seedlings become more and more hardy. Increasing photoperiod and higher temperatures in spring cause seedlings to lose hardiness rapidly. This is why late frosts can be so damaging.

One would suspect that removal of a seedling from these environmental signals by placing it in cold storage would interfere with the development of natural hardiness. Further, since carbohydrate reserves undergo a net loss during storage and since hardiness development requires an expenditure of metabolic energy, one would expect a loss of hardiness with time in storage.

Unfortunately, very little information exists on the effect of cold storage on hardiness in tree seedlings. However, the limited data which do exist (table 1) tend to confirm the above predictions. Seedlings lifted early in winter while hardiness was developing did not continue to harden in storage - rather they slowly lost hardiness. Seedlings lifted in spring continued to deharden in storage.

More research is needed on this question for it has important implications. Suppose, for example, that seedlings are fall-lifted for mid-winter planting. If they have not developed adequate hardiness before lifting and are planted on a very cold site they might suffer considerable winter damage. One

Table 1.-- Estimated values of LT_{50} (deg. C)¹ for lodgepole pine and interior spruce seedlings at time of lifting and following 2 or 6 months in storage at -1°C . Reproduced with permission from Canadian Journal of Forest Research 15(4): 640, 1985.

Date Lifted	Storage Period (months)	Date Tested	Lodgepole Pine	Interior Spruce
October 4, 1982	0	October 4, 1982	(-20) ²	(-26)
	2	December 4, 1982	(-14)	-27
	6	April 4, 1983	----	-14
November 1, 1982	0	November 1, 1982	-29	-30
	2	January 1, 1983	-26	-26
	6	May 1, 1983	-20	-25
March 28, 1983	0	March 28, 1983	-18	<-18
	2	May 28, 1983	(-11)	<-18
	6	September 28, 1983	-7	<-18

¹ LT_{50} = lethal temperature for 50% of the test population.

² Values in parentheses are extrapolations, others are interpolations of percent injury over temperature curves from whole-plant freeze tests.

wonders how much overwinter damage can be attributed to this cause. On the other hand, seedlings which are lifted in winter can be held well into spring for high elevation planting where exposure to low temperatures is expected. In the table 1 data, for instance, seedlings lifted in November were still hardy to -20° or -25°C when tested the following May.

Water Relations

Seedling water relations are very complex and a complete discussion is far beyond the scope of this paper. Suffice it to say that during mid-winter conifers exhibit very "favorable" water relations properties -- i.e. they are able to tolerate substantial desiccation of both tops and root systems without incurring appreciable damage (Ritchie and Shula 1985, Ritchie 1986). By spring (March) when growth begins, water relations properties shift abruptly to a far less favorable status and seedlings become very sensitive to water-related stresses. The success of the mid-winter lifting window may be due in part to these highly favorable seedling water properties.

The question is: what effect does storage have on seedling water status? Do seedlings maintain favorable water status in storage or does water status deteriorate? Unfortunately this question has not been researched. One might speculate, however, that since carbohydrates are depleted in storage, and since water relations reflect osmotic relations which depend to a degree on dissolved carbohydrates in the cells, that we would see a gradual deterioration of seedling water status with time in cold storage. This might partially explain why storage beyond six to nine months almost invariably results in poor performance of planting stock. This is an interesting and important question and deserves to be investigated.

SUMMARY AND CONCLUSIONS

When tree seedlings are held in cold, dark storage for prolonged periods of time they are separated from the sources of environmental energy and information they need to develop in synchrony with the changing seasons. This affects many important physiological processes and variables.

Effects of cold storage on dormancy release, carbohydrate depletion and root growth potential have been studied and are reasonably well understood - at least in an

empirical sense. Effects on some other important variables such as cold hardiness and water relations are less well known.

On balance, positive effects of cold storage heavily outweigh negative effects, hence it has become a widespread and very useful practice throughout most of the Pacific Northwest.

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Freezer Storage Practices at Weyerhaeuser Nurseries¹

Stephen M. Hee²

Abstract.--The storage of conifer seedlings in freezer units at a temperature of -2°C has become a matter of routine practice at Weyerhaeuser Forest Nurseries in Washington and Oregon. This paper provides background information on the evolution of this practice in Weyerhaeuser and describes current operating procedures.

NEED FOR LONG-TERM SEEDLING STORAGE

The need for long-term storage of seedlings in our Washington and Oregon operating areas exists for a number of reasons. Our nursery facilities west of the Cascade Range are situated at low elevations, less than one thousand feet. At these nurseries, seedlings must be lifted between December and early March in order to take full advantage of their frost hardiness and root regeneration potential. Because some of our planting sites at higher elevations are not accessible until May or June, storage periods of two to six months are common.

For our nursery in the Klamath Basin east of the Cascades, situated at four thousand feet elevation, spring lifting is often confined to four to six weeks duration because of winter freeze up and late thaw conditions. Long-term freezer storage allows lifting during late autumn and shipping the following spring. This provides for a more balanced work load, split between the fall and spring, and enables shipping to planting sites which thaw earlier than the nursery during the spring.

It has been our experience that shipping orders from the field can fluctuate widely depending on weather conditions and crew logistics. We attempt to operate our nursery lift and pack operations on a constant production flow basis and find that freezer storage provides us with such options as lifting in advance of field outplant orders and packing seedlings for transplanting when there is slack in outplant orders. Thus the freezer provides us with an effective surge buffer between nursery and field production.

DEVELOPMENT AND TESTING

During the early and middle 1970's most of our long-term storage needs were met using conventional cold storage methods where storage temperatures are kept at +1°C to +2°C and relative humidity conditions at 85% or higher. Though these conditions held seedlings satisfactorily for the most part, we did experience some problems with storage molds and fungi. Naturally the more mud and dirt included in the packing bags, the larger the problem with storage fungi. In an effort to eliminate this problem, we decided in 1976 to explore the alternative of storing seedlings at a temperature just below freezing, -1°C to -2°C.

In 1977, we lifted various lots of coastal and cascade source seedlings during mid January, divided these into two groups and placed one group into the freezer for storage at -2°C and the remaining group into the cooler at +2°C (Gutzwiler, 1978). Coastal lots were held in storage for six weeks and

¹Paper presented at the Western Forest Nursery Council Meeting, [Olympia, Washington, August 12-15, 1986].

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cascade lots were stored for six months. At the end of the storage period, the coastal lots were outplanted at a site in our Twin Harbors Tree Farm and the cascade lots were outplanted at our Vail Tree Farm. In the Twin Harbors test, both freezer stored and cooler stored coastal lots survived at 100 percent. For the cascade sources at Vail, no significant differences between cooler storage and freezer storage for like seedlots were observed (Table 1).

Similar tests were conducted with ponderosa and lodgepole pine at Klamath in 1978 comparing freezer stored seedlings with cooler stored (Stevens and Heninger, 1986). Here seedlings were lifted in mid October, stored overwinter then outplanted in late April at Buck Mountain and mid May at Coyote creek the following spring. Survival percentages (Table 2) indicate no significant differences in performance between freezer and cooler storage for either species.

Table 1.--Survival percentage of seedlings stored in the cooler versus freezer for six months and outplanted at the Vail Tree Farm in 1977. Standard errors shown in parenthesis.

Species Class	North Aspect		South Aspect	
	Cooler	Freezer	Cooler	Freezer
Douglas-fir / 2+0	85 (5)	90 (3)	23 (8)	15 (5)
Douglas-fir / Plug	94 (2)	91 (4)	40 (1)	31 (8)
Western Hemlock / 1+1	50 (3)	53 (4)	2 (2)	3 (2)

Table 2.--Survival percentage of pine seedlings stored overwinter in the freezer versus the cooler and outplanted at the Klamath Tree Farm in 1978. Standard errors shown in parenthesis.

Species	Cooler	Freezer
Ponderosa Pine	87 (8)	84 (10)
Lodgepole Pine	88 (10)	93 (6)

A year later, additional tests were performed using coastal and cascade Douglas-fir lots, a noble fir lot and western hemlock lot. These were lifted in mid January at our Mima Nursery and stored in the freezer for intervals of zero, two, four and six months. After the designated storage period these seedlings were outplanted in a research test area at the nursery except for the six months stored treatment. The latter was potted and evaluated in the greenhouse because by then (mid July) the soil in the research test area had become excessively dry. The results of this test showed no significant decrease in survival percentages with time in freezer storage up to six months (Table 3). This applied across all three species tested.

Initially, we were somewhat concerned over how seedlings for the freezer should be packaged. We knew that the freezer could desiccate the seedlings if the moisture barrier

provided by the packaging was not adequate. We, therefore, experimented with a number of different options (Gutzwiler, 1978). These included using:

the standard ply kraft bag
(50#WS+10#PE/50#WS/50#WS),

the standard bag with its seam waxed dipped
(50#WS+10#PE/50#WS/50#WS + waxed seam),

the standard bag plus a 1.5 mil poly liner
(50#WS+10#PE/50#WS/50#WS + liner)

and the standard bag with the wax dipped seam plus the poly liner
(50#WS+10#PE/50#WS/50#WS + waxed seam +liner).

Acceptable results were obtained with all treatments and the additional safeguards of the wax dipped seam of poly liner were not justified (Table 4).

Table 3.--Survival percentage of seedlings stored for 0 to 6 months in the freezer versus the cooler and outplanted at the Mima Nursery test area in 1978. Standard errors shown in parenthesis.

Species	Seedlot	Months in Storage			
		0	2	4	6 ¹
Douglas-fir	411-15-01	100 (0)	100 (0)	100 (0)	95
Douglas-fir	030-05-01	100 (0)	100 (0)	99 (2)	100
Noble fir	430-20-04	98 (4)	99 (2)	86 (7)	100
Western Hemlock	412-30-02	78 (16)	100 (0)	95 (5)	100

¹Evaluated in greenhouse.

Table 4.--Survival results for various packing bag treatments.

Bag Treatment	Survival (%)	S.E.
50#WS+10#PE/50#WS/50#WS	97	(1)
50#WS+10#PE/50#WS/50#WS + waxed seam	94	(3)
50#WS+10#PE/50#WS/50#WS + liner	97	(2)
50#WS+10#PE/50#WS/50#WS + waxed seam + liner	94	(1)

CURRENT FREEZER STORAGE PRACTICE

The use of freezing temperatures for long-term seedling storage has become a routine practice for our nurseries since 1978. We currently store about 25 million seedlings annually in freezers. Over the years we have found that the species which can be freeze stored at -2°C are numerous. A partial listing of those species which we have successfully freezer stored is presented in Table 5.

Table 5.--Some species which have been successfully stored in the freezer.

Douglas-fir	Norway Spruce
Noble Fir	Ponderosa Pine
White Fir	Lodgepole Pine
Shasta Red Fir	Scots Pine
Grand Fir	Western White Pine
Balsam Fir	Eastern White Pine
Pacific Silver Fir	Western Larch
Fraser Fir	Giant Sequoia
Western Red Cedar	Western Red Alder
Western Hemlock	Quaking Aspen
Sitka Spruce	Oregon Grape
Englemann Spruce	Eastern Red Maple

Some basic elements that are important in the freeze storing of conifers include physiological condition of the seedlings, packaging and thawing before planting. As with conventional cold storage it is always advisable to start with seedlings which are clean, healthy and disease free. Though most fungi will not grow and spread in freezer storage these will still be viable when the trees are removed from storage for thawing and planting.

The seedlings should be exposed to natural chilling conditions which occur in autumn in order to promote dormancy and frost hardiness. In our nurseries west of the Cascades, we find that by the first to second week in December virtually all seedlings are hardy to -5°C and LT_{50} 's of -10°C are not uncommon. At our Klamath nursery these conditions will occur at least a month earlier. Once seedlings attain these levels of hardiness they will store well under freezing conditions at -2°C .

The freezer storage facilities which we use are simply conventional refrigerator units which are operated at -1°C to -2°C . There are no provisions in these units for humidity control and since the evaporators are placed directly in the storage areas themselves the humidity will be quite low. It is therefore

important to provide a moisture barrier in the packaging of the seedlings. Storage of seedlings in exposed bales will not work as the trees will desiccate.

We pack seedlings in both bags and boxes depending on customer preference. The bags are standard kraft seedling bags which are widely used by Washington and Oregon forest nurseries. These bags are of 3-ply construction with the inner ply treated with a 10# polyethylene spray coating. This coating provides a suitable moisture barrier. Seedlings are packed in the bags in a moist (not waterlogged) condition and the bag is sealed by folding and rolling the top down. The application of two or three straps secure the package. These are then placed on pallets with racks that allow for stacking and the entire palletized stack is moved directly into the freezer.

In the case of boxes, we use a 1.5 mil poly liner placed inside the box to prevent loss of moisture. The liner is sealed by twisting and tucking and is held secure by the top flap. Once palletized the boxes of seedlings are moved directly to the freezer.

Whatever is used to package the seedlings must provide a seal against moisture loss and be durable enough to withstand normal impact and abrasion in the production operation without sustaining tears and punctures. Should a bag or box be punctured, it can be patched with tape provided a wax coated surface is not involved. Wax surfaces are a challenge to repair.

Freezer temperatures should be checked daily and maintained at -1°C to -2°C . A continuous measuring device such as a thermograph is recommended as it provides the operator with a permanent record of temperature over time. Once in the freezer, seedlings may take up to ten days before they freeze solid. Plug seedlings will take longer than bareroot because of the potting soil and additional moisture contained in the root plug. Seedlings handled and packed in the manner described will keep well up to six months in the freezer.

Seedlings must be thawed before they are planted as frozen root systems or stems can cause transpirational drought stress. We thaw seedlings at the nursery before they are shipped to the customer. Thawing is done in a warehouse or similar structure at ambient temperature ($+10^{\circ}\text{C}$ to $+15^{\circ}\text{C}$). The pallets are spread out to allow for ample air circulation between pallet stacks. Bareroot seedlings normally take three to five days for thawing whereas plug seedlings will require ten to

fifteen days. Once thawed, the seedlings can be shipped to the customer for planting. It is preferable to plant seedlings as soon as they have thawed, however, our experience to date shows that they can be held in cooler storage after thawing up to four weeks without detriment.

SUMMARY

Storing seedlings at -2°C is a practical and proven means for holding conifers in a dormant, viable condition for periods up to six months before planting. Though cooler storage at $+2^{\circ}\text{C}$ can provide similar results the probability of problems with storage molds is much greater. Most western conifers can be freezer stored provided they are in a dormant and hardy condition before lifting and storing. Packaging seedlings for the freezer must include a moisture barrier. A polyethylene bag placed in the packing box or a

polyethylene coating applied to the inner ply of the packing bag serve well in this function. Unlike cooler stored trees, freezer stored seedlings require thawing. This step is most practically achieved by simply spacing pallets of seedlings out in a warehouse at $+10^{\circ}\text{C}$ to $+15^{\circ}\text{C}$.

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Seed Laboratory Computerization: A Database for the Forest Tree Seed Industry¹

RODGER DANIELSON²

Abstract.--Recent computerization of the Oregon State University Seed Testing Laboratory has created a large, expanding database. The computer system and benefits of the resulting database to the forest industry are discussed.

INTRODUCTION

In 1984 the Oregon State University Seed Testing Laboratory began to look at computers to replace their aging mechanical card/tape system of recording and storing data.

A Masters candidate (Alberto Maristany) was hired on a half-time basis to design, develop and implement a computer system to meet the needs of the laboratory. His copyrighted programs were named Seed-Lab and have application for use in any seed laboratory. More complete details of his work may be found in a paper by Maristany and Danielson (1986).

The purpose of this paper is to describe the computer system and benefits it may have for the forest tree seed and nursery industries.

SYSTEM

Figure 1 is a schematic showing the flow of samples through the lab and the flow of information through the system of networked computers.

Samples are received in the entering room. Information pertaining to the samples (i.e. kind of seed, lot number, etc.) is entered into the computer system at this point and is stored on the hard disk of the central file server. Laboratory cards are generated

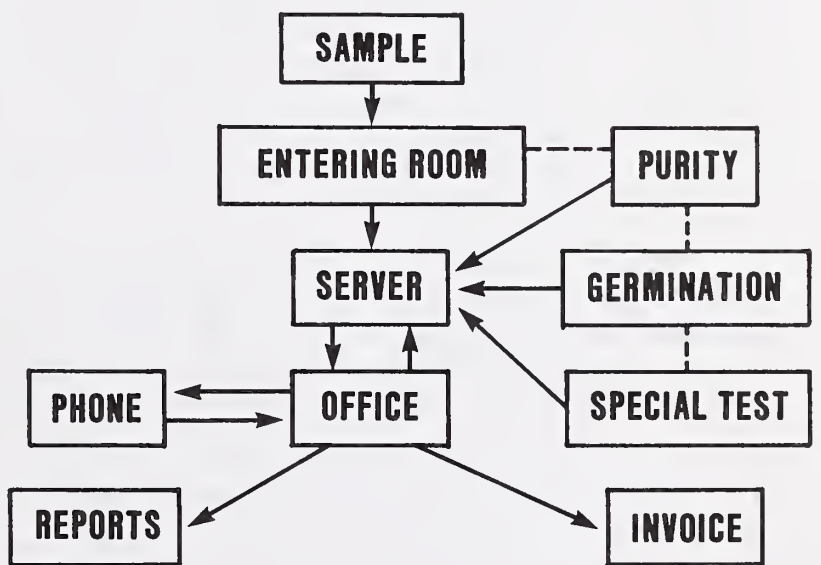


Figure 1.--Diagram showing flow of samples and information through the Seed Lab and computer system.

for internal use by analysts to record their results. Samples then move to purity, germination, or special testing for various quality tests. Results of these tests are entered into the computer where they are stored in the file server and reports are generated in the office. Data on the reports is checked against information on the lab card before reports are mailed. Billing is conducted once a month using a billing program which gathers information on individual customers and prints an invoice listing, date of sample receipt, test number, lot number, kind of seed, tests requested, test charges, past due and total amount due. Incoming telephone calls requesting information on completed tests or tests in progress are handled in the office by accessing the file server which provides the necessary information.

¹Paper presented at the Western Forest Nursery Council Meeting, Olympia, WA, August 12-15, 1986.

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Key data stored upon sample entry includes: the assigned laboratory number, kind of seed, customer sending the seed, lot number, size of lot, seed zone, elevation, and tests requested.

Record and system security is accomplished by two file servers, one of which serves as a backup in event of failure of the main server. File servers are protected from loss of power by an uninterruptible power supply unit (UPS). Data that cannot be held in the file server because of lack of space is archived to tape.

BENEFITS

The computer system just described results in more uniform reports, which are generated faster and contain fewer errors. This results in less fatigue to office personnel, has resulted in less staff and frees them to concentrate on other jobs. Telephone inquiries about status of test results are now handled more accurately and quickly. The monthly billing can now be done in a few hours compared to several days under the old system.

However, the main benefits to the forest industry may relate to the ever expanding database being created and the information it can supply to seedsmen, nurserymen, geneticists, seed technologists, and various researchers.

To maximize use of this database will require planning and close cooperation with all segments of the industry. For instance, if it is deemed desirable to include information about seed vigor on seed germination reports, lot numbers will have to be standardized to insure that vigor results can be sorted by as many factors as possible (i.e. seed kind, seed zone, elevation, year of collection, etc.). The areas described below are examples of how information in the database can be used.

Germination

Seed Vigor

Seed vigor is an indicator of seed quality used for many species. It is particularly useful whenever rapid, uniform emergence is desired, which is certainly the case with the production of conifer seedlings.

Germination values, described by Czabator (1962), combine speed of germination and completeness of germination and can be used to evaluate seed vigor. Currently, germination reports issued by the OSU Seed Laboratory provide all the information needed for calculating germination values (also called germination rates or germination rate indexes).

These values could easily be included on the germination report.

For them to be meaningful, however, would require: 1) the development of germination values for each species (i.e. Douglas fir, Ponderosa pine, etc.); 2) controlled field plantings of the same seed lots tested for vigor to correlate laboratory and field results; 3) a grouping of germination values into high, medium, and low vigor classifications; and, 4) sufficient testing over several years, seed zones, elevations, etc. to validate conclusions.

Quality Guidelines

By analyzing germination data, categories of germination could be developed which would be useful in marketing as well as being useful to seedsmen making decisions about seed storage and to nurserymen for determining seed sowing rates.

Again, categories of low, medium, and high germination values could be developed for each species and further broken down by seed zone and elevation.

Research

Data gleaned from the computers could be used by seed technologists to identify species needing research to enhance germination. For instance, the study of the sporadic germination response of White fir (*Abies concolor*) may be facilitated by utilizing information from the proposed database. Pregermination treatments, such as the length of stratification, could also be better evaluated utilizing the database. Information gained from such studies would be useful to seedsmen, nurserymen, and seed laboratories.

Other Seed Quality Factors

We have spoken about the value of a germination database. However, similar data could be collected on purity, seed moisture content, seed weight, X-ray, and the various quick tests such as tetrazolium and hydrogen peroxide. Correlations between any of these could be run to monitor their validity or to aide in a larger research effort.

CONCLUSIONS

Information about many quality factors is readily available at the Oregon State University Seed Testing Laboratory. With their recent change to computers, this information can be viewed as an expanding database which may have potential uses to many persons associated with the testing of conifer seed. To maximize use of this information, planning

should begin now with input from all interested persons.

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Nursery Crop Management Computer System¹

Valery P. Wyant²

Abstract: This paper discusses a computer inventory system Weyerhaeuser uses in all its nursery and greenhouse facilities in the West, South and Canada. It is called the Nursery Crop Management computer system. It provides automated support for many of the crop inventory procedures used to manage our crops. The computer system provides management with control and information relating to the quantity and characteristics of nursery and greenhouse stock.

SYSTEM STRUCTURE

The Nursery Crop Management computer system runs on Weyerhaeuser's Honeywell 6600 computer in Tacoma, Washington. At this time it is being converted to an IBM mainframe and bringing as much as possible down to the IBM PC level. Access to the computer and to the Nursery Crop Management computer system is made by using terminals or IBM PCs. The computer system is comprised of six major components, each designed to support a specific set of functions. These components are:

Time-Share Executive (TS EXEC) allows the operators to interface with all aspects of the computer system. The TS EXEC accepts, edits and interprets all requests and data entered into the system and engages the other components at the request of the operator.

Update component is used to apply (or post) transactions passed to it by the TS EXEC against the database. The Update component also maintains a log of all transactions submitted to the system.

Report component is used to service requests for reports available from the system. Report requests are passed to the Report component to select data from the database and format the desired report.

Fieldsheets component is used to request the creation of inventory field-sheets.

Inventory component is used to load data onto the sample data files and to run the inventory calculation program.

Data Maintenance component is used to perform a variety of tasks pertaining to technical operation of the system.

Through these components the Nursery Crop Management computer system is capable of many different functions.

FUNCTIONS

Functions available on the Nursery Crop Management System are:

Data Entry function is used to create transactions to be used by the update component.

Report Request function is used to request production reports.

Inventory function is used to enter estimated inventories into the system.

Fieldsheets function is used to request fieldsheets on which to record inventory sample data.

Maintenance function is used to perform various functions that are part of the normal realm of the system.

Reload function is used to reload and restore the update transactions to the database from the history file.

Site function may be used to specify any site or nursery location.

¹Paper presented at the 1986 Western Forest Nursery Council Meeting held at Vance Tye Hotel Tumwater, Washington, August 12-15, 1986.

²Valery P. Wyant, Administrative Assistant, Weyerhaeuser Company, Mima Forest Tree Nursery, Olympia, Washington 98502.

List function is used to allow the operator to list the contents of the various transaction, edit table and request files.

Help function is used to list the available options to the last question issued.

Delete function is used to delete update transactions from the update transaction file.

Run function is used to enter a job into the computer for processing.

Print function is used to print the errors or the reports.

JSTS function is used to check the status of a particular job that has been entered into the system.

Done function is used when the operator has completed a session.

Another important part of the Nursery Crop Management computer system is Tables.

TABLES

Tables are used by the system to cross check the operators input to see if the input is valid. They are lists of valid codes used within the Nursery Crop Management computer system.

Customer is a list of the current customer codes and names.

Gcustomer is a list of the group customer codes and names.

Facility is a list of valid facility codes and names.

Gfacility is a list of valid group facility codes.

Storage is a list of storage facility codes and names.

Gstorage is a list of group storage facility codes.

Zone is a list of valid zone codes.

Species is a list of species codes and names.

Treatment is a list of treatment codes and charges.

Class is a list of valid class codes.

Ncustomer is a list of customer names and addresses.

When Ncustomer table is listed, the operator will have the option of creating mailing labels for those customers on the file.

Components, functions and tables are the inner workings of Nursery Crop Management computer system. To utilize these the system must be updated.

UPDATING DATABASE

The update process is logically divided into three steps which must occur in sequence for each update.

Data Entry (DATA) - The first step in updating the database is to enter the transactions to perform the activities desired. This is done by answering the queries and entering data for the appropriate transactions. These transaction types are:

Bareroot Bed Description - add, modify, delete
Plug Bed Description - add, modify, delete
Reference Number - add, modify, delete
Order Revision - surplus, release, modify, transfer
Current Order Modify - class, outplant, amount
Sowing / Transplant - bare, plug, delete
Inventory - user, modify, delete
Stock Order - add, modify, delete
Lifting - add, modify, delete
Storage / Packing - add, modify, delete
Stock Transfer - add, modify, delete
Shipping - add, modify, delete
Crop Book Comments - add, delete
Destroy Stock - in-storage, in-ground, add, modify
Transplant - add, modify, delete

Depending on what you want to achieve, you can add, modify, or delete with any of these transactions.

This simply records the transactions on a file. They are not actually loaded to the database until the update program is RUN.

Program Execution (RUN) - Once all transactions have been entered, the update program must be run. This program will check the transactions for errors and post the good ones to the database.

Error Checking (PRINT) - To determine if the transactions entered were accepted by the system, the Error and Control Report must be listed. This report lists the transactions in which an error was found during processing.

The report will then list all transactions, wrong and right, and a summary total.

Operators must be certain that all three steps, data entry, program execution and error checking, are performed when

updating the database. Failure to do so may mean lost or incorrect data stored on the database.

Whenever the update component is correct and has the data you want, you may request any report you need.

REQUESTING REPORTS

The report process is also logically divided into three parts which must be done in sequence.

Report Request (REPORT) - The first step in obtaining reports is to enter the information to select the reports desired. This is done by answering the queries and entering requests for the appropriate reports. This procedure simply records the requests on a file. Many report types available are:

Block/Bay - facility, block, crop
Crop Book - lifting/sowing, facility, crop, reference #, date

Production Summary - many assorted options

Customer Inventory - facility, customer, type of stock (transplant, outplant, both)

Stock Order Status - facility, customer, status, type, sort sequence

Storage Facility Inventory - facility

Customer (Region) Seedling Inventory - facility, customer, outplant year

Shipment Summary Report - facility, customer, from date, to date, sort sequence

Depending on what you want to see, there are many different ways to sort these reports. Most can be sorted by facility, crop, customer or reference number.

Program Execution (RUN) - Once all requests have been entered, the report program must be run. This program will check the requests for errors and compile the required reports.

Report Printing (PRINT) - Once the report program is complete, the reports are available to be printed.

DIRECTING OUTPUT

When a job has been completed there are two options of where to print, at the facility or at Tacoma.

Another feature of Nursery Crop Management computer system is the seedling inventory component.

SEEDLING INVENTORY

Nursery Crop Management seedling inventory process consists of two major components, Inventory Fieldsheet Creation and Inventory Calculation.

An inventory begins with the request for creation of the inventory fieldsheets. These fieldsheets are produced by the computer and specify the location of each sample point. The inventory crews use the fieldsheets to locate the sample plots and to record the seedling counts. As the inventory progresses, the operator enters the sample data from the completed fieldsheets onto a data file. When all the data has been entered, the inventory calculation program is run. This program calculates the seedling numbers and stores the information on the database.

SYSTEM MAINTENANCE

The system maintenance process is to aid the maintenance and operations staff in performing functions that are not done during normal field processing. Within the systems maintenance component are the functions of History File Update, File Reorganization, Database Listing, Locking/Unlocking System and Database Recovery.

CONCLUSION

With Nursery Crop Management computer system Weyerhaeuser has been able to keep track of hundreds of millions of seedlings at a dozen different locations. All information is easily accessible to the facility or management at any time.

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Using the HP71 Hand-Held Computer for Seedling Inventory¹

Douglas A. Bluhm²

The J. H. Stone Nursery has used a Hewlett-Packard hand held computer since 1985 for data collection during seedling inventory. The use of the HP71B has resulted in improved inventory accuracy, better information handling, and cost savings.

INTRODUCTION

Each nursery has its own method for seedling inventory, but all nurseries have the same need to collect this data for evaluation and reporting. Until 1985 the J. H. Stone Nursery recorded inventory data on paper forms and then transferred the information manually into our computer system. This method was time consuming, allowed for entry errors, was costly, and did not provide timely access to the inventory data. From the beginning of operations at Stone Nursery, we identified the need for a field data recorder to assist the inventory process. In 1984, nursery personnel with assistance from Randy Lunceford of the Deschutes National Forest tested and evaluated the Hewlett-Packard HP71 Hand Held Computer. We found this computer satisfactorily met the requirements for seedling inventory; we embarked upon a process to develop an inventory program and operating procedures for the HP71.

EQUIPMENT

HP71 Hand Held Computer - This is a powerful computer/calculator that is programmable in BASIC language. The standard memory for this computer is a 64K

ROM and a 17.5K RAM. Both the ROM and RAM are expandable. The nursery is uses an expanded RAM of 32K. The cost of the HP71 is \$350 (GSA contract). The expanded memory module costs \$395.

HP-IL Interface Module - The HP Interface Loop allows the HP71 computer to operate with a variety of peripheral devices, such as, printer, cassette recorder, and other computer systems through an RS-232 Interface. The cost of the module is \$53 (GSA contract).

HP-IL RS-232 Interface - This device allows the HP71 to "talk" with other computer systems. This permits the transfer of data from the handheld computer to a main computer system for storage and additional processing. The cost is \$210 (GSA contract).

Digital Cassette Drive - The cassette drive is a very necessary peripheral device. The mini-cassettes can be used for storing data and programs. The programs can be loaded from the cassette into the HP71. This makes loading of different programs very easy. The cost is \$320 (GSA contract).

Thinkjet Printer - We have used the printer primarily for listing and troubleshooting programs. The HP71 has TRACE FLOW and TRACE VARIABLE commands that aid in analyzing program troubles by printing out the program steps or variables. The cost is \$350 (GSA contract).

The minimum equipment required to successfully use the HP71 for data collection would be the HP71, the HP-IL

¹ Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

² Production Supervisor, J. Herbert Stone Nursery, Central Point, Oregon.

Interface Module, and the RS-232 Interface. The expanded memory may be necessary depending on the amount of data to be collected and the proximity of the collection area to a main computer for data transfer. The cassette drive and printer are very helpful tools, but not essential for field data collection

PROGRAM DEVELOPMENT

Each nursery conducts its inventory differently, as was mentioned above; therefore, there is not a need to discuss the "mechanics" of the inventory program (formulas, statistics, sampling requirements). Great consideration must be given to the abilities of the individuals doing the work. A program that relies on specialized knowledge of the equipment may present problems to the person who hasn't any experience with computers. Designing a program which is inter-active in format can overcome "computer induced trauma". By querying the operator for input, by presenting clear cut choices on the display, by requiring operator confirmation of data input, and by building error traps and escapes into the program, the chance for operator error is reduced.

Once a program is successfully completed and debugged, the inventory crew must be trained in the operation of the computer. A program flow chart is one of the best tools that can be used in any training session. Practice with the equipment under the guidance of accomplished operators is also mandatory. It is much easier to answer questions and to look at operator

problems in a classroom setting than in the field with the crew scattered out over ten or twenty acres. During our training sessions "sample inventories" are entered into the computer. The samples are designed to produce specific results which give operators the opportunity to correct errors, escape from mistakes, and see "correct" machine responses. A well designed training program will help insure that the operators perform the inventory quickly and with few errors.

CONCLUSION

The Stone Nursery's experience in using the HP71 for seedling inventory has been a positive one. The following advantages were evident:

1. Paperwork was reduced.
2. Errors were reduced
3. Cost of inventory was reduced
4. The inventory figures were available on a timely basis.
5. The flexibility afforded by the HP-71 allowed modifications to the program during the inventory.

The high cost of the equipment and alterations to previously established procedures were the only perceived disadvantages to using the HP-71. Since this equipment has only been used for two years we can not assess its durability. There are many types of hand held computers on the market, and regardless of which brand is chosen, a hand held computer can improve the seedling inventory process.

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Root Growth Capacity System¹

Gary R. Hileman²

Abstract.--Design of a Root Growth Capacity (RGC) System that has the capability of creating a favorable environment for initiation of root growth. System construction, parts, and labor were done for approximately \$5,500. Blueprints are available.

SYSTEM SEQUENCE

Heated water is pumped from the holding tank, through a solenoid controlled valve, a self-cleaning filter, the mist-chamber pressure gauge, and fog-nozzels. The water is collected on the bottom of the mist-chamber and is gravity carried through a screen-plug in the chamber drain hole and gravity carried through a cartridge filter before going back into the holding tank. Water level in the holding tank is controlled by a float valve on a hose from the water source.

HEATER AND PUMP ASSEMBLY

A 1/2 h.p. pump is used to circulate water from the holding tank to the fog-nozzels in the mist-chambers, 45 p.s.i. It runs constantly, bypassing back to the holding tank when not pumping to the mist-chambers. The reason for this is because of the constant on-off cycle of the mist timer. If the pump had to turn on and off so frequently, it would soon burn out. The misting sequence is triggered by a timer that can be set in 5 second intervals every 10 minutes. When triggered, an electric solenoid opens and allows the water to go through a self-cleaning filter into the designated mist-chambers.

¹Paper presented at the Western Forest Nursery Council Meeting, Tumwater, WA., August 11-15, 1986

²Gary R. Hileman is Welding Worker for Lucky Peak Nursery, U.S.D.A. Forest Service, Boise National Forest, Boise, ID.

ROOT GROWTH CHAMBER

The mist-chamber is a fiberglass tank approximately 8'x2½'x2½'--just the size of a coffin liner. The tank was painted black to eliminate light in the root zone. Tanks were mounted on an angle-iron frame with walkways between the chambers. The clamps that hold the seedlings are made of two pieces of cedar with foam attached to prevent damage to the seedling stems. The hinges are woven nylon strips stapled to the ends of the cedar boards. Each clamp holds 20 seedlings, and each tank holds approximately 300 seedlings.

Blueprints for the entire system are available from the author.

ROOM SPECIFICATIONS

To have year-round capability of the system, the room requires forced-air heating/cooling, adequate lighting, and room-air humidity control. We accomplished this with a propane furnace, air humidifier, swamp cooler, side and roof windows, and four banks of fluorescent lights. Good insulation helps reduce energy consumption.

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Root Regeneration Potential¹

R. Daniel Dolata²

Abstract.--Evaluating root regeneration potential using an intermittent mist chamber is being operationally conducted at the U.S.F.S., Lucky Peak Nursery in Boise, Idaho.

INTRODUCTION

Back in 1970, Dr. E. Stone (1970) gave a paper where he started out chastising foresters and nursery operators for (1) planting "dead trees", and (2) not going beyond the outward physical characteristics of a seedling in their grading of trees. Lucky Peak Nursery has taken one of their first steps to operationally evaluating root regeneration potential of our bare-root nursery stock.

In 1981 Dr. Day piqued our interest in finding a way to economically and efficiently evaluate the root regeneration potential of our seedlings. Are we growing trees that given the proper conditions, will re-establish intimate contact with the soil? Or are they dead? Are we lifting at the right time? Lucky Peak Nursery would like to welcome the advancement of root regeneration potential.

WHAT IS IT? WHAT CAN IT TELL US?

Root regeneration potential, what is it? Day, (1981) recommended this definition; the potential of transplanted or outplanted nursery stock root systems to initiate or elongate new white roots shortly after transplanting or outplanting.

What is it really telling us? We think that in the future we will be better able to help predict survival and establishment of each "source" of seedlings we produce.

¹Paper presented at the Western Forest Nursery Council Meeting, Tumwater, WA., August 11-15, 1986

²R. Daniel Dolata is the Forester for Lucky Peak Nursery, U.S.D.A., Forest Service, Boise National Forest, Boise, ID.

