Managing Seedborne Diseases in Western Forest Nurseries

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Fungi that contaminate conifer seed frequently cause seed rot and seedling disease. In this paper, we discuss criteria for seed treatment, assay procedures for the seedborne fungus Fusarium, *and safe and effective seed treatments. Subjects needing further investigation are summarized.* Tree Planters' Notes 41(4):3 -7 ; 1990.

The Problem

Conifer seeds are normally contaminated with a variety of different microorganisms, including potentially pathogenic fungi. The fact that many seedling diseases can be caused by seedborne pathogens has been recognized by forest nursery pathologists for many years. The true scope of the problem was not realized, however, until conifer seedlings began to be grown in container nurseries, where the losses are readily apparent (fig. 1).

Because both containers and growing areas are cleaned and "sterilized" between crops, and artificial growing media are also considered disease-free, contaminated seed is the most likely means of disease introduction (7). In container nurseries, fungi frequently can be seen fruiting on the seed coat and often are associated with damping-off, cotyledon blight (fig. 2), and root rots.

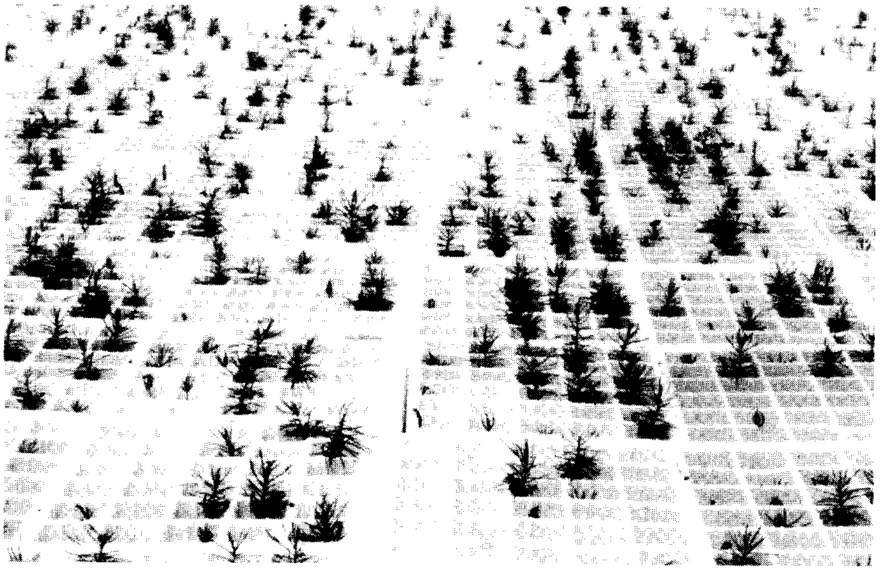

Figure 1—*Seedborne disease problems are particularly evident in container nurseries.*

A number of different pathogenic fungi have been isolated from conifer seed (table 1), including *Alternaria* spp., *Cladosporium* spp., *Cylindrocarpon* spp., *Fusarium* spp., *Penicillium* spp., and *Tricho -*

Table 1—*Common genera of seedborne fungi in Pacific Northwest conifers*

Fungus	Appearance in culture	Associated disease
Alternaria	Gray-green to black; septate, club-shaped spores	Radicle and cotyledon disease of white spruce
Caloscypha	Beige, whitish-gray, orange to pale yellowish brown; smooth, colorless round spores	Seed rot, reduced germination
Cladosporium	Dark velvety green; sickle-shaped spores	Reduced vigor of germination
Fusarium	White, salmon to pinkish-red; sickle-shaped spores with 3 to 4 septations	Reduced germination; cotyledon, hypocotyl, and root disease
Penicillium	Green to bluish-green; small, round spores	Reduced vigor of germination
Trichoderma	White turning to green; small, round spores	None; this is usually a beneficial fungus
Trichothecium	Pinkish; 2-celled spores	Reduced germination

Source: Modified from Littke (1990).

The authors thank the working group of forest nursery pathologists from the western United States, who have contributed much of the information on which this article is based at the annual meeting on disease problems in forest nursery seedlings.

***Figure 2**—Cotyledon blight is one fungal disease that is obviously seedborne. In this picture, the fungus can be seen growing from the seedcoat to the cotyledons.*

thecium spp. *(2,8).* These fungi can, under certain conditions, cause seed or seedling disease. Other fungi are frequently isolated from seed but either are not harmful (e.g., *Trichoderma* spp.) or their pathogenic abilities are unknown. Fungal contamination of conifer seed can occur while the cone is still on the tree, during collection and storage, during seed extraction and processing, or during stratification. Cones collected from squirrel caches are particularly vulnerable (9). Because it is impractical to try to protect the seed from contamination throughout the entire period between cone harvest and seed sowing, it is logical to treat seed for pathogens before stratification or sowing.

Three general methods have been used to treat seed; they are listed in order of increasing severity:

1. Surface cleansing (washing the seed with running water and/or detergents to remove contaminants).
2. Surface disinfecting (treating the seed coat with heat or chemical disinfectants, such as sodium hypochlorite or hydrogen peroxide).
3. Coating the seed with fungicides (such as thiram or captan).

In the past, nursery managers routinely treated their seed with fungicides before sowing. However, this practice has come under increasing scrutiny because of possible toxicity to the germinating seed as well as adverse effects on human health and the environment. Cleansing or disinfecting the surface of the seed is becoming increasingly popular as a way to control seedborne pathogens.

Steps for Managing Seed Disease

The following recommendations, based on the collective practical experience and operational trials of western nursery pathologists, will be refined and improved as new information becomes available. They are listed in sequential order:

Determine if seed treatment is warranted. Because any seed treatment is a potentially damaging operation, nursery managers should first attempt to determine if a seedborne disease problem exists and assess the potential seriousness of the problem. We recommend seed treatments for the following situations:

- Seeds to be grown in container nurseries, where pathogens can be introduced into a relatively sterile environment and the value of seedlings is high.
- Seedlots showing problems, such as low germination rates, visible mold, or a history of poor germination or seedling disease (fig. 1).
- Seeds of high-risk species that typically exhibit high levels of disease in the nursery, which could be caused by seedborne pathogens (for example, sugar pine *(Pinus lambertiana* Dougl.), western white pine *(Pinus monticola* Dougl.), western larch *(Larix occidentalis* Nutt.), and Douglas-fir *[Pseudotsuga menziesii* (Mirb.) Franco.].
- High-value seeds such as those used for tree improvement, especially those of high-risk species.

Assay seeds and identify species of pathogens. Before considering any seed treatment, suspected problem lots should be assayed for the presence of pathogenic fungi. Because it is impossible to identify contaminated seed lots simply by looking at them, nursery managers should send samples of seed from problem lots to a plant pathogen laboratory that offers assays for specific seed pathogens.

Characteristics of colonies and spores of common seedborne fungi are described in table 1. Currently, *Fusarium* spp. are the only seedborne pathogens that are frequently assayed in the Pacific Northwest, and the following procedure is recommended:

1. For each seedlot to be analyzed, randomly select 500 seeds; if the lot is extremely small, a representative sample is sufficient. Do not wash or surface sterilize this sample.
2. Place up to 25 seeds (depending on seed size) on a petri dish of Komada's medium (6), using forceps or a specially prepared template.
3. Incubate the plates, agar side down, under constant light for 5 to 7 days, at room temperature [20 to 25 °C (68 to 77 °F)] .
4. Identify and count the number of colonies of *Fusarium* spp. associated with seed under a compound microscope (fig. 3).
5. Report results as a percentage of seeds with *Fusarium* spp. present on them.

Treat seed lots that show contamination. Once a problem lot has been identified, seeds should be cleansed with running tap water or disinfected with bleach, ethanol, or hydrogen peroxide. Currently registered seed fungicides are not recommended for use.

1. *Cleansing seed surfaces* with a running water rinse is recommended for all species. A running water rinse is more effective than a standing water soak for the pre-stratification imbibing treatment. The following tap water rinse has no phytotoxic potential, has been effective in reducing pathogen loads (5,10), and can be easily implemented in any nursery operation:

   Place seeds loosely in mesh bags that have twice the volume of the seed. Run cold tap water over seeds with periodic gentle agitation for at least 48 hours before stratification.

2. *Disinfecting seed surfaces* can be phytotoxic, but the following seed treatments have been effective in reducing pathogen loads on problem seedlots. Several chemical disinfectants have proven effective for different species, but any such treatment should be tested on a small scale before being implemented operationally:

   Bleach treatments have been tested with several species of pine [ponderosa (*Pinus ponderosa* Dougl.), lodgepole (*P. contorta* Dougl.), western white, Scotch (*P. sylvestris* L.), and Austrian *(P. nigra* Arnold)] and Douglas-fir (10). Soak the seeds for 10 minutes in a 40% solution of household bleach [2 parts bleach (5.25% sodium hypochlorite) in 3 parts tap water], then rinse thoroughly in running water for at least 48 hours. Place seeds in mesh bags

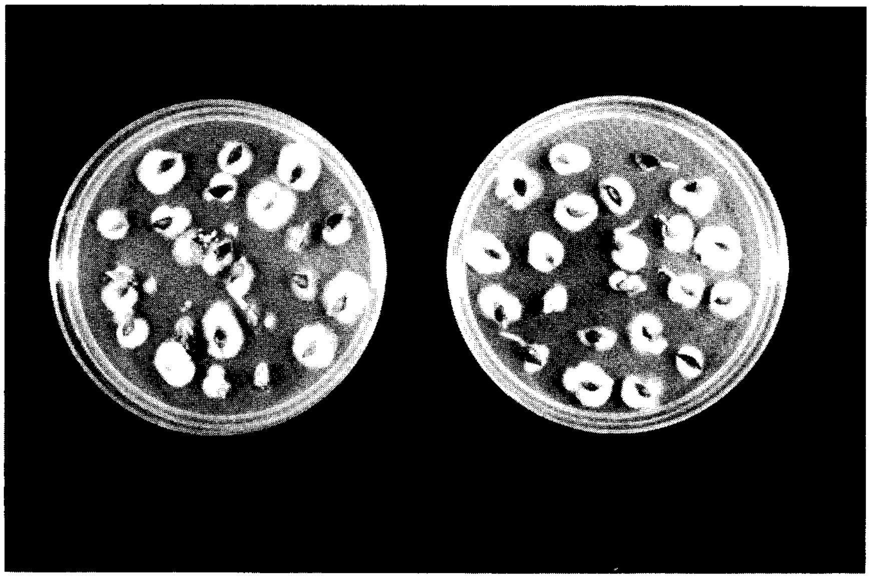

***Figure 3**—Pathogenic assays of suspected problem seedlots confirm the presence of seedborne fungal pathogens. In this photograph, the mycelia of* Fusarium *spp. can be seen growing from the seeds.*

that have twice the volume of the seed. Seeds can be treated before or after stratification.

Ethanol treatments have been tested with Douglas-fir. Dumroese and others (4) found that placing seeds in 95% ethanol for 15 seconds reduced levels of pathogens. A trial with a 10-minute soak in 70% ethanol, followed by a 48-hour rinse with running tap water reduced pathogens but also inhibited seed germination (1). Seeds should be placed in mesh bags that have twice the volume of the seed. Seeds can be treated before or after stratification.

Hydrogen peroxide treatments have been tested with sugar pine and Douglas-fir (4). Soak seeds in a 3% hydrogen peroxide solution for 3 to 5 hours, then rinse them thoroughly in running water for at least 48 hours. Seeds should be placed loosely in mesh bags that are twice the volume of the seed. Seeds have been treated before (sugar pine) or after (Douglas-fir) stratification.

Surface-dry seed during extended stratification. Any seed lot stratified for more than 30 days should be surface-dried and then put back into stratification. The objective of this procedure is to reduce or prevent mold development, which is more likely to develop in the high humidity conditions that exist in long-term stratification. This procedure is currently used by Federal nurseries in Oregon and Washington.

Ideas For Future Work

Because so little is known about seedborne pathogens and their effect on forest nursery production, additional work is needed on this subject. We present the following ideas for future research:

1. Determine the pathogenicity of fungi, other than *Fusarium* spp., that are associated with the seeds of western conifers. Identify the types and modes of injury as well as the potential for economic damage.
2. Determine the importance of seed-contaminating fungi versus seed-infecting fungi, and the effect that seed quality has on the impact of each.
3. Develop biological control organisms, such as *Trichoderma* spp. or *Gliocladium* spp., that can be applied to seed to reduce or prevent infection of seeds or seedlings by seedborne pathogens.
4. Run operational trials on conifer seed with commercial formulations of biocontrol organisms produced for other crops.
5. Test new seed treatments [for example, microwaving, hot

water soaks, use of kelp formulations (Kelpak 66), use of oil] for their effectiveness at controlling pathogenic seedborne fungi.

6. Retest and refine seed treatments that are currently used operationally or have been previously tested, including household bleach, ethanol, and hydrogen peroxide. These treatments should be tested on other conifer and hardwood species, both before and after-stratification.
7. Test seed fungicides and new methods of applying fungicides to seed. New, untested chemicals may prove effective and safe. New technology exists for applying fungicides that may minimize phytotoxicity and maximize effectiveness; both old and new fungicides may be more effective if appropriately applied to seed.

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Tree Planter's Notes, Volume 41, No. 4 (1990)

Insecticides Effectively Control an Aphid Pest of White Fir Seedlings

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Severe damage from a fir aphid (Mindarus victoria Essig) was first reported for white fir (Abies concolor (Gord. & Glend.) Lindl.) bareroot nursery seedlings at Placerville, CA, in 1987. One and two applications of acephate, chloropyrifos, diazinon, dimethoate, or fluvalinate were tested for control of this fir aphid on white fir seedlings in 1988. One application of one of these insecticides significantly reduced aphid infestations for at least 73 days; two applications significantly reduced aphid populations throughout the growing season. All insecticide treatments significantly reduced the occurrence of dead apical buds on seedlings ready to be harvested for outplanting. Two applications of acephate produced side effects that significantly reduced the height and increased diameter growth of white fir seedlings. Tree Planters' Notes 41 : 8 -12; 1990.