How can you do it operationally? (Test the root growth potential that is). First of all we had to look at what we were trying to do. Stone grows his transplants in pots in a warm water bath for twenty eight days then washes the roots off. Day has tried (1) pot bioassay methods, (2) root mist chambers, and (3) root growth boxes. Following MacDonnel's (1981) work we decided to build our Root Growth Capacity System utilizing an intermittent root mist chamber. Now we can evaluate RRP before the stock is shipped.

How large of scale can this be? Is it expandable? Is it faster than the 28 days of Dr. Stone's process? How much did it cost to build? How much does it increase the cost of your stock per thousand? For more information also see paper titled Root Growth Capacity System by Gary Hileman.

HOW DO WE (LPN) DO IT OPERATIONALLY?

Operationally we follow this sort of scenario, (1) during the packing season we have a team doing "THE TESTING" of each source of seedlings as they come into the packing shed. We added to their responsibility that of obtaining a sample of seedlings for testing from each source for RRP evaluation. They are placed into cold storage until the next days batching to go into the RRP system.

The next morning the seedlings are taken down to the RRP room to be measured as they are placed into the holding slats. Height, caliper are recorded and any new "white" roots are removed. A sample of ten seedlings from each lot are tested and not placed in adjacent slats.

We've even been able to evaluate seedlings in the summer by using a chamber temperature of 80 degrees Fahrenheit and adding a swamp cooler for cooling and humidity.

Most pines are kept in the chambers for 10 days. This is long enough for the majority of the new growth to occur without the tips turning brown and becoming obscured from the counting and measuring. East side Douglas-fir and Engelmann spruce may take up to twenty eight days before quantifiable growth has taken place.

The work really begins when the seedlings are removed from the chambers. Each replication trees are re-measured for height, caliper, and bud burst, as well as the total number of new roots greater than 1.5 centimeters, the length of the three longest roots in centimeters and the root class of the number of roots less than 1.5 centimeters. See Table 1

At first this was the most time consuming part but with practice it becomes faster. the counting and measuring takes from one minute to five minutes depending on what species and the fibrousness of the root system. As Gary has said it cost us about \$5,500 to build this system. To run it cost us last packing season about \$1,000 for 4mm trees shipped. That works out to about twenty one cents per thousand seedlings. (\$849.00/4,000m seedlings shipped)

Root class originally started out as a way to at least acknowledge that those roots less than 1.5 cm in length could still be of value to the plant in establishing contact with the soil and be faster and more accurate than using a volumetric measurement on the total root system. After a year of trying to average the length of the longest three roots and coming up with some obscure numbers we decided to try and use the same root classes for the longest roots. See Table II

Table II.--Root Class

Root Class	<1.5cm	>1.5cm
0	None	None
1	1-5	1-5
2	6-15	6-15
3	16-30	16-30
4	30+	30+
5	Dead	Dead

To simplify coding and record keeping (we enter this into the U.S.F.S. NMIS Data Base) we record the two classes as RRP 3/4.

Table 1.--Sample data taken after 10 days in Root Mist Chamber

Lot ID	Tree #	Top Height cm	Caliper mm	#New Roots 15cm	Length of 3 longest -----cm-----			Root Class
LP02850065	1	20	3.5	37	5.0	4.5	4.0	4
	2	18	3.0	40	5.5	4.5	4.5	4
	3	22	3.8	35	5.0	5.0	4.0	3

RECORDS

We realize that this data is important from the product we produce, but more important is how this information relates to the survival through the fifth year. To understand and relate these classes to survival is our hope and project. Lucky Peak Nursery will continue to operationally test each seedlot that is produced in the future. It has taken fifteen years but Lucky Peak is going beyond the outward physical characteristics.

NOTE IN CLOSING: Various authors over the years have tried to quantify these measurements, in many different ways, each a little different than the other. Ours too is unique and I personally feel uneasy in trying to compare my "apples" to anyone else's. A standardized way of expressing the results will be the key to further operationally testing seedlings at the nursery and justifying the cost to the buyer rather than relying on whether or not the minimum morphological grade standards were met.

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Relation Between Cold Hardiness, Root Growth Capacity, and Bud Dormancy in Three Western Conifers¹

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Abstract.--Ponderosa pine, Douglas-fir, and Engelmann spruce seedlings were greenhouse container grown, then cold acclimated and deacclimated in growth chambers over 19 weeks. Stem cold hardiness, new root length at 14 days, and days to budbreak were measured weekly. During acclimation, root growth capacity had doubled when stem cold hardiness reached -22 °C. During deacclimation, root growth capacity was not lost when two-thirds of maximum cold hardiness was lost. At budbreak, both cold hardiness and root growth capacity were minimum.

INTRODUCTION

The tree nursery industry has long recognized the need for accurate measures of seedling quality (Duryea 1985, Rook 1980). To date, morphological tests predominate, because they are quick and easy to perform, and there is a long history of correlation with survival and growth in the field. Physiological testing at an operational level is still in its infancy, because the tests require more expensive instrumentation and are frequently time-consuming, and in many cases we don't know how to interpret the results. Nevertheless, physiological testing has the prospect of eventually being a far better predictor of field performance than morphological characteristic.

To become established in the field, seedlings must first make root contact with the surrounding soil (Tinus 1974), and it is the new white root tips that are the low resistance pathway for water uptake (Carlson 1986). This is why root growth capacity (RGC) has become an important test and has been found well correlated with field survival and growth (Jenkinson 1980, 1984).

Next, the seedling must grow in height. Meeting chilling requirements for budbreak is rarely a problem with bare-root stock, but can be with container-grown seedlings. More important,

budbreak has long been the criterion for judging plantability of stock, yet spring budbreak is the last in a series of physiological changes from winter dormancy to summer growth.

To be a useful management tool, a test has to yield results early enough to change the course of events. Measuring bud dormancy by counting days to budbreak takes much too long. Assessing root growth capacity by the pot test takes 28 days; this can be cut to 7-14 days in the aeroponic mist box (Ritchie 1985, DeWald et al. 1985, Burdett et al. 1983), but probably not less. However, there are tests for cold hardiness that can be done in a matter of minutes to 2 days (Burr et al. 1986, Greer 1983a, 1983b, Pelkonen and Glerum 1985, Colombo et al. 1984, Andrews et al. 1983). Knowing the cold hardiness and the rate of acclimation or deacclimation is valuable for protection of the seedlings, such information could also be used as a quick estimator of bud dormancy and root growth capacity if a good, consistent relation between the three parameters could be found.

The purpose of this study was to find whether such a relation exists. Our research showed that RGC and cold hardiness tests can indicate loss of quality weeks before visible budbreak.

MATERIALS AND METHODS

Ponderosa pine (*Pinus ponderosa* Laws., Chevelon District, Apache-Sitgreaves National Forest, elev. 2,300 m), Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, Cloudcroft District, Lincoln National Forest, elev. 2,700 m), and Engelmann spruce (*Picea engelmannii* (Parry) Engelm., Springerville District, Apache-Sitgreaves National Forest, elev. 3,000 m) were seeded in

¹ Paper presented at Western Forest Nursery Council Meeting, Tumwater, Wash., August 12-15, 1986.

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400-ml Roottrainers² in peat-vermiculite in October 1985. They were grown in greenhouses at Flagstaff, Ariz., with night temperatures averaging 18-21 °C and day temperatures 23-25 °C until April 1986, when day temperatures began to rise, reaching about 28 °C by June. Daylength was extended to 22 hours with fluorescent light. Other cultural conditions were as recommended by Tinus and McDonald (1979). On June 24, the seedlings were sorted; those of uniform size were placed in four Percival HL-60 growth chambers under 43,000 lux from sodium and multivapor arc lights and kept watered as needed with nutrient solution under a cold acclimation and deacclimation regime (indicated in table 1). All seedlings were of a single population that went through the same succession of stages. At weekly intervals, samples of seedlings were taken for concurrent tests of cold hardiness, root growth capacity, and bud dormancy.

Table 1.--Conditions of cold acclimation and deacclimation

Stage	Dura- tion (weeks)	Day temp. (°C)	Night temp. (°C)	Day length (hours)	Nutrient solution
1	3	20	15	10	Low N, high PK
2	7	10	3	10	Low N, high PK
3	5	5	-3	10	Low N, high PK
4	4	22	22	16	High N

Cold hardiness was measured by a whole-plant freeze test. One book of four seedlings of each species was placed in each of three styrofoam coolers, and the rootballs supported and covered to a depth of 5 cm with dry vermiculite. The coolers were instrumented with thermistor probes in the crowns of the seedlings, the lid wired shut, and the coolers placed in a 650-L household chest freezer. The temperature was lowered rapidly from ambient to 0 °C and at a rate of 3-5 °C per hour thereafter. To reach temperatures below -25 °C, a baking pan was placed in the freezer and filled with liquid nitrogen. The size of pan and degree of insulation controlled the rate of temperature fall. For each species, three temperatures were selected 5 °C apart, which were expected to encompass the LT₅₀ of the stem. When a designated styrofoam cooler⁵⁰ reached one of these benchmark temperatures, it was removed from the freezer and placed in a refrigerator at +1 °C where it thawed overnight. The seedlings were then removed from the coolers and placed in a warm greenhouse (day 26 °C, night 19 °C, 22-hour day).

After 7 days, the stems were sliced open and the cambium and phloem examined for browning

²Trade names are used for brevity and specificity and do not imply endorsement by USDA or Colorado State University to the exclusion of other equally suitable products.

and cell turgor. For each seedling, the proportion of stem that had been killed was estimated. Rates of increasing injury with decreasing temperature were compared across days and species, and data with similar rates was subjectively placed into 5 groups. This pooling of data was necessary because 12 trees for a particular day did not provide adequate information for statistical analysis. For each group, injury in the range 10-90% was regressed against temperatures, and the 50% injury point was estimated by calibration methods (Graybill 1976). The range 10-90% was chosen because the relation between injury and temperature was primarily linear, but nonlinear above and below this range.

At the same time the cold hardiness test was run, eight additional seedlings per species were placed in an aeroponic mist box in a greenhouse (day 26 °C, night 18 °C, ambient day length) to measure root growth capacity. The seedling stems were inserted through holes in plywood strips and held in place with urethane foam plugs. The intact rootballs were exposed to 100% relative humidity at 27 °C maintained by a warm-water intermittent mist. After 14 days, the new white roots that emerged from the rootball were measured (cm ± 1) and counted, and RGC expressed as total new root length per seedling. RGC was measured without damaging the seedlings, which were then returned to the mist box.

The seedlings were left in the mist box until they broke bud. A seedling was considered to have broken bud when 50% of its buds had broken. Days to 50% budbreak were recorded when four of the eight seedlings had broken bud. When this was not observed directly, days to 50% budbreak were calculated by linear interpolation. The observations were plotted against day number during acclimation and deacclimation, with intervals plotted for the interpolated points. The endpoints of the intervals indicate actual measurements.

RESULTS AND DISCUSSION

Budbreak proceeded approximately as expected from previous work (Lavender 1985), but with some differences between species with respect to timing (fig. 1). Engelmann spruce did not break bud at all until day 42, or after 1,176 chilling degree hours below 7 °C. Chilling requirements were fully met by day 71, after 2,800 chilling degree hours. Days to 50% budbreak remained stable at about 21 days until the deacclimation period, during which days to 50% budbreak declined to zero in 21 days.

Douglas-fir did not break bud until day 56, after 1,960 chilling degree hours. Chilling requirements were fully met by day 71 (2,800 hours). Thereafter, days to 50% budbreak remained stable at about 26 days until the deacclimation period, during which days to 50% budbreak declined to zero in about 28 days.

Ponderosa pine did not require any chilling to break bud, and broke bud even at the earliest test dates except at day zero. After 21 days at day

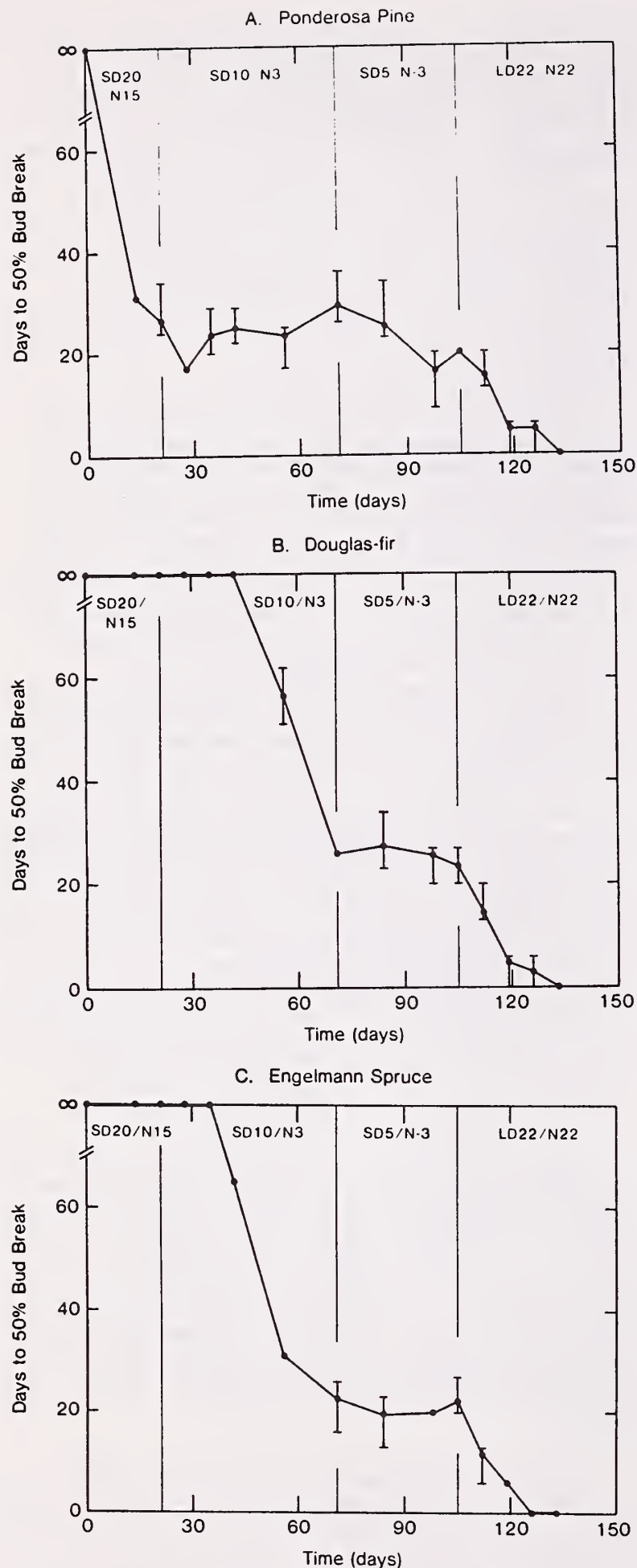


Figure 1.--Days to 50% budbreak of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time. Temperature stages are described in table 1. Plotted intervals indicate interpolated values, the endpoints of the intervals being the actual measurements.

20 °C, night 15 °C, days to 50% budbreak declined to a plateau between 18 and 30 days, but with more variability than Engelmann spruce and Douglas-fir. Days to 50% budbreak declined to zero in about 28 days.

Root growth capacity (fig. 2) of Douglas-fir (fig. 2B) was low (100 cm per seedling) at the beginning of the acclimation period. Two weeks into the second stage of hardening (day 10 °C, night 3 °C) RGC began a rapid rise to a 400 cm peak at day 84 during the third stage of hardening (day 5 °C, night -3 °C). RGC dropped to about 250 cm and then rose to a second peak 1 week into deacclimation. Because of variability, the two peaks separated by a valley may not be distinguishable statistically, but the second peak especially makes sense biologically. Many workers have found an inverse correlation between root and shoot growth, with a particularly strong burst of root growth shortly before budbreak (Riedacker and Arbez 1983, Jenkinson 1980, El Nour and Riedacker 1984). After more than 1 week under deacclimation, RGC declined to a low level (50 cm) at budbreak.

RGC of Engelmann spruce (fig. 2C) was initially low (70 cm); but 2 weeks into the second stage of hardening, RGC rose abruptly to about 230 cm per seedling with a lot of variability. Maximum RGC (320 cm) occurred 1 week into deacclimation; but again, because of variability, the peak may not be statistically distinguishable from the preceding plateau. After the peak, RGC dropped rapidly with the approach of budbreak.

RGC of ponderosa pine (fig. 2A) began at midrange (290 cm) and declined to a low of 100 cm. Two weeks into the second stage of hardening, RGC rose abruptly to over 400 cm, where it remained until the third stage, when RGC again dropped to 300 cm. As with Engelmann spruce and Douglas-fir, a second peak appeared 1 week into deacclimation, followed by a rapid decline as budbreak approached. Again, because of variability, these relations are not clearcut. However, the pattern (fig. 2) is remarkably similar to the one reported by Jenkinson (1980) for bare-root seedlings of the Arizona ecotype (Read 1980, 1983) grown in California nurseries.

Although there are distinct differences between species, the pattern of RGC during cold acclimation and deacclimation showed some very interesting similarities. First, the rise in RGC early in the second stage of hardening occurred at the same time for all three species, although the rise was abrupt in ponderosa pine and Engelmann spruce and more gradual in Douglas-fir. Second, maximum RGC was five to seven times minimum RGC. Third, a second peak (albeit not distinct statistically) occurred 1 week into deacclimation, or 2-3 weeks before budbreak, depending on species. Fourth, RGC declined rapidly as budbreak approached. Although RGC appears to have multiple peaks for each species (fig. 4 below), the variability in the data (fig. 2) is too great to know if the peaks are real.

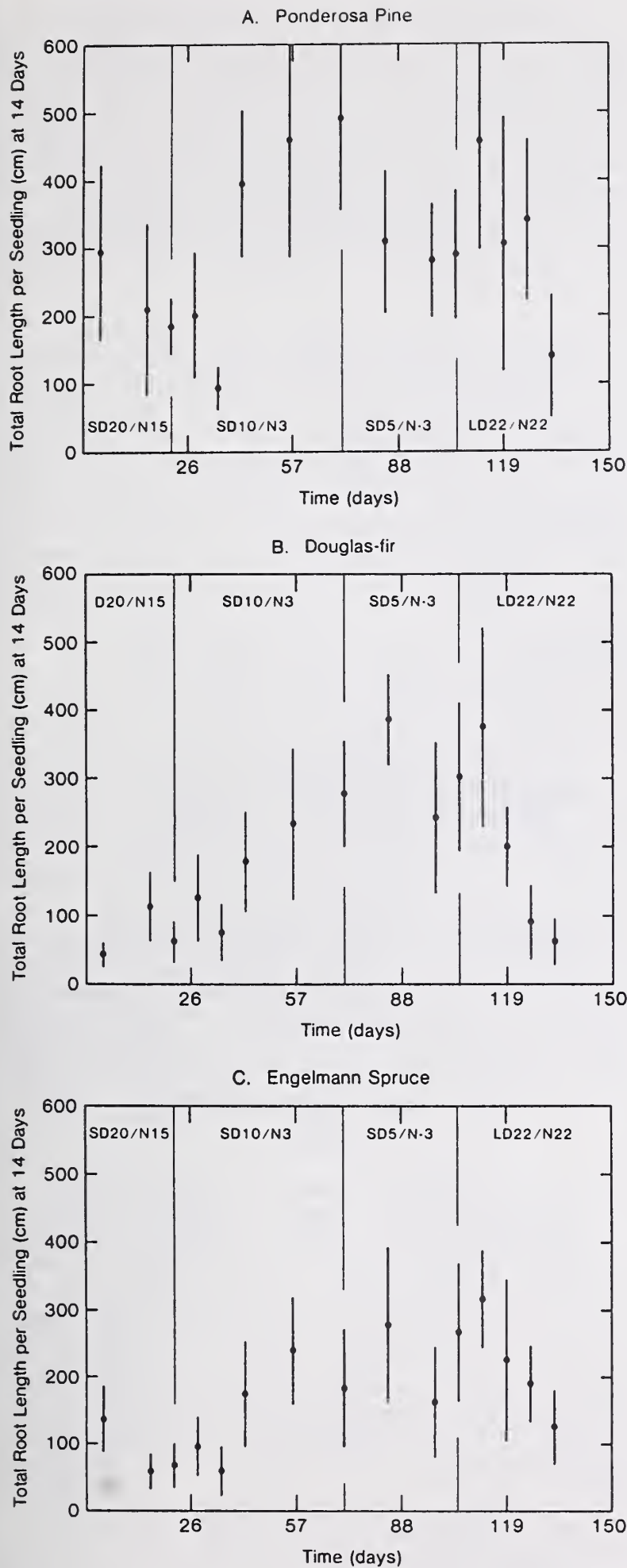


Figure 2.--Root growth capacity as total new root length per seedling at 14 days of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time. Vertical bars are 95% confidence levels. Temperature stages are described in table 1.

Cold hardiness of each species (fig. 3) was gained and lost as a function of the four successive temperature stages. In the first stage (day 20 °C, night 15 °C, 10-hour day), ponderosa pine (fig. 3A) did not harden, but stem cold hardiness was about -16 °C (LT_{50}). During the second stage, there was no hardening for the first week. Thereafter, hardening proceeded at about 0.4 °C per day until maximum hardiness was reached at about -32 °C on day 71. Upon entering stage 4 (day 22 °C, night 22 °C), deacclimation began immediately and proceeded at about 1 °C per day to a minimum hardiness at about -14 °C.

Douglas-fir stems (fig. 3B) started at minimum hardiness of -11 °C and did not harden during the first temperature stage. During the second stage, there was no significant hardening for 3 weeks. Thereafter, hardening proceeded at about 0.5 °C per day, reaching an LT_{50} of -47 °C by the end of stage 3 (day 105). Gain in hardiness was continuous with no sign of leveling out, as there was in ponderosa pine. Therefore, -47 °C may not represent maximum possible cold hardiness of Douglas-fir stems. Upon entering stage 4, deacclimation began immediately and proceeded at about 2.3 °C per day to -11 °C.

Like ponderosa pine and Douglas-fir, Engelmann spruce (fig. 3C) did not harden during the first stage, nor did it harden during the first 2 weeks of the second stage. Thereafter, Engelmann spruce stems hardened at about 1 °C per day from about -15 °C to -63 °C on day 84. By day 93, 27 days into the third stage, Engelmann spruce was unkillable at -77 °C, which was the low limit of the freezer. Upon entering stage 4, Engelmann spruce deacclimated to -35 °C in 1 week, a rate of at least 6 °C per day. The rate of dehardening declined rapidly thereafter, finally reaching a minimum hardiness of -13 °C.

The principal differences between species seem to be in their rate of hardening and the maximum attainable hardiness, which is much in keeping with the altitude of their native habitat. In Arizona, ponderosa pine grows from 1,800 to 2,700 m, Douglas-fir from 2,400 to 3,000 m, and Engelmann spruce from 2,700 to 3,300 m.

In addition, there are some striking similarities between species. No hardening occurred at warm temperature even with a short day. Based on work on deciduous species, partial hardening might have been expected (Ketchie 1985, George and Burke 1977), but does not seem to occur in conifers (Aronsson 1975) except in high latitude seed origins (Cannell and Sheppard 1982). When the temperature was lowered to day 10 °C, night 3 °C, there was a 1-3 week lag before hardening began. On the other hand, there was no lag in the loss of cold hardiness when deacclimation was initiated, and the rate of deacclimation was two and one-half to six times faster than acclimation. Aronsson (1975) has made similar observations on Scots pine and Norway spruce.

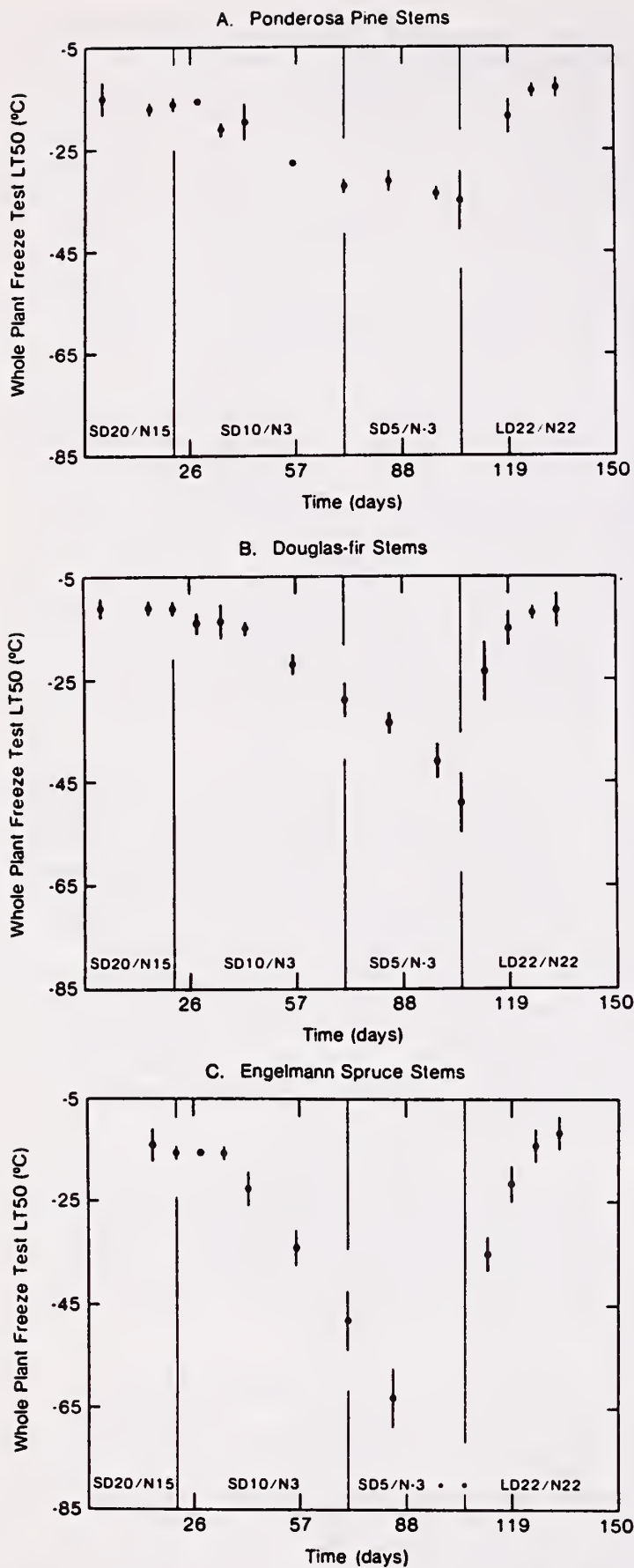


Figure 3.--Stem cold hardiness of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time. Each LT_{50} and its 95% confidence interval were calculated by calibration methods. The confidence interval is for the mean of 12 observations. Temperature regimes are described in table 1. For day number 112, ponderosa pine was less hardy than the warmest temperature used. On day numbers 98 and 105, Engelmann spruce is indicated at -77°C , but the stems were not visibly injured.

When cold hardiness, RGC, and bud dormancy are compared, some interesting and possibly useful relations emerge (fig. 4). During acclimation, when stem LT_{50} reached -22°C , root growth capacity had just doubled. RGC was then on a high plateau in the case of ponderosa pine and Engelmann spruce, and on a continuing rise in the case of Douglas-fir. If this relation were to hold up under further testing, measuring cold hardiness could become a quick way to determine when to begin fall lifting in bare-root nurseries.

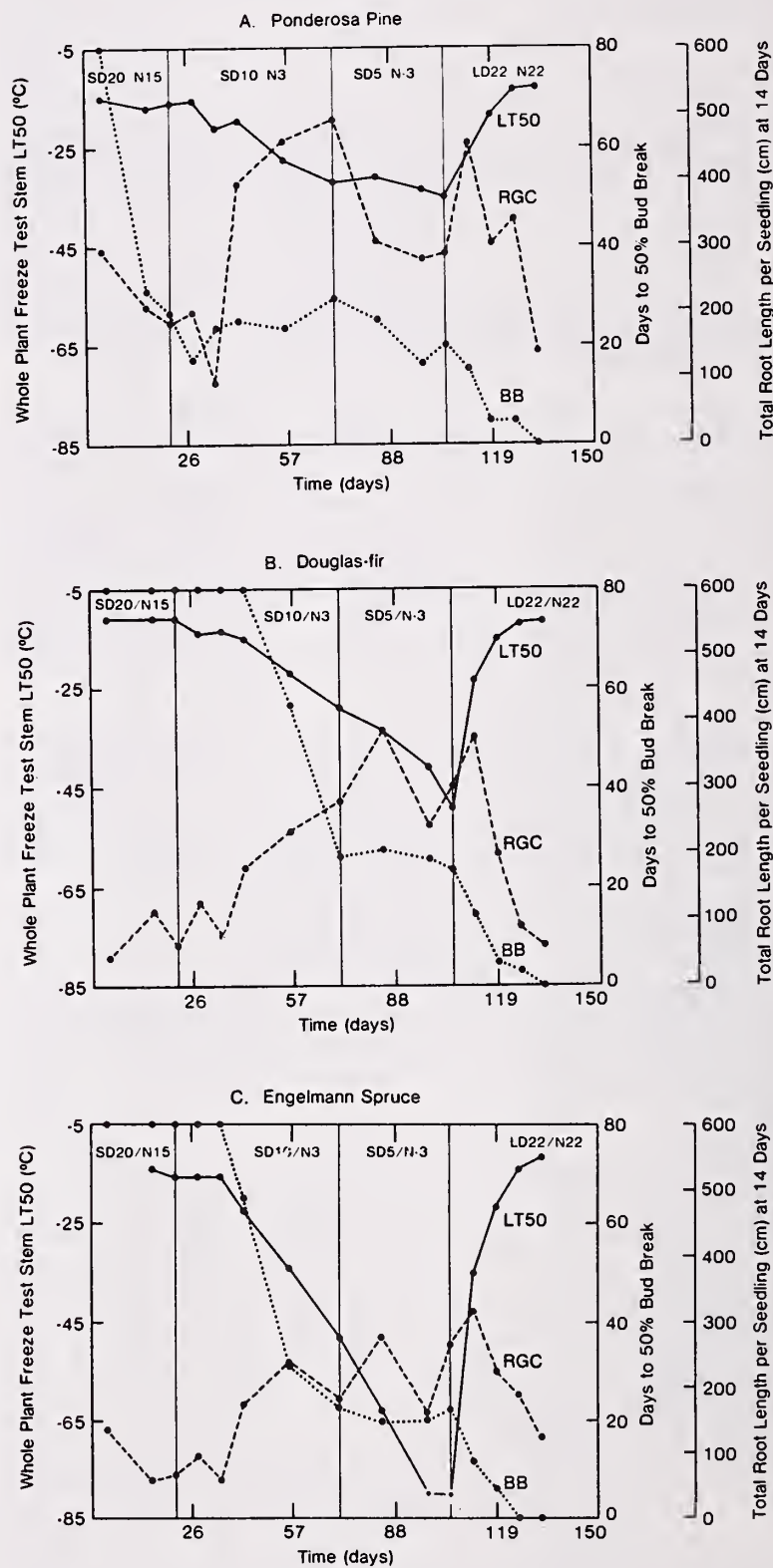


Figure 4.--Composite showing relation between stem cold hardiness (LT_{50}), root growth capacity (RGC), and days to 50% budbreak (BB) as a function of time for (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce.

Satisfaction of bud chilling requirements occurred at a level of cold hardiness that varied with species: in ponderosa pine -15 °C (no hardening), Douglas-fir -29 °C, and Engelmann spruce -48 °C. This relation may be species- and ecotype-specific, further testing will be required to substantiate this. However, some relation between cold hardiness and bud dormancy is likely as evidenced by the successful use of chilling degree hours to predict bud dormancy in many species (Cannell and Smith 1983, Owens et al. 1977).

During deacclimation, the putative second peak in RGC coincided with a two-thirds loss of stem cold hardiness and one-third of the time toward budbreak from the plateau representing days to budbreak after the chilling requirements were met. This relation could be very useful for determining planting stock quality in the early spring by measuring cold hardiness. By the time 50% budbreak occurred, both RGC and cold hardiness were at their minimum. It is therefore crucial to know the physiological condition of the seedling weeks and even months before 50% budbreak (Lavender 1985).

For ponderosa pine, requirements for budbreak were met about 2 weeks before the precipitous rise in RGC, but in Douglas-fir and Engelmann spruce meeting of bud chilling requirements occurred close to the first peak in RGC. For all three species days to 50% budbreak declined steadily from the beginning of deacclimation, whereas RGC appears to peak and then decline. A pulse of root growth prior to budbreak has been observed in many species (Ritchie and Dunlap 1980).

In this experiment, temperatures were selected for rapid deacclimation. Under less favorable conditions deacclimation would be slower, but the same sequence of events would probably occur. Whether the observed relations between cold hardiness, RGC, and budbreak will be the same under different conditions remains to be tested.

CONCLUSION

Relationships between cold hardiness, RGC, and bud dormancy have been found that support a hypothesis by Ritchie (1985) that such relations exist. At present, it is uncertain how far these results can be generalized. Other ecotypes of ponderosa pine (Jenkinson 1980, Read 1983) and Douglas-fir (Jenkinson 1984) are known to behave differently in many ways. Less is known about Engelmann spruce. Furthermore, these relations were observed under a single set of temperature and photoperiod conditions. Therefore, it would be a mistake to apply them immediately without further testing.

These results suggest cold hardiness testing could be a promising avenue for a quick estimate of RGC and bud dormancy. The whole-plant freeze test is not particularly fast, as it takes 7 days and sometimes longer, but faster tests are becoming available (Burr et al. 1986). It also appears that meaningful information from an RGC test may not be obtainable in less than 14 days (Burr, Tinus, and

Wallner, unpublished data), and certainly not in less than 7 days (Burdett et al. 1983).

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Comparison of Four Cold Hardiness Tests on Three Western Conifers¹

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Abstract.--Container-grown ponderosa pine, Douglas-fir, and Engelmann spruce seedlings were cold acclimated and deacclimated in growth chambers over 19 weeks. A whole-plant freeze test and three tissue tests were performed weekly. The whole-plant freeze test provided results in 7 days and indicated differences in cold hardiness between stems, buds, and needles. Results from a freeze-induced electrolyte leakage test and differential thermal analysis were available in 2 days and 1 hour, respectively. Both tests were good predictors of tissue cold hardiness when calibrated against the whole-plant freeze test. Ethylene and ethane evolution were poor predictors of the development of cold hardiness.

INTRODUCTION

The ability to measure cold hardiness is necessary for successful production and establishment of high-quality greenhouse and field-grown tree seedlings (Glerum 1985, Warrington and Rook 1980). It provides an essential tool for developing optimum greenhouse hardening regimes and for determining the timing of removal of stock from greenhouse to storage or field environments. It provides critical information for sound decisions regarding the timing of lifting, storage and handling, and outplanting of bareroot stock. Knowledge of cold hardiness can also substantially reduce losses from late spring and early fall frosts by establishing the need for protective measures.

The primary method used to assess seedling cold hardiness is the whole-plant freeze test (Ritchie 1984). Though the test is highly reliable, it is time-consuming and the results are not available for at least 7 to 14 days, which is not as soon as usually needed. There are,

however, physiological parameters which can be conveniently measured and utilized as tissue tests for cold hardiness that can provide results within 1 to 2 days, or as soon as 1 hour, depending on the test. If a consistent relationship exists between the results of the whole-plant freeze test and one or more tissue tests, seedling cold hardiness could be measured quickly. The reliability of the results from a tissue test would then depend on the calibration, or adjustment, of the tissue test results to match the whole-plant freeze test results.

This paper describes our evaluation of three tissue tests: freeze-induced electrolyte leakage, differential thermal analysis, and ethylene and ethane evolution. Each is quick, objective, and non-destructive of whole plants. Each has its strengths and weaknesses, however, and none are universally applicable. The purpose of this study was to assess the usefulness of these three tissue tests for predicting cold hardiness, and to make the first calibrations of the tissue tests against the whole-plant freeze test.

MATERIALS AND METHODS

Ponderosa pine (*Pinus ponderosa* Laws.), interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), and Engelmann spruce (*Picea engelmannii* (Parry) Engelm.) were greenhouse container grown, then cold acclimated and deacclimated in growth chambers over a 19-week regime as described by Tinus et al. (1986). At weekly intervals, samples of seedlings were taken for whole-plant freeze tests and root growth capacity

¹Paper presented at the Western Forest Nursery Council Meeting. [Tumwater, Wash., August 12 - 15, 1986].

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and bud dormancy tests. To establish a firm relationship between the whole-plant tests and the three tissue tests, all were done concurrently each week. An upper lateral branch or a pair of fascicles, depending upon the species, was removed from each of 20 trees per species in the weekly sample for use in the tissue tests, and then the seedlings were used for the whole-plant tests.

Whole-Plant Freeze Test

The procedures for the whole-plant freeze test and subsequent analysis were as described by Tinus et al. (1986). In addition to measuring percent injury to stem tissue in the whole-plant freeze test, percent injury to buds by a count of live and dead buds, and percent injury to needles by visual estimation of browning, were also measured after 7 days to provide a reference for comparison of the three tissues. The 50% injury points for the three tissues were estimated by regression and calibration methods, following pooling of the data by rate of injury across species, days, and tissue types.

Freeze-Induced Electrolyte Leakage

Measurement of electrolyte leakage from stressed tissue to assess viability is a technique developed by Dexter et al. (1930, 1932). When plant tissue is cooled to temperatures that cause injury, cell membranes are disrupted and electrolytes leak out. The greater the injury, the greater the leakage.

Needle segments, 1 cm long, cut at both ends, were prepared from the tissue samples pooled from the 20 trees per species each week. Segments were washed in distilled water and transferred in random groups of 10 to culture tubes containing 0.5 ml distilled water. Three control tubes per species were stoppered and placed in a refrigerated ice-water bath at 1°C. Treatment tubes, 21 per species, were placed in a Forma Scientific methanol bath at -2°C. After 0.5 hour, the water in the treatment tubes was nucleated with a -80°C wire and the tubes were stoppered. The methanol bath was then cooled at the rate of 5°C per hour. At each of seven test temperatures, selected to span 0 to 100% injury, three treatment tubes per species were removed to thaw in the ice-water bath. After all the tubes were removed from the methanol bath and thawed, 3 mls of distilled water were added to each of the 24 tubes per species and all tubes were stoppered and placed in a 100 rpm shaker at 24°C for 20 hours incubation. Conductivity of the solution in each tube was measured after incubation, and the tubes were then placed in a boiling water bath for 10 minutes to induce complete tissue injury. Conductivity was remeasured after an additional 20 hours incubation in the shaker.

³Trade names are used for brevity and specificity and do not imply endorsement by USDA or Colorado State University to the exclusion of other equally suitable products.

Test results, which were available in 2 days, were reported as percent index of injury (I), calculated by the formula

$$I = 1 - \frac{1-(T_1/T_2)}{1-(C_1/C_2)} \times 100$$

where T_1 and T_2 are the conductivity of the treatment solution before and after boiling, respectively, and C_1 and C_2 are the conductivity of the control solution before and after boiling, respectively (Flint et al. 1967). The formula adjusts the leakage resulting from the low-temperature stress for the leakage from unstressed controls and for the total leakage possible with complete injury of the individual samples of needle segments. The greater the index of injury, the less the cold hardiness at a test temperature.

A weekly data set consisted of 21 observations (three replicates at seven temperatures) for each species. A modified Gauss sigmoid model (Grosenbaugh 1965) was fitted to each set of 21 points (except Engelmann spruce data from days 84, 98, and 105 where linear regression was used) such that

$$I = b_1(1-b_2e^{-b_3t^{b_4}}),$$

where t represents temperature. Temperatures at various index of injury levels were estimated by inverting these models.

Differential Thermal Analysis

The cold hardiness of some tree species is related to a capacity for supercooling, or the cooling of water below the freezing point without ice formation (Burke et al. 1976). The extent of supercooling can be measured by differential thermal analysis. The profile of a cold-hardened bud that supercools (Burr et al. 1986) has two peaks or exotherms representing heat released by the freezing of water within the bud. The first exotherm represents freezing of extracellular water at approximately -6°C, which generally causes no injury to the bud. The second, or low-temperature, exotherm represents freezing of deep supercooled intracellular water and is associated with lethal injury (Sakai 1978). The temperatures at which low-temperature exotherms occur have been correlated with bud acclimation and deacclimation to cold (Tinus et al. 1985). This test can be used with members of many gymnosperm and angiosperm genera such as *Abies*, *Acer*, *Carya*, *Fraxinus*, *Gleditsia*, *Juniperus*, *Larix*, *Picea*, *Pseudotsuga*, *Quercus*, *Tsuga*, and *Ulmus* (Becwar 1980, George et al. 1974, Sakai 1978, 1979). In non-supercooling genera such as *Pinus*, however, the differential thermal analysis profile is of no diagnostic value because there is no low-temperature exotherm.

Nine well-developed buds of both Douglas-fir and Engelmann spruce were randomly selected each week from the pooled tissue samples for differential thermal analysis. Buds were excised from the stem tissue below the base or crown of the bud to ensure the integrity of morphological features promoting

supercooling (Sakai 1979). The cut surface of an excised bud was wetted with distilled water and dipped in a powdered synthetic mica nucleator to reduce supercooling of extracellular water. The bud was then placed in a small cylinder of aluminum foil. The foil cylinder was crimped around a copper-constantan differential thermocouple to insure contact between the thermocouple and bud. A similar foil cylinder without a bud was placed around a reference thermocouple. Several differential thermocouples and the reference were individually covered with small plastic centrifuge tubes and then placed in an aluminum block, which provided uniform cooling. The aluminum block, wrapped with heat tape to regulate temperature, was cooled in a -80°C freezer at 1°C per minute. The cooling rate was automatically controlled by a microprocessor-based controller connected to a variable transformer. Cooling of the block and freezing of water within the buds were documented by wiring the thermocouples through amplifiers and into strip chart recorders.

The aluminum block could be fitted with buds, assembled, cooled, and the data extracted from the strip charts within 1 hour. Mean low-temperature exotherm temperatures with 95% confidence intervals were calculated from each group of nine buds per species each week.

Ethylene and Ethane Evolution

Intact plant tissues synthesize ethylene at different rates during the various developmental stages of the annual growth cycle, with rates highest during active growth periods and lowest during dormancy (Seibel and Fuchigami 1978). Ethylene evolution from excised tissue harvested on different dates has been related in the same manner to the level of vegetative maturity and hardiness in white pine. Ethylene levels were highest in spring during active growth, declined to low levels in fall with vegetative maturity, and were not detectable during winter. Ethylene and ethane evolution have also been found to rise under conditions of stress and strain, respectively (Harber and Fuchigami 1986). The evolution of these two gases was examined not as a viability test, but to explore the hypothesis that the seasonal pattern of evolution of one or both might provide a predictive tool for determining the beginning and ending points of the winter dormancy period, or the starting of acclimation and deacclimation to cold.

Ponderosa pine needle tissue was used for the ethylene and ethane evolution test. Needle tip segments, 2 cm long, were prepared from the tissue samples pooled from the 20 trees each week. Segments were randomly placed into 10, 2 cc gas-tight serum vials, 10 segments per vial. Vials were incubated for 24 hours at 24°C in darkness. Following incubation, a 1 cc gas sample was taken from each vial using a gas-tight syringe, and analyzed for both ethylene and ethane using an Perkin-Elmer 990 gas chromatograph. An activated alumina column was used, and injection port, column, and detector temperatures were 75°C , 50°C ,

and 150°C , respectively. Preliminary results were available shortly after injections were completed, and final results, reported as ppm/mg dry wt./hour, were available after a 48 hour oven drying period.

Box plots were used to flag outliers in the final data set (Chambers et al. 1983). Six observations that were several, often more than 10, standard deviations from the mean were omitted after each was found to be biologically unreasonable or indicative of problems in experimental procedures. Mean rates of ethylene and ethane evolution with 95% confidence intervals were calculated for each week from the remaining observations.

RESULTS AND DISCUSSION

Whole-Plant Freeze Test

During acclimation and deacclimation, changes in the cold hardiness of needle and bud tissue of the three species followed the same general patterns as stem tissue (fig. 1). Ranking of the tissue types by maximum cold hardiness attained was the same in all three species when tissue differences occurred. Stem tissue achieved the greatest cold hardiness. Needle tissue cold hardiness was similar to that of stems during the first two stages of acclimation and during deacclimation, but did not reach the very hardy levels that stems did. Buds were consistently the least cold hardy of the three tissues in all three species.

The rate of cold hardening in all three tissues of ponderosa pine (fig. 1A) appeared to level out in the third stage of the regime, while in Douglas-fir (fig. 1B), only the hardening of bud and needle tissue stabilized. In Engelmann spruce (fig. 1C), there was no indication that maximum cold hardiness was reached in any of the three tissues.

Needle tissue may be slightly more cold hardy than stem tissue in Douglas-fir and Engelmann spruce during the last 2 weeks of deacclimation, but not in ponderosa pine. The last flush of growth in Douglas-fir was readily distinguishable from earlier growth, before the onset of hardening. During this time, the newest needles were significantly less cold hardy than older needle tissue, at the 95% level of confidence.

The importance of assessing the cold hardiness of the tissue types separately because of differential hardening, such as described here, has been recognized by other researchers (Blake et al. 1979, Timmis 1977). The differential hardening of tissues has a critical impact on the assessment of economic viability of planting stock. For this reason the Industrial Forestry Association has also incorporated separate ratings of needle, bud, and stem injury following freezing tests into their operational cold hardiness testing program (Glerum 1985).

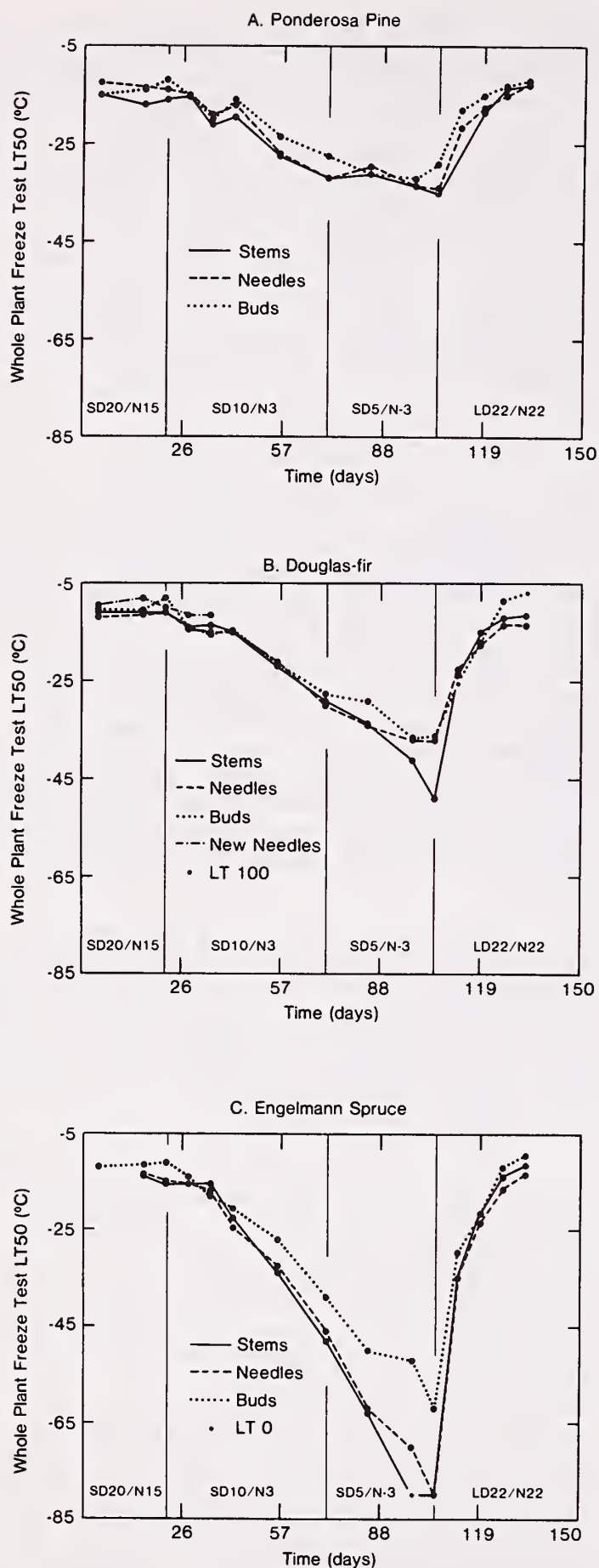


Figure 1.--Stem, bud, and needle cold hardiness of (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce as a function of time, determined by the whole-plant freeze test. Growth chamber conditions are indicated across the bottom of each graph and are described in Table 1 of Tinus et al. (1986).

The weekly models of percent index of injury of needle tissue as a function of stress temperature for the three species (fig. 2) are labeled by the day number on which the test was run. Models from days 0, 14, and 21 were from the first stage of acclimation; models from days 28, 35, 42, 56, and 71 were from the second stage; the third stage included models from days 84, 98, and 105; and the remaining models, 112, 119, 126, and 133, were from the deacclimation stage. The range in R^2 for all modified Gauss sigmoid models was .998 to .874. The three linear models, Engelmann spruce days 84, 98, and 105, had R^2 values of .867, .693, and .669, respectively.

Statistical differentiation of the models has not been completed, but preliminary indications are that the test can detect significant differences in cold hardiness of just a few degrees C, at the 95% level of confidence. After little change during the first stage of the regime, there was a gradual progression in cold hardening to day 105, the last data set before deacclimation. The proportionately large loss of cold hardiness during the first week of deacclimation was indicated by a similar change in index of injury from day 105 to 112. Deacclimation then proceeded at a slower rate to day 133 at the end of the 19 weeks. The difference in cold hardiness between new growth and the previous season's growth, after bud break at the end of the 19 weeks, was readily detectable. The new growth, model 133N, was less hardy than the previous season's growth, model 133, in all three species. Once hardened, the previous season's needles did not deharden by day 133 to the level of the new tissue, but retained some residual cold hardiness.

There was also a gradual change in the shape of the models with acclimation and deacclimation. For minimally hardy seedlings (e.g., days 0, 14, 21, and 133), any decline in temperature produced a large increase in injury. As plants became more hardy (e.g., days 84, 98, and 105), a similar decline in temperature produced less injury. This change in sensitivity to declining temperature is an important consideration when assigning critical minimum temperatures to seedlings.

The stress temperatures resulting in 50% index of injury of needles each week were estimated from the data in figure 2 and compared to the whole-plant freeze test temperatures resulting in 50% needle injury (LT_{50}) to examine the relationship between the results of the two tests (fig. 3). The freeze-induced electrolyte leakage test followed the changes in cold hardiness as indicated by the whole-plant freeze test quite well for all three species. However, with the exception of the last week of deacclimation, the freeze-induced electrolyte leakage test was a more conservative test because 50% index of injury occurred at a higher temperature than did 50% injury in the whole-plant freeze test. Calibration of the freeze-induced electrolyte leakage test was necessary because of this difference. Preliminary calibration indicated that the

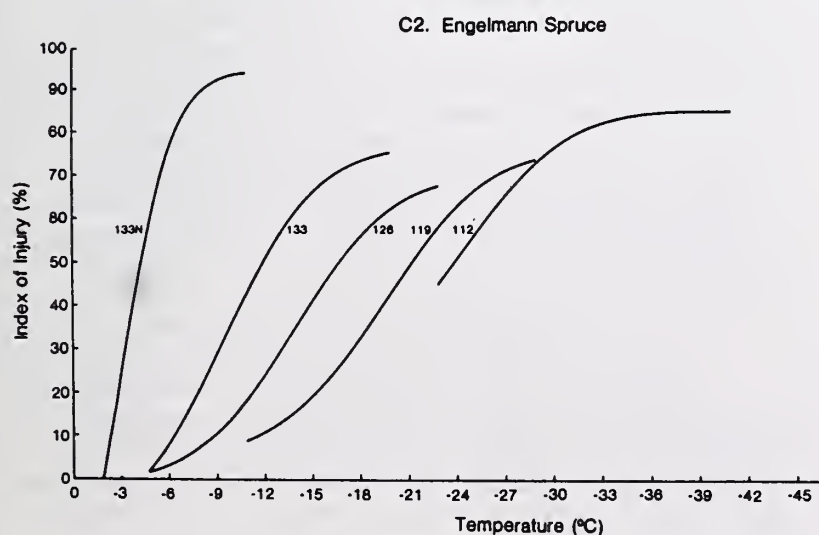
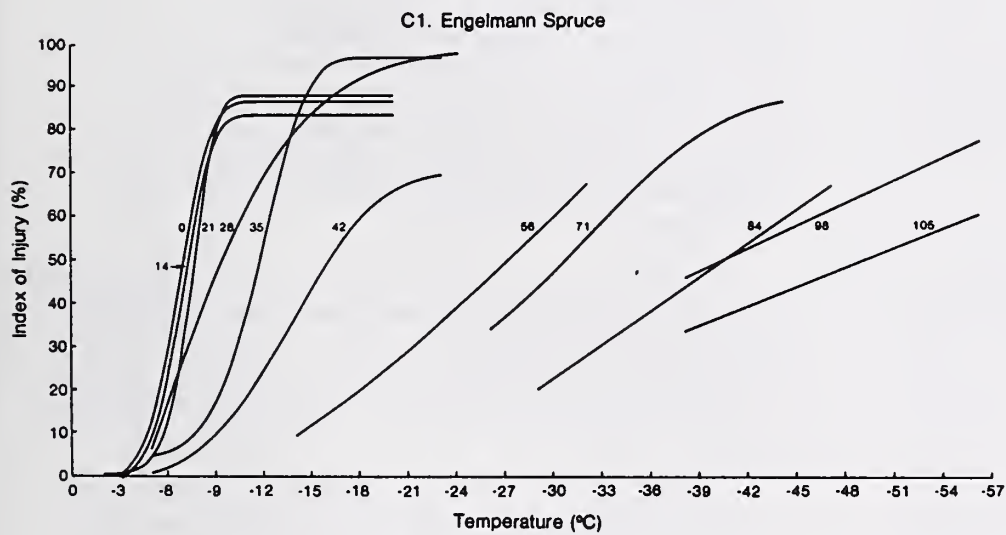
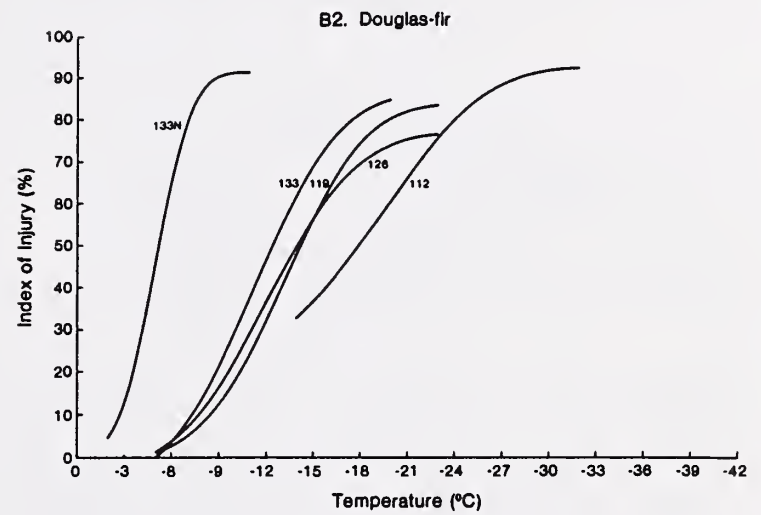
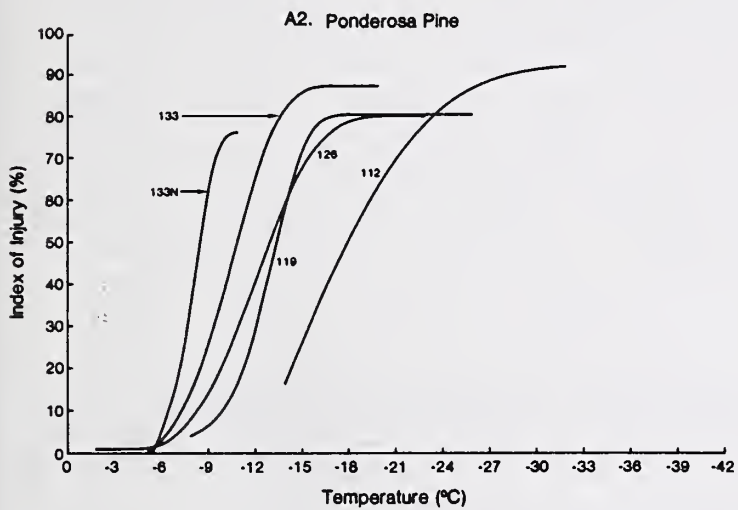
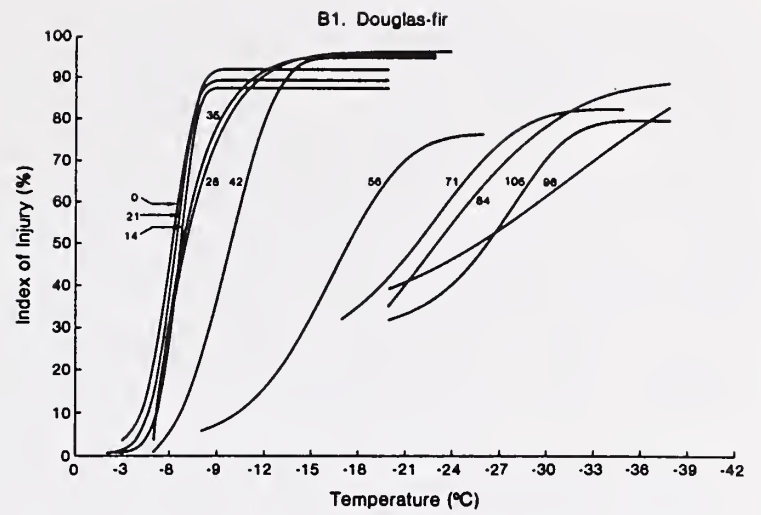
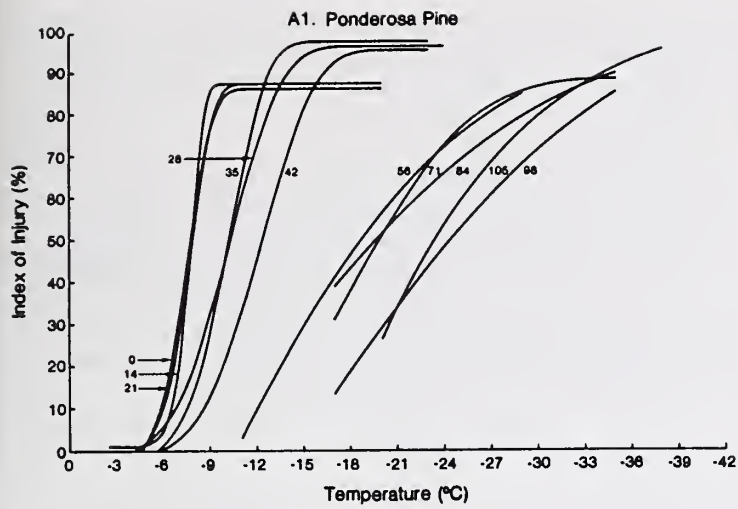


Figure 2.-- Weekly models of index of injury as a function of stress temperature for (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce determined by the freeze-induced electrolyte leakage test on needle tissue. Graphs A1, B1, and C1 show the weeks of acclimation, and graphs A2, B2, and C2, the weeks of deacclimation. Models are labeled with the day number on which the test was run, beginning with day 0 and ending with day 133. Model 133 N represents new needle tissue produced following bud break.

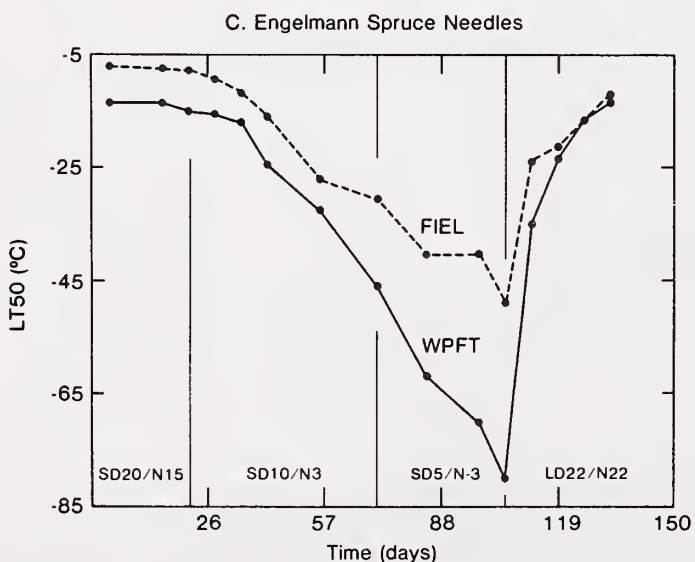
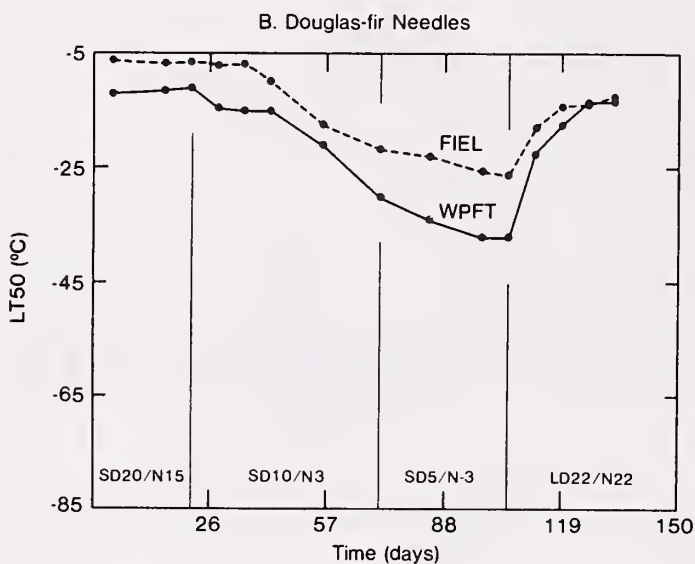
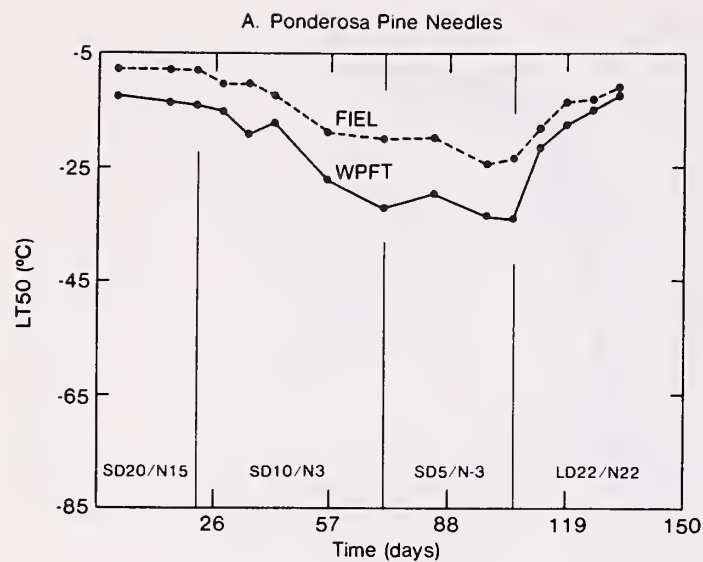


Figure 3.--Temperatures resulting in 50% index of injury to needle tissue in the freeze-induced electrolyte leakage test (FIEL) and 50% needle browning in the whole-plant freeze test (WPFT) as a function of time for (A) ponderosa pine, (B) Douglas-fir, and (C) Engelmann spruce. Growth chamber conditions are indicated across the bottom of each graph and are described in Table 1 of Tinus et al. (1986).

stress temperature resulting in 70 to 90% index of injury in the freeze-induced electrolyte leakage test frequently matched the whole-plant freeze test LT₅₀ during acclimation.

This test has been used by a number of workers on a range of coniferous tree species, including Scots pine (*Pinus sylvestris*) (Aronsson and Eliasson 1970), Monterey pine (*Pinus radiata*) (Green and Warrington 1978), Douglas-fir (*Pseudotsuga menziesii*) (van den Driessche 1969, 1976), and black spruce (*Picea mariana*) and white spruce (*Picea glauca*) (Colombo et al. 1982). These workers have reported a close relationship between electrolyte leakage from tissue samples and longer term development of visible injury symptoms of intact plants exposed to whole-plant freeze tests. Attempts to predict the lethal temperature of whole plants subjected to freezing tests based on electrolyte leakage of composite tissue samples (e.g. entire stem sections with needles and buds attached) met with variable success. Calibration of electrolyte leakage from a particular tissue to the response of that same tissue in a whole-plant freeze test has not been previously reported.

Differential Thermal Analysis (DTA)

The average weekly low-temperature exotherm temperatures of Douglas-fir and Engelmann spruce buds were compared to the whole-plant freeze test bud LT₅₀'s to examine the relationship between the results of these two tests. The DTA test results for both species followed the changes in cold hardiness as indicated by the whole-plant freeze test, but DTA was a consistently more conservative test (fig. 4). DTA data were not available during early acclimation, when bud cold hardiness was warmer than approximately -6°C, because any low-temperature exotherm was masked by the first exotherm.

Based on a sample size of nine, the precision of the low-temperature exotherm means allowed differences during acclimation of ± 2°C to be statistically detected (p=.95). Differences of ± 3 to 4°C were significant during deacclimation when the change in cold hardiness was more rapid.

In preliminary calibrations of DTA to the whole-plant freeze test, the average temperature at which the low-temperature exotherm occurred corresponded well with the lowest temperature at which no visible injury to buds occurred, or an LT₀, in the whole-plant freeze test (Tinus et al. 1986). Since the buds were the least hardy of the tissues, the average low-temperature exotherm temperature represented the lowest temperature at which there was no injury to the seedling as a whole.

Ethylene and Ethane Evolution

There was a general decline in the evolution of both ethylene and ethane from ponderosa pine needle segments during the 19-week regime (fig. 5). However, the data were so variable that both were poor predictors of seedling or tissue cold

hardiness. Some interesting patterns were evident, though. Each time the environmental conditions changed, ethylene evolution was stimulated. The peak in the first stage of acclimation followed the move of the trees from the greenhouse to the growth chambers, and the remaining three peaks occurred at the start of each of the subsequent stages. Greenhouse temperatures averaged approximately 26°C during the day and 20°C at night, with day length extended to 22 hours with fluorescent light. The change from greenhouse to growth chamber conditions was comparable in magnitude to

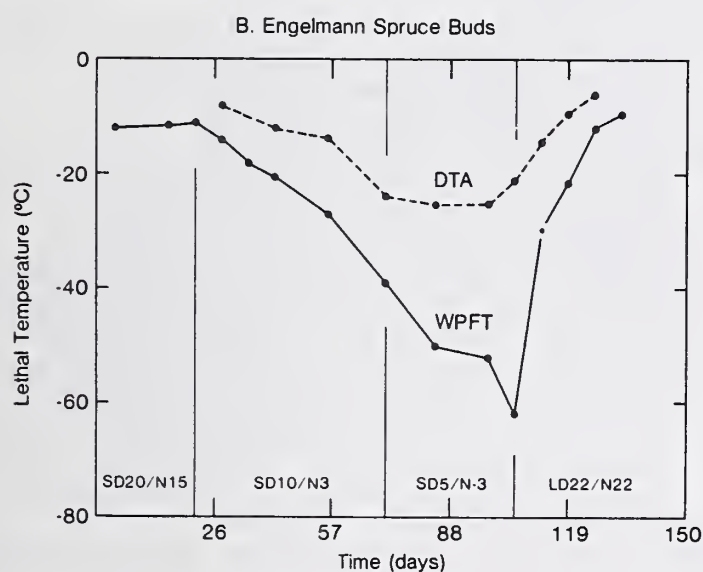
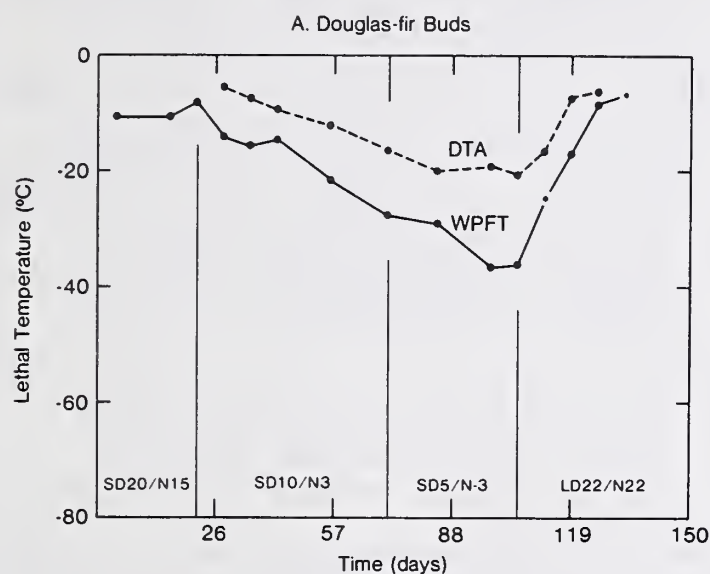


Figure 4.--The average low temperature exotherm temperatures from differential thermal analysis (DTA) of buds and the temperature resulting in 50% bud mortality in the whole plant freeze test (WPFT) as a function of time for (A) Douglas-fir, and (B) Engelmann spruce. Whole-plant freeze test data for Douglas-fir on day 112 represent an LT_{100} at -25°C, and on day 133 represent an LT_{85} at -7°C. Whole-plant freeze test data for Engelmann spruce on day 112 represent an LT_{100} at -30°C. Growth chamber conditions are indicated across the bottom of each graph and are described in Table 1 of Tinus et al. (1986).

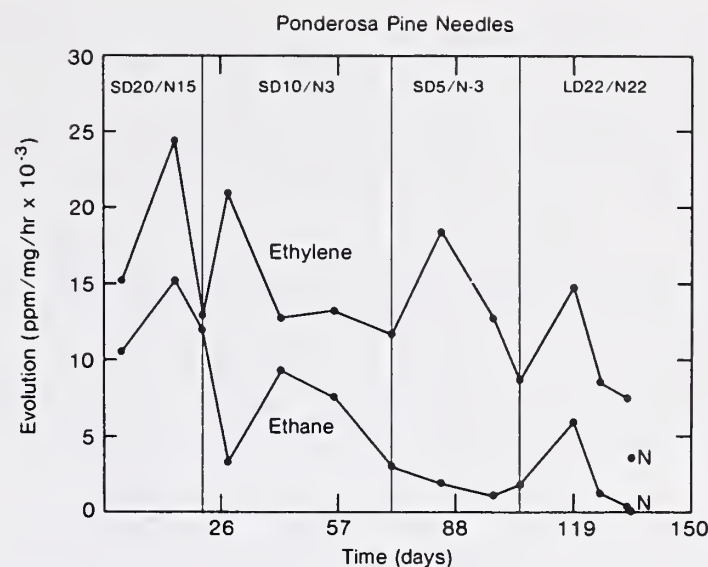


Figure 5.--Ethylene and ethane evolution from ponderosa pine needle segments as a function of time. Data points labeled 'N' represent evolution from new growth produced following bud break. The upper point is ethylene, the lower, ethane. Growth chamber conditions are indicated across the top of the graph and are described in Table 1 of Tinus et al. (1986).

the other changes. Though a rise in ethylene evolution may be an indicator of environmental change in general for ponderosa pine, the large standard errors of the means made detecting statistically significant differences over time difficult with the sample size of 10 that was used. Differences in ethylene evolution from new growth produced following bud break and the previous season's growth were not statistically significant (fig. 5).

The ethane evolution means were much more precise, and all the departures in the data from the general declining trend were significant at the 95% level of confidence. There was a large drop in ethane evolution as the trees began to cold harden in the second stage, and a large rise in ethane evolution as the trees began deacclimation in the fourth stage. Thus, ethane evolution may be a good indicator of the start of acclimation and deacclimation in ponderosa pine, even though the trees show no visible signs of these turning points in development.

CONCLUSION

The four cold hardiness tests are compared in Table 1. The whole-plant freeze test was most accurate, and could conceivably be used with all species, but the test was cumbersome, destructive of whole plants, and time consuming. Operationally, reliable whole-plant freeze test estimates would also require more plants than used here because of increased variability in field-grown crops.