Species of *Mindarus* infest fir and spruce trees across the northern United States, with population levels often highest in young trees (4). Severe damage attributed to the balsam twig aphid (*M. abietinus* Koch.) has been reported to Christmas tree plantations of grand fir [*Abies grandis* (Dougl. ex D. Don) Lindl.], white fir [*A. concolor* (Gord. & Glend.) Lindl.], and Eraser fir [*A. fraseri* (Pursh Poird (5-7). In 1987, the aphid *M. victoria* Essig was first noted in the USDA Forest Service Nursery at Placerville, CA, in the central Sierra Nevada. Initial infestations were on 2+0 seedlings of white fir and bristlecone fir (*A. bracteata* D. Don ex Poiteau). This is the first known report of *M. victoria* in California and the first time this species has been reported on white fir or bristlecone fir nursery stock.

Favorable conditions in the Placerville Nursery apparently allow *M. victoria* to survive for 30 to 60 days longer than the life stages described by Essig for the aphids in Victoria, British Columbia (3). The winged or alate stage apparently migrated into 2+0 white fir beds in May and into the 1+0 white fir beds in early August from nearby Christmas tree plantations. In 1987, damage to 1+0 stock resulted in curled needles and an enlarged, club-like apex of current growth, in conjunction with the formation of an abnormal bud rosette. On 2+0 seedlings, *M. victoria* feeds on elongating shoots, causing discoloration and curling of new needles and distortion of terminal growth. Retarded bud formation and tip dieback could result in increased mortality or delay in growth during the first year of outplanting.

Effective chemical control for *Mindarus* has been reported in *Abies* Christmas tree plantations in Maine and North Carolina (1, 5-6). However, multiple applications of malathion, an insecticide registered for *M. abietinus* Koch., did not appear to control infestations or reduce damage by *M. victoria* in either 1+0 or 2+0 white fir nursery beds at the Placerville Nursery in 1987. The cull rate for 2+0 white fir seedlings harvested in 1987, even with three applications of malathion, was 47%. In the past, normal cull rates for white fir grown in this nursery ranged from 20% to 30%. Therefore, we can infer that *M. victoria* was probably responsible for a 17 to 27% increase in the cull rate, or the rejection of 227,000 to 360,000 white fir seedlings. In light of demand for reforestation of fire damaged stands, seedling losses of this magnitude are clearly intolerable.

In 1988 we evaluated the effectiveness of five registered insecticides for control of aphids to reduce the damage to 2+0 white fir seedlings. We had two goals: to determine the minimum number of applications of each insecticide needed to adequately reduce populations of *M. victoria* and thus reduce the number of damaged seedlings, and to evaluate possible phytotoxic effects of each insecticide to buds and new foliage.

Materials and Methods

Study location. This study was conducted at the USDA Forest Service Placerville Nursery (administered by the Eldorado National Forest), which is located 3 miles north of Placerville, CA. The nursery is surrounded by a mosaic of natural forest, fruit orchards, and Christmas tree plantations.

Many (20% or more) of the white fir seedlings processed in December 1987 were severely damaged by *M. victoria*. Inspection of 1 + 0 seed beds on February 17, 1988, indicated that a significant portion of 4.5 acres of white fir seedlings (1 .8 million) was infested with *M.* victoria and had sustained damage during the first growing season.

Experimental design. The experiment was conducted as a randomized, split-plot design. One of six main treatments (5 insecticides and an untreated control) was randomly assigned to each white fir bed. Once the treatments had been assigned, each white fir bed was subdivided into three 10-foot plots and randomly assigned the number of applications of a specific insecticide (table 1). Each of the 15 insecticide treatments (5 insecticides with 1, 2, or 3 applications) had 11 replicates; the untreated check was replicated 30 times.

Insecticides were applied with a pressurized garden sprayer with a single, hand-held nozzle, at a rate of approximately 100 gallons per acre.

The white fir beds were examined before the first insecticide application, and every week thereafter, through September 1988. At each examination, 4 sample points within each plot were located by a random coordinate system based upon the length of seed bed. At each sample point, 5 seedlings were examined and the proportion infested with *M. victoria* was recorded.

Insecticide was first applied on March 28, to precede terminal bud flush and coincide with the first appearance of *M. victoria* in the spring. When the seedling infestation rate in the insecticide-treated plots increased to a threshold of 10%, the insecticide was applied again (May 27) to the remaining two-thirds of the treatment plots. After the second treatment, infestation rates were again monitored to determine whether a third spray would be applied to the remaining one-third of the treatment beds. A natural decline of the aphid population in late June eliminated the need for a third application of insecticide.

Seedlings were examined for phytotoxic effects to the foliage for 2 consecutive weeks after each insecticide application. The percentages of discolored needles on both infested and uninfested seedlings were visually estimated. In addition to observations of foliage, two sampling points in each treatment were flagged, and 10 seedlings were selected for morphological measurements. Once every 14 days during shoot elongation (from bud break until the end of the growing season), height and caliper were monitored. Height measurements were taken from the cotyledon scar to the tip of the visible stem or the nearest tip of the bud. Seedling diameter was measured directly below the cotyledon scar. In November, 4 randomly selected sample points were established in each treatment bed, and 5 seedlings per sample point were examined for apical bud damage.

Analysis. Differences among treatments in the proportion of seedlings infested with *M. victoria*, with apical bud damage and differences in height and diameter were evaluated by analysis of variance. Differences among treatments were tested for significance at the 0.05

Table 1—*Insecticides tested on the aphid* Mindarus victoria *Essig infesting 2+0 white fir seedlings at the USDA Forest Service Placerville Nursery in 1988*

Common name	Formulation	Application rate (lbs. ai/acre)
acephate	Orthene 75S	0.50
chlorpyrifos	Dursban 4EC	0.50[a]
diazinon	Diazinon 25% EC	0.50
dimethoate	Cygon 23.4% EC	1.00
fluvalinate	Mavrik 2EC	0.50

[a] First application of chlorpyrifos was at the rate of 0.50 pounds active ingredient (ai) per 100 gallons, as reported in Nettleton and Hain (*3*). The second application was at the labeled rate of 0.25 pounds of ai per acre.

level. Dunnett's multiple comparison procedure was used to make pairwise comparisons of differences between treatment means and the untreated control, to maintain an experimentwise alpha level of 0.05 (2).