With the species we tested, the freeze-induced electrolyte leakage test and differential thermal analysis were good, objective predictors of tissue

cold hardiness when calibrated to the whole-plant freeze test. They were both precise and thus detected slight changes in cold hardiness. The freeze-induced electrolyte leakage test, though it required two, 20-hour incubation periods, could be tested for use with all conifers, and a great many samples could be measured concurrently with no increase in equipment. It is already being used operationally, with modified methods, because of these advantages (Colombo et al. 1984). The main advantage of differential thermal analysis is that the results can be available within an hour. Buds are also very convenient to sample, require minimal preparation, and exhibit well-defined exotherms. However, the test can only be used with species that deep supercool, and only when reasonably well-developed buds are present. Additionally, differential thermal analysis requires complex equipment which is not readily expandable to handle large sample sizes.

Ethylene and ethane evolution from needle tissue were both poor predictors of cold hardiness in ponderosa pine, but further research may show ethane evolution to be a good indicator of the start of acclimation and deacclimation in this species. The usefulness of this test for assessing the development of cold hardiness in other species has yet to be investigated. The major advantage of such a test is that the tissue sampled requires no exposure to stress temperature treatment.

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Table 1.--Comparison of four cold hardiness tests.

	Predictive ability	Species applicability	Tissue needed	Time required
Whole plant freeze test	excellent	all	whole plant	7-14 days
Freeze induced electrolyte leakage	good	all conifers	needles	2 days
Differential thermal analysis	good	only supercooling	buds	1 hour
Ethylene and ethane evolution	poor	unknown	needles	1 day

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A New, More Efficient Method to Evaluate Root Growth Potential of Planting Stock Using a Root Area Index¹

W. J. Rietveld²

Abstract.--Root growth potential (RGP), the ability of seedlings to promptly and abundantly initiate and elongate new roots after transplanting, is an important and useful attribute of planting stock performance. However, it is generally laborious, tedious, and subjective to measure. A method was developed that employs aeroponic culture of seedlings in a root mist chamber (RMC) and measurement of root growth by changes in root area index (RAI) with a TV camera-based microprocessor area measurement system. The area meter scans each horizontal TV line and sums the segments that are traversed by roots. A high resolution camera was used for accurate area measurement of roots. The method consists of: (1) pre-measuring RAI of individual seedlings, (2) growing seedlings in the RMC for ca. 2 weeks (depending on species), (3) staining new roots to make them visible to the camera, and (4) remeasuring RAI of individual seedlings.

An experiment was conducted to compare xylem water potential (XWP) of seedlings grown in the RMC with that of seedlings grown in pots of medium and seedlings grown in hydroponic culture. XWP, measured with a pressure chamber, of seedlings grown in the RMC was similar to that in potted seedlings, and increased (became less negative) when new roots were initiated. Seedlings in the RMC initiated new roots 1 week sooner than potted seedlings. XWP in hydroponically grown seedlings steadily decreased and very few new roots were present after 20 days.

A second experiment determined the relationship between root growth quantified by difference in RAI and that quantified by direct measurement of new root number and length. A range in RGP was accomplished by placing groups of 10 jack pine 2-0 seedlings in a forced-air oven (40°C, 30% RH) for 0, 10, 20, 30, and 40 min, then growing them in the RMC for 17 days. Root growth of individual seedlings was evaluated by the RAI method and by counting and visually estimating length of all new roots >0.5 cm. Linear regression of individual seedling data revealed r^2 values of 0.88 and 0.90 for predicting number of new roots and length of new roots, respectively, from difference in RAI. Eleven seedlings/person/hour were completed using the visual estimation method compared to 32 seedlings/person/hour using the RAI method.

This research documents the accuracy and productivity of the RAI method. Observer subjectivity is nearly eliminated.

¹ Paper presented at the Proceedings of the Western Forest Nursery Council

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Monitoring Cold Hardiness of Tree Seedlings by Infrared Thermography¹

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Abstract.--In this first known attempt, infrared imaging was used to relate foliage temperature to dormancy and degree of cold hardiness in tree seedlings. Species studied were Engelmann spruce, ponderosa pine, and Douglas-fir from northern Arizona. Preliminary results suggest that the dynamic responses of the foliage to changes in light (on/off) are potentially related to degree of cold hardiness. Until these initial results are confirmed in more exhaustive studies, and understood, infrared thermography cannot be recommended as an operational tool for seedling evaluation.

INTRODUCTION

For successful plantation establishment, tree seedlings must be in proper condition to survive the shock of outplanting and to establish a root system in intimate contact with the soil. The condition of a seedling at any time is determined by the interaction of its genetic capacity and the sequence of events to which it is exposed, including the magnitude, timing, and duration of the environmental conditions (Jenkinson and Nelson 1984).

Even if it were possible to know in detail the entire history of the seedling, current understanding of plant physiology would not allow a precise determination of seedling capacities from that history. For this reason there has been a significant amount of effort spent over the last few decades looking for a test or measure of seedling condition that is

related to, or predictive of, a response of interest. For the nursery manager, the response of interest could be the capacity to grow new roots at a rate sufficient to ensure seedling survival and rapid early growth following outplanting. The time of interest could be when the seedlings in the nursery enter the physiological condition that makes them capable of being lifted, processed, and outplanted and still retain the capacity to respond favorably in the field. For the regeneration forester, the response of interest may be the same, but the time of interest is later, after everything but planting has become part of the seedling's history. In both cases, once seedling condition is known, decisions can be made and options chosen based on a reasonable anticipation of outcome. To be useful, however, such knowledge must be readily available in time to make the decision or choose the option.

The test applied must meet several criteria. It must be reliable, reasonably easy to use, and not particularly subject to error. In addition, it must be based on principles, processes, or relationships that are sufficiently "known and understood" so that variations in test conditions and results can be interpreted.

This paper reports a study of infrared thermography as a potential means of identifying when tree seedlings change physiological state (e.g., change in dormancy status or frost hardiness level).

¹Paper presented at the Western Forest Nursery Council Meeting. [Olympia, Washington, August 12-15, 1986].

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INFRARED THERMOGRAPHY

Using thermal imaging technology currently available commercially, it is possible to create a clear and precise TV-quality image based on surface temperature patterns within a scene. Temperature differences of as little as 0.1°C are apparent, and quantitative data can be extracted from the image.

The major plant factor affecting seedling temperature under a given set of environmental conditions is stomatal conductance (a function of stomatal aperture), because of its effect on transpiration rate and therefore the degree of evaporative cooling. Stomatal conductance is affected by several plant and environmental factors--e.g., plant water stress, light intensity, relative humidity--that usually vary over relatively short time periods. In addition, however, some evidence suggests that stomatal behavior varies over longer, phenology-related periods, perhaps associated with state of dormancy and cold hardiness. Most of this evidence suggests that stomata are more nearly closed (decreased conductance) and respond less to environmental factors including light, when the seedling is dormant (Christersson 1972; Kozlowski 1943; Parker 1963). However, some trees (e.g., coastal Douglas-fir) increase stomatal conductance (stomata more open) during the winter, and their stomata remain open at night (Murphy 1979; Running 1976). If it were possible to isolate seedling temperature patterns attributable to phenology-related changes in stomatal behavior, infrared thermography might be developed into a useful tool for evaluating seedling dormancy or cold hardiness or both.

Current infrared technology is sensitive, easy to use, does not affect the seedling in any way, and produces images that potentially contain far more information than would a single point measurement of temperature or transpiration rate. Preliminary observations of several coniferous species suggested that seedling temperature (as measured by thermography) varies in relation to length of time since beginning of emergence from the last stage of dormancy (Weatherspoon and Laacke 1985).

Thermography could be used for other purposes such as monitoring effectiveness of irrigation systems through effect on relative water stress (Vicek and King 1983).

Stage 1	Stage 2	Stage 3	Stage 4
3 weeks	7 weeks	5 weeks	4 weeks
10-hr day	10-hr day	10-hr day	16-hr day
20°C day	10°C day	5°C day	22°C day
15°C night	3°C night	-3°C night	22°C night

Figure 1.--Environmental conditions during the four stages of the 19-week regime. Stages 1 through 3 were successive steps in hardening, stage 4 was the dehardening time.

METHODS

This study was designed and implemented as an addition to the ongoing work of Dr. Richard Tinus of the Rocky Mountain Forest and Range Experiment Station, USDA Forest Service.

Seedlings of Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), and ponderosa pine (*Pinus ponderosa* var. *scopulorum* Engelm.) were greenhouse grown in 400 ml Rootainers,⁴ one seedling in each of the four compartments of the folded container, or "book." Beginning in June, 1985 they were moved to growth chambers where photoperiod and day/night temperatures were altered in four stages over a period of 19 weeks, first to induce cold hardiness and then to promote dehardening (fig. 1). A full description of the environmental conditions maintained during each stage, as well as the physiological results of the hardening and dehardening regime, are described in papers by Tinus et al. and Burr et al. elsewhere in these proceedings.

Apparent foliage temperatures were measured with an Inframetrics 525 Imaging Radiometer at the time of each scheduled stage change. At each measurement time, infrared images of seedlings were recorded on video tape which, along with appropriate instrument data and verbal notes, permitted later quantification of seedling temperatures.

Seedling temperature is affected not only by stomatal conductance, but also by a number of environmental variables. To try to minimize the effects of these other variables, we made most of the thermographic measurements in a separate "measurement" growth chamber maintained as nearly as possible under constant environmental conditions. Temperature was set at 20°C

⁴ Tradenames and commercial products and enterprises are named solely for information. No endorsement by the U.S. Department of Agriculture is implied.

during both light and dark periods. Relative humidity generally ranged from 25 to 35 percent. During light periods, sodium and mercury₂ vapor lamps provided about 150 $\mu\text{Es}^{-1}\text{m}^{-2}$ of PAR (photosynthetically active radiation) at seedling height. This level of radiation permitted near-maximum stomatal conductance in actively-growing, well-watered seedlings, yet minimized temperature differences between shaded and directly irradiated portions of a seedling.

Eight seedlings of each species were removed from the conditioning environment at the end of each stage throughout the hardening/dehardening cycle and placed in the measurement chamber. Infrared temperature measurements were begun the day following removal and were continued for 2 days. During this time thermographic measurements were taken through transition periods from lights off to lights on, and from lights on to lights off. Measurement began before light conditions were changed and continued for up to 3 hours. The seedlings were then placed in the root growth capacity test described by Tinus et al. (these proceedings).

For measurements in the chamber, the sensor was mounted on a remotely controlled swivel and the seedlings were arrayed in a semi-circle equidistant from the swivel point. Air temperature in the chamber was monitored in three ways: (1) A dial thermometer was inserted through the wall of the chamber and into the air flow before it passed over the seedlings. Temperature indicated on this thermometer was recorded at the beginning of each sensor scan. (2) A recording hygro-thermograph was placed in the chamber in the center of the semi-circle of trees and below the level of the foliage. Air temperature and relative humidity were recorded continuously on a 7-day chart. (3) Additional temperature references, readable by the infrared sensor, were placed in the chamber to provide a real-time indication of air temperature in the vicinity of the seedling and as a visual reference in reviewing the video tapes. These non-standard temperature references, or "wicks," were wedges of filter paper held by one end in plastic soda straws and displayed as fan-shaped objects close to the foliage of the trees to be measured. One was kept wet by immersing one end in a bottle of distilled water. This was intended to provide, along with the temperature of a similar but dry wick, a reference to relative humidity. Ultimately, only the temperature of the dry, white wicks was used as the thermal reference for air temperature. In this report, all foliage temperatures are described as degrees centigrade above or below air temperature.

During the dehardening stage, supplementary measurements were taken on a table outside the

measurement chamber. For the first 2 weeks of the dehardening stage, these measurements were taken daily to monitor anticipated rapid changes in physiological condition of seedlings. For the time required to take the measurements, seedling containers were placed on a rack inside a large 3-sided cloth enclosure open at top and bottom. This was done to measure seedling temperature responses without the forced air flow--unavoidable within the chamber--that tended to mask the effects of stomatal conductance on seedling temperature. A bank of lights--producing 4000 lux of cool, white, fluorescent light--was suspended 60 to 90 cm (2 to 3 ft) above the seedlings. A shielded mercury thermometer was suspended just above the seedling tops. As in the measurement chamber, dark-to-light and light-to-dark transitions were monitored.

When the dehardening stage began, a supply of seedlings of each species was held in conditions of the third stage of hardening (fig. 1). Two books of four seedlings of each species were removed at about 2-day intervals and placed in the dehardening conditions of stage 4 (fig. 1). This provided the opportunity to test seedlings at three different states of dehardening at the same moment and under the same conditions. Measurements were continued daily for 10 days.

RESULTS AND DISCUSSION

Hardening Period

At the end of the greenhouse phase, and before seedlings were placed in stage 1 hardening conditions, foliage/air temperature differences were near zero during dark periods for all species. When lights were turned on, foliage temperatures dropped to between 1° and 2°C below air temperature. In successive light periods no one species was consistently warmer or cooler than the others. The general pattern of temperatures is consistent with the type of stomatal behavior expected in actively growing plants.

At no other time in the 19-week regime did foliage temperatures warm up to air temperature in the dark, even after 16 hours of uninterrupted darkness during dehardening. The time when foliage temperatures returned to air temperature corresponded with the only time in the 19 weeks that fully matured, current-year's foliage, as yet unexposed to hardening conditions, was present.

At the end of the first stage of hardening, differences between species in general foliage temperature appeared. Ponderosa pine and Douglas-fir were similar and both warmer, on the average, than Engelmann spruce. During light-to-dark and dark-to-light transition, ponderosa pine and Douglas-fir foliage temperatures overlapped.

At the end of the second stage of cold hardening, relative temperature of Engelmann spruce fell farther below the other two species. On the first day after removal from the treatment chamber, ponderosa pine was warmer than Douglas-fir. By the second day, ponderosa pine was cooler than Douglas-fir, and Engelmann spruce became even cooler relative to the other two. A possible explanation for the change in relative position of the species is that low soil temperature in the container (residual from the induction treatment) affected ponderosa pine more than Douglas-fir, and the resulting increase in resistance to water uptake and movement reduced the amount available for transpiration and, therefore, increased the tissue temperature. By the second day, sufficient warming could have occurred to allow pine to absorb and transport water more easily. This relative difference would be consistent with data on other species that indicate a greater effect of cold soil on low elevation or low latitude sources relative to those from higher elevation or higher latitude (Kozlowski 1943; Kramer and Kozlowski 1979) and with the relative elevations of the sources of all three species.

At the end of the third stage of cold hardening, relative temperatures of the species changed again. At this time Douglas-fir and Engelmann spruce had equivalent temperatures and both were warmer than ponderosa pine.

On the first day after placement in dehardening conditions, the foliage temperatures of all three species were equivalent. However, after 4 weeks in uniformly warm temperatures, Engelmann spruce had again assumed, on the average, a lower temperature than the other species.

It was obvious during the three cold hardening stages that foliage temperature varied from place to place on seedlings of all species. A common situation, especially for Engelmann spruce, was an area of foliage that was distinctly cooler than the rest of the seedling. Occasionally areas would develop that were distinctly warmer than the rest of the seedling. For example, branch tips of Engelmann spruce were occasionally up to a degree warmer than the general foliage. Temperature patterns periodically developed on seedlings with a range of 1.3° to 4.3°C difference between the warm areas and the cool areas.

More detailed data were gathered during the dehardening period because it was possible to measure the same seedlings repeatedly over an extended time. During the transition time from maximum to minimum cold hardiness (time of bud break), response of seedlings to light changes varied at different stages of dehardening. By the time the process was complete, seedlings within each species responded very much alike (fig. 2).

If physiologically reactive stomates tend to close in the absence of light, transpiration should be reduced and foliage temperature should increase relative to air temperature when lights are turned off. Until Douglas-fir seedlings had lost an estimated 30% of their acquired cold hardiness, the temperature of the cool areas on the seedlings decreased or remained unchanged relative to air temperature when the lights were turned off. After losing about 30% of the total hardiness gained, temperature of the cool portions of the plant increased in the absence of light.

General temperature response patterns to changes in light (on or off) did not change although differences between foliage and air temperature did change with water availability. Foliage temperatures increased as container medium dried between waterings.

For ponderosa pine, foliage temperatures began to increase relative to air temperature when lights were turned off, after 20% of the maximum attained hardiness was lost. Engelmann spruce, however, never did settle into a stable pattern. Temperatures did generally stop dropping relative to air temperature after about 20% of the maximum cold hardiness was lost. Only after about 75% of the acquired hardiness was lost did the foliage temperature increase relative to air temperature when the lights were turned off.

SUMMARY AND CONCLUSIONS

The study reported here was the first step toward determining applicability of thermal imaging systems in assessing physiological state of seedlings (for example, their status regarding dormancy or cold hardiness). As such, it must be viewed as exploratory. Because the study was opportunistic in the sense that it was added on to another, more intensive study designed to answer different questions, the amount of manipulation was limited. For this reason, and because of restrictions on the randomness of seedling selection (seedlings were

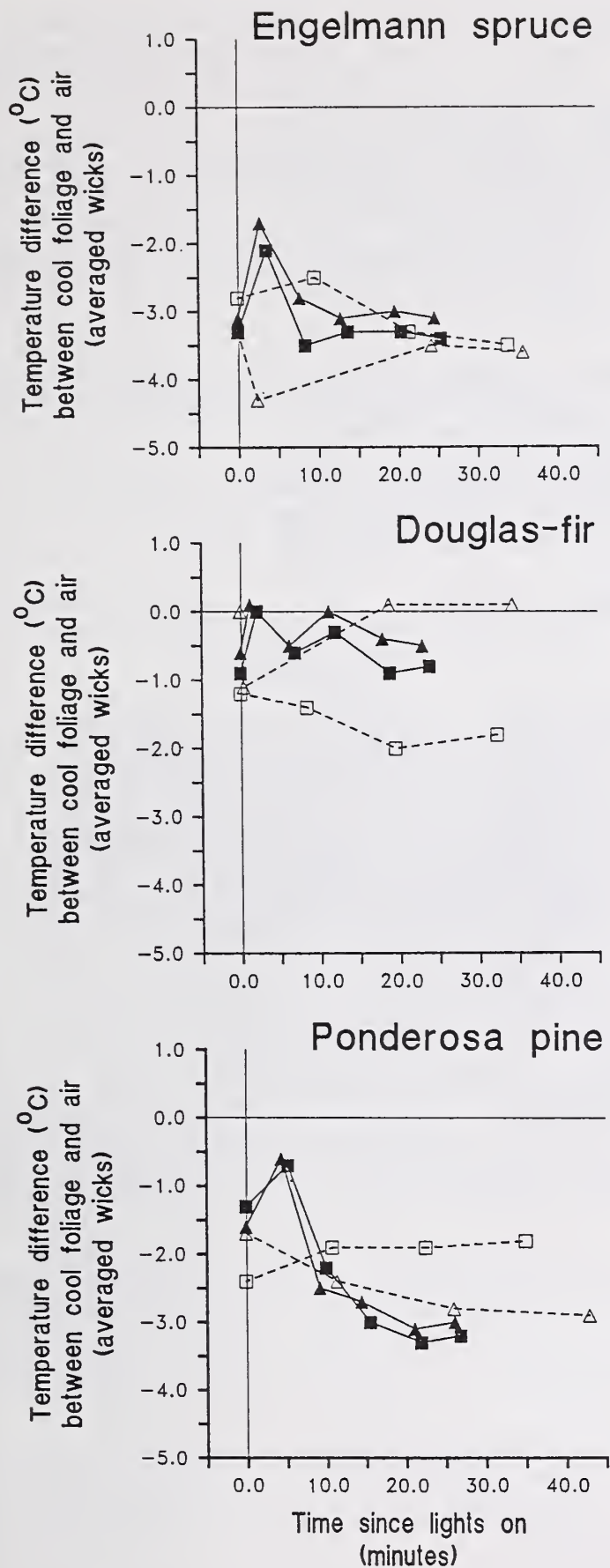


Figure 2.--Temperature response of cool regions on the seedlings during the first hour after turning lights on. Data are average temperatures of seedlings 1-4 at 3 days (open triangles) and 29 days (shaded triangles) and of seedlings 25-28 at 3 days (open boxes) and 22 days (shaded boxes) after removal from stage 3 hardening conditions.

in books of four seedlings each, were limited in number of books, and were measured in the same growth chamber) statistical analysis was limited to description of averages only. Notwithstanding, several responses were observed that could be important to further research:

- Confirmation of the observed change in temperature response with relative degree of cold hardiness during the dehardening period, and demonstration of similar changes during the hardening process, could be the basis of a useful tool.

- The observation that changes in water availability do not change the initial temperature response pattern, but only the actual temperatures achieved, must be carefully verified. If true, a series of potential obstacles to the operational use of thermography (e.g. differing soil water potential, low soil temperatures) are reduced or removed.

- Seedling response to the transition from light to dark is potentially more useful to monitor than is the transition from dark to light.

- The time of most useful response appears to be in the first 20 minutes after a change in light.

- Foliage on a seedling is not all the same temperature, and the cool areas appear to be more useful in defining response patterns than is the general temperature of the seedling.

- Engelmann spruce foliage temperatures were surprisingly low relative to air temperature and dropped as hardiness developed. This observation suggests that stomatal conductance could be high in the winter, a situation similar to coastal Douglas-fir but unexpected in a high elevation continental species.

This study has clearly identified some significant areas for further research and suggests that much could be learned about seedling physiology using thermography. There are tantalizing hints of approaches for use of the method in tracking dormancy or cold hardiness. For example, if the patterns of temperature change following removal of light are verified to be related to cold hardiness state, then an operational test might be developed that would be completed in less than 30 minutes rather than days or even weeks.

For future studies, given the timing of root growth capacity and development of cold hardiness described by Tinus et al. and Burr et al. (these proceedings), it would be desirable to schedule thermographic measurements during

the time the seedling physiology is changing rather than at times when growth chamber conditions change.

However, thermography cannot be suggested as a useful tool until some of the responses noted in the study are verified and understood.

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Root Growth Potential in Coastal Container Species: Trends from Operational Testing and Prediction of Outplanting Performance

B.G. Dunsworth¹

Abstract. One-week root growth potential tests appear adequate for operational go/no go decisions on coastal container and bareroot planting stock. Stress resistance mechanisms related to dormancy intensity and cold hardiness appear to play a more significant role than root growth potential for seedlings with a reasonable ability to produce roots.

INTRODUCTION

Assessments of a seedling's ability to produce roots have been evolving since the work of E.C. Stone in California in the late 1950s. Much of the initial work focused on understanding the progression of root phenology in seedlings, what the root growth stimulus was, and how it might be related to such things as bud dormancy, carbohydrates (current or stored) and outplanting vigor.

The major impediment to using root growth potential assessments as an operational forestry tool was the two-month duration of the test. By the time "poor" seedlots were identified, it was too late to act. A.N. Burdett² (1979) developed a rapid test (1 week) and assessment method which made possible operational assessment in white spruce and lodgepole pine. This method was found to be well correlated with outplant survival.

MacMillan Bloedel (MB) had been concerned about plantation performance in coastal conifers for many years prior to the development of Burdett's test in 1979. Most foresters believe many of their plantation failures could have resulted from poor stock quality.

The establishment of a private container nursery in 1979 and confirmation of a number of bareroot plantation failures in 1982 being directly related to low root growth potential,

led to MB instituting operational root growth potential monitoring in 1984.

The operational testing was established as the first in a series of steps to:

- eliminate planting stock with a low probability of success prior to shipment
- improve nursery culture to such a point that the probability of producing low vigor planting stock was minimized.

ROOT GROWTH POTENTIAL (RGP) METHODOLOGY

The rapid RGP test² has been used as an operational monitoring system by MB in the following fashion:

1. Sampling: Samples (25 trees/seedlot) are taken on a regular basis from time of lift to time of plant.
2. Growing Medium: Seedlings are potted in 20-centimeter diameter pots, 5 seedlings per pot. Medium consists of a 1:1 peat:vermiculite mix maintained at a pH of 4.5.
3. Growing Environment³: Pots are kept at field capacity in a controlled environment for one week at:

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²Burdett, A.N. 1979. New methods for assessing root growth potential: their value in assessing lodgepole pine stock quality. Can. J. For. Res. 9:63-67.

³Recent evidence from the B.C. Ministry of Forests (Dr. W. Binder) suggests that the optimal environment for root expression in most coastal conifers is closer to 22°C/18°C (D/N). Our 1986 operational evidence using both environments confirms this, particularly for species with poor heat tolerance. However, improvement of prediction of outplant success (survival and growth) has yet to be proven.

30°C day temperature 400u einstein light intensity
 25°C night temperature 75% relative humidity
 16 hr photoperiod

4. Indexing: After one week each seedling is scored for root activity using the index developed by Burdett (1979). These values are averaged to give a single value for each seedlot. The index is as follows:

Indexing Value	Number of New Roots	Indexing Value	Number of New Roots
0	none	4	11-30 >1 cm
1	some, none >1 cm	5	31-100 >1 cm
2	1-3 >1 cm	6	101-300 >1 cm
3	4-10 >1 cm	7	>300 >1 cm

RESULTS OF OPERATIONAL MONITORING AND PREDICTION OF OUTPLANT SURVIVAL

The following graphs illustrate how RGP of operational planting stock is related to operational and research outplant performance during 1984 and 1985. Note: RGP of 1.0 is currently considered the silvicultural soundness level. Plantation survival of 80 percent is the MB, Designated Forest plantation target.

1984/85 Operational Results

The shape of the RGP versus time curve (Fig. 1) illustrates the general case of RGP rising and then falling as planting stock progresses from lift through storage. Our operational evidence suggests that the positioning and shape of this generalized curve for any given season is dependent on species, seedlot, and cultural factors at the nursery level related to dormancy induction and hardiness. Chilling (natural and stored) may play a strong role in controlling RGP levels and timing.

Analysis of operational RGP testing and plantation performance data (Fig. 2) indicates that RGP can be used as a red light/green light tool for survival and that seedlings with some new roots, none >1 centimeter, would be a reasonable cutoff for sound planting stock.

Our ability to accurately predict outplant survival for seedlings exhibiting any number of new roots >1 centimeter is weak. For these seedlings, other physiological processes interact with limiting planting site conditions to influence seedling survival to a much greater degree than RGP.

1985 Common Garden Results

Douglas-fir seedlots were lifted February 15 and either planted or stored for 6 weeks or 21 weeks and planted. Outplantings were established in a non-irrigated, seed orchard field. The site was plowed to facilitate planting; vegetation was

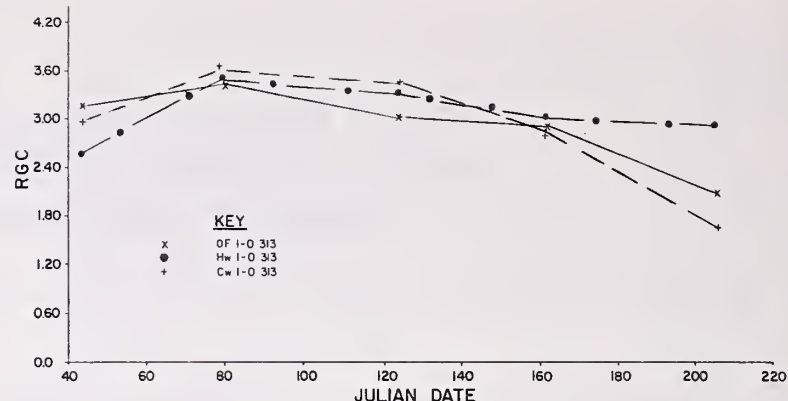


Figure 1. This figure illustrates the progression of root growth capacity in storage for three containerized coastal species: Douglas-fir, western hemlock, and western red cedar. All seedlings were lifted during the first week of February 1985.

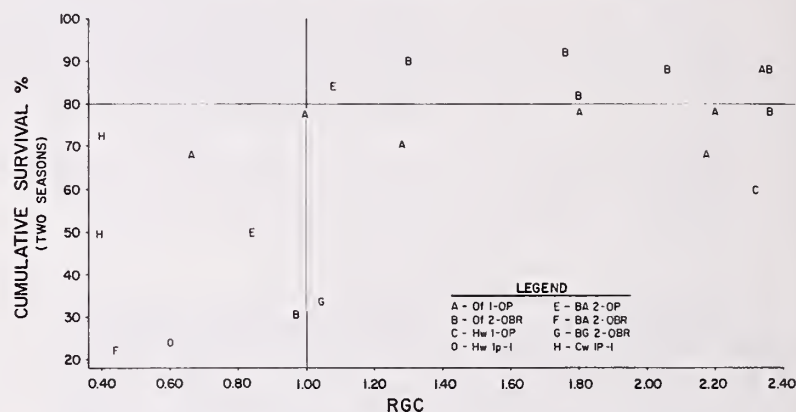


Figure 2. Plantation survival tends to drop rapidly for seedlots with no new roots >1 centimeter in most coastal conifers.

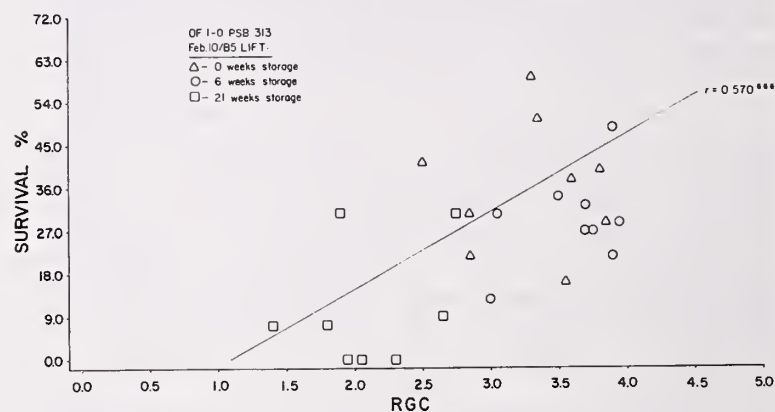


Figure 3. Containerized Douglas-fir seedlings exhibit high survival with high RGC and low survival with low RGC.

not controlled during the growing season. Seedlings were also potted and assessed for dormancy intensity⁴ under greenhouse conditions at each outplant date.

The outplant site and the 1985 growing season combined to provide severe drought for our test. Mortality was high but this provided a unique opportunity to assess the predictive powers of RGP and dormancy intensity under severe outplant conditions.

Figures 3 through 5 illustrate the relationships between RGP, dormancy intensity

⁴Dormancy Intensity = 10/number of days to budburst.

(DRI) and survival among a number of coastal Douglas-fir seedlots during 1985.

Within any of the three storage durations, RGP was a poor predictor of survival (Fig. 3). However, when considered as a group, seedlots with high RGP tended to survive better than those with low RGP. All seedlots had some roots greater than one centimeter in a one week-test ($RGP = >1.0$).

Survival was also reasonably well correlated with dormancy intensity (Fig. 4). Within a storage duration-planting date combination, those seedlings which burst bud rapidly consistently survived the best. This may be due to the fact that rapid initiation of growth (shoot and root) enhances a seedling's chances of occupying a larger rooting volume and capturing enough moisture and nutrients to survive through the rapid onset of drought.

To adequately determine the significance of this trend, we must expose a wider range of dormancy intensities to the same range of stresses. During the 1986 season, this hypothesis will be explored more fully under a range of moisture regimes.

Seedlings which burst bud rapidly tended to have low RGP (Fig. 5); however, as in the RGP versus survival relationship, no consistent trend existed among storage duration-planting date combinations.

CONCLUSIONS

- RGP assessment using the one week, 30°C/25°C (D/N) and Burdett's (1979) index method appears useful in identifying planting stock with a low probability of survival for a wide range of coastal species and stock types.
- An RGP value of 1.0 appears reasonable as a cutoff for silvicultural soundness to achieve a plantation survival target of 80 percent.
- RGP does not appear to have good predictive power beyond the roots/no roots determination.
- Evidence from Douglas-fir containerized stock suggests that stress resistance mechanisms related to cold hardiness and dormancy may play a significant role in seedling survival under stressful conditions.

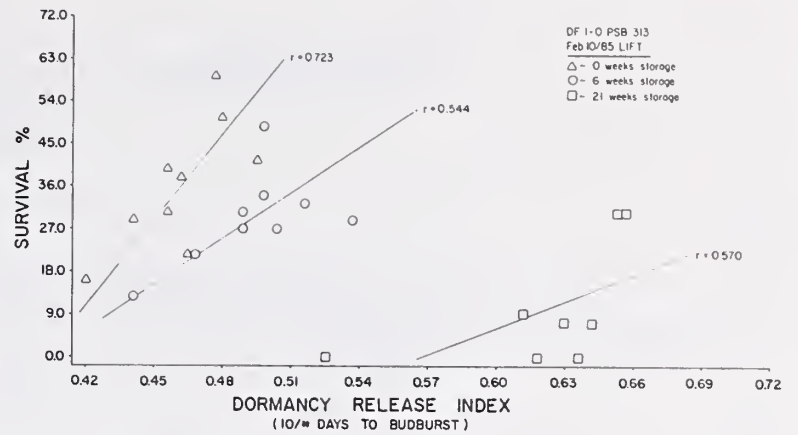


Figure 4. Under varying levels of outplant stress, Douglas-fir seedlings which burst bud rapidly tend to survive better than those which burst bud slowly.

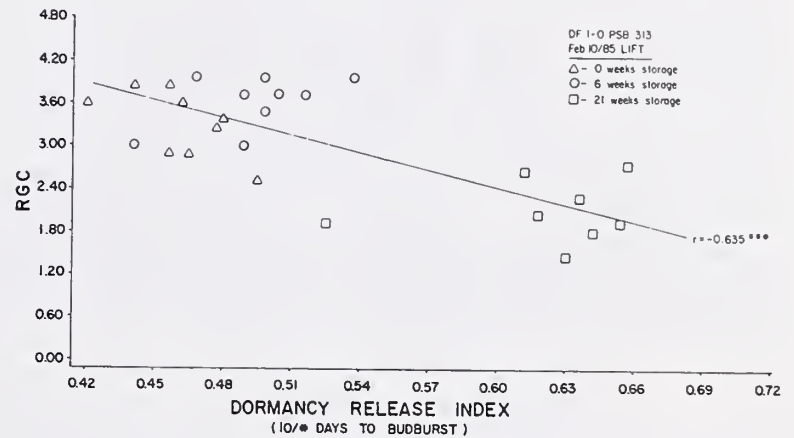


Figure 5. Containerized Douglas-fir seedlings which burst bud rapidly tend to have lower RGC.

- Challenge for the future is to use a more integrated approach to planting stock culture, allocation, and assessment by:
 1. Developing a battery of stress resistance tests which accurately predict outplant survival and growth.
 2. Using the battery of tests to provide an indication of stress prior to damage to facilitate preventative action and avoid batch culling.
 3. Using test battery to improve nursery culture and seedling allocation through:
 - reducing the frequency of low quality seedlots
 - more adequately match seedling physiology to limiting site conditions.

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Stem Canker Diseases of Douglas-fir in Nurseries¹

Philip B. Hamm & Everett M. Hansen²

Abstract--Diseases that kill above ground portions of Douglas-fir formerly called "Top Blight," are listed. Disease recognition, time of infection, infection site, and causal agents are described.

"Top Blight" was a term coined in the early 1980's to describe death of aboveground portions of Douglas-fir in bare root nurseries in the Pacific Northwest. Because the damage was extensive, and the causal agents and times of infection were unknown, a research effort was undertaken with the support of the Industrial Forestry Association and Weyerhaeuser Company. Five distinct diseases were identified as part of this complex. They are, in their order of occurrence; Fusarium Hypocotyl rot, Upper stem canker, Lower stem canker, Phomopsis canker and Botrytus Canker (Hamm et al. 1985).

FUSARIUM HYPOCOTYL ROT

Mortality due to this disease appears in the 1+0 beds usually in July or August, generally associated with the first prolonged, hot weather of the summer (Fig. 1), and may continue through September or October. As the name implies, infection generally occurs in the hypocotyl region of the seedling but is not limited to that location. The causal agent, Fusarium oxysporum has also been seen attacking higher on the seedlings regardless of the point of infection, seedlings are quickly killed. Symptoms include stunting and chlorosis, leading to wilting and death. Dead and dying seedlings typically have a crooked top and tend to be randomly scattered throughout the nursery. Fusarium hypocotyl rot is the most damaging disease in Pacific Northwest nurseries at the present time.

¹ Paper presented at the combined meeting of the Western Forest Nursery Council and Intermountain Nurseryman's Association, Olympia, WA, August 12-15, 1986.

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Fusarium oxysporum in the past has been best known for causing root rot of 1+0 Douglas-fir (Bloomberg & Lock, 1972). Field symptoms are quite like Fusarium hypocotyl rot. Individual symptoms, however, are markedly different and are easily differentiated at the early stages. Roots of Fusarium hypocotyl infected seedlings are healthy in contrast to rotted roots associated with Fusarium root rot. Observations seem to indicate Fusarium root rot is more likely to occur in nurseries which do not regularly fumigate sowing areas.

UPPER STEM CANKER

This disease occurs in the fall (Fig. 1) of the 1+0 year. Upper stem canker has been responsible for spectacular epidemics in Northwest bare root nurseries. Phoma eupyrena and Fusarium roseum are the causal agents. Diseased seedlings are usually not noticed until their tops die, with affected seedlings often concentrated in discrete areas in nursery beds. Close observations of individual seedlings will identify small sunken areas on the stem, called cankers, that are often red in color. The margin between healthy and diseased tissue is distinct but once the stem is girdled and the top begins to dry, the upper lesion boundary is no longer easily identified.

Infection most often is associated with bark fissuring on the stem, apparently a normal physiological response to rapid growth. Fissures expose the xylem and heal quickly under normal conditions. Conidia (spores) produced by these fungi by chance land in these wounds and cause infections. Top killing is more severe when weather favoring fast seedling growth in the fall suddenly became cool and moist, slowing wound healing while favoring fungal spore production and dissemination. Spore production has often been seen on infected bark fissures. Infection can also occur through needles and lateral branchlets.

Damage may be more apparent than real. Depending on the height of cankers on seedlings,

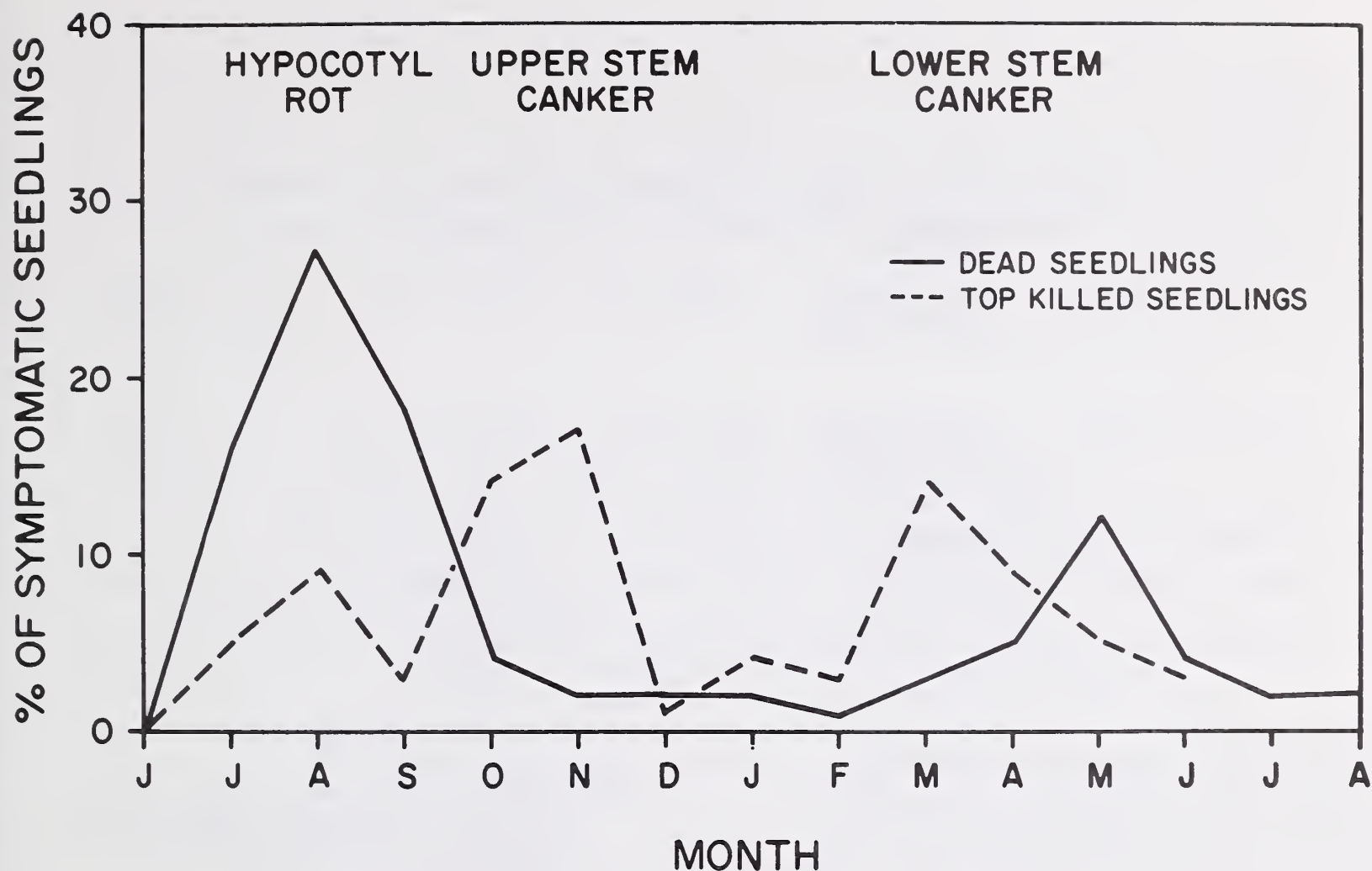


Figure 1. Chronology and symptom occurrence of three diseases affecting bare root Douglas-fir seedling in the Pacific Northwest.

the effect may be no more than early top pruning since cankers seldom expand downward. Loss is most likely to be due to seedlings failing to meet height packing standards.

LOWER STEM CANKER

The third disease identified was lower stem canker. This disease, also caused by Fusarium roseum and Phoma eupyrena, acting alone or together, attacks seedlings apparently sometime after dormancy in the fall and before growth begins in the 2+0 year (Fig. 1). Again a canker develops on the stem, but lower, usually at or near the soil line, and nearly always beneath the buildup collar of soil that forms around the lower stem. Because cankers are typically found below the lowest branches, seedlings are killed. Infections probably occur on the stem through abrasion wounds caused by the freezing and thawing of soil, blowing soil, or through needles, needle scars, or lateral buds smothered by the soil collar. Mortality is concentrated in lower areas and therefore may be confused with Phytophthora root rot. Roots of seedlings recently killed by lower stem canker, however, are always healthy.

Two other diseases reported to attack above ground portions of Douglas-fir in Pacific Northwest Nurseries could be confused with lower stem canker; Fusarium stem rot (Morgan 1983) and Phoma Blight (Kliejunas et al. 1985). Fusarium stem rot, caused by Fusarium roseum, is apparently identical to lower stem canker, but in our experience both Fusarium and Phoma are involved. Phoma blight caused severe needle loss at a nursery in California but seldom girdled seedlings in contrast to lower stem canker. Those reports identify problems specific to individual nurseries. From a regional view, both P. eupyrena and F. roseum are capable of causing mortality.

BOTRYTIS AND PHOMOPSIS CANKER

The last two disease situations occur during the 2-0 growing season and is caused by two agents, Botrytis cinerea and Phomopsis sp. Each causes a canker, almost always on the new growth but generally at different locations or times. Phomopsis is usually isolated from cankers forming at the base of new growth; usually within 4-6 weeks after shoot elongation. B. cinerea infects generally higher on the new

Table 1. Canker Diseases of Douglas-fir seedlings in the Pacific Northwest.

Disease	Fungi	Season	Location	Entry
Fusarium Hypocotyl Rot	<u>Fusarium oxysporum</u>	1+0 Summer	Hypocotyl and above	Soil abrasions direct
Upper Stem Canker	<u>Phoma eupyrena</u> <u>Fusarium roseum</u>	1+0 Fall	Mid-upper stem	Bark fissures Needle scars Lateral branches
Lower Stem Canker	<u>Fusarium roseum</u> <u>Phoma eupyrena</u>	1+0 Winter Spring	Lower stem	Soil Collars Soil abrasions Dead needles
Phomopsis Canker	<u>Phomopsis</u> sp.	2-0 Summer	Base of new growth	Bud scales
Botrytis Canker	<u>Botrytis cinerea</u>	2-0 Summer	New shoots	Wounds, lateral branches

growth, often entering the stem through a lateral twig. Both fungi cause stem girdling but do not kill seedlings. Trees generally recover and make packing standards. Botrytis canker was more frequently seen in high density beds but overall, much less damage was caused by both of these organisms than by any other "top blight" disease.

A summary of the canker diseases of Douglas-fir seedlings, fungi involved, time of infection, and location of infection on the seedling as well as mode of entry is listed in table 1.

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Occurrence of *Fusarium* on Conifer Tree Seed from Northern Rocky Mountain Nurseries¹

R. L. James²

Fusarium spp. are common colonizers of conifer seed from northern Rocky Mountain nurseries. Assays of ponderosa pine, Douglas-fir, western larch, and spruce seeds indicate great variability in extent of contamination among seedlots. In some spruce seedlots almost 90 percent of the seeds tested were colonized by Fusarium; most seedlots of other species were much less contaminated. Fusaria are commonly found both on the seedcoat and within the endosperm of colonized seed. Seven species of Fusarium have thus far been isolated from seed, although F. oxysporum was encountered most frequently. Types of diseases associated with seedborne fusaria and techniques used to reduce levels of seed contamination are discussed.

INTRODUCTION

Investigations of diseases incited by Fusarium spp. indicate that these fungi are often introduced into both bareroot and container nurseries on conifer seed, sometimes causing extensive losses (Cooley 1983; Graham and Linderman 1983; James 1983b). Although Fusarium can infect conifer seed during flowering and cone formation (Anderson et al. 1980; Mason and Van Arsdel 1978; Sharma 1978), probably most infection occurs when cones or seed contact soil that harbors inoculum (James 1983a; Karrfalt 1983). Cones collected from squirrel caches often contain large populations of fungi including many pathogenic fusaria (James 1984b; James and Genz 1981; James and Genz 1982). During seed extraction, infection by Fusarium may intensify (Salisbury 1955), resulting in both seedcoat and endosperm colonization

(James 1984a; James 1984b). Seedborne diseases often increase after prolonged seed and cone storage (Bloomberg 1969; Harman et al. 1978; Harvey and Carpenter 1975). Seed colonization by pathogens can also increase during the extended seed stratification periods that are common in conifer nurseries (Bloomberg and Trelawny 1970).

OCCURRENCE ON SEED

Investigations to elucidate the role of seedborne Fusarium spp. as incitants of disease in northern Rocky Mountain Nurseries began in 1981 (James and Genz 1981). Most evaluations have involved incubating seed from representative lots on a selective agar medium for Fusarium (Komada 1975). Placing seed directly on the medium gives an indication of abundance of Fusarium on the seedcoat. By aseptically dissecting seed and carefully separating the seedcoat from the endosperm, abundance of Fusarium on these two components can be determined.

Results of investigations to determine abundance of Fusarium on or within conifer seed are summarized in table 1. Many of these investigations have dealt with Douglas-fir (Pseudotsuga menziesii Dougl.)

¹Paper presented at the Western Forest Nursery Council Meeting, Tumwater, WA, August 12-15, 1986.

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seed since disease incidence is usually most noticeable and widespread on this species, especially in container operations. Other species investigated include ponderosa pine (Pinus ponderosa Laws.), western larch (Larix occidentalis Nutt.), blue spruce (Picea pungens Engelm.) and Black Hills spruce (P. glauca var. albertiana (S. Brown) Sarg.). Results indicate that, in general, great variation exists in the occurrence of Fusarium among tested lots. Also, most lots tested have evidence for Fusarium within the endosperm as well as on the seedcoat, indicating either infection during seed formation or penetration of the seedcoat by the fungus.

As yet there have been no studies which have statistically evaluated the correlation between amount of seed infection and subsequent disease incidence. However such a correlation would be expected, since experience indicates that seedlots with poor germination and seedling emergence are generally infested by Fusarium to a greater extent than lots with better germination (James, unpublished).

TYPES OF DISEASES

Five types of diseases caused by seedborne fusaria are generally recognized on conifer seedlings. These include seed decay, pre-emergence damping-off or germination failure, post-emergence damping-off, top damping-off or cotyledon blight, and root disease or late damping-off (Bloomberg 1971; Matuo and Chiba 1966). Seed decay occurs when fungi penetrate the seedcoat, colonize it and break down internal seed contents (Bloomberg 1969). If decayed seed are sown, decreased germination will result and potentially pathogenic fungi introduced into seedbeds or containers (James 1985a; Landis 1976a). Pre-emergence damping-off occurs when the emerging radicle of germinating seed is attacked by fungi carried either on the seedcoat or present in soil (Bloomberg 1971; Graham and Linderman 1983). If the radicle is colonized by pathogenic fungi, decay results and no germinant emerges (Rathbun-Gravatt 1931). Post-emergence damping-off refers to disease of newly emerged germinants in which lesions often appear at the ground line, causing infected germinants to fall over (Bloomberg 1971; Landis 1976a). Decay of the germinant follows and sporulation of fungi may occur on decayed tissues. Top damping-off caused by Fusarium occurs as cotyledon blight (Mason and van Arsdel 1978), hypocotyl rot (Brownell and Schneider 1983), or stem rot (Morgan 1983). Cotyledon blight is

especially common on species, such as ponderosa pine and Douglas-fir, which retain their seedcoats on the tips of cotyledons for extended periods after germination (Mason and van Arsdel 1978). Root disease caused by seedborne fusaria usually occurs on seedlings that are several months old. Disease results from decay of feeder roots (Pawuk and Barnett 1975); affected seedlings become slow growing and chlorotic (Landis 1976b) and may develop wilt symptoms and needle tip dieback (James 1983b; James 1984b; James 1984c). This disease may cause seedling mortality or reduced seedling vigor, which adversely affects outplanting survival (LaMadeleine 1979).

SPECIES OF FUSARIUM

Seven species of Fusarium have thus far been isolated from conifer seed at northern Rocky Mountain nurseries (table 1). The most common species isolated is F. oxysporum Schlect., an important pathogen of many different plants including conifer seedlings (Booth 1971; Cooley 1983; Gerlach and Nirenberg 1982). It is capable of causing vascular wilts (Booth 1971; Neergaard 1977) and cortical rots of seedling stems (Brownell and Schneider 1983; Morgan 1983) and roots (James 1983c; James 1984a). Although F. oxysporum exhibits a wide host range (Booth 1971; Gerlach and Nirenberg 1982), individual strains of the fungus, called formae specialis (f. sp.), usually infect only a few selective hosts (Gordon 1965; Snyder and Hansen 1940). Only one f. sp. (designated pini) has thus far been recognized for isolates that attack conifers (Gordon 1965). However, responses of different conifers to infection by several F. oxysporum isolates have sometimes been sufficiently variable to indicate that designation of additional f. sp. (other than pini) which attack conifers might be warranted (James and Gilligan 1984; Matuo and Chiba 1966). Additional pathogenicity tests on a wide range of conifer hosts will be needed to help clarify this issue.

Another Fusarium species commonly isolated from conifer seed is F. solani (Mart.) Sacc. (table 1). It is a common root decay organism that is especially damaging on agricultural crops (Booth 1971; Gerlach and Nirenberg 1982; Neergaard 1977). The fungus is occasionally associated with diseases of conifer seedlings (Landis 1976b; Merrill et al. 1981; Tint 1945). However, the pathogenic potential of seedborne sources of this fungus is unclear for conifer seedlings.

Table 1.—Abundance of *Fusarium* spp. on conifer seed from Northern Rocky Mountain Nurseries.

Species ¹	Nursery ²	No. lots sampled	Percent lots w/ <i>Fusarium</i>	Percent seed w/ <i>Fusarium</i>		Associated <i>Fusarium</i> species	Reference
				Seedcoat	Endosperm		
PP	CDA	1	100	4-12	4-20	FOKY	James 1986c
PP	MSN	1	100	2-4	—	FSAM; FACU; FSPO	James 1985b
PP	CTN	8	75	0-8	—	FOKY; FSOL	James & Genz 1982
PP	CTN	2	100	—	—	FOKY	James & Genz 1981
DF	CDA	5	100	1-22	2-8	FOKY; FAVE	James (unpub. 1986)
DF	UIN	3	100	6-43	—	—	James & Dumroese (unpub. 1986)
DF	CDA	5	80	0-10	—	FOKY; FSOL	James 1983d
DF	PCN	4	75	0-7	—	FOKY; FACU	James 1986a
DF	CTN	4	75	0-13	—	FOKY; FSOL	James 1984a
DF	MSN	1	100	4	4	FOKY; FSOL	James 1983b
WL	NN	2	100	5-88	—	FOKY; FSAM	James 1986b
BS	TN	5	100	0-52	—	FOKY; FSOL; FTIRI	James 1985c
BRS	TN	3	100	18-78	—	FOKY; FSOL; FTIRI	James 1985c

¹PP = ponderosa pine; DF = Douglas-fir; WL = western larch; BS = blue spruce; BRS = Black Hills spruce

²CDA = USDA Forest Service Nursery, Couer d'Alene, ID; MSN = Montana State Nursery, Missoula, MT; CTN = Champion Timberlands Nursery, Plains, MT; UIN = University of Idaho Nursery, Moscow, ID; PCN = Plum Creek Nursery, Pablo, MT; NN = Nishak Nursery, Bonners Ferry ID; TN = North Dakota Forest Service Nursery, Towner, ND.

³FOKY = *F. oxysporum*; FSAM = *F. sambucinum*; FACU = *F. acuminatum*; FSPO = *F. sporotrichioides*; FSOL = *F. solani*; FAVE = *F. avenaceum*; FTIRI = *F. tricinctum*.

Other species of *Fusarium* isolated from conifer seed include *F. acuminatum* Ell. & Ev., *F. avenaceum* (Fr.) Sacc., *F. sambucinum* Fuckel, *F. sporotrichioides* Sherb., and *F. tricinctum* (Corda) Sacc. (table 1).

Although some of these fungi are pathogenic (James 1985c; James and Gilligan 1984), many are probably saprophytic (Booth 1971; Gerlach and Nirenberg 1982). Many seedborne isolates of these fungi need to be evaluated for their pathogenic potential.

DISEASE CONTROL

The extent of *Fusarium* contamination on seed varies great among different conifer species and seedlots (table 1). These differences may be related to cone collection, storage, and seed extraction practices. For example, cones collected from squirrel caches often have high levels of fungal contamination. Also, cones and seed stored under damp conditions for longer time periods are more prone to damage by fungi.

Seed treatment before sowing may reduce disease losses caused by seedborne fusaria (Johnson and Harvey 1975; Johnson and Linton 1942). Most growers soak seed in water to condition them for sowing; some use standing water and others a running water rinse (James 1984a). If infected seed is soaked in standing water, fungal propagules can spread, causing widespread infection (James 1983b). However, placing seed under a running water rinse can reduce seedcoat contamination and does not spread infection (James 1983b; James 1984a).

Sterilants such as hydrogen peroxide and sodium hypochlorite (commercial bleach) have frequently been used to reduce fungal contamination and enhance germination of conifer seed (James and Genz 1981; Partridge et al. 1985). Hydrogen peroxide usually reduces or eliminates fungal contaminants (Barnett 1976; James and Genz 1981). The effect of hydrogen peroxide on seed germination has been variable. For example, some investigators (Edwards and Sutherland 1979; James 1983b) report reduced seed

germination, whereas others (Ching and Parker 1958; James and Genz 1981; Mason and van Arsdel 1978) report improved germination. Detrimental effects of hydrogen peroxide generally increase with chemical concentration and exposure period. Sodium hypochlorite usually reduces fungal contamination (James and Genz 1981) and sometimes enhances seed germination (Partridge et al. 1985).

Several fungicides have been used for seed treatments to reduce damping-off caused by seedborne pathogens (Mittal and Sharma 1981; Strong 1952). However, reports of fungicide toxicity to seed and germinants have limited their use (Cooley 1983; James 1983b; Lock et al. 1975). For example, use of captan has resulted in reduced seed germination (Peterson 1970), and has caused seedling injury following germination (Cayford and Waldron 1967; Lock et al. 1975). Thiram, another common seed-treatment fungicide, has reduced seed germination (Dick et al. 1958; Shea 1959) and caused deformed germinants (Hedderwick and Gadgil 1966). Effectiveness of seed-treatment fungicides is apparently related to dosage levels (Hamilton and Jackson 1951), activity spectrum against target organisms, development of resistant fungal strains, and persistence on seed (Sutherland and van Eerden 1980).

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Management of the Top Blight Disease Complex¹

Alan Kanaskie²

Abstract.--The "top blight disease complex" refers to five separate but related diseases affecting above-ground portions of bareroot Douglas-fir seedlings. Disease losses can be reduced by altering cultural practices or applying fungicides³. The following paper provides practical approaches and techniques for reducing losses from top blight.

INTRODUCTION

The top blight disease complex refers to diseases of above-ground portions of bareroot Douglas-fir seedlings. They are described elsewhere in these proceedings by P. Hamm. Five distinct diseases comprise the complex (Hansen and Hamm 1985):

1. Fusarium hypocotyl rot. Caused by Fusarium oxysporum. Affects hypocotyl region and above during summer of the 1-0 year;
2. Upper stem canker. Caused by Phoma eupyrena and Fusarium roseum. Affects mid to upper stem in late summer and early fall of the 1-0 year;
3. Lower stem canker. Caused by Fusarium roseum and Phoma eupyrena. Affects lower stem near soil level from winter through flush of new growth on 2-0 seedlings;
4. Phomopsis canker. Caused by Phomopsis sp.. Affects new growth of seedlings during summer of the 2-0 year;

5. Botrytis canker. Caused by Botrytis cinerea. Affects new shoots during summer of the 2-0 year.

Losses to top blight can be substantial. Mortality exceeding 30% of the crop has been caused by both hypocotyl rot and lower stem canker.

Disease occurrence varies widely among nurseries. Some nurseries may experience recurrent epidemics of one disease only, while others may suffer from all five. Disease severity also varies highly from year to year, and appears practically unpredictable. In a given nursery, a top blight disease may be epidemic one year and absent the next.

Factors influencing occurrence and severity of top blight are poorly understood. Consequently, disease prediction is difficult. Fortunately, research by Oregon State University, the USDA Forest Service, and Weyerhaeuser Company, has greatly improved our understanding of these diseases and of techniques for controlling them. The purpose of this paper is to present management strategies, based on current knowledge, that should reduce losses to diseases of the top blight complex.

APPROACH TO DISEASE MANAGEMENT

Occurrence and severity of top blight diseases apparently are governed by a complex of factors including weather, sowing date, pathogen populations, soil moisture, etc. - in short, anything that affects the seedling or the pathogens likely affects disease. In plant pathology jargon this concept is called the "disease triangle", which states that disease

¹Paper presented at the Western Forestry Nursery Council Meeting. Vance Tye Hotel, Tumwater, Washington, August 12-15, 1986.

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³The use of company names or proprietary products in this paper does not constitute endorsement or guarantee by the Oregon Forestry Department, and does not imply criticism of those not mentioned.

results from the interaction of the plant (host) and pathogen as regulated by the environment. This is the basis for understanding disease development and should also form the basis for control strategies.

Nursery cultural practices alter the environment, the seedling, and even the pathogen. However, no single practice stands out as the trigger to an epidemic. Fumigation and fungicides can reduce disease in many cases, but even the most intense chemical regime does not guarantee a disease-free crop. In fact, some of the most severe top blight losses have occurred in nurseries despite fumigation and fungicide treatments.

The suggested approach to disease management is to consider the probable effects of nursery practices on disease development and, whenever possible, adjust them in a way that should reduce disease severity. Even though a single cultural practice may have little apparent effect on disease incidence, the cumulative effect of adjusting several different practices should reduce losses.

The remainder of the paper presents several opportunities for reducing disease losses. Many recommendations, particularly fungicide treatments, are based on several years of data from Oregon, Washington, and California. Other suggestions, concerning soil splash and soil moisture conditions, rely on observations over several growing seasons. Finally, some recommendations are unproven logical deductions. Suggestions may change as understanding of disease dynamics improves.

THE FIRST STEP - RECOGNIZING THE PROBLEM

The most important step in disease management is recognizing and identifying the problem in your nursery. Few nurseries will have all diseases, and the same disease may behave differently in one nursery than in another. To assume that all diseases are present could result in wasting resources to control insignificant diseases. Accurate identification allows a focused and efficient control effort.

Pathologists, and many nursery personnel, are adept at disease identification, but identification is only part of the issue. Understanding disease development over time in your nursery is critical. This can be accomplished by

assigning disease responsibility to someone (a consultant or nursery employe are logical choices) who provides nursery-specific monitoring and understanding of diseases over time. This person also could maintain liaison with pathologists from universities and government agencies.

DISEASE MANAGEMENT BEFORE SOWING

Cover Crops

Cover crops are used commonly in forest nurseries to protect soil, replenish nutrients, and maintain organic matter content. They may increase or decrease disease occurrence, or they may have no effect.

In the pacific northwest, preliminary data indicate that cover crops of beans, peas, oats, and sudan grass result in higher populations of soil-borne Fusarium than in bare fallow areas⁴. Bare fallow with frequent tillage has reduced pathogen and nematode levels in British Columbia forest nurseries⁵. However, the correlation between soil pathogen populations and disease incidence has not been established.

High soil pathogen populations likely increase probability of disease occurrence, particularly for hypocotyl rot. Nurseries that experience chronic losses from hypocotyl rot could reduce Fusarium levels by bare fallowing rather than cover cropping.

Monitoring Populations of Soil-Borne Pathogens

The most important pathogens of the top blight complex, Fusarium and Phoma, occur in the soil. Fusarium populations can be quantified by assaying soil samples on culture media that allow only Fusarium and a few other fungi to grow. Abundant Fusarium in the soil appears to increase

⁴Hamm, Phil. 1986. Personal conversation. Oregon State University, Corvallis, Oregon.

⁵Sutherland, Jack. 1984. Personal conversation. Pacific Forest Research Centre, Victoria, British Columbia.

probability of Fusarium-caused disease⁶. Techniques for selective isolation of Phoma from soil are unavailable, and the importance of Phoma populations are unknown.

Reliable correlations between soil pathogen counts and amount of disease have been difficult to establish. It is thought that soil populations could form the basis for disease prediction. Consideration of soil pathogen counts with disease history, crop history, and other factors has enabled crude disease prediction in several nurseries. British Columbia, Washington Department of Natural Resources, and private consultants successfully use soil counts as input to pest management decisions (McElroy 1984).

How much Fusarium is too much? Should I fumigate if I have 1,500 propagules of Fusarium per gram of soil? It is doubtful that anyone can give an answer that will apply to all nurseries. However, after monitoring soil pathogen counts and disease levels for a few seasons, a nursery should be able to address these questions with some confidence. It is certainly an improvement over complete guesswork. Soil pathogen assays are available from certain consulting firms. Some nurseries chose to do their own assays.

Fumigating Nursery Soils

Fumigation can effectively reduce soil pathogen populations and improve conifer seedling yield and quality (Bloomberg 1965, Sinclair et al 1975). Methyl Bromide/chloropicrin is most widely used and is highly effective. Efficacy of other chemicals is discussed elsewhere in these proceedings by F. McElroy and by Y. Tanaka.

Despite demonstrated effectiveness for disease control at many nurseries, fumigation does not guarantee a disease-free crop. Conversely, nurseries have produced excellent crops without fumigation. Pathogens can recolonize fumigated soils during the time between fumigation and sowing, and although they may not attain levels as high as those before fumigation, they may be high enough to initiate serious disease. It has also been speculated that fumigation alters the

balance of microflora in a way that gives advantage to pathogens growing among reduced populations of antagonistic organisms.

Fumigation is an expensive treatment, so the question often becomes "is it worth it?" Reliable disease prediction would help answer that question. Other benefits such as weed control, as well as pesticide use regulations and economics must be weighed along with disease control benefits. Soil assays and continual evaluation of fumigation effectiveness can be used to decide whether or not fumigation is necessary.

Seed Treatments

The occurrence of Fusarium-caused disease in 1-0 beds that have been fumigated prompts questions about the source of Fusarium. Fusarium spores can blow into a field on dust or debris particles or they can recolonize upward from soil beneath the level of fumigation (Marois et al 1983). Fusarium occurs in and on Douglas-fir seed (Bloomberg 1966), and seed-borne Fusarium can cause seedling disease (Graham and Linderman 1983, James 1985). However, the importance of Fusarium on seed in bareroot nurseries is poorly understood.

It seems reasonable to assume that Fusarium on seed could contribute to increased disease. Many seedlots will have little or no Fusarium. Those that do can be detected by assaying seed samples on culture media selective for Fusarium (the same media is used for the soil assays mentioned earlier). Monitoring disease levels in seedlots with different pathogen levels will add another bit of information to nursery-specific understanding of disease behavior.

Treating seeds with fungicides has had variable success, and often has reduced seed viability (Sutherland 1984). Rinsing seed for up to 48 hours in running water should remove much of the surface Fusarium⁷. Strong recommendations about seed treatment will be possible only after additional research and nursery field studies.

⁶McElroy, Fred. 1985. Personal conversation. Peninsu-Lab, Inc., Kingston, Washington.

⁷James, Robert. 1986. Personal conversation. USDA Forest Service, Missoula, Montana.

MANAGING SPECIFIC TOP-BLIGHT DISEASES

Fusarium Hypocotyl Rot

Seed treatment.

Fusarium on seed can cause hypocotyl rot in Douglas-fir seedlings⁸. The effectiveness of treating seeds with fungicides needs clarification through research. If Fusarium seedlot assays reveal abundant Fusarium, rinsing seeds in running tapwater for 48 hours should reduce probability of hypocotyl rot.

Sow seed early.

Observations strongly suggest that sowing as early as possible reduces amount of hypocotyl rot. Early sowing has also been recommended to reduce hypocotyl rot severity in sugar pine seedlings (Brownell and Schneider 1985). Early sowing may allow seedlings to attain large size and develop resistance to hypocotyl rot before the environment of the nursery bed favors disease development.

Fertilization.

Sinclair et al (1975) reported that fertilization with urea increased severity of Fusarium root rot of bareroot Douglas-fir seedlings. Summer mortality, which may have been partly due to hypocotyl rot, was highest in seedlings receiving pre-sow urea. A "best guess" recommendation at this time is to avoid urea fertilization during the first 8 weeks following sowing. Effects of form of nitrogen fertilization and timing of its application are being studied in several northwest nurseries during 1986⁹.

Irrigation.

Irrigation regimes, particularly those used for cooling during summer, appear to affect hypocotyl rot severity. Elsewhere

⁸Littke, Willis. 1986. Personal conversation. Weyerhaeuser Company Centralia Forestry Research Center, Centralia, Washington.

⁹Cooley, S. J. and A. Kanaskie. 1986. Unpublished study plan - effect of nitrogen fertilization on disease of Douglas-fir seedlings in the first growing season. USDA Forest Service, Portland, Oregon.

in these proceedings, Ken Russell discusses a strategy of deep watering (as opposed to frequent shallow watering) to reduce hypocotyl rot losses.

During 1986 at the Oregon State Forest Nursery, uneven irrigation affected hypocotyl rot occurrence. Portions of beds within 10 feet of sprinkler heads remained wet longer than areas between 10 and 15 feet of sprinkler heads, indicating that more water was deposited at the heads than between them. In parts of the nursery where hypocotyl rot occurred, disease severity in the dry areas was nearly double that occurring in wet areas (35% versus 20%, respectively). Drier soils may have permitted higher temperatures near ground level which stressed seedlings and favored disease development (Brownell and Schneider 1985).

Fungicides.

Among fungicides tested in Pacific Northwest nurseries from 1983-1985, Benlate, Daconil 2787 and Chipco 26019 (Chipco not registered for forestry use) appeared most effective, but effectiveness was highly variable (Cooley and Kanaskie 1986). Other factors such as weather and cultural practices appear capable of overriding the effects of fungicides applied as often as twice per week¹⁰. If fungicide treatments are used, begin treatments at full emergence and follow label rates. Tank mixes and alternating chemicals are recommended.

Preliminary studies suggest that Bayleton may reduce incidence of hypocotyl rot¹⁰. Further testing of this material is recommended.

Upper Stem Canker

Cultural practices.

Upper stem canker appears most severe in seedlings whose growth is prolonged through late summer into early fall, and in seedlings grown at very high densities (50-75 trees per square foot). Infections often are associated with splits in the stem which may result from rapid seedling diameter growth in late summer. Disease

¹⁰Kanaskie, A. 1986. Unpublished data on file at Oregon State Department of Forestry, Salem, Oregon.

risk should decrease if cultural practices such as fertilization and irrigation are used to limit rapid diameter growth and to prevent succulence from continuing into fall. If upper stem canker is a serious concern in your nursery, consider inducing bud-set earlier than normal.

Fungicides.

Chipco 26019, Daconil 2787, Difolatan, and Benlate were most effective in Pacific Northwest nurseries, but only Daconil 2787 and Benlate are registered (Cooley and Kanaskie 1986). Treatment should continue through budset of the 1-0 year. Tank mixing and alternating chemicals are recommended. Coverage of the seedling stem (not foliage) is important; spreader-stickers should enhance performance. Time applications so irrigation or rain will not wash materials off before they dry.

Lower Stem Canker

Avoid creating areas of poor drainage.

During evaluations of fungicides, lower stem canker occurrence appeared more strongly related to wet areas in the beds than to fungicide treatments (Cooley and Kanaskie 1986). Increased disease has also been observed in beds receiving heavy tractor traffic during winter months¹¹. Ripping tractor paths, eliminating low spots during land-planning, and limiting tractor traffic on wet fields should help reduce occurrence of lower stem canker.

Soil splash on seedling stems.

The accumulation of rain- or irrigation-splashed soil on lower foliage and stems of seedlings, called "soil cones" or "soil collars", is strongly associated with lower stem canker (Hansen and Hamm 1985, Kliejunas et al 1985, Morgan 1983). Soil accumulation usually begins during summer of the 1-0 year and continues through winter. Soil collars put the soil-borne pathogen in close contact with seedlings and may provide an environment conducive to disease development.

¹¹Littke, Willis. 1986. Personal conversation. Weyerhaeuser Company Forestry Research Center, Centralia, Washington.

Prevention of soil collar formation can reduce losses to lower stem canker. The addition of redwood mulch or shade lath reduced soil cone formation and Phoma blight incidence on fir and Douglas-fir in a northern California nursery (Kleijunas et al 1985). At a Washington nursery during 1983, fewer seedlings had lower stem cankers in moss-covered beds (no soil collars) than in moss-free beds (abundant soil collars)¹².

Establishing a thick carpet of moss appears to be the simplest and most economical method of preventing soil collars, but this approach will only work in nurseries with naturally-abundant moss. Mosses are often eliminated from nursery beds with herbicide treatments. However, choosing herbicides that do not kill mosses will allow moss to develop during the 1-0 year.

Of the shade lath and mulch treatments, the latter is most practical. Other types of mulch may be effective and should be field-tested. A liquid latex acrylic sealant was tested in northern California, but it was ineffective¹³. Mulch treatments must be applied before soil buildup occurs.

Fungicides.

Field trials indicate generally poor control with fungicides. Fungicide ineffectiveness for preventing lower stem canker probably occurs because: 1) fungicides may not penetrate soil collars, and; 2) weather can prevent timely applications during the likely period of infection (winter). Of materials tested, Daconil 2787 was most effective; Benlate and Difolatan (Difolatan not registered) had variable effectiveness (Cooley and Kanaskie 1986). Exact time of infection is unknown, so fungicides may need to be applied from budset through shoot emergence in spring.

¹²Kanaskie, Alan. 1984. Unpublished data. Weyerhaeuser Company Centralia Forestry Research Center, Centralia, Washington.

¹³Kliejunas, John. 1985. Efficacy of Soil Seal concentrate for reducing soil cone formation in nursery beds at Humboldt nursery, unpublished report. USDA Forest Service, San Francisco, California.