Results and Discussion

Aphid control. A single application of any of the tested insecticides (acephate, chlorpyrifos, diazinon, dimethoate, and fluvalinate) significantly reduced the percentage of 2+0 white fir seedlings infested with *M victoria* from 38 through 73 days after spraying (table 2). The March spray was applied at anticipated egg hatch. Despite the 29-day lapse between the first application and initial aphid migration into the 2+0 white fir beds, insecticide residues on the foliage apparently were sufficient to decrease the survival of arriving aphids and reduce the number of resulting *M victoria* colonies.

Although all the insecticides we tested were effective, the application rates of acephate and chlorpyrifos, at 0.5 pounds active ingredient per acre (ai/acre), were twice the recommended labeled rates. Based on results from a concurrent operational effort at the Placerville Nursery, acephate appeared to be an ineffective treatment when applied twice in 1988 at the recommended rate (0.25 pounds ai/acre) during the growing season (8). Our success at significantly reducing aphid infestation rates with acephate at 0.5 pounds ai/acre, indicates that for acephate to be used effectively, an increase in the recommended application rate will be necessary.

Fluvalinate, the only pyrethroid in the test, was as efficacious as dimethoate despite the 20-fold difference in active ingredients applied per unit area (table 1). Application of a slightly higher rate of fluvalinate would undoubtedly be more potent without compromising cost or environmental safety.

The *M. victoria* population apparently recovered 51 days after the initial insecticide application (table 2). A second spray was applied on May 27 as the infestation rate in treated beds reached an arbitrary threshold established at 10%. All five insecticide treatments immediately caused a significant reduction in aphid-infested seedlings for 27 days after spraying (table 3). The three insecticides without systemic properties (fluvalinate, chlorpyrifos, and diazinon) caused nearly a threefold (15 versus 5.5) reduction in the percentage of infested seedlings. The two systemic insecticides (acephate and dimethoate) reduced aphid populations to zero or close to zero. Chlorpyrifos was efficacious for the second spray treatment (at the labeled rate of 0.25 pounds ai/acre). This was half the effective rate used by Nettleton and Hain (6) in Christmas tree plantations.

By July 6, *M. victoria* populations naturally declined. Therefore, the third insecticide application was not necessary after the first week of July.

A single application of any of the insecticides significantly reduced

Table 2—*Percentage of 2+0 white fir seedlings infested with the aphid* Mindarus victoria *Essig after a single application of insecticide on March 28, 1988*

		Percentage of infested seedlings					
Treatment	N	Prespray (3/28)	16 days (4/13)	38 days (5/5)	51 days (5/18)	59 days (5/26)	73 days (6/19)
acephate	11	0.0	0.0	0.0	7.7*	11.4*	9.1*
chlorpyrifos	11	0.0	0.0	2.3	8.2*	11.4*	4.1*
diazinon	11	0.0	0.0	0.0	6.8*	12.7*	9.1*
dimethoate	11	0.0	0.0	0.0	6.4*	6.4*	9.1*
fluvalinate	11	0.0	0.0	0.0	8.6*	8.6*	10.9*
untreated	30	0.0	0.0	5.0	35.0	39.0	30.5
LSD				5.1	21.6	22.8	14.8

Treatments with an asterisk differ significantly from the control at the 5% level (*2*). LSD = least significant difference value.

Table 3—*Percentage of 2 + 0 white fir seedlings infested with the aphid* Mindarus victoria *Essig after a second insecticide application on May 27, 1988*

Treatment	Prespray (5/26)	Percent seedling infestation 6 days (6/2)	13 days (6/9)	27 days (6/22)	41 days (7/6)
acephate	11.4	0.9*	0.0*	0.5*	0.0
chlorpyrifos[a]	11.4	0.5*	0.0*	4.6*	0.0
diazinon	12.7	0.0*	0.0*	6.8*	0.0
dimethoate	6.4	0.0*	0.0*	0.0*	0.0
fluvalinate	8.6	4.6*	3.6*	5.5*	0.0
untreated	39.0	41.7	30.5	15.0	0.0
LSD		19.7	21.9	7.5	

Treatments with an asterisk differ significantly from the control at the 5% level (*2*). LSD = least significant difference value.

[a] The second application of chlorpyrifos was at the registered rate of 0.25 lbs active ingredient per acre.

the percentage of seedlings with dead apical buds at the end of the growing season (table 4), and a second application significantly protected terminal buds. Apical bud damage did not differ significantly among the single and double spray applications for any of the five insecticides.

Phytotoxic effects. Two of the insecticides had a significant effect upon growth of 2+0 white fir seedlings (table 5). The first spray was applied when lateral buds were open with new foliage less than 1 inch (2.5 cm) in length. Chemicals were purposely applied before terminal bud burst to minimize potential toxic effects on new terminal foliage. The second application was made when new growth was present on both terminal and lateral branches. None of the treatments applied to new lateral or terminal growth had any apparent impact upon foliage coloration. Seedlings treated with the double application of acephate or diazinon significantly affected seedling growth for 12 weeks after spraying (table 5). Acephate caused a 96% reduction in height growth associated with a 196% increase in seedling diameter, and diazinon had a positive effect upon white fir growth, with a 169% increase in diameter and no significant reduction in height growth.

Table 4—*Percentage of 2 + 0 white fir seedlings previously infested with the aphid* Mindarus victoria *Essig with dead terminal buds, November 1988*

Treatment	% of seedlings with dead terminal buds Single insecticide application	Two insecticide applications
acephate	5.9*	6.4*
chlorpyrifos	6.8*	5.5*
diazinon	12.7*	7.3*
dimethoate	6.4*	5.0*
fluvalinate	10.5*	5.0*
untreated	65.7	65.7
LSD	8.3	7.6

Treatments with an asterisk differ significantly from the control at the 1% level (*2*). LSD = least significant difference value.

Table 5—*Height and diameter growth (June 23–October 27) of 2 + 0 white fir seedlings sprayed twice with insecticides at Placerville Nursery, 1988*

Treatment	N	Height (cm)	Diameter (mm)
acephate	2	0.05*	1.06*
chlorpyrifos[a]	1	0.40	0.38
diazinon	2	0.95	0.91*
dimethoate	2	1.00	0.79
fluvalinate	2	0.30	0.54
untreated	4	1.30	0.54
LSD		1.10	0.36

Treatments with an asterisk differ significantly from the control at the 5% level (*2*). LSD = least significant difference value.

[a] Least significant difference for chlorpyrifos was 1.42 for height and 0.47 for diameter.

Conclusions

One application of acephate, chlorpyrifos, diazinon, dimethoate, or fluvalinate, early in the season, significantly reduced the percentage of aphid-infested 2+0 white fir seedlings for 73 days and significantly increased the percentage of seedlings with live apical buds. With two spray applications of insecticide, the period of reduced infestation was extended until the time when *M. victoria* populations declined naturally. The second chlorpyrifos spray, at the labeled rate of 0.25 pounds ai/acre, was efficacious even when reduced to half the effective application rate for a similar aphid species in Christmas tree plantations (5).

A single application of any of the insecticides significantly protected apical buds, with no particular advantage to spraying a second time. If a viable terminal bud is important to seedling survival in plantations, a single spray application early in the aphid infestation apparently will significantly increase the number of apical buds surviving on nursery stock destined for spring planting.

In the absence of phytotoxicity with chlorpyrifos, diazinon, dimethoate, and fluvalinate, an early season spray of any one of these four insecticides could be delayed until the appearance of terminal shoot growth. This would allow a management program to better assess the infestation potential of *M. victoria* and manipulate spray schedules to correspond with aphid biology and existing cultural practices within the nursery. If application of pesticide is delayed until late April, the window of chemical effectiveness would be present when the aphid population is at its peak and may eliminate the need for repeated applications during the same growing season.

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Tree Planter's Notes, Volume 41, No. 4 (1990)

Seedbed Coverings Affect Germination, Growth, and Frost Heaving in Bareroot Nurseries

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At a bareroot nursery in central British Columbia, seedbed coverings-including a bedhouse and clear, white, black, or porous clear polyethylene- were evaluated on seedbeds of white spruce (Picea glauca (Moench) Voss] and lodgepole pine (Pinus contorta Dougl. ex Loud). The bedhouse treatment resulted in the most consistent germination and seedling growth improvement, and the clear polyethylene resulted in substantially reduced germination. The other treatments had small and inconsistent effects on germination; however, the porous clear bedcovering increased seedling growth. Lower frost heaving losses in bedhouse-grown spruce seedlings could be due to the greater root weight (size) of those seedlings. Tree Planters' Notes 41(4):13-16; 1990.

In bareroot forest nurseries in the Pacific Northwest, much of the seed sown does not produce planting stock. Most losses occur during-the first year in the nursery and are associated with failure of seed to germinate. These losses occur for various reasons, including low seed vigor, poor germination, disease and insects, environmental damage, and failure to meet culling standards. The failure of seed to germinate in the nursery bed not only wastes seed but also causes irregular bed spacing, further reducing production of acceptable seedlings.

These studies were undertaken to identify some nursery bed coverings that would give improved seed germination and better seedling growth with white spruce and lodgepole pine in bareroot nursery beds.

Methods

In 1979, 1980, and 1983, experiments were undertaken at the Red Rock Forest Nursery near Prince George, British Columbia (53° 41' N, 122° 40' W). In 1979 the treatments included: a bedhouse that was 3 m wide, 10 m long, and 1.2 m high covered with clear polyethylene as well as an uncovered control treatment.

In 1980, in addition to the bedhouse treatment, clear, white and black polyethylene bedcoverings were applied directly on the seedbed. In 1983, a porous clear polyethylene that is used in disposable infant diapers and had shown potential after testing at Weyerhaeuser Canada's Grandview Nursery was evaluated along with uncovered areas. The polyethylene bedcoverings were applied over 10-m sections of 1.2-m-wide nursery beds immediately after sowing and left in place for approximately 6 weeks. The edges of the polyethylene were secured with soil, and small ridges of soil between the drill rows kept the polyethylene slightly above the soil surface.

Germination counts after 6 weeks and measurements of seedling morphology after the first growing season were made on several plots in each treatment. In the 1980 experiment, substantial numbers of seedlings suffered from frost heaving due to unusual winter weather. Early in 1981, frost heaving losses were assessed on randomly located plots in each treatment.

Data from each experiment were subject to analysis of variance, and when treatment effects were significant, differences between means were tested with Duncan's multiple range test. SAS/STAT7" computer programmes (SAS Institute, Inc., Cary, NC) were used for the preceding analysis.

Results and Discussion

Seed germination. The viability of white spruce and lodgepole pine seedlots in laboratory tests (data supplied by the British Columbia Ministry of Forests Seed Centre) ranged from 49 to 86% and 37 to 92%, respectively (table 1). In most cases, field germination rates in the control plots were lower than laboratory germination rates, the

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The author thanks W. Taylor, S. Andersen, and K. Odlum, all formerly of the British Columbia Forest Service, Research Branch, for technical assistance, and Weyerhaeuser Canada, Grandview Forest Nursery, Armstrong, BC, for providing the porous clear polyethylene.

reduction ranging from 1 to 41%. In the 1979 experiment, germination in the bedhouse treatment was as good as germination in the laboratory, indicating that all the viable seeds in the two seedlots (1839 and 2835) had germinated.

Likewise, in the 1980 experiment, the bedhouse treatment caused all viable seed of seedlot 1931 to germinate; however, in seedlot 2658 germination was poor and not affected by the bedhouse treatment. Also, in the 1980 experiment, white and black polyethylene bedcoverings slightly improved germination of seedlot 1931 but had little effect on seedlot 2658.

Clear polyethylene bedcovering had a definite negative effect on germination, with only 15% of seed germinating in seedlot 1931. In the 1983 experiment, 3 of 4 spruce seedlots covered with the porous clear polyethylene germinated better (2 to 17%) than the controls. However, in lodgepole pine, 2 of 3 seedlots had lower germination (21 and 23%) than the control treatments.

Considered together, the results from these experiments suggest that the bedhouse treatment resulted in the most consistent improvement in germination rates; clear polyethylene substantially reduced germination; and white, black, and porous clear polyethylene had little, if any, consistent effects on seed germination.

Nursery growth. In the 1979 and 1980 experiments, at the end of the first nursery year, the seedlings from the bedhouse treatment were larger, except in height, compared to the control seedlings (table 2). In the 1980 experiment, the seedlings from the clear polyethylene treatment were smaller than the controls, while the seedlings from the white and black polyethylene treatments were generally of similar size to the controls. In the 1983 experiment, both spruce and pine seedlings from the porous clear polyethylene treatment were larger than the noncovered controls.

Although there were some differences between the seedlots treated in each of these experiments and in some cases there were treatment seedlot interactions, there was substantial variance associated with the treatments in all three experiments. It seems reasonable, therefore, to assume that the results observed here would be generally applicable to white spruce and lodgepole pine grown in similar environments.

Although the bedhouse resulted in better germination and larger seedlings at the end of the first growing season, it is not clear why this occurred. Soil temperature measurements made at 8:30 am each day on 10 days in June during 1979 indicate that the soil was slightly (1 .4 °C) warmer in the bedhouse (fig. 1).

Measurement of other environmental parameters were not made; however, it can be assumed that air temperature and humidity in the bedhouse were higher and windspeed was lower; all these factors influence moisture stress and thus germination and growth. The porous clear polyethylene bedcovering applied in 1983 similarly increased morning soil temperatures (1.7 °C)

Table 1—*Percentage germination of white spruce and lodgepole pine seed under various bedcovering treatments, by seedlot*

	White spruce								Lodgepole pine		
	1979		1980		1983				1983		
Treatments	1839	2835	1931	2658	2871	3121	4205	4286	1950	2099	8532
Laboratory viability*	80	49	80	64	65	81	80	86	37	66	92
Control	52	27	65	23	62	61	50	77	36	63	80
Bedhouse	83	48	85	23	–	–	–	–	–	–	–
Polyethylene											
Black	–	–	70	26	–	–	–	–	–	–	–
Clear	–	–	15	20	–	–	–	–	–	–	–
White	–	–	70	21	–	–	–	–	–	–	–
Porous clear	–	–	–	–	64	79	66	70	45	38	59

*Supplied by the British Columbia Ministry of Forests Seed Centre.