Botrytis Canker

Cultural practices.

Reducing seeding density improves air flow and lowers humidity, providing conditions unfavorable for disease development. Avoid seedling injury: anything that injures seedlings - machinery, frost, excessive fertilization, herbicides - increases the risk of Botrytis-caused losses. Clipped seedling tops following top-mowing may also encourage Botrytis buildup.

Fungicides.

Benlate, Daconil 2787, and vinclozolin (Ronilan, Ornalin) are among chemicals registered for Botrytis in bareroot conifer nurseries. Daconil appeared most effective in northwest nurseries, and Benlate yielded variable results (Cooley and Kanaskie 1986).

Fungicide applications, if necessary, should begin when disease appears. Apply with techniques that put the chemical on the target, i.e., use rollers to bend seedlings during spraying, or use high tank pressures or atomizing nozzles. Reduce likelihood of developing fungicide resistance by applying minimum effective rates and alternating (not tank mixing) chemicals with different modes of action. In many cases, fungicide treatments for other top blight diseases may provide adequate Botrytis control.

Phomopsis Canker

Phomopsis canker usually is not severe enough to warrant specific fungicide treatments. Information on fungicide effectiveness is limited, but protective treatments during the flush of growth should be effective, and should be tested.

COMMENTS ON FUNGICIDE USE

Fungicide treatments can be cost-effective in bareroot nurseries, particularly for diseases that cause mortality. Because fungicide application costs tend to be small, even slight increases in disease-free seedlings may pay for treatment costs (Cooley and Kanaskie 1986). However, applying fungicides only when necessary will improve economic returns and may prevent development of fungicide-resistant pathogens.

Most fungicide testing has yielded variable results within and among nurseries. Fungicide evaluations should be ongoing and nursery specific - it may take several years to determine the most effective materials. Effectiveness can only be evaluated if treated areas are compared to untreated areas; leaving a few small areas untreated whenever applying fungicides will provide a wealth of information.

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Phytophthora Root Rot in Forest Nurseries of the Pacific Northwest¹

Philip B. Hamm and Everett M. Hansen²

Abstract--Phytophthora root rot continues to cause significant damage in some Pacific Northwest nurseries. Recognition of the disease is discussed as is fungal biology, host-pathogen interactions and origin in nurseries.

Phytophthora root rot in Pacific Northwest bare root nurseries was first reported in 1975, causing severe damage to Douglas-fir (Pseudotsuga menziesii) (Pratt et al. 1976). That report and subsequent ones (Hamm & Hansen 1981, 1982A, 1982B, 1983) have identified the Phytophthora species that cause damage in Northwest nurseries (Table 1) and the susceptibility of conifer seedlings grown in the region (Table 2). Phytophthora root rot has rarely been found in containerized situations, due to the ability to regulate contamination from water, media and pots.

Table 1. Species of Phytophthora that cause root rot in Pacific Northwest Nurseries.

<u>P. drechsleri</u>
<u>P. pseudotsugae</u>
<u>P. cinnamomi</u>
<u>P. cactorum</u>
<u>P. cryptogea</u>
<u>P. megasperma</u> Douglas-fir
<u>P. megasperma</u> Broad host range

Typically, symptoms of Phytophthora infection are not exhibited until seedlings are approaching their second growing season, or following transplanting. Pre and post-emergence damping off can occur during the first year, but this is more commonly due to Fusarium and Pythium species. By early spring of their second year, root rotted trees begin to yellow as they break dormancy. Damage is often concentrated in low areas in the field where

¹Paper presented at the combined meeting of the Western Forest Nursery Council and Intermountain Nurseryman's Association, Olympia, Washington, August 12-15, 1986.

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surface water accumulated during winter. By early summer the most severely infected seedlings have died. Seedlings not as severely infected commonly exhibit delayed bud break, poor elongation of the new terminal and lateral shoots (giving a bottle brush appearance) and chlorosis. Seedlings with light infection may not express distinct top symptoms. Below ground, severe Phytophthora damage is easily recognized. In trees moderately to severely rotted, root systems noticeably lack lateral roots and have a shortened tap root; less severely rotted trees possess fewer lateral roots and a shortened tap as compared to healthy seedlings. Light scraping of the root cortex of diseased seedlings with a knife exposes the cambial region and reveals the characteristic reddish brown discoloration of Phytophthora infected tissue in contrast to white, healthy tissue further up the stem.

Table 2. Conifer seedlings susceptible to Phytophthora root rot. Susceptibility of species marked with an asterisk (*) is known only from artificial inoculations.

Douglas fir	Western white pine
Western Hemlock	Grand fir
* Mt. Hemlock	White fir
* Incense cedar	Noble fir
* Sitka Spruce	Shasta red fir
* Englemann Spruce	Pacific Silver fir
* Lodgepole pine	* Western larch
Sugar pine	Ponderosa pine

With the exception of P. cinnamomi, these species of Phytophthora are quite adapted to the environmental conditions found in Pacific Northwest nurseries. Roth and Kulman (1966) concluded that P. cinnamomi was not a threat to the Douglas-fir forests of the region due to its requirement for simultaneous warm soil temperatures and high soil moisture. This requirement apparently holds for nurseries as well since P. cinnamomi has caused substantial

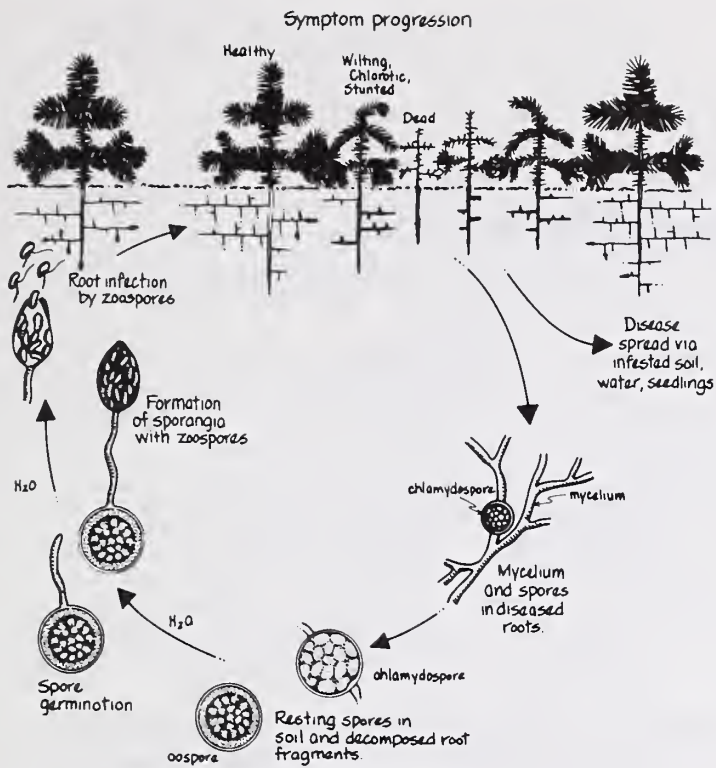


Figure 1. -- Life cycle of *Phytophthora* spp. on conifer seedlings.

damage only in: 1) a warmer coastal nursery; 2) in a bare root seed orchard; and 3) in containerized seedlings propagated for transplanting to a seed orchard. In contrast, the remaining *Phytophthora* species have been found in most major bare root nurseries in Oregon, Washington and into British Columbia. These species apparently survive well in nurseries under normal conditions. Moist periods favor production of sporangia, which in turn develop and release swimming spores called zoospores (Fig. 1).

While dissemination of zoospores in the soil is quite limited (Duniway 1976), widespread infection can result if surface water accumulates or water or equipment moves through contaminated blocks. Zoospores are attracted to exudates from roots of susceptible hosts. This may partially explain why root pruned transplants are sometimes severely damaged. Zoospore production and dissemination decrease with declining soil moisture, although root rot severity on infected trees may continue to increase through the summer. Irrigation extends the period of dissemination on poorly drained soils.

Phytophthora can be isolated from live, infected seedlings throughout the year. Long-term survival apparently is by resistant structures (e.g., oogonia, chlamydospores) in soil or in infected roots or dead trees (Hansen et al. 1980). Fortunately other factors must be limiting disease development on forest sites.

These *Phytophthora* species lower survival of infected outplanted seedlings but do not spread from infected stock to adjacent healthy trees (Hansen et al. 1980).

Losses due to *Phytophthora* root rot are highly variable. Factors such as crop type (1+0, 2+0, 2+1 etc.) seedling species, moisture (artificial and natural) and/or soil type are important. Most extensive damage in past years has been seen in transplanted Douglas-fir. As mentioned previously, wound sites on transplanted seedlings apparently attract zoospores but high soil moisture due to watering after transplanting (favoring zoospore formation), seedling stress from uplifting, storage, root pruning, etc., and transplanting into unfumigated, possibly heavy and warming spring soils and the amount of *Phytophthora* present on seedlings or in the soil, probably all contribute to disease severity. Substantial losses also occur in 1+0 and 2+0, usually when seedlings have been planted in areas where water is allowed to stand particularly in bed ends or low spots in the field (Hansen et al. 1979).

Susceptibility of the tree species grown in Northwest nurseries varies as does the aggressiveness of the *Phytophthora* species. *P. cinnamomi*, where conditions allow, and *P. cryptogea* have been shown to be highly aggressive to most native conifers (8); *P. megasperma* Douglas-fir (Hamm and Hansen 1981, Hansen and Hamm 1983) is generally less aggressive but more damaging than *P. drechslei* and *P. cactorum*, while *P. megasperma* Broad host range (Hamm and Hansen 1981, Hansen and Hamm 1983) and *P. pseudotsugae* are usually only weakly aggressive. Interestingly, these later two species are the most often isolated from diseased seedlings. Pathogenicity information is based on controlled *in vitro* testing for a period of 8-10 weeks. The extended length of time seedlings are grown in nurseries (1-3 years), coupled with a long favorable environment, can allow even the least aggressive of these fungal species to cause significant damage in a nursery setting. Generally, hemlock, true firs and Douglas-fir seedlings are the most susceptible to *Phytophthora* infection, followed by spruce and pine. Western red cedar was undamaged by any *Phytophthora* species in our tests (Hamm and Hansen 1982B, S.A. Cooley & P.B. Hamm unpublished).

Host specificity was generally not evident, except that isolates of *P. cryptogea* from sugar pine caused significantly greater root rot on that host than did isolates of the same species from other hosts (Hamm and Hansen 1982B). Although both groups of *P. megasperma* are pathogenic on most conifers tested, *P. megasperma* Douglas-fir is pathogenic only to conifers while *P. megasperma* Broad host range has a larger host range (Hansen and Hamm 1983).

The origin of Phytophthora in nurseries of the region is an ongoing question. Most likely Phytophthora was present in the soil prior to nursery establishment. The species found (except P. pseudotsugae) are common agricultural pathogens and since most nurseries were established on long used agricultural sites, their prior presence seem reasonable. This is supported by the fact that some isolates which attack Douglas-fir can cause disease on soybean and alfalfa. The occurrence of many of the same Phytophthora species in many nurseries is best explained by movement of transplant stock between nurseries.

During the twelve years since Phytophthora was first reported in the Pacific Northwest bare root nurseries, these fungi have been directly responsible for the closure of two large nurseries and substantial reduction in production in several others. Dollar loss also occurs through poor survival of infected seedlings outplanted to forest sites (Hansen et al. 1980). More basic and applied research is needed to better understand the biology of these organisms and to develop integrated control strategies. This point is exemplified by the continual, sometimes extensive losses that occur due to Phytophthora throughout the region.

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Management of Phytophthora Root Rot in Pacific Northwest Conifer Nurseries¹

Sally J. Cooley²

Abstract.--Various cultural and chemical strategies to reduce the incidence and severity of Phytophthora root rot on conifers in bareroot nurseries are discussed.

Management of Phytophthora root rot can be approached culturally and chemically. Both methods give some control of the disease. The best strategy is to use good cultural practices and supplement, when needed, with fungicides and fumigants.

CULTURAL MANAGEMENT

Cultural practices, which discourage the development of Phytophthora root rot, include good water management, sanitation, and use of tolerant or resistant species in areas where Phytophthora root rot is or may be a problem.

Water Management

Because the development and spread of Phytophthora is very dependent on high soil moisture and water movement, management of water in the nursery is integral to controlling the disease. A number of things are often involved when good water management is practiced.

1. Ideally, your nursery should be located on light, well-drained soil; realistically, very few nurseries in the PNW have the good fortune to be situated on light-textured soils.
2. Those nurseries with heavy, slow-percolating soils must add drainage systems. Subsurface drainage systems are common in PNW nurseries; some have been installed at the very onset when the area was initially developed

and some have been installed years later after the field has grown numerous crops.

3. Drainage of surface water from nursery beds and onto roads or ditches can be enhanced by crowning fields and ensuring that all bed areas slope downwards towards roads or ditches.
4. Beds can be raised above the level of the tractor paths to allow water to run from beds into paths. When paths become compacted or beds are not raised, tractor paths can be subsoiled to allow water to drain into the cut made by the sub-soiler. Several PNW nurseries routinely sub-soil 1-year-old fields in the fall before the onset of rainy weather. Similarly, wrenching will enhance drainage in the bed itself.
5. Low, poorly drained areas in fields should be noted and, after the crop is lifted, these areas can be filled in or taken out of production until corrective work can be done on them.
6. Irrigation practices often influence the development of Phytophthora root rot. Watering needs should be coordinated to avoid constant saturation of soils, particularly during the spring, summer, and fall when the fungus is active. Irrigation for cooling, pesticide application, or following fertilization should coincide as much as possible with routine irrigation. Over-irrigation and alternating drying and saturation should be avoided, particularly in areas known to be infested with the fungus.

Sanitation

Sanitation practices are a vital part of management of any disease. Phytophthora root rot is no different. Diseased seedlings should be

¹Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

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removed from nursery beds and disposed of, particularly if you do not plan to fumigate prior to the next crop. Rogued seedlings and packing house culls should not be returned to the fields as organic matter. Resting spores are able to survive in dead plant tissue and could serve as a source of infection if left in the field. Even composted culls are suspect. We feel that composting will not kill 100% of Phytophthora inoculum in seedling tissue; various fungi, including Pythium (a close relation to Phytophthora), have been recovered from seedlings composted for over 1 year.

Diseased seedlings and seedlings from diseased areas of a nursery should not be moved to other nurseries or to "clean" fields within the same nursery. Moving diseased stock will introduce the disease and, once there, it is extremely difficult, if not impossible, to get rid of. Also, additional species of Phytophthora, not present previously, could be introduced into a nursery by contaminated stock. Similarly, equipment that has been in diseased fields, should be washed free of soil to prevent contamination of the next field it enters. This is very important for nurseries that borrow or trade equipment.

Resistance

Tree species vary in their susceptibility to Phytophthora root rot. True firs, western and mountain hemlock, and Douglas-fir are very susceptible to Phytophthora species found in PNW nurseries. Pine species, spruce, larch and incense cedar are moderately susceptible. Western redcedar is resistant. These groupings are based both on field observations and greenhouse pathogenicity tests. In areas of your nursery which are poorly drained, prone to flooding, or where Phytophthora root rot was present in the previous crop, resistant or tolerant species should be sown or transplanted. Very susceptible species should be planted in areas which are well-drained and, if possible, have not had a history of Phytophthora root rot.

CHEMICAL MANAGEMENT

Various fumigants and fungicides are available to control Phytophthora root rot.

Fumigants

Fumigants are general biocides which are used to treat fallow soil prior to sowing or transplanting. The fumigants methyl bromide-chloropicrin, vapam, and dazomet will reduce soil populations of Phytophthora spp. when used correctly. For nurseries with widespread, continuous problems with Phytophthora root rot

and other soil-borne diseases, fumigants are an efficient and effective way to reduce disease levels. Phytophthora root rot has occurred in fumigated fields, however, due to re-introduction of the fungus, e.g., transplanting of already-diseased stock; use of contaminated water for irrigation; movement of contaminated soil during flooding or on equipment.

Fungicides

A number of fungicides are registered for use on conifer seedlings for control of Phytophthora and Pythium spp.:

1. metalaxyl (Subdue®, Ciba Geigy)
2. phosethyl Al (Aliette®, Rhone-Poulenc)
3. ethazole (Truban®, Mallinckrodt)
4. propamocarb HCl (Banol®, Tuco)
5. fenaminosulf (Lesan®, Mobay)
6. ethazole-methyl thiophanate (Banrot®, Mallinckrodt)

Use of fungicides can supplement cultural practices. They should not be depended upon to protect or cure seedlings, especially those that are in an environment that promotes disease, such as a wet, poorly drained field. We have sufficient data and experience to demonstrate the effectiveness of metalaxyl. The other fungicides have been used with success on other crops, but we have not yet been able to show their effectiveness on conifers against Phytophthora spp. There are a couple of reasons for this: There have been relatively few field trials in PNW conifer nurseries where the disease intensity has been high enough to conduct a meaningful test. Additionally, application techniques and timing, particularly with new products such as Aliette, have not been optimal so that the full potential of the fungicide has not been seen.

Metalaxyl is a systemic material which is taken up by the roots and moved acropetally (upwards and outwards) in the plant. It can be applied as a liquid onto the foliage and then watered into the root zone (Subdue 2E) or it can be incorporated as granules into the soil or onto the surface of the soil, with release of the product occurring after watering (Subdue 5G). Once in the plant, metalaxyl inhibits further development of Phytophthora so that disease progression is halted. The fungus is not eradicated from the seedling, however. The consequences of non-eradication can be either minimal, such as when you out-plant a treated, but infected, seedling into a dry, well-drained forest environment, or quite severe, such as when you transplant a treated, but infected, seedling into a poorly drained portion of another nursery.

Metalaxyl should be used sparingly and thoughtfully since strains of Phytophthora, tolerant to metalaxyl, can become predominant in soils which have had repeated, frequent applications of the fungicide. Repeated use can also result in decreased effectiveness due to the build-up in the soil of microbes capable of degrading metalaxyl. Highly susceptible seedling species in high-risk areas (areas which are poorly drained, prone to flooding, or which have had disease in the previous crop) should have the first priority for treatment. One well-timed application of metalaxyl per year can adequately control Phytophthora root rot in most cases. Several applications in 1 year will give increasingly more benefit with each additional application, but each increase is very small and probably is not worth the additional application cost (Hamm et al. 1984). Application in the fall or spring prior to the development of symptoms will be the most effective. Timing of fungicide applications, as well as cultural activities, are discussed by Cooley et al. (1985) in greater detail.

Chlorination

In some locations, water supplies which are used for irrigation are contaminated with Phytophthora spp. Inoculum in the water can be eliminated or reduced to non-damaging levels by chlorination of the water before it enters the irrigation lines. We are still learning to adequately measure and interpret chlorine levels; for example, how much chlorine gas needs to be added to get 5 ppm free chlorine and how much free chlorine is required to reduce Phytophthora to undetectable levels in the water? Other factors, such as pH and the amount of organic material in the water, will also affect how chlorine reacts and how much is needed to kill propagules of Phytophthora.

Some sources of water are more likely than others to become contaminated with Phytophthora. Well-water and municipal water are probably more disease-free than water from open canals and agricultural districts. To determine if your water source is contaminated, Phytophthora can be detected by baiting. The baits are green fruit (of apple or pears, for example) which are placed in the water; spores of the fungus are attracted to the fruit and will enter it and cause decay. The fungus can then be isolated from the decayed tissue on a petri plate and identified.

In conclusion, I would urge all of you who have experienced Phytophthora root rot to keep at your drainage problems, continue to upgrade your field topography, be conscientious about coordinating your water uses and keep good histories of your fields so that you can plan where to sow or transplant your susceptible species. I urge you not to depend on fungicides; they are for emergencies, for marginal situations, not for routine applications. FORTUNATELY, because Phytophthora is very dependent on its environment, it can be very easily controlled with good cultural practices.

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Some Insect Pests of Conifer Seedlings in British Columbia¹

Gwen Shrimpton²

Abstract.--Girdling damage to conifer seedlings caused by the Cranberry girdler, *Crambus nevadellus*, the European Marsh Crane fly and adult weevils is described. A monitoring program for fungus gnat populations in greenhouses is also discussed.

INTRODUCTION

Conifer seedling nurseries in British Columbia (B.C.) have sustained girdling damage from several insect pests. Criteria to differentiate the types of girdling have been compiled so that control programs can be readily implemented. This paper briefly outlines the insect girdlers found, describes the type of damage they do and discusses some control programs that have been developed in B.C. A program used to monitor populations of fungus gnats that occasionally become pests of container seedlings is also described.

INSECT GIRDLERS OF CONTAINER SEEDLINGS

The Cranberry girdler *Chrysoteuchia topiaria* was confirmed as a pest in B.C. in 1981. Pheromone trapping programs have determined its presence at all ministry nurseries in the province. To date damage has been confined almost exclusively to bare-root, 2+0, true firs and Douglas fir. Transplant stock, container stock and seedlings of other species are rarely affected. Damage is caused by the larvae that live in the duff layer at the surface of the soil. The larvae feed on stock from late August to mid-November. The solitary larvae appear to stay in one place long enough to feed on up to 5 seedlings and then move on for about 20 inches before feeding again. Damage generally occurs in scattered patches. The larvae eat the bark and chew into the wood, though the stem is not always completely ringed. The area, approximately one inch above and below the soil line, is attacked; some chewing may be

found on the upper roots. An excellent control program using pheromone traps has been developed for this pest (Triebwasser & Overhulser, 1980).

In 1985 and 1986 another small moth *Crambus nevadullus*, a relative of the cranberry girdler, was found girdling container seedlings at two nurseries in the Okanagan. Damage appears as a uniform ring about $\frac{1}{4}$ - $\frac{1}{2}$ inch wide just at soil line. It resembles adult root weevil damage, but fine silk webbing is often seen at the surface of the plug and larvae may be found near the damaged seedling. To date, damage has occurred during the month of August and only spruce seedlings have been attacked. Damage is distributed in small pockets of 1-7 seedlings throughout the greenhouses. Moths of this species have been caught in low numbers in cranberry girdler pheromone traps for a number of years and their life histories are similar.

The European Marsh Crane fly *Tipula paludosa* has been a chronic pest at several coastal nurseries for the past ten years. Girdling caused by the soil dwelling larvae occurs from March to May. Any stock present at the nursery during this time can be attacked. To date, most damage has occurred in bare-root stock, where there seems to be no host preference. The damage consists of a uniform ring about one inch wide just at soil line. The stem is nearly always completely ringed and only the bark is consumed. Some of the upper roots may also be stripped. Damage has a spotty distribution with small patches of 1-7 seedlings attacked throughout an infested area. Each patch is generally the work of one larva which is often found with the damage.

Several species of adult weevils have been confirmed or are suspected to girdle conifers in greenhouses. Adults of three root weevils *Otiorhynchus ovatus* the strawberry root weevil, *O. rugosostriatus* the rough strawberry root weevil and *O. sulcatus* the black vine weevil have been observed feeding on seedlings.

¹ Paper presented at the Western Forest Nursery Council Meeting, Tumwater, Washington, August 12-15, 1986.

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Adults of Trachyphloeus bifoveolatus the small grey grass weevil and Strophosoma melanogrammum have been observed in sufficient numbers where damage has occurred to suspect them as the cause.

Girdling consists of a uniform little ring about $\frac{1}{4}$ " wide, often just below the point at which foliage begins in the fleshiest part of the stem. Damage usually occurs in June and July. Weevils seem to attack seedlings for a limited period of time when enough bark tissue has developed for them to feed, but before the stems have become too woody. Most girdled seedlings are between $3\frac{1}{2}$ and 6 inches in height. Seedlings at the edges of the greenhouses and ones on the outsides of the styroblocks are attacked most frequently. Usually only one seedling is girdled at a time. There appears to be a preference for spruce, however cedar, larch, fir and pine have also been attacked.

Adult root weevils are elusive, feeding at night and hiding during the day. As a result, populations usually go undetected until damage occurs. Monitoring programs have been attempted at several nurseries. Weevil boards, bait stations, pitfall traps, indicator plants such as rhododendrons and sticky traps have all been tried without success.

A control program to reduce girdling by adult weevils using Pydrin (fenvalerate) has been developed and was successfully implemented at one nursery in 1986. The timing of the applications is critical for effective control. Adult weevils emerge when the weather becomes warm in the spring around the middle of May. This is also the time when the seedlings have reached a susceptible stage. Pydrin is applied as a foliar spray during the second week of May, and this is followed by a second application 3 weeks later. It appears that the insecticide acts more as a repellent than as an insecticide. These insects have a large host range and will move on to feed on plants in a more favourable environment.

SMALL FLY POPULATIONS IN GREENHOUSE FACILITIES

Many nurseries in B.C., especially the older established greenhouse facilities, have large populations of small flies. In 1981 and 1982, adult and larval flies were collected from seven nurseries and eleven different families were identified (table 1). Of these the shore flies family Ephydriidae were the most common. These insects breed in algae and decaying matter in wet areas and are not nursery pests. Occasionally, however, populations of fungus gnats family Sciaridae have

been observed damaging container seedlings. The larvae infest the plugs feeding on the upper roots, and in heavy infestations, they can girdle the stems just below and at soil line. Infestations of fungus gnats are not common and the seedlings attacked have usually been predisposed, often by an infection of Fusarium. Once the seedlings are well established and vigorously growing, these insects are generally not pests.

Table 1.--Families of small flies collected in container facilities.

Agromyzidae
Anthomyiidae
Cecidomyiidae
Chironomidae
Dolichopodidae
Empididae
Ephydriidae
Muscidae
Psychodidae
Sciaridae
Sphaeroceridae

In 1986, a monitoring program for populations of small flies was conducted at 4 nurseries in B.C. Yellow sticky ribbons were hung throughout the greenhouses. Yellow is a color that attracts many species of insects which then become stuck to the surface of the ribbon.

The purpose of the program, was to monitor the populations of insects present, and to train nursery personnel to distinguish between the innocuous shore flies and the potentially damaging fungus gnats using the characteristics in table 2. The second purpose was to actually reduce the numbers of flies present in the greenhouses. Although many of the flies present are not directly damaging to the stock, large swarms can be annoying to nursery workers. In cucumber greenhouses, growers have successfully reduced fly populations using these yellow sticky ribbons at a density of one every ten square feet.

Insect girdlers generally are not major pests of conifer seedlings. However, effective control programs can be developed once characteristics have been determined to differentiate the various types of girdling. Fungus gnats can occasionally become pests on the nurseries but the majority of the flies present will not feed on conifer stock and are only a problem because of their nuisance value.

Table 2.-- Characteristics used to differentiate shore flies and fungus gnats.

	Shore Flies	Fungus Gnats
Family	Ephydriidae	Sciaridae
Body	size and shape of fruit flies	resemble tiny mosquitoes
Size	2 - 4 mm	2 - 4 mm
Wings	have pale spots	grey with "Y" shaped vein
Antennae	short with a bristle	long bead-like
Flight	tend not to fly but are strong fliers when they do	easily excited into flight but are poor fliers
Larvae	maggots have no distinct head	maggots are slender with dark shiny heads

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**Reducing *Fusarium* Top Blight in 1-0 Douglas-fir
by Irrigation Scheduling¹**

Kenelm W. Russell²

Abstract.-- Dry Pacific Northwest summer weather is when one phase of Top Blight caused by *Fusarium* spp. infects 1-0 forest nursery seedlings. Top Blight appears when nurseries use short cycle cooling irrigation during hot weather. Infection is prevented by deep watering up to one inch at infrequent intervals.

MIDSUMMER CRISIS

Time: Monday, August 4, 1986

Place: Department of Natural Resources
Pathology Lab south of Olympia, Wa.

1100 Phone call. Anxious nursery reports dying 1-0 DF seedlings. Bill (grower) on vacation. Trees sprayed weekly- 8 oz./ac captan/benomyl mix. No rain for 26 days. Weather- HOT! Short cycle cooling irrigation schedule being followed.

"Uh oh! I'd better get right over!"

1130 I arrive at nursery. Found 1-0 DF seedlings wilting, yellowing, and finally red.

No evidence of fungus anywhere on seedlings.

Soil moist in top inch- dry below that. Seedlings appear stressed.

Initial diagnosis- *Fusarium* Top Blight.

Action: Recommended immediate deep watering to relieve stress on seedlings. Fungicides NOT needed now.

1300 Spent PM looking through microscope for sign of fungus. Nothing!

Deep watering in progress at nursery.

1700 Placed dozen seedlings in plastic bag with wet paper towel to keep them moist. Left them on counter and went home.

0800 Tuesday. Seedlings in moist chamber bag fluffy white with fungus mycelium.

0815 Placed a bit of the mycelium from the root crown area on a glass slide, added a drop of lactophenol/cotton blue stain and a cover slip. Under the microscope at 100 power, I found thousands of *Fusarium* species macrospores. Their cellular banana shape with several cross walls were a dead giveaway.

0817 Top Blight confirmed. Nursery notified and advised that mortality will taper off as stress on seedlings decreases.

1200 Deep watering (one inch) in progress. After an inch, no water will be added until soil dries to just above seedling stress point. Short cycle cooling irrigation stopped.

¹Paper presented at the Western Forest Nursery Council Meeting, Tyee Motor Inn, Tumwater, Wa. August 12-15, 1986.

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INTRODUCTION

The most common midsummer disease in Pacific Northwest forest nurseries is Top Blight. Conifer seedlings are most susceptible to infection

in their first growing season. Outbreaks can often be tied back to water stress or improper nutrient application. One or more Fusarium species are involved and other fungi have been isolated from Top Blight symptom trees as well (Hamm 1986).

Many years ago on a hot summer day approaching July 4th, Bill Fangen and I were trying to figure out what was killing the 1-0 Douglas-fir seedlings in the Washington State Department of Natural Resources Webster Nursery a few miles south of Olympia. Once again, just as in the crisis situation above, then nursery manager, the late Red Ward, was on a trip to Japan.

Our timing for looking was perfect as we caught the fungus (Fusarium spp) with its pants down and I was able to identify it immediately under the microscope. I found masses of spores in crust like fungal mats near the root crowns of droopy yellow and red colored seedlings. The numerous banana shaped macrospores were easy to identify.

The nursery was then in a cooling irrigation mode. I remember saying, "Bill, these seedlings look stressed. We need to get some heavy water to them right now."

When Red arrived home, Top Blight was under control and the seedlings were one-third taller. The nursery looked beautiful.

I've since nicknamed this summer seedling malady the "Fourth of July Disease" because it coincides with the onset of the hot dry summer weather which often arrives west of the Cascade Mountains just before or after the holiday.

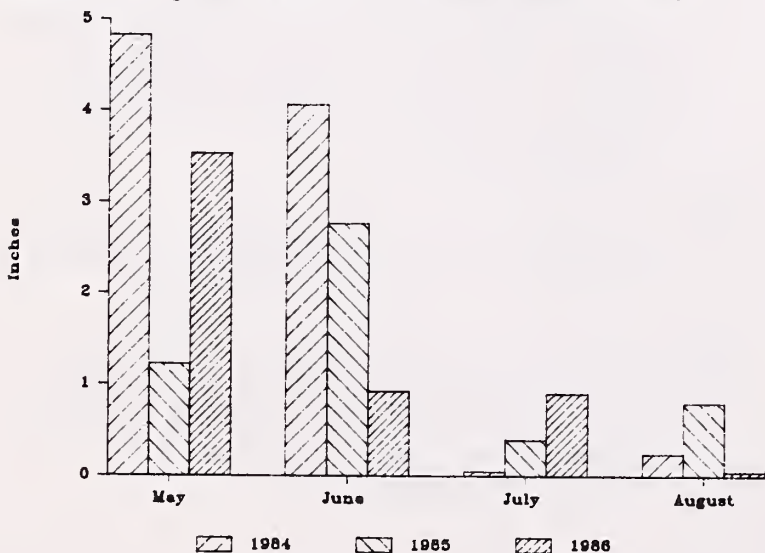


Figure 1.--No rain in late summer, 1986 saw ideal Top Blight conditions at Webster Nursery. The 1985 summer rain was more evenly spaced and Top Blight was reduced.

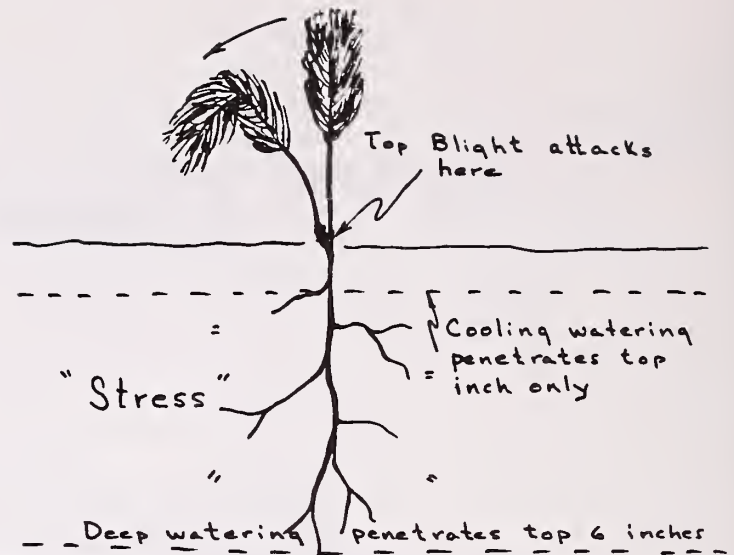


Figure 2.--Summer Top Blight incubates in warm, moist upper soil and attacks at the root crown when seedlings are stressed.

Top Blight as described above does not appear to be a serious problem during wet summers, or summers where rainfall is periodic. The most probable reason is that seedlings are not stressed as much as they could be during a long hot summer. Research needs to explore this.

TOP BLIGHT BUILD UP CONDITIONS

Warm weather, summer rainfall (both amount and timing), irrigation scheduling, and nitrogen availability are key ingredients that determine potential for infection. Summer, 1986 saw a higher than normal incidence of Top Blight in several nurseries. It turned hot and dry in July and no rain fell from July 11 until September 8 (fig. 1).

Trouble from Top Blight builds during the hottest part of the summer when rain is absent and trees are watered on a short daily schedule for cooling. This irrigation pattern cools and wets the top inch or so of soil but little water reaches the main moisture absorbing part of the root system two to five inches lower.

The seedlings become stressed and infection is triggered. They wilt, gradually fading to yellow, then red (fig. 2). Mortality is not great at first, but red trees scattered intermittently along the rows appear alarming. If left unchecked Top Blight could severely deplete the seedling beds. The fungus tends to build up in the warm, moist upper soil layer created by the frequent, short cycle cooling irrigation. The warmer the weather, and the

longer the interval between prolonged rains, the higher the chances for infection. The tender seedling stems are set up for attack just above the root crown.

Check lower root zone soil moisture in your own nursery on a hot summer day after you have been watering on short cooling cycles. Dig through the top eight inches of a 1-0 seedbed and look for dry soil lower than one inch from the surface. If the lower soil is dry the stage may be set for Top Blight infection.

TOP BLIGHT PREVENTION

Prevention of Top Blight means anticipating infection when the weather looks like it will favor the disease. Be ready with prevention techniques when the stable summer high enters the Pacific Northwest.

After a week of hot, dry weather use an infrequent deep watering schedule equivalent to at least an inch of rain at a time. CREATE YOUR OWN SUMMER RAINSTORMS ON YOUR OWN SCHEDULE. You don't even have to have the clouds! Repeat this schedule until rain appears.

This kind of watering is the heart of Top Blight prevention. It takes courage to hold to it when the soil heats up. Under some conditions, seedbeds may need to be cooled. Use your judgment to decide when to water based on knowledge of your soil's moisture holding capacity.

Preventive fungicide applications must be timed to prevent loss or movement of active ingredient from the target tree. A regular fungicide schedule will help reduce or prevent infection, provided it is not washed off the target tree during watering or rain. This is what may have happened in the crisis situations described at the front of the paper.

Fungicide applications must be flexible so they can be changed if rain is on the way. Fungicides must be applied after watering or rain to avoid washing them away before they can be absorbed into plant tissues or otherwise activated. Preventive applications should include alternate fungicides so that no one fungus gets the upper hand.

Summer applications of nitrogen have been shown to favor incidence of various Fusarium species. Minimize mid summer applications of nitrogen fertilizers.