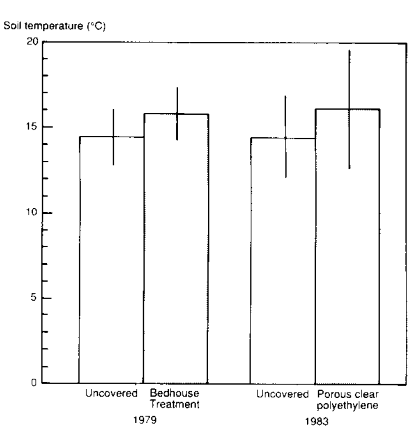

Figure 1—*Mean soil temperature 1 cm below the surface, measured on uncovered and bedhouse (1979) and uncovered and porous clear polyethylene-covered (1983) plots at 8:30 am on 10 days between June 15 and 28, 1979, and on 4 days between May 23 and June 20, 1983. Standard deviation is indicated around mean temperatures.*

relative to the beds that were not covered (fig. 1). The air temperature and humidity under the porous clear polyethylene would also be expected to increase relative to the control. Because the bedhouse and porous clear polyethylene treatments were not evaluated in the same year, it is not possible to contrast their relative effects on seedbed microclimate. Further study of the treatment effects on microclimate and seedling physiology is required to determine how the bedhouse and porous clear polyethylene affect conifer seedling growth. Of particular interest would be how the pattern and rate of growth throughout the growing season can be influenced by treatments applied for only 6 weeks.

Frost heaving losses. In many forest nurseries, seedlings can be lost during their first winter due to frost heaving. Seedlings are uprooted by ice that forms during repeated freezing-thawing of the nursery beds. Usually an insulating blanket of snow prevents frost heaving; however, in the winter of 1980-1981, the nursery beds were not covered by snow for much of the winter. Repeated freezing-thawing in the early spring resulted insubstantial frost heaving at Red Rock Forest Nursery that year. An examination of the seedlings sown in 1980 indicated that there were substantial treatment effects on frost heaving. Approximately 17% of bedhouse-treated seedlings were frost-heaved, whereas seedlings in the control plots had between 3 and 4 times more frost heaving. Reduced frost heaving in the bedhouse-grown seedlings may be due to the larger (heavier) root systems in those seedlings; there was a significant ($P < 0.05$) correlation between root weight and frost heaving (fig. 2). That reductions in frost heaving are due to larger root weights is also suggested by the observation that more frost heaving occurs in white spruce than in

Table 2—*Seedbed covering effects on first-year nursery growth of white spruce and lodgepole pine*

			Dry weight (mg)	
	Height (cm)	Root collar (mm)	Shoot	Root
White spruce				
1979				
Bedhouse	2.8 a	0.94 a	83 a	28 a
Control	2.7 a	0.85 b	64 b	21 b
1980				
Bedhouse	1.5 a	0.72 a	42 a	24 a
Black polyethylene	1.3 b	0.64 c,b	31 c	16 b,c
Clear polyethylene	1.2 b	0.61 c	30 c	14 c
White polyethylene	1.4 a	0.65 c,b	35 b,c	17 b
Control	1.4 a	0.67 b	37 b	16 b,c
1983				
Porous clear poly	3.3 a	1.01 a	109 a	48 a
Control	2.8 a	0.88 a	95 a	39 b
Lodgepole pine				
1983				
Porous clear poly	3.8 a	1.52 a	396 a	135 a
Control	2.7 b	1.27 b	254 b	86 b

Within-experiment means followed by similar letters do not differ significantly ($P \leq 0.05$) according to Duncan's multiple range test.

lodgepole pine. Lodgepole pine seedlings grown in experiment 3 had root weights 2 to 3 times those of white spruce (table 2).

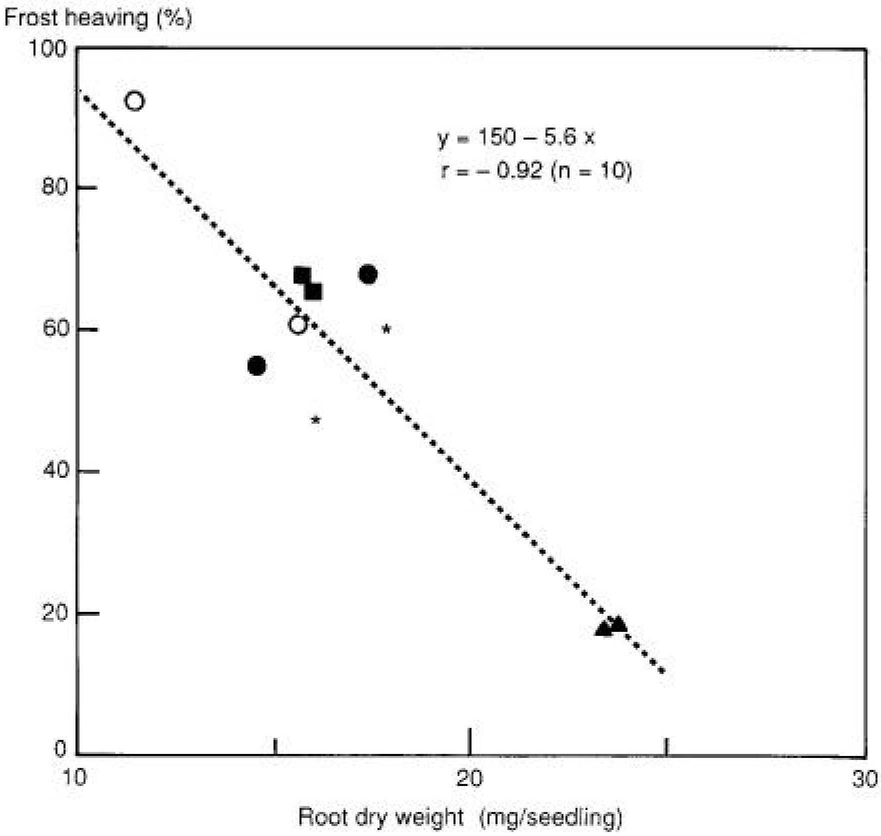

Figure 2—*Frost heaving in early spring 1981 of 1+0 white spruce seedlings as affected by root dry weight. Each point represents the average root weight of 100 seedlings randomly selected from 10 nurserybed plots measuring 0.5 by 1.2 meters. Plots received one of five treatments in the 1980 experiment: uncovered (controls,* ***solid circles****), black polyethylene (***solid squares***), clear polyethylene (***open circles***), white polyethylene (***asterisks***), or bedhouse (***solid triangles***).*

Conclusions and Recommendations

Increases in seed germination and seedling size can be expected by using clear polyethylene bedhouses over white spruce and probably lodgepole pine bareroot nursery beds at northern nurseries such as Red Rock Forest Nursery (53° 40' N). Although the effects on seedling growth are small and due to factors as yet unclear, increased growth may be important in nurseries that experience frost heaving of 1-year-old seedlings. The use of bedhouses in the production of bareroot planting stock should not be considered until economic analysis and larger scale trials have been undertaken. Seedbed coverings, whether white, black, or porous clear polyethylene, may in some cases improve germination and growth. Clear polyethylene seedbed covering should not be used because they substantially reduce seed germination.

Tree Planter's Notes, Volume 41, No. 4 (1990)

Deeper Planting of Seedlings and Transplants Increases Plantation Survival

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Heat, often confused with drought, is probably the most over looked cause of death of newly transplanted bareroot trees. just as neglected is that part of the stem most affected by heat, that is, the transition zone where stem and root meet, the stem-root junction, which is commonly referred to as the root collar. A standard of planting bareroot stock with emphasis on depth to protect part of the stem, regardless of method used, is suggested. Tree Planters' Notes 41(4):17-21; 1990.

Tree planting methods for hand-planted bareroot stock used currently in North America were developed decades ago when a comparatively small number of small seedlings were planted, usually in deep, sandy soil. Gradually, larger bareroot seedlings with bulky roots (even after pruning) were produced in the nurseries in ever-increasing numbers and planted on a variety of sites, yet the planting methods have remained basically unchanged to date. Moreover, guidelines developed strictly for conifers were erroneously recommended for hardwoods. For example, for best results, the wedge method (requiring two or four cuts into ground, depending on site conditions) was recommended for seemingly all types of stock and sites with trees planted "at the original depth at which they grew in the nursery" (23), that is, with their root collar at ground level. This latter misconception is also recommended in textbooks (27, 28) and planting guidelines (2, 22).

Evidence shows that deeper planting and deeper root placement is beneficial: it resulted in better survival of southern pines (1, 4-6, 15, 16, 26) and red pine (*Pinus resinosa* Ait.) (18, 21) and better height in loblolly pine (*Pinus taeda* L.) (26), slash pine (*Pinus elliotti* Engelm.) (33), and Norway spruce (*Picea abies* (L.) Karst.) (31). However, no consistent or significant effects of depth of planting on survival or height growth were found in white spruce or white pine (19, 20), although weather conditions were not reported. Deep planting should not be used on wet or poorly drained sites (5, 35) and on sites where small trees could be buried by silt from excessive rains (14).

Transplanting a tree at its original depth contradicts one of the basic requirements of any tree before it can produce appreciable growth, regenerate roots, and survive-that is, stem stability (8, 32). A tree loses much of its natural stability as well as physiological quality after lifting and transplanting. However, deeper planting can help it to regain stability with reduced stress in a new environment during the period of recovery. Conventional planting guidelines do not satisfy requirements for stability or recovery.

Heat exposure and shallow planting (rather than drought) can often be blamed for high tree mortality after transplanting.

The Stem-Root Junction

Heat, often confused with drought, is probably the most overlooked cause of death of newly transplanted bareroot trees. Just as neglected is part of the stem most affected by heat, the **root collar** (12) or transition zone where stem and root meet. The length of this zone varies considerably with species: nonetheless, this is the area where heat can exert the greatest influence on the flow of water, nutrients, hormones, and assimilates (7).

The **root collar** is normally a narrow, pale-colored ring around the stem (sometimes slightly swollen), about 1 cm wide, just below the ground level. It should not be equated with the wider stem-root junction extending above and below the collar and containing numerous dormant or adventitious buds. They can develop either shoots or roots, depending on the tree's need to restore the stem or regenerate roots. Several evergreens and (sprouting) hardwoods, in particular, have this ability.

Heat causes stress from direct and/or reflected sunlight to the cambium, which is most sensitive at the interface of the soil surface

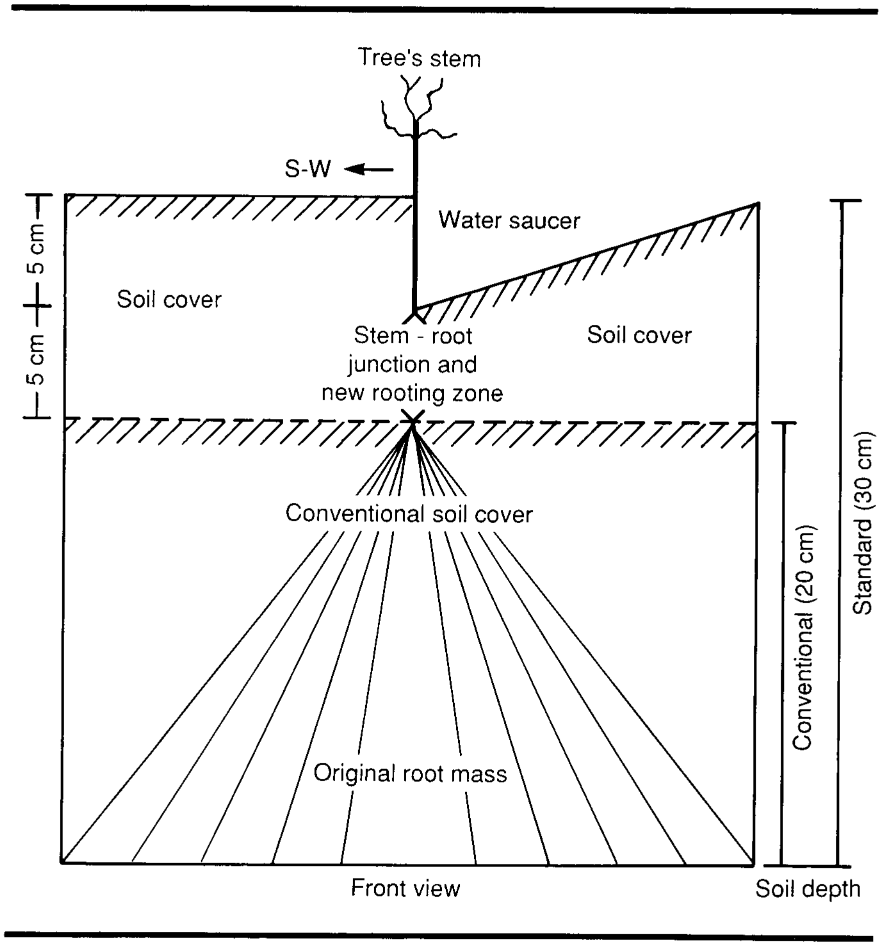

Figure 1—*The modified slit or half-hole planting method, a standard of planting bareroot stock at a greater than conventional depth to protect the stem-root junction and thus improve survival, stem stability, and rooting.*

and the tree's stem. This stress can be lethal, particularly if seedling quality is not high (9), normally within 5 cm of the soil level on the south, southwest, or west sides of the stem (24).