CONTROLLING TOP BLIGHT

If you are caught with an outbreak and if it is confirmed in similar fashion to my description above, control it at first with water. Add at least one inch to relieve seedling stress and then and only then, apply a fungicide. Fungicides seem to do little good until seedling stress is relieved.

HOW TO IDENTIFY FUSARIUM TOP BLIGHT

If your Top Blight Integrated Pest Management techniques are working during the hot months you should not see enough infection to worry about. In the event the weather brings on a problem despite your best efforts, here is how you can identify the disease on suspected seedlings.

In first year seedbeds look for drooping yellow-green, then yellow and finally red seedlings scattered intermittently along the rows. When you dig the seedlings, the lower roots appear to be healthy. The area immediately above the root crown is dead and the tops are limp. Observe root crown areas carefully for presence of crusty looking whitish mats of mycelium. A 10x hand lens can be used in the field. If fungus mycelium is found you need to place a scraping of this material under the microscope to look for the distinctive macrospores.

If fungal growth of any kind is absent place a dozen seedlings in a plastic bag along with a small piece of wet paper toweling to provide a moist chamber.

Leave the seedlings at room temperature overnight or as long as it takes to allow fungus mycelium to grow out of the lower seedling stems. Usually, the fungus grows out overnight and can be observed the next day.

Place a bit of the mycelium on a clean slide with a small knife or scalpel. Add a drop of lactophenol/cotton blue for staining, then carefully drop a cover slip in place, and observe under 100 to 400x (fig. 3). Microscope power is determined by multiplying the numbers in each lens together. For example, 10x eyepieces times the 10x objective lens equals 100x. Usually, this is sufficient magnification to positively identify Fusarium species macrospores. You will need help from a pathologist to identify Fusarium to individual species.

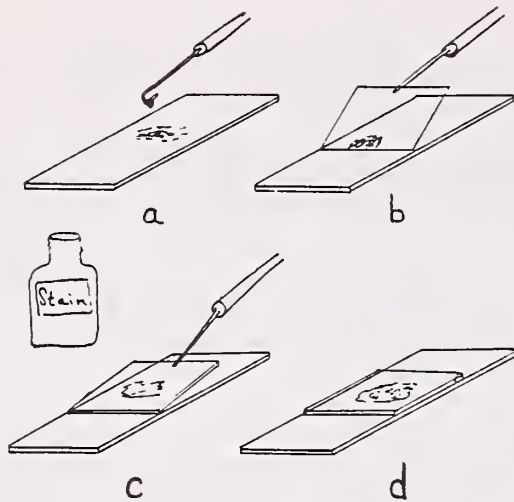


Figure 3.--Place strands of fungus growing on seedlings in the moist chamber bag on a slide and add one drop of stain (a). Place cover slip gently to avoid bubbles (b-d). Observe under microscope at 100x.

Fusarium species have three kinds of spores, macro, micro and chlamedospores. Look for the distinctive banana shaped macrospores which are about two to four times longer than the small rather nondescript microspores (fig. 4). Chlamedospores would not normally be found on a newly killed seedling because they are a type of resting spore and do not appear until later stages of growth.

The suggestions above are meant to help you get quickly on top of a problem. I recommend a call to your neighborhood pathologist to confirm your diagnosis and look into any subtle conditions of the infection pattern that might be peculiar to your nursery. Top Blight varies a little from nursery to nursery.

BALANCING TOP BLIGHT PREVENTION WITH HARDENING OFF

Infrequent, deep watering to minimize Top Blight infection could be a problem if it is late in the growing season. The grower wishes to slowly harden the seedlings off to force dormancy. This is usually done by withholding water and nutrients. Growers walk a tight wire between creating disease development conditions and hardening off.

Personally, I would rather irrigate on the deep, infrequent pattern in hot July and August to minimize infection potential when seedlings are still tender. Then, I would harden the seedlings off when weather is unfavorable for Top Blight and they have more natural infection resistance.

Irrigation schedules may be so inflexible that they do not allow human judgment while

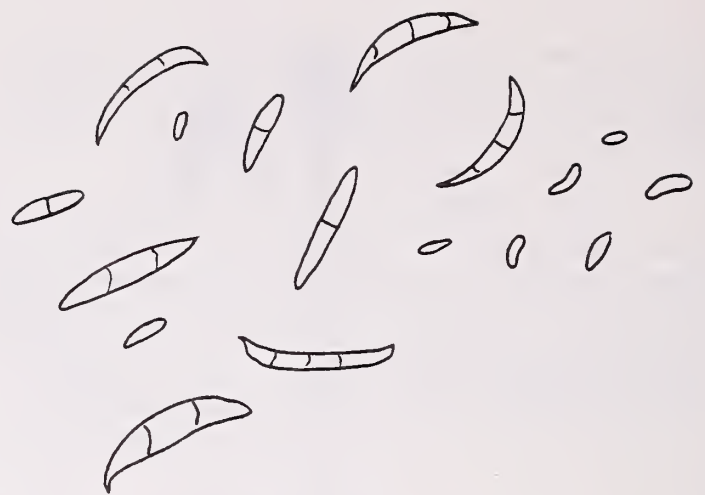


Figure 4.--Distinctive Fusarium spp. macrospores under the microscope at 100x are banana shaped with 2 to 3 crosswalls. Microspores are small bean shaped and may or may not have crosswalls.

actually watering. Valves simply get turned on and off for a specified number of minutes without close looks at the trees. This is where green thumb gardening pays off in disease prevention.

Persons with watering responsibilities do better when they combine green thumb gardening experience with the rigid scheduling. Practiced gardeners often have a natural tendency to closely observe what the plants and outside agents (disease) are doing and may strike good balance between watering, disease development and dormancy inducement. This natural gardening attitude can be a helpful factor in helping to minimize disease.

Growers, irrigation managers, and their helpers should be carefully trained (1) to recognize Top Blight build-up conditions (2) to apply prevention techniques when weather and conditions favor infection, and (3) to recognize and treat the actual disease. I've seen some excellent results when growers follow these principles of Integrated Pest Management.

Don't feel bad if this critter pops up in your nursery once in a while. The summer of 1986 was nice for recreating and outdoor enjoyment, but it was a heck of a year for the "Fourth of July" disease.

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Options in Controlling Soilborne Pests¹

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My purpose in selecting this topic for presentation is two-fold. First, it serves as an excellent prologue to our fumigation studies, which will be presented next. Second, and most importantly, I hope that it will stimulate some reevaluation of the subject of soil fumigation. This process of reconsideration is addressed both to nurserymen and researchers.

WHY THE CONCERN?

The first concern is the possible loss of registration of presently used soil fumigants. It may take anywhere from 1-5 years, but when it occurs it could happen quickly as it has in the past. The continued increase in technology of detecting chemicals in the environment, and the continued concern for environmental contamination suggests that it's only a matter of time.

Working out alternatives to presently used pesticides involves considerable time and money. We should be in the positive position of having a replacement waiting in the wings and ready to go as soon as the primary pesticide is lost.

Another concern is that the most common presently used fumigant is a biocide, which is hazardous to both humans and the environment. Again, with the increased pressure to reduce the use of these soil sterilants, it may only be a matter of time before pressure is brought to bare in this area.

The other problem with this presently used fumigant is the high cost. Soil fumigation is presently the most costly soil management activity conducted in a nursery. With the downturn in the forest nursery economy, and competition increases, those nurseries that can keep their cost of production down will be the most competitive.

Soil fumigation in forest nurseries using Methyl bromide-chloropicrin, is overkill. Many times the rates are too high and the biocidal activity of the chemical is too broad spectrum. This results in destroying both the beneficial and pathogenic organisms. It's rather like using a nuclear weapon to stop a riot. We have difficulty sorting out the good guys from the bad guys and so we kill everyone. This always results in a loss of a lot of innocent bystanders, and in this case, these are the beneficial soil organisms. Container nurserymen have learned the difference between pasturization and sterilization of the soil, but it's a lesson yet to be understood and learned by bareroot nurserymen.

Ironically, however, even with sterilization many 1-0 crops routinely experience a certain percent mortality each year from damping-off and lower stem canker diseases. Even if soil treatment is effective at sowing, its effect is gone soon after sowing. This suggests there may be a better way of dealing with this short-term problem.

More judicious use of the presently used pesticides may delay their loss from registration. If it can be demonstrated that these materials are used only under necessary conditions, and then with the consideration of environmental protection, they are less likely to be lost from registration.

Finally, a time may be approaching when future regulations may require a prescription prior to the application of a soil treatment. This has already been tried for several pesticides in some states. While it has

¹Paper presented at Western Forest Nursery Council Meeting, Tumwater, WA, Aug. 12-15, 1986.

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created many problems, there may be some instances in which it's justified. In the case of irreparable changes in the environment as a result of the application of a pesticide, a more thorough evaluation of that environment may be necessary prior to the application of such a pesticide. This may require laboratory tests to determine several things about the environment in order to evaluate what impact this treatment may have. These might include an evaluation of the soil microorganisms, soil type, geology and hydrology of the area, etc. Then a pesticide would be recommended which would be least damaging under these circumstances (Holden, 1986).

Presently law suits involving groundwater contamination are in progress throughout the United States. Growers that have been most successful in defending their actions have had records of laboratory analyses to determine the need for fumigation. Many of these cases date back to the late 1970's and early 1980's before groundwater contamination was known to be a problem. Therefore, it's possible that at some future date nurserymen could be sued for the use of registered hazardous chemicals in the soil environment even though they are presently legal. These are very complex issues. A lot of innocent growers are being hurt in this sorting-out process. We, therefore, need to be forewarned about such issues and be taking some steps now to protect ourselves.

WHAT ARE OUR OPTIONS?

The use of crop rotation and/or fallow has controlled soilborne pests on a wide range of crops. This practice is currently being used on a number of agricultural crops as an effective management tool. Tests are presently being conducted by researchers at Oregon State University to evaluate this as a management practice in forest nurseries. This is a positive step forward and needs to not only be encouraged by the nurserymen, but they should actively be involved in some testing on their own.

There is a need to get away from overkill, and to apply pesticides against the specific target organisms. This, of course, requires determining what those target organisms are and developing control measures specifically against those organisms. More research is needed in this area.

Seed protection is another approach in controlling seed and soilborne pests. Even if soil treatments correct the problems in the soil, they are frequently reintroduced on contaminated seed. Occasionally a more severe problem is created by planting fungus infected seed in a relatively sterile soil environment. The beneficial organisms have been removed from the soil, and thus the fungus introduced on the seed has nothing to keep it in check and frequently creates more loss than if the soil had not been sterilized.

The use of biological control agents is another area which has not been fully explored in the forest nursery industry. There have been several breakthroughs in the use of beneficial fungi and bacteria for controlling soilborne agricultural pests. These are applied either as seed treatments or soil amendments (Cook & Baker, 1983).

In the final analysis, alternatives to biocidal soil fumigation will probably involve a combination of the above practices. The exact combination will be determined by the nurseryman's unique set of conditions and needs. There are probably also other practices which may be beneficial, but have not been fully evaluated or enumerated at this point.

PREDICTIVE EVALUATIONS

As was mentioned earlier, in order to avoid the "biocidal-overkill" approach we have to be able to sort out the "good guys" from the "bad guys". Having made that determination we can then select the correct weapon for the job. Below I have selected the areas I believe we need to be concerned about and discuss them in terms of our present knowledge and our future needs.

Soilborne Microorganism Assay

In terms of predictive assays, we probably have the greatest knowledge about nematodes. Preplant nematode assays have been used for several decades to determine soil treatment needs (Taylor, 1971, Oostenbrink, 1972). Procedures are more or less standardized and many government as well as private laboratories routinely conduct nematode assays for growers.

Routine assays for soil fungi (e.g. *Fusarium*, *Pythium*, *Rhizoctonia*, *Phytophthora*, etc.) appear to still be in developmental stages, although the technology has been available for several years. Several assays are presently being used for agricultural crops, but these too are limited.

The precedent for use of soilborne assays in forest nurseries was set several years ago. The Canadian Forest Service in British Columbia routinely analyzes proposed sowing blocks for soilborne fungi. Since Methyl bromide-chloropicrin is not registered for use in British Columbia, soil showing high levels of *Pythium* and *Fusarium* are taken out of production and alternative sowing areas are sought. Population reduction is accomplished by bare fallowing for one year.

The Department of Natural Resources Nursery in Olympia, Washington uses a similar technique to determine need in proposed sowing blocks (Russell, 1976). The registration of Methyl bromide-chloropicrin in Washington provides soil fumigation of heavily infested soils as an additional option.

Peninsu-Lab was the first, and still is, the only commercial laboratory offering this service to Pacific Northwest Nurserymen. Cooperative tests with Peninsu-Lab, Canadian Forest Service, B.C., Department of Natural Resources, Olympia, Wa., U.S. Forest Service, Portland, Or., and Oregon State University, Corvallis, Or. has established the accuracy and reproducibility of these tests.

Two of the weak links in the present program are an understanding of population dynamics of the fungi throughout the year, and an ability to interpret the results in different situations. Our findings over the years have suggested that the interpretation is best done on an individual nursery basis, avoiding generalities between nurseries. Unique conditions within a nursery influence the amount of damage caused by a certain population of soil fungi. The presence of certain soilborne biological antagonists probably play a major role in this variation. At the present time there is very little understanding of what these organisms are, and their importance in the nursery situation. A better understanding of these beneficial organisms will enable us to improve our interpretation. Also with a better understanding of these organisms, we may be able to reintroduce them into the soil

following treatment to regain a more balanced soil microorganism population.

Seed Assays

Another predictive tool which would be useful would be the assay of each seed lot for seedborne fungi. Pathogens such as *Fusarium* are frequently found both externally and internally associated with seeds, which in turn influences the amount of loss experienced by the nurserymen. If a seedlot is found to be heavily contaminated with *Fusarium* and cannot be cleaned up, less disease loss may be experienced by planting into a nonfumigated soil rather than into a sterilized environment. Also a knowledge of whether the fungus is internal or external will determine the efficacy of surface seed disinfection. From a research standpoint we need more information regarding the affect of the various fungi that are found on seed as well as more adequate means of treating the seed to control these organisms.

Weed Surveys

This is something the nurserymen can and should be doing routinely. Armed with the knowledge of weed species present in a particular block in the nursery, the nurserymen can then make a decision as to whether or not effective herbicides are available for their control or whether a biocide treatment is necessary. Often judicious use of selective herbicides is less costly than the soil fumigation.

Soil Insect Surveys

Soil insects are not ususally a major problem in forest nurseries. They do, however, occur on occasion and can be quite damaging. The White Grub of the Tenlined June Beetle is a good example. However, if proper surveys are conducted ahead of time the least costly control measure can be applied.

ADVANTAGES

There are several advantages in using predictive evaluations to determine the need for soil fumigation. First it allows us to target the organism to be controlled. We can then select a control measure specific for

that organism. If a pesticide is required, the population level will enable us to determine the proper rate necessary for control. At the present time we are aiming for 100% control, whereas proper pest management techniques suggest that it is most beneficial to just bring the populations back into balance with the beneficial microorganisms in the soil.

This type of an approach also optimizes the per acre cost for treatment. In other words, the nurseryman applies just the pesticide needed at the proper rate to bring things back into balance, which enables him to produce the healthiest seedling with a minimum input of expense.

Finally, this approach becomes the prescription which may some day be required by government regulation. The pest population has been determined by field observation and laboratory analysis, a pesticide and rate and/or management technique has been selected to minimize the effect of the pest, optimize growth of the seedling, with minimal affect on the environment.

It may seem that we are a long way from such an ideal situation. However, I believe we are closer than many of us realize. Much of the technology is already available and simply needs to be put together and tested at the field level. I believe this can be accomplished in a relatively short time through the cooperative efforts of nurserymen, researchers, and private industry. It is not necessary for the nurseryman to wait until all

the answers have been provided at the research level. Some of these tests can be conducted at the nursery level, and in fact, each nurseryman will eventually have to conduct these tests at their nurseries to determine what will and will not work.

My challenge, therefore, is to consider some of the options I have outlined, think of some of your own, take the initiative and act now rather than react when your number of options are more limited.

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Use of Metam-Sodium and Dazomet Fumigants¹

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Controlling disease causing microorganisms in the soil environment prior to seed sowing is a difficult task. When a chemical is used for this purpose it must not only be capable of killing the organisms, but also be able to penetrate areas where those organisms are, remain there long enough to be effective, and leave the soil without a residual which might damage subsequently planted seed.

A number of soil fumigants have been used for this purpose over the years. In the last decade Methyl bromide-chloropicrin has become the standard since it very effectively meets the above criteria. However, it also has several disadvantages (e.g. cost, overkill, handling danger, etc.) as discussed in my previous talk on "Options in Controlling Soilborne Pests".

Peninsu-Lab is continually investigating new methods for dealing with soilborne pest problems, and as a part of this program has tested a number of soil fumigants. Over the last three years two of these chemicals tested under contract by Peninsu-Lab, have shown promise for use in forest nurseries. These compounds are Metam-sodium (Vapam, Soil-Prep) and Dazomet (Basamid-Granular).

With some minor differences, both compounds form the active ingredient Methyl isothiocyanate (MIT) when in contact with moist soil. This gas diffuses through the soil pore spaces moving mainly upward, killing the living organisms with which it comes into contact. This substance has a broad spectrum of activity against soil organisms such as insects, fungi, nematodes, and weeds.

Because of the differences in formulation, the two chemicals are applied by different means. Dazomet is a fine white granular material which is applied to the soil surface by means of a shaker, Gandy, or similar applicator. It is then tilled into the soil with a cultivator or hoe, and the soil surface sealed by compacting and irrigating.

Metam-sodium is a liquid and is applied through the irrigation system. The chemical is applied in about an inch of water and must be metered in during the entire time of irrigation (5-6 hours).

In comparison, Methyl bromide-chloropicrin is a gas which is injected into the soil to a depth of about 8-10" using shanks drawn behind a tractor. The soil must immediately be sealed with a polyethylene tarp to prevent rapid escape from the soil.

With all of these chemicals the soil must be tilled 1-2 weeks after treatment to allow escape of the gas prior to planting. This time interval is determined by a number of factors such as chemical, temperature, moisture, etc.

The following summarizes our findings over the past three years in several nurseries, and presents data from the 1985-86 tests. In all studies with Dazomet and Metam-sodium, Basamid-Granular and Soil-Prep respectively were the commercial products used.

¹Paper presented at Western Forest Nursery Council Meeting, Tumwater, WA, Aug. 12-15, 1986.

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1984 - Spring Application

At nursery A, Dazomet, Metam-sodium, and MC-33 were applied at 531, 100 and 350 lbs. per acre (ppa) respectively. Pre-treatment populations of Pythium and Fusarium were low and were significantly and equally reduced by all treatments. Because of the low population of soilborne fungi there was no significant difference in damping-off amongst the plots.

Based on paired sampling studies conducted by Peninsu-Lab of several nursery soils containing healthy and diseased seedlings, we consider populations of Fusarium and Pythium in excess of 1000 and 100 propagules per gram (ppg) of soil to be potentially damaging to conifer seedlings.

Approximately 1" of rain fell 3 days after treatment with Dazomet, which resulted in moving the material deep into the soil profile. The chemical did not escape from the soil until after sowing, resulting in phytotoxicity to the seedlings.

In nursery B, Dazomet at 350 ppa was compared to MC-33 at 350 ppa. In this nursery Fusarium, Pythium, Phytophthora, and 5 genera of plant parasitic nematodes were present in moderate to high populations. MC-33 and Dazomet reduced soil fungus populations by 88% and 70% respectively, which were both significantly below the untreated plots. Both treatments eliminated all nematode genera. Damping-off in the Dazomet treated plots was 1.8% compared to 12% in the untreated. A combination of a lower rate of Dazomet and minimal rainfall following treatment resulted in no phytotoxicity in these plots.

1985 STUDIES

Dazomet Rate Study - No Sowing

Dazomet was tested as a spring application at 0, 95, 187, 267, and 367 ppa. The material was applied operationally using a Gandy 1-bed (4') drop spreader, immediately tilled to 8", rolled with a bed roller and irrigated. Soil fungus populations and weed growth were evaluated and are shown in Tables 1-3.

The three highest rates all reduced both Pythium and Fusarium populations significantly below the untreated plots. Given the initial soil populations and the time of year, the 187 ppa rate would have been sufficient to reduce populations below damaging levels. All rates reduced weed populations significantly below the untreated controls. There was little difference between the 95 and 187 ppa rates, and between the 267 and 367 ppa rates.

For forest nurseries, it appears that a rate of 267 ppa may be as effective in reducing fungus populations as higher rates. It may even be possible to reduce this rate to near 187 ppa and still obtain adequate control. While weed control at 95 and 187 ppa was not as good as the two higher rates, it was significantly better than the untreated and may be adequate for a nursery program.

Dazomet Rate Study - No Post Treatment Herbicides, No Sowing

To determine the effectiveness of Dazomet alone in controlling weeds, 2 rates of material were applied with no post treatment herbicides.

Both rates of Dazomet gave good soil fungus control (Table 4) and weed control (Table 5). Although weed control was significantly better in the treated plots 4 weeks after sowing, by 6 weeks all plots were heavily infested with weeds. This demonstrated that while Dazomet is effective in significantly reducing weed seed populations in the soil, the standard nursery practice of applying a pre-emergence herbicide (such as Goal) is essential. Dazomet reduces the total weed population to a more manageable level using the pre-emergence herbicides.

1985-86 STUDIES

A series of tests were set up at each of four nurseries comparing different rates of Dazomet with other soil treatments. Two rates of Dazomet were selected for each nursery based on pretreatment soil fungus populations in that nursery. This was an attempt to determine if the level of soil fungus populations within a nursery could be used to select the lowest effective rate of Dazomet.

TABLE 1.--EFFECT OF 5 RATES OF BASAMID-GRANULAR ON FUSARIUM SOIL POPULATIONS - NURSERY A

TREATMENT (ppa)*	FUSARIUM (ppg)**		% CHANGE
	PRE TREAT	POST TREAT	
0	1833	1075	41.4
95	1674	684	59.1
187	1193	51	95.7
267	1209	193	84.0
367	1259	0	100

Values are an average of 3 replications

*ppa = pounds/acre

**propagules/gram of soil

TABLE 2.--EFFECT OF 5 RATES OF BASAMID-GRANULAR ON PYTHIUM SOIL POPULATIONS - NURSERY A

TREATMENT (ppa)*	PYTHIUM (ppg)**		% CHANGE
	PRE TREAT	POST TREAT	
0	87	178	+104.6
95	82	102	+24.4
187	371	38	89.8
267	33	0	100
367	119	0	100

Values are an average of 3 replications

*ppa = pounds/acre

**propagules/gram of soil

TABLE 3.--EFFECT OF 5 RATES OF BASAMID-GRANULAR ON WEED POPULATION 5 WEEKS FOLLOWING TREATMENT - NURSERY A

TREATMENT(ppa)*	TOTAL WEEDS/50' BED
0	50
95	17
187	14
267	1
367	1

Values are an average of 3 replications

*ppa = pounds/acre

TABLE 4.--EFFECT OF BASAMID-GRANULAR ON SOIL POPULATIONS OF FUSARIUM AND PYTHIUM - NURSERY A

TREATMENT (ppa)*	PRE TREAT**		POST TREAT	
	FU	PY	FU	PY
0	1000+	213	1000+	100+
267	1000+	147	44	0
490	1000+	100	4	0

Values are an average of 3 replications measured in propagules/gram of soil.

*ppa = pounds/acre

**FU = Fusarium, PY = Pythium

TABLE 5.--EFFECT OF BASAMID-GRANULAR ON WEED POPULATIONS 12 WEEKS FOLLOWING TREATMENT - NURSERY A

TREATMENT (ppa)*	TOTAL	WEEDS/1 FT. OF BED**			
		CHK	COT	GRASS	OTHER
0	826	808	3	12	3
267	19	15	4	0	0
490	12	7	5	0	0

Values are an average of 3 replications

*ppa = pounds/acre

**Chk = untreated, Cot = cottonwood, Other = unidentified weeds

Soil fungus populations were evaluated in mid September of 1985, and treatments applied in late September or early October of the same year. Post-treatment soil fungus evaluations were made in late October of that year, and March and June of 1986. Seed was sown into the plots in May of 1986. Results from the various nurseries are shown below.

Nursery A

Treatments at this nursery consisted of MC-33 (350 ppa), Vorlex (35 gpa), Dazomet (150 and 300 ppa), and an untreated check. Fusarium populations (Table 6) declined significantly for all chemical treatments. Populations in all plots, including the untreated check, continued to decline until March of 1986. By June all populations had risen slightly, but all chemical treatments remained below the untreated check. Also, all remained below the damage threshold level of 1,000 ppg.

MC-33 gave the best control, followed by Vorlex, Dazomet 300, Dazomet 150, and untreated check. Pythium populations followed a similar pattern.

There was no significant difference in number of live seedlings or damping-off in any of the treatments. This correlates well with the soil populations of Fusarium and Pythium, all of which were below threshold levels at time of sowing. While all chemical treatments reduced soil fungus populations, soil treatment of any kind was probably not justified at this nursery.

Nursery B

Dazomet was applied at three rates (0, 250, and 300 ppa), applied as the only treatment at this nursery. A procedure similar to nursery A was followed here. Similar declines in soil fungus populations (Table 8) were observed at this nursery in the 250 and 300 ppa Dazomet plots.

By spring, populations of both Pythium and Fusarium in all treatments had declined to below threshold levels. As a result there was no significant difference in number of live seedlings or mortality.

Nursery C

Treatments at this nursery consisted of MC-33 (325 ppa), Metam-sodium (100 gpa), Telone II (30 gpa), Dazomet (150 and 300 ppa), and an untreated check. All chemical treatments reduced soil fungus and nematode populations below the untreated check (Tables 9, 10, and 11).

Telone II and Metam-sodium were not originally included in this test, so pretreatment samples were not collected. However, these treated areas were close to the other plots, so it can be assumed that pretreatment populations of soilborne organisms were within the range of those shown for the other plot areas. Further, Metam-sodium was not applied in the prescribed manner. A prescribed rate of material was all applied during a 15 minute period, and was followed by approximately 1 hours irrigation.

The first post-treatment sampling for Fusarium showed lowest populations in the Telone plots, followed by Metam-sodium, MC-33, Dazomet 300, Dazomet 150, and untreated check. However, by March 1986, lowest populations were in the MC-33 plots followed by Dazomet 300, Dazomet 150, Metam-sodium, Telone, and untreated check. Both Telone and Metam-sodium applied in this manner theoretically should not have had significant affect on Fusarium populations. This eventually proved to be true by the March sampling. The unexpected initial drop in populations is unexplained.

MC-33 gave the best overall control. There was little difference between the two rates of Dazomet by spring of 1986. Similar trends occurred with Pythium populations.

At this test site there were five plant parasitic genera of nematodes present. Only the Root-lesion nematode (*Pratylenchus penetrans*) is of importance to conifers, and so is the only one reported on here (Table 11). MC-33 gave best control, followed by Dazomet 300, Dazomet 150, Telone, Metam-sodium, and untreated check.

Nursery C

At this nursery Dazomet at 200 and 350 ppa were compared with Vorlex for control of soilborne fungi. Pretreatment samples were collected by nursery personnel, and therefore

only one composite was collected for the Dazomet and check plots, and one composite for the Vorlex plot which was applied operationally to another portion of the block. The Vorlex treated area had almost 9 times the level of Fusarium, as did the Dazomet treated areas. This should be kept in mind in evaluating the results in Table 12.

Both rates of Dazomet and the Vorlex treatment all reduced populations by approximately the same percentage (97-99%), at the first post treatment sampling. By sowing time populations under all chemical treatments had reached approximately the same level. This was approximately 1/2 that of the untreated plots.

Both Dazomet treatments reduced Pythium populations to 0 at the first post treatment sampling, and they remained at that level until sowing. The Vorlex treatment reduced populations to below 10 ppg of soil and this too remained at that level until sowing.

There was no significant difference in seedling stand or mortality amongst the plots. Again, populations at sowing were below threshold levels, which would probably explain this situation.

SUMMARY AND CONCLUSIONS

Efficacy

All the soil fumigants tested, (MC-33, Vorlex, Dazomet, and Metam-sodium), at appropriate rates gave equal control of soilborne microorganisms. Vorlex is somewhat less effective in weed control.

Ease of Application

Each fumigant has its own advantages and disadvantages. MC-33 requires very specialized equipment both for injecting the material into the soil and for immediate tarping. Further, tarp removal and disposal must be considered. However, because it is injected as a gas, treatment time is very short and is less prone to subsequent phytotoxicity problems, although seedling stunting has been associated but not demonstrated to be related.

TABLE 6.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF FUSARIUM - NURSERY A

TREATMENT	FUSARIUM/SAMPLE DATE			
	9-13-85	10-29-85	3-19-86	6-2-86
0	1198	1043	410	837
MC-33	1698	7	10	53
VORLEX	722	97	63	80
BG 150ppa	1303	813	360	543
BG 300ppa	1547	400	203	213

Values are an average of 3 replications and reported as propagules/gram of soil. Sampling date 9-13-85 is pretreatment, remainder are post-treat.

Treatments: 0 = no treatment; MC-33 = Methyl bromide-chloropicrin @ 350 #/ac (ppa); Vorlex = @ 100 gal/ac; BG = Basamid-Granular @ 150 & 300 ppa.

TABLE 7.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF PYTHIUM - NURSERY A

TREATMENT	PYTHIUM/SAMPLE DATE			
	9-13-85	10-29-85	3-19-86	6-2-86
0	91	70	154	113
MC-33	84	0	0	0
VORLEX	60	0	0	13
BG 150ppa	89	90	0	23
BG 300ppa	97	47	17	22

(See notes Table 6).

TABLE 8.--EFFECT OF BASAMID-GRANULAR ON SOIL POPULATIONS OF PYTHIUM AND FUSARIUM - NURSERY B

TREATMENT	PYTHIUM & FUSARIUM/SAMPLE DATE					
	10-17-85		10-29-85		3-19-86	
	PY	FU	PY	FU	PY	FU
0	122	1677	108	525	3	205
250 ppa	140	3703	35	160	90	420
300 ppa	147	1528	5	50	10	180

Values are an average of 4 replications and reported as propagules/gram of soil. Sampling date 10-17-85 was pretreat, remainder post treat.

TABLE 9.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF FUSARIUM - NURSERY C

TREATMENT	FUSARIUM/SAMPLE DATE		
	10-2-85	10-29-85	3-19-86
0	1402	1575	453
MC-33	1297	123	65
TELONE	-	58	430
SP	-	120	238
BG 150	1120	980	168
BG 300	1370	720	155

Values are an average of 4 reps and reported as propagules/gram of soil. Sampling date 10-2-85 was pretreat, remainder post-treat. Treatments: 0 = untreated; MC-33 @ 325 #/ac; Telone II @ 30 gpa; SP = Soil-Prep @ 100 gal/ac; BG = Basamid-Granular @ 150 & 300 #/ac; - = no sample taken.

TABLE 10.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF PYTHIUM - NURSERY C

TREATMENT	PYTHIUM/SAMPLE DATE		
	10-2-85	10-29-85	3-19-86
0	125	77	183
MC-33	121	3	3
TELONE	-	40	123
SP	-	20	65
BG 150	126	30	60
BG 300	113	13	35

(See notes Table 9).

TABLE 11.--EFFECT OF SOIL FUMIGATION TREATMENTS ON ROOT LESION NEMATODES - NURSERY C

TREATMENT	NEMATODE/SAMPLE DATE		
	10-2-85	10-29-85	3-19-86
0	294	463	200
MC-33	387	1	33
TELONE	-	69	88
SP	-	257	100
BG 150	513	156	44
BG 300	356	1	0

Values are an average of 4 replications and reported as number/pint of soil. (also see notes Table 9).

TABLE 12.--EFFECT OF SOIL FUMIGATION TREATMENTS ON SOIL POPULATIONS OF FUSARIUM & PYTHIUM - NURSERY D

TREATMENT	FUSARIUM & PYTHIUM/SAMPLE DATE							
	10-14-85		11-8-85		3-19-86		6-3-86	
	FU	PY	FU	PY	FU	PY	FU	PY
0	656	97	393	149	333	3	497	63
BG 200	656	97	3	0	40	0	265	0
BG 350	656	97	13	0	3	0	203	0
Vorlex	5827	142	210	7	-	-	148	8

Values are an average of 3 reps and reported as propagules/gram soil
Sample date 10-14-85 is pretreat, remainder are post-treat.

Treatments: 0 = untreated; BG = 200 & 350 #/ac; Vorlex = 35 gal/ac.
- = no sample taken.

Vorlex also requires special soil injecting equipment, but does not require tarping. Treatment time and evacuation from the soil is somewhat longer than MC-33, but about equal to Dazomet and Metam-sodium.

Dazomet and Metam-sodium carry only warning labels, and are much safer to handle. Less specialized safety equipment is necessary during the application of these chemicals.

Cost

Metam-sodium requires large quantities of water applied over a long period of time. It further requires a well designed irrigation system with proper sprinkler overlap to get complete coverage. It is also subject to wind displacement of the irrigation water, and volatilization under high temperatures. However, if properly set up, it is actually an easy and inexpensive method of application.

Treatment costs depend a lot upon whether or not a nursery owns the specialized pieces of equipment needed to apply the chemicals. Treatment with MC-33 is probably the most expensive, followed by Metam-sodium, Dazomet, and Vorlex. These costs will vary somewhat according to rate used and whether total area or bed treatments are employed.

Dazomet is a very fine granular and is subject to being wind blown at application if proper equipment is not available. Calibration can also be a problem without proper equipment.

The selection of a soil fumigant will depend upon the soilborne problems within a nursery. Once the problems have been clearly defined, selection of a fumigant can be based on the above criteria, i.e. ease of application, efficacy, safety, and cost. All of this should be done in light of the processes outlined in my previous presentation on "Options in Controlling Soilborne Pests".

This chemical is actually the easiest to apply as it may only require slight modification of standard nursery equipment. Our tests have shown that bed treatments can be applied in the fall and still remain effective by sowing the following spring.

Safety

MC-33 and Vorlex are the most dangerous chemicals of those tested. They both carry a danger-poison label, and are restricted use pesticides. Special protective gear is required during application of these chemicals.

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Fumigation Effect on Soilborne Pathogens, Mycorrhizae, and Growth of Douglas-fir Seedlings¹

Yasuomi Tanaka², K.W. Russell³ and R.G. Linderman⁴

Abstract.--Soils were treated with methyl bromide/chloropicrin (MBC) at 360 lbs/A and 720 lbs/A or with Basamid at 350 lbs/A in a field trial with a randomized block design at two bare-root Douglas-fir nurseries near Olympia, Washington in 1984-85. The results showed that fumigation (1) increased fall 1+0 seedling count, (2) caused no 1+0 stunting or growth loss, (3) did not hinder formation of mycorrhizae, (4) suppressed and maintained low soilborne pathogen populations and (5) suppressed root infections by Fusarium spp. but not Pythium spp.

INTRODUCTION

The stunting of 1+0 Douglas-fir seedlings is frequently observed in the bare-root nurseries in the Pacific Northwest. It is characterized by a short stem (usually less than three inches long), short needles and a well defined terminal bud resulting from an early cessation of seedling growth. The distribution of stunted seedlings is random often occurring in patches. To determine the cause of stunting we conducted a number of studies the past several years. Although the stunt syndrome is not fully understood it appears that first-year Douglas-fir seedlings develop these symptoms under various stressful conditions. Based on our observations and those of other researchers, a number of factors appear to contribute to stunting, both singularly and more possibly in combination. They

include an insufficient level of soil nutrients -- mainly phosphorus and to some extent nitrogen, an excessively high pH resulting from liming, a short growing season resulting from late sowing, an excessive buildup of soil pathogens or undesirable substances in the soil, and a deficiency or delay of mycorrhization of the root system. The involvement of some of these factors is supported by experimental evidence, while the involvement of others is still hypothetical at this time.

The effect of soil fumigation on mycorrhizal infection and/or microbial recolonization has been investigated in bare-root nurseries (Carpenter and Boyd 1980, Ridge and Theodorou 1972), but its effect on stunting is not well understood. An excessively high rate of application may delay recolonization and thus hinder normal formation of mycorrhizae which may, in turn, contribute to stunting due to decreased capacity for nutrient uptake. On the other hand, an excessive buildup of soilborne pathogens resulting from an insufficient rate or skips of fumigation may result in increased root disease causing stunted trees. To investigate these relationships and as a part of the effort to determine the cause of stunting, we conducted a study on the effect of fumigation on seedling establishment, 1+0 stunting, seedling growth, mycorrhizae development, and incidence of root disease of Douglas-fir as well as changes in population of soilborne pathogens.

¹Paper presented at the 1986 Western Forest Nursery Council Meeting held at Vance Tyee Hotel, Tumwater, Washington, August 12-15, 1986.

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For comparison, the study was carried out at two bare-root nurseries near Olympia, Washington; the Mima Nursery of Weyerhaeuser Company and the L.T. Webster Nursery of the Washington State Department of Natural Resources. The results reported here are only for Mima except where mention of the Webster data illustrates important points, but the trends were the same for both nurseries. A full report of data from all treatments at both nurseries is in preparation for publication elsewhere.

MATERIALS AND METHODS

A total of four fumigation treatments were applied at both the Mima and Webster nurseries in a randomized block design with three replications. The fumigation treatments were established in September 1984 as follows:

Treatment 1: Fumigation with methyl bromide/chloropicrin (MBC) (2:1) at 360 lbs/A rate (1x); tarp removed after 1 month.

Treatment 2: Fumigation with MBC at 720 lbs/A rate (2x); tarp removed after 1 month.

Treatment 3: Fumigation with Basamid at 350 lbs/A; no tarp.

Treatment 4: Unfumigated control; no tarp.

MBC was applied in the standard manner by injection at the 6" depth followed immediately by tarping. Basamid granules were applied to the surface then rototilled into the top 6" of soil.

Soil samples were collected from the three replicate plots for each treatment at 1, 2, 4, 6, 8, and 10 months after the September, 1984 fumigation. Three 1" diameter core samples from each plot were separately pooled from two depths, 0-6 inches and 6-12 inches. The core sampler was flamed between plot samples to prevent cross contamination. Combined samples weighing approximately 500 g were screened to eliminate large particles and debris, and refrigerated until soilborne diseases were assayed, usually within one week.

Standard soil dilution plating techniques were employed to determine populations of species of Pythium and Fusarium on selective media for each, namely Rose bengal (Russell 1986a) and Komada's medium (Komada 1975) respectively.

Inoculated Rose bengal plates were incubated in the dark at 20°C for 60-72 hrs, then washed with running tap water to remove the soil particles and thereby facilitate counting. Pythium species were not differentiated, and populations were expressed as propagules/g moist soil.

Fusarium populations were assayed as in the Pythium assays except that the soil was suspended in 0.3% water agar and plates were incubated for 5 days at 22-24°C in natural light and colonies were counted as described by Komada (1975).

Seeds were sown in early May 1985. Seedling emergence counts were made in June based on the number of seedlings present in 6 square feet of bed (1.5 linear feet of bed) determined at 2 locations within a plot. The 1+0 stand counts were made in October. The incidence of 1+0 stunting was also determined within the same 6 square feet areas used for the seedling counts. A seedling was considered stunted if it was less than 3 inches tall from ground to apical bud. Actual stunting incidence was based on linear feet of bed rows within the measured area.

Seedlings used for determination of mycorrhizae colonization were collected from each plot in October 1985 and again in May 1986. A total of 10 seedlings per replicate plot were collected in fall and 15 seedlings in the spring. They were carefully washed to remove adherent soil, bagged and shipped on ice to Corvallis, Oregon where each was examined for presence of mycorrhizae. The percent seedlings with mycorrhizal roots were compared among treatments. Root collar diameter and dry weight of shoots and roots (oven dried at 70°C) were determined for seedlings harvested in October 1985.

The incidence of Pythium and Fusarium root rot was determined on 1-year-old seedlings collected in May, 1986. Root systems were washed thoroughly and cut into approximately 1 cm lengths. Root pieces from 5 seedlings per replicate plot were pooled, surface sterilized with 1.0% sodium hypochlorite for 3 min. and rinsed in sterile distilled water. Twenty-five root pieces from each replicate plot were plated on Pythium or Fusarium selective medium, 5 pieces per plate. Recovery of Pythium was determined after 3-day dark incubation at 20°C; Fusarium plates were incubated in natural light for 10 days at 22-24°C. Recovery was considered positive if one or more colonies emerged from the root piece. The number of positive recoveries became % recovery as an index of root rot incidence.

All data were analyzed using analyses of variance. The treatment differences were tested using the Duncan's new multiple range test at a 5% level of probability (Steel and Torrie 1960). Percentages were analyzed after arcsin transformation.

RESULTS AND DISCUSSION

The results from treatments at the two nurseries were comparable in most regards. No striking treatment effects on seedling emergence were observed. There was, however, a trend toward higher emergence in all fumigation treatments compared to the untreated control and Basamid did significantly increase the emergence by 11% (Fig. 1). The 1+0 seedling count was significantly greater in MBC (1x) and Basamid treatments (by 12%) than in the control. The reduced 1+0 count in the control is probably due to the higher levels of pathogens in soils at the time of sowing as reported below.

The incidence of 1+0 stunting was very low at both nurseries in the blocks used for this study, the highest level being 0.1% at Mima and 2.5% at Webster. The bulk of stunting was found in the control treatments at both nurseries.

In general, fumigation treatments tended to produce larger seedlings and MBC (1x) significantly increased root collar diameter and dry weights of shoots and roots compared to the control (Fig. 2). Root collar diameter and root dry weight were significantly greater in MBC (1x) than in MBC (2x). It is not certain why the higher rate of MBC reduced seedling size. It is possible, however, that beneficial micro-organisms, which were not measured in the study, could have been adversely affected at the 2x rate, which, in turn, contributed to size reduction. An adverse effect (on germination and survival) associated with an increased rate of MBC has been reported for white spruce and several other conifers (Hill 1965).

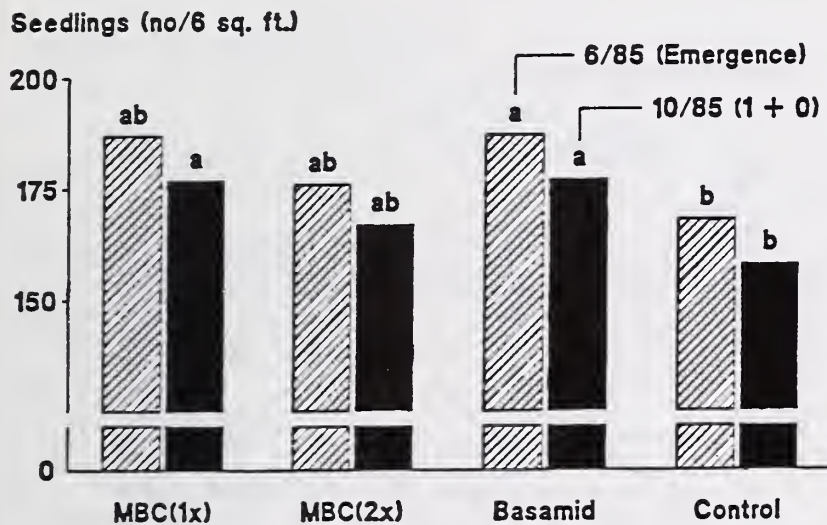


Figure 1.--Effects of soil fumigants on Douglas-fir seedling emergence and 1+0 stand count. The treatments followed by the same letters are not significantly ($p < 0.05$) different within each assessment time.

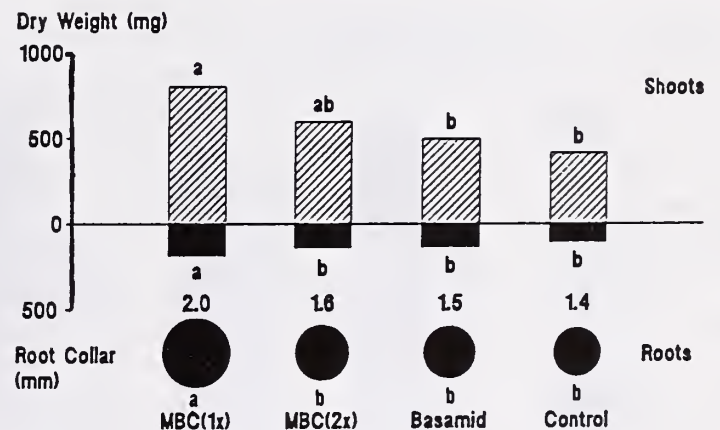


Figure 2.--Effects of soil fumigants on Douglas-fir seedling growth assessed in October 1985. The treatments followed by the same letters are not significantly ($p < 0.05$) different in each variable.

The percent seedlings with mycorrhizae ranged from 60% in the control to 80% in the Basamid treatment in October 1985 (Fig. 3). By May 1986, virtually all seedling roots in the four treatments were mycorrhizal (96%-100%). The differences among treatments were not significant at either assessment time. Contrary to our hypothesis, MBC fumigation up to 720 lbs/A did not hinder mycorrhization of 1+0 Douglas-fir seedlings. Twenty to 40% of seedlings (depending on treatments) had no mycorrhizae, and yet there was virtually no 1+0 stunting in this block at the Mima nursery in 1985. These data suggest that lack of mycorrhization is not the cause of stunting in 1+0 Douglas-fir, although under certain circumstances its presence may prevent stunting.

Fusarium and *Pythium* populations were assayed at various times after fumigation at the 0-6" and 6-12" depths to determine the efficacy of the fumigation treatments and to determine when these pathogens reinvaded the fumigated treatment plots. The propagule

count was usually greater at 0-6" depth than at 6-12" depth (especially with *Fusarium*), but the trend was the same with respect to seasonal changes and treatment differences. The means of propagule counts for two depths are summarized for *Pythium* and *Fusarium* in Figure 4. The data clearly show the effectiveness of MBC fumigation at the normal 1x rate, and that the 2x rate was unnecessary. Basamid was nearly as effective as MBC fumigation in reducing propagule counts.

Pythium populations were effectively reduced by fumigation treatments and remained low throughout the study. In the untreated control, the populations increased in March with the onset of warmer weather, peaked in the May sampling and then declined rapidly by the July sample. Although the magnitude was ten-fold greater, *Fusarium* population in the unfumigated control fluctuated with a similar trend as those of *Pythium*. The main difference was that it peaked in March and began to decline thereafter reaching the lowest level in July.

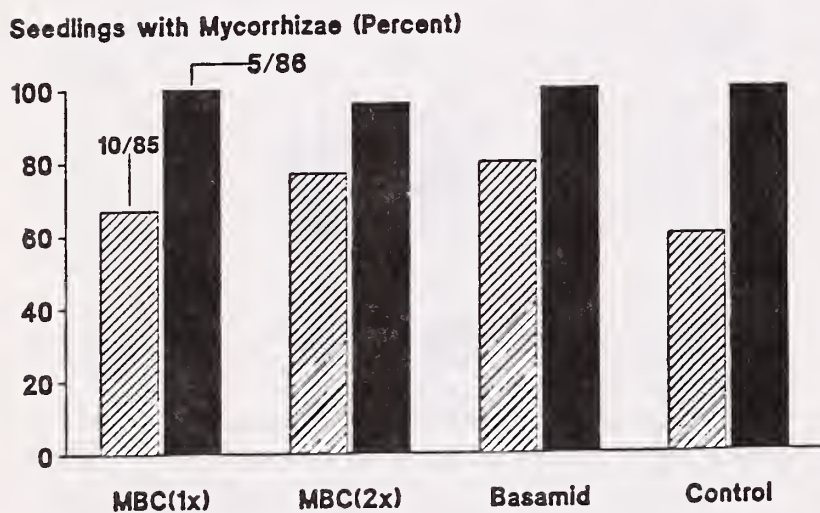


Figure 3.--Effects of soil fumigants on development of mycorrhizae on Douglas-fir seedlings. The treatments followed by the same letters are not significantly ($p < 0.05$) different within each assessment time.

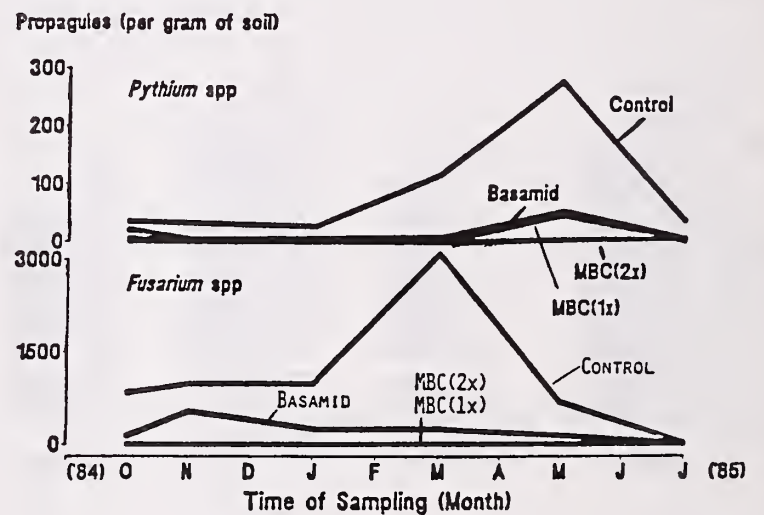


Figure 4.--Effects of soil fumigants on changes in populations of soilborne pathogens.

The reason for the decline in propagule counts of these pathogens in the unfumigated control in mid-summer (July) is not known; however, two possible reasons may be offered: (1) Application of fungicides (Benlate, Captan and Daconil) after sowing possibly reduced the level of fungi, and (2) Dry soil conditions created by the infrequent, deep watering may have contributed to the reduction (Russell 1986b).

The incidence of root rot by *Fusarium* in May 1986 was highest in the non-fumigated control (Fig. 5). It was not reduced by Basamid as effectively as by MBC at 1x or 2x. *Pythium* root rot incidence, on the other hand, was nearly as high in all fumigation treatment plots as the non-fumigated control plots in the spring of the second year, presumably due to the aggressive recolonization of fumigated soil from below the fumigation layer. Although pathogenicity of these fungi was not tested in this study, it appeared that species of *Pythium* involved may not have been as pathogenic as the species of *Fusarium* based on seedling growth data and 1+0 seedling counts.

CONCLUSIONS

Based on the results of this fumigation study, the following conclusions were reached.

1. MBC (1x) and Basamid significantly increased 1+0 seedling count by 12% in both treatments.
2. None of the fumigation treatments [MBC (1x), MBC (2x) or Basamid] caused 1+0 stunting or growth loss in root collar diameter and shoot and root dry weights.
3. None of the fumigation treatments caused a reduction in mycorrhizal roots.
4. MBC (1x) and Basamid suppressed and maintained low levels of soilborne pathogens (*Fusarium* spp. and *Pythium* spp.) throughout the first full year of seedling growth. MBC at the 2x rate was not necessary for disease control.
5. MBC (1x) and MBC (2x) suppressed root infections by *Fusarium* spp. but not *Pythium* spp. in the spring of the second year.

ACKNOWLEDGEMENTS

The authors wish to thank the following people: W. Littke, Weyerhaeuser Co. for his contribution to the disease assay portion of this study, W. Weiland-Alter, USDA/ARS, J. Arthurs and S. Nelson, Department of Natural Resources (DNR) and P. Oster and T. Vu, Weyerhaeuser Co. for their excellent technical assistance, J. Bryan, T. Stevens and J. Hodgins, Weyerhaeuser Mima Nursery and K. Curtis and B. Fangen, DNR L.T. Webster Nursery for their cooperation and support in fumigation treatments and other activities, J.K. Ruthford for preparation of the manuscript, and S. Kaluzny, the Applied Math Department, Weyerhaeuser Co. for her advice in design and statistical analyses. The critical review of the manuscript by W. Littke and T. Stevens, Weyerhaeuser Co., and P. Hamm, Botany and Plant Pathology Department, Oregon State University is greatly appreciated.

Infected Root Segments (Percent)

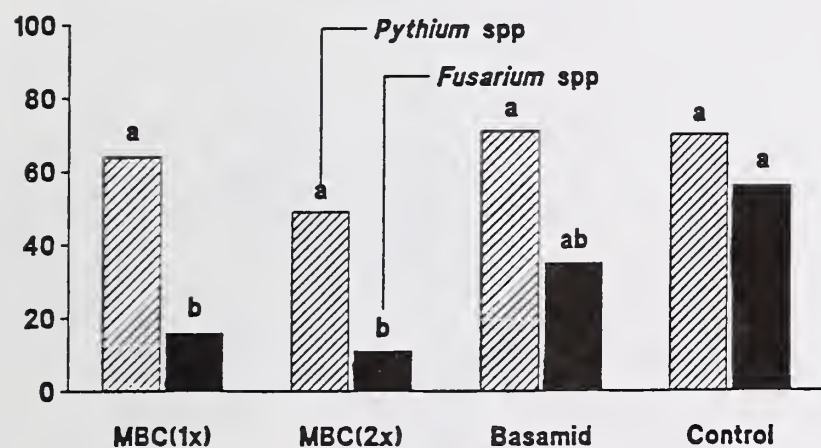


Figure 5.-- Effects of soil fumigants on the incidence of infections of Douglas-fir roots by species of *Pythium* and *Fusarium*. The treatments followed by the same letters are not significantly ($p < 0.05$) different in each fungus.

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Control and Impact of *Lygus* Damage on 1-0 Douglas-fir Seedlings¹

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P. D. Morgan
R. Miller

Abstract.--*Lygus* bug feeding on 1-0 Douglas-fir significantly increases cull and the occurrence of forking at harvest. Multiple pesticide applications between July and September can reduce damage by 80-90%.

INTRODUCTION

Since the 1970's, nurserymen in the Willamette Valley have noticed that 2-0 seedlings with multiple tops are associated with deformed terminal growth during the 1-0 year. However, the connection of "bushy-topped" seedlings with the effects of *Lygus* bug feeding is a recent observation (Shrimpton, 1985; South 1986; and Schowalter, et al., 1986). In western Oregon, *Lygus hesperus* Knight is now

recognized as a common cause of bud abortion and terminal growth deformation in bare root Douglas-fir (D.f.) seedlings. *Lygus* feeding near the growing tip of 1-0 seedlings results in stem lesions, distorted needles, and deformed tops (Figure 1). Following bud damage, lateral shoots frequently form weak multiple tops (forking) that persist through harvest (Figure 1). Although *Lygus* bugs are a common problem in agricultural crops, they are an unfamiliar pest to most nursery managers.

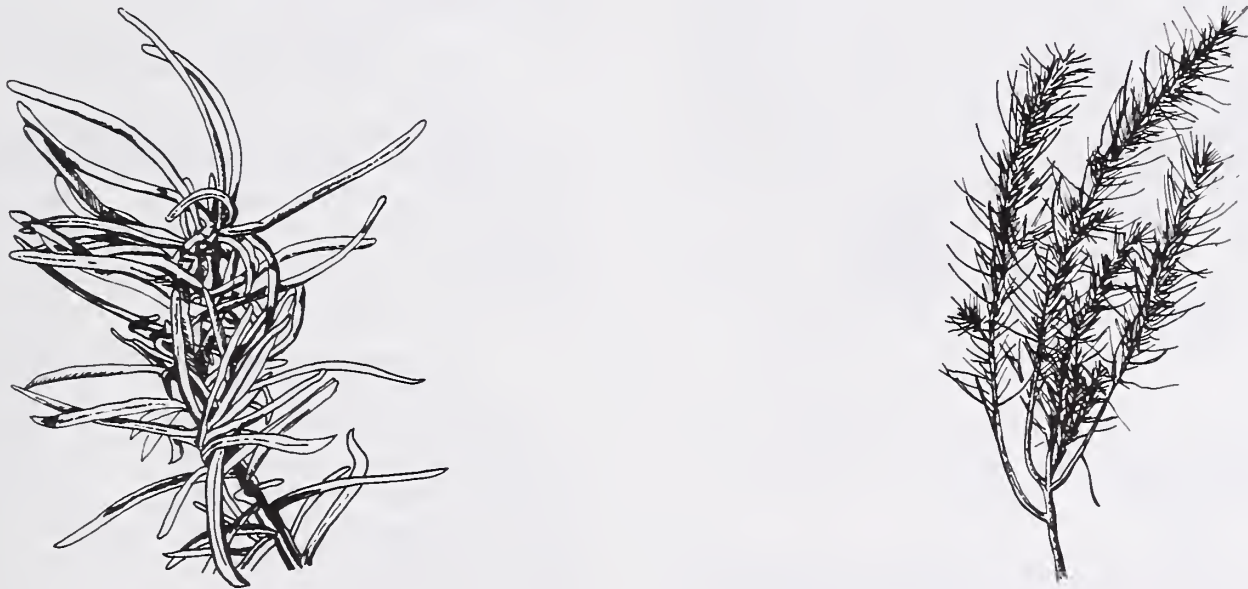


Figure 1.--Appearance of *Lygus* damage in 1-0 D.f. seedling (L) and resulting multiple tops in the 2-0 year (R).

¹Paper presented at the Western Forest Nursery Council Meeting, Olympia, WA, August 12-15, 1986.

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Lygus bugs (family Miridae) are sucking insects that feed on the growing tips, buds, and flowers of many plants (Figure 2). Agricultural crops such as alfalfa and cover crops like buckwheat and clover can support high Lygus populations. Weed species such as whitetop, tansy, lambsquarter and Queen Anne's lace are also attractive to Lygus. During feeding, Lygus secrete saliva containing substances that affect the development of plant tissues, often resulting in deformed or aborted growth (Tingey and Pillemer, 1977). Adult Lygus overwinter in and around conifer nurseries. During the early spring adults feed and lay eggs in the stems of agricultural crops or herbaceous weeds. The eggs incubate for 10-14 days before hatching into flightless nymphs which, like adults, feed on plant tissue (Kelton, 1975). Three to four generations are completed per year in western Oregon (Berry, 1978). The adult insects are active fliers and readily move from one crop to another. Damage to nursery seedlings starts in July or August and increases gradually through September. During this period, 1-0 D.f. seedlings typically grow 2.5"-4.3" and produce the succulent growth preferred by this insect.

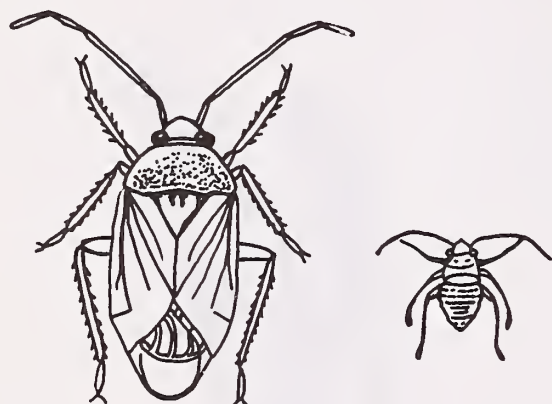


Figure 2.--Adult Lygus bug (L) and nymph (R). Adult bugs are 6-7mm long while nymphs vary from 1-6mm in length.

Since 1983, a series of studies on Lygus impact and damage prevention have been conducted at bare root nurseries. The objectives of the studies included identifying pesticides effective in reducing damage, timing spray applications, and describing the effects of damage on seedling yields and quality.

MATERIALS AND METHODS

Study Areas

In the summer of 1983 a pesticide screening study was conducted in 1D-0 D.f.

(60 seedlings/ft²) at Weyerhaeuser's Aurora Nursery near Canby, Oregon. Subsequent work on spray timing and the effects of Lygus damage on seedling yields were conducted at the D. L. Phipps State Forest Nursery at Elkton, Oregon. Seedling densities at the Phipps nursery varied from 17-25/ft².

1983 Pesticide Screening

Insecticides for this study were selected on the basis of registration for nursery crops and use in agriculture for Lygus control. 1D-0 seedlings were sprayed weekly between July 21 and September 26. The following insecticides were evaluated:

<u>Insecticide</u>	<u>Rate</u> (Active Ingredient/Acre)
fenvalerate	0.1 lb
acephate	1.0 lb
endosulfan	1.0 lb

The experimental design for the test was a randomized complete block with each block replicated seven times. Treatment plots were 41 ft. x 150 ft. with a 20 ft. buffer separating adjacent treatments. Lygus damage was measured in twelve one ft² subplots located in the center two beds of each treatment plot.

1983 Impact Assessment

Douglas-fir seedling survival was evaluated in conjunction with the pesticide screening study. Numbers of live seedlings present in a one ft² plot located in each treatment replication was recorded in the fall.

1984-85 Pesticide Timing Studies

Based on the gradual damage increase shown in earlier work, it was decided the detection of initial damage among 1-0 seedlings was a suitable marker for timing pesticide applications. In both 1984 and 1985, ten subplots (8 inches x 24 inches) located in four untreated plots were used to monitor seedling damage. The following pesticide regimes were tested using fenvalerate at 0.1 lb active ingredient per acre (A.I./A).

<u>Treatments</u>	<u>Application Timing</u> (weeks from initial damage)
1 (check)	-
2	3
3	2, 5
4	2, 5, 7
5	2, 4, 6, 8, 10, 12

The design for the 1984 study was a randomized complete block with each treatment replicated six times. Treatment plots were 38 ft. wide and over 200 ft. in length. Lygus damage was evaluated on the mean of all fifteen 1.5 ft² subplots located in the center two beds of each treatment.

During 1984, the effects of Lygus damage before and after 20% of the crop had set bud (September 19) was evaluated on 1-0 D.f. The pesticide used to protect seedlings was fenvalerate at 0.1 lb A.I./Acre. This timing study consisted of the following unreplicated treatments installed in four 34 ft. x 150 ft. plots.

Treatment	Protected Period	Pesticide Timing
1 (check)	-	-
2	Aug.-Oct.	Bi-weekly
3	Aug.-Sept.	Bi-weekly
4	Sept.-Oct.	Bi-weekly

The 1985 pesticide study evaluated an operational recommendation of bi-weekly sprays commencing two weeks after Lygus damage was first detected. Insecticides chosen for this test were fenvalerate (0.1 lb A.I./A) and acephate at 1 lb A.I./Acre. The design for this test was a randomized complete block with each treatment replicated five times. Treatment plots were 38 ft. wide and over 200 ft. in length. Damage assessment was the same as the replicated 1984 pesticide timing study.

1985 Harvest Assessment

The impact of Lygus feeding in the 1-0 year on seedling yields and morphology at harvest was examined using treatment 1 (check) and treatment 5 (6 applications of fenvalerate) from the 1984 pesticide timing study. The three replications evaluated were all located among standard density 2-0 stock (25 seedlings/ft²). Following undercutting, ten 2 ft² seedling samples were removed from the center two beds of the treatment areas. The following data were collected from each sample; live trees/ft², % acceptable seedlings, % cull seedlings, and % forked seedlings. Seedlings were classified as cull if their caliper was less than 3mm or height less than 20cm.

Statistical Analysis

Lygus damage was evaluated in the fall of the 1-0 year in the replicated pesticide

studies. Seedlings were considered damaged if there were any visible signs of Lygus feeding such as distorted needles, stem lesions, deformed buds and forks. Information on tree forking in the unreplicated test was collected during the spring following Lygus damage. Seedling forking was evaluated on ten 1.5 ft² subplots within each treatment. Seedlings were considered forked if they lacked a dominant terminal shoot. An \bar{x} % forking was calculated for each treatment. For the replicated pesticide studies, a \bar{x} % of Lygus damaged seedlings in each subplot was calculated. Differences between treatments were tested by analysis of variance on arcsine-square-root-transformed percentages. While statistical tests were performed on transformed data, raw data is presented in the tables. Significant differences among several means were tested using Tukey's test (Sokal and Rohlf, 1968). A percentage damage reduction due to pesticide treatments was calculated using the method of Abbott (1925).

RESULTS AND DISCUSSION

Pesticide Tests

Results of the 1983 screening study demonstrated a significant reduction in seedling damage consistent with Lygus feeding being the major cause of seedling deformation (Table 1). All of the pesticides evaluated in 1983 provided an acceptable level of control at this high frequency of application.

Table 1.--Percent Lygus damage in 1D-0 Douglas-fir seedlings treated with weekly pesticide applications between July 21 - September 26, 1983 at the Aurora Nursery.

Treatment	No. of applications	Seedlings ¹ damaged X(%) 1 plot	Damage reduction (%)
Check	-	14.5 a	-
endosulfan	10	2.4 b	83
acephate	10	2.2 b	85
fenvalerate	10	1.2 b	92

¹Means not significantly different are followed by the same letter.

When the frequency of application was reduced in 1984, a substantial level of damage reduction was still maintained with as few as two applications of fenvalerate

(Table 2). The 1984 study also indicated that pesticide applications starting two weeks after damage was initially detected provided satisfactory control.

Table 2.--Percent Lygus bug damage to 1-0 Douglas-fir seedlings with different treatment frequencies of fenvalerate (.1 lb A.I./A) at D. L. Phipps Nursery in 1984.

Treatment	No. of applications	Seedlings ¹ Damaged \bar{X} (%)	Damage reduction (%)
1 (Check)	-	33 c	-
2	1	13 ba	61
3	2	6 ba	82
4	3	6 ba	82
5	6	3 a	91

¹Means not significantly different are followed by the same letter.

Additional information on pesticide timing resulted from the evaluation of crop protection in relationship to bud set. Seedling protection prior to bud set was critical to reducing the frequency of forked tops (Table 3). Late pesticide application (Sept.-Oct.) did not reduce the frequency of multiple tops.

Table 3.--Effect of pesticide application timing during the 1-0 year (1984) on the occurrence of multiple tops in Douglas-fir seedlings the following spring.

Timing	No. of applications	Forking (\bar{X} % \pm SE)
Check	-	18.8 \pm 2.7
Aug./Oct.	7	4.6 \pm 1.5
Aug./Sept.	4	5.9 \pm 1.6
Sept./Oct.	3	19.8 \pm 2.8

The 1985 pesticide study, showed that four applications, starting two weeks after damage was first detected and continuing on a bi-weekly basis could reduce damage by 80% (Table 4). The timing of the 1985 spray regime in relationship to Lygus damage occurring in check plots is shown in Figure 3. Results from all studies show 80-90% damage reduction with 2-10 pesticide applications.

Another approach to timing pesticide applications for Lygus control used by some nursery managers is to monitor for adults and nymphs on weeds in and around seedling beds.

If 1-0 D.F. seedlings are of a susceptible size (1-1.5" in height) and Lygus is detected on weed species, pesticide treatments are initiated. With this system of spray timing, applications will start earlier than in our studies.

Table 4.--Percent Lygus bug damage in 1-0 Douglas-fir seedlings treated with pesticide at two week intervals between July 17 and September 6, 1985 at the D. L. Phipps Nursery.

Treatment	No. of applications	Seedlings ¹ damaged \bar{X} (%) 1 plot	Damage reduction (%)
Check	-	61.9 a	-
acephate	4	10.0 b	84
fenvalerate	4	10.6 b	83

¹Means not significantly different are followed by the same letter.

Since relatively low levels of damage can be achieved with 2-4 pesticide applications, it is possible that much of the damage occurring in untreated areas is produced by the flightless nymphs. Lygus nymphs are easily eliminated with pesticide applications. However, the highly mobile adult Lygus enter and leave nursery beds throughout the summer and are a difficult target for foliar sprays. Spraying in the early morning, when adult Lygus are sluggish, may increase the effectiveness of contact insecticides. Factors rapidly reducing pesticide efficacy on Lygus include heavy irrigation of 1-0 crops and the rapid growth of seedlings.

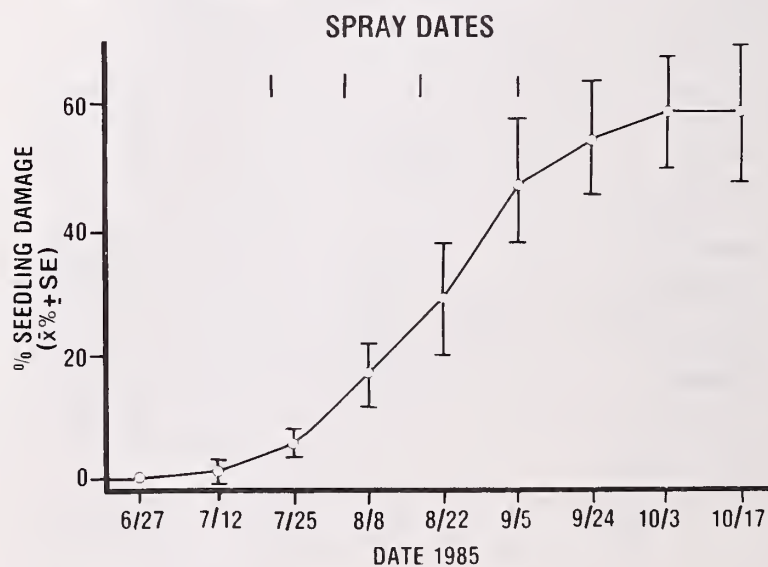


Figure 3.--Mean percent Lygus damage in 1-0 Douglas-fir check plots at the D. L. Phipps nursery in relationship to the 1985 spray schedule.

An unexpected result of the 1983 insecticide test was a significant increase in seedling survival in treated plots (Table 5). Increased seedling survival paralleled the trend in damage reduction. A possible explanation for this phenomena might be increased competition and disease in untreated beds. One effect of Lygus damage is increased production of lateral shoots which result in greater shading in high density seedling beds and produce conditions favorable for the foliage disease Botrytis.

Table 5.--Average fall 1-0 seedling density in beds treated with insecticide for control of Lygus damage at the Aurora Nursery in 1983.

Treatment	¹ X̄(%) seedlings/ ft ²	Increased survival (%)
Check	53.4 a	-
endosulfan	61.4 b	15
acephate	61.7 b	16
fenvalerate	62.3 b	17

¹Means not significantly different are followed by the same letter.

The 1985 harvest study showed a significant decrease in cull associated with treated seedlings (Table 6). Many seedlings classified as cull had clear evidence of Lygus damage in the 1-0 year. Reduction of Lygus damage also produced a significant reduction in forked tops. There was no significant difference in the average number of surviving seedlings associated with treatment. Lygus damage occurring in the 2-0 year was not significant enough by itself to produce cull. However, seedlings stunted by Lygus damage in the 1-0 year and attacked again as 2-0 seedlings were sometimes culled for size.

Table 6.--Harvest evaluation of 2-0 Douglas-fir protected from Lygus damage in the 1-0 year (1984) at the D. L. Phipps Nursery.

X̄ Trees/ft ²	¹ X̄%			
	Acceptable	Cull	Forked	
Check	25.8 a	81.2 b	18.8 b	29.1 b
Treated	29.4 a	89.0 a	11.1 a	6.1 a

¹Means not significantly different are followed by the same letter.

Lygus damage to 1-0 Douglas-fir seedlings can result in significant increases in cull for caliper and size at harvest. Seedlings not protected from Lygus feeding have a higher percentage of multiple tops. Lygus feeding on 1-0 seedlings prior to the start of bud set is the greatest contributor to multiple tops. At the D. L. Phipps State Forest nursery, pesticide applications start within 2 weeks of initial damage to the 1-0 crop and are repeated at bi-weekly intervals through August. This procedure has reduced Lygus damage to seedlings by 80-90%.

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Meeting Notes

MINUTES FROM THE BUSINESS MEETING

A short meeting was held during the noon lunch on Thursday, August 14.

The main topic was to discuss the location of the meeting in 1988.

Ralph Huber, B.C. Forest Service advised us they would host the meeting at Vernon B.C.

It was also noted that the meeting for 1990 may be hosted by the Phipps Nursery at Elkton, Oregon, however, a representative from Phipps was not available for confirmation.

MESSAGE FROM CHAIRPERSONS

Beautiful Northwest weather, excellent speakers and great field trips made this conference very informative and enjoyable.

Our thanks go to all of the speakers, and to everyone of the 187 attendees registered, for helping make this an outstanding meeting.

It is our hope that everyone gained a lot of useful information from excellent presentations by the speakers, and also retain outstanding memories of the field trips highlighted by blocked roads, or seeing the large herd of elk on the final days visit to Mt. St. Helens.

We wish to thank the nursery staffs at the I.F.A. Inc. Toledo Nursery, the Weyerhaeuser Mima Nursery, and the Dept. of Natural Resources Webster Forest Nursery, for the help and support they gave to make this meeting a success.

We look forward to seeing all of you again in 1988.

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Rocky
Mountains



Southwest



Great
Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

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