Planting trees with soil at the root collar often results in shallow planting (1), with roots unable to penetrate to the **crucial depth** during the first growing season. This leaves the entire stem of trees exposed and more vulnerable to heat damage than those of trees planted deeply. The crucial depth is the depth to which the root system of a new seedling must penetrate during the first growing season to remain in contact with soil that does not dry out to the wilting point. For trees that have access to moisture at greater depths, it does not matter if the uppermost 0.5 to 1 m of the soil is drier than at the wilting point (33).

In fact, the danger of drought injury is obviously great even without a deficiency in soil moisture (13). Moreover, rain sometimes washes away the soil around the stem, thus exposing some of the roots. Better moisture conditions are frequently too late to normalize transpirational stress and restore the roots' regenerating capacity.

In the modified slit or half-hole planting method (fig. 1), placing part of the tree's stem underground protects the stem-root junction containing dormant buds ready to produce adventitious or "hunger" roots (10) near the soil surface after transplanting. For example, for a tree with roots 20 cm long, a planting hole 30 cm deep is dug to cover 5 to 10 cm of the tree's stem. The tree planter's heel firms the soil, preferable on the north to east side of the stem, creating a saucer to collect rain water. Covering the roots to a greater depth also adds more soil weight around the stem, thus minimizing the effect of swaying and heaving.

Figure 2 shows white pine with new roots developed above the original ones following transplant-

Figure 2—*Examples of root development in white pine 2 + 2 nursery stock planted at a depth of 7.5 cm above the root collar, 3 years after field planting.* **Top:** *Development of new primary lateral roots above the original old ones following deep planting.* **Left:** *Horizontal and vertical extension of vigorous roots from both new and old root systems following deep planting as above.* **Right:** *Horizontal extension of a new root system above the stagnant old system following deep planting.*

ing to a depth of 7.5 cm above the root collar in shallow soil over limestone bedrock (29). Similar superficial roots were developed by 2+0 white pine following transplanting with the root collar 7.5 cm or 15 cm below the soil surface (3). Other species may react similarly, for example, white spruce (31) and Norway spruce (30). Practical deviations from this standard can be expected with certain types of stock and site, for example, plugs on blow sand or undisturbed container stock: nonetheless, the standard should serve as a basis for making other planting methods more reliable. Deep planting on sites with good drainage has several advantages:

1. Better physical stem stability against wind and snow pressure and resistance against climatic heat, summer drought, and winter desiccation.
2. Better protection of the roots that proliferate immediately below the root collar, should rainfall settle or wash away the soil.
3. Better protection of the stem root junction containing dormant buds ready to produce sprouts or adventitious roots. The likelihood of survival by sprout formation is particularly important to hardwoods should damage befall the top.
4. Better use of available moisture and aeration by breaking up the soil to a greater depth.
5. Better accumulation of rain in the water saucer at the tree's stem and, thus, direct penetration to the roots.

Discussion and Recommendation

Planting seedlings (and transplants) too shallow is believed to be the leading cause of seedling mortality, as the root system is unable to withstand the lack of moisture during severe dry periods of summer (6). Periods of drought frequently inhibit establishment and growth of young trees in North America. Moreover, trees planted at a shallow depth may become affected by heat long before moisture stress occurs. Drought compounds the effect of both. We can counteract this scorching and drying process by modifying planting practices. Deeper planting provides a good option.

Although deeper planting encourages root bending during plantings, slight J or L rooting is not detrimental to growth performance (11, 17, 36). To avoid severe root bending, which could impede water movement (32) and affect stem stability (11), judicious pruning of roots is recommended (5), thus facilitating planting at a greater stem depth with full vertical root extension.

Recommendations based on detailed analyses of the many planting guidelines needing improvement are beyond the scope of this article. However, these following suggestions could improve general planting practices and survival of hand-planted bareroot nursery stock:

1. Recognition of the importance of the depth to which soil should cover the tree's stem, helping to increase its physical stability and physiological recovery, regardless of the method of planting.
2. Revision of conventional planting guidelines, for example, improving illustrations with more practical descriptions and defining precisely their limits-of application according to types of stock and site. Excessive generalizations ascribed to one method, such as wedge planting, should be avoided.
3. Development of a full-scale tree planter's certification course at the same level as other traditional courses in forestry (scaling, tree marking, and soils), including instruction on the interactions between planting depth and environmental factors influencing survival of transplanted bareroot stock.
4. Development of a licensing system for tree planters in North America.

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Irrigation Rate Calculation for Nursery Crops

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Determination of the irrigation rate based on the concept of potential evapotranspiration has gained full recognition and is widely applied in agriculture. The atmospheric approach for irrigation rate calculation rests upon firm physical principles, is based on well-researched models, and with the help of available high-tech equipment, lends itself to unattended operation. Application of irrigation rates determined on this basis prevents over watering and leaching of nutrients, particularly NO_3, from sandy nursery soils. An automated system of weather data monitoring and irrigation rate calculation for operational use in forest nurseries (developed at the Ontario Forest Research Institute) is based on existing equipment (sensors and micrologger) for monitoring air temperature, global solar radiation, air relative humidity, wind, and rainfall. Data are transferred and archived automatically into an IBM-AT computer that calculates the potential evapotranspiration and then converts it into the irrigation rate expressed in minutes of operation for sprinkler installations based on spacing of sprinklers, pressure, and nozzle type. Tree Planters' Notes 41(3):22-27; 1990.

The consumptive use of water by nursery crops is an essential factor of growth. It is driven mainly by the atmospheric demand for evapotranspiration and satisfied from the soil water reservoir, which in the case of sandy, permeable soils is limited.

A steady supply of water to crops secures active transpiration and foliage cooling, which, in turn, allows for a positive balance between photosynthesis and respiration. As a physiological process, foliage transpiration occurs in response to a demand, exerted by the immediate atmosphere, that is satisfied-to the extent possible from the root zone of soil. The same demand exerted towards the bare soil results in direct soil evaporation. During the growing season, a crop of seedlings experiences a significant and consistent change in the relationship between these processes; initially the soil evaporation is predominant, but, as the foliage develops, transpiration starts to prevail. The two processes are normally lumped in a unique term: evapotranspiration (ET), expressed as water amount per time and area, most frequently in liters of water per square meter and per day ($1/m^2$ /day) or in millimeters per day (mm/day).

Correct irrigation water management is a delicate activity, performed under numerous constraints. *First,* by choice, in North America, the vast majority of forest nurseries are located on sandy, permeable soils, which are prone to develop severe water stresses if not resupplied with water at regular intervals. *Secondly,* with their reduced cation exchange capacity, sandy soils do not effectively bind the nutrients, especially the soluble inorganic nitrogen fertilizers, which are easily moved out of the root zone during significant rains or excessive irrigation. *Thirdly,* the root zone of nursery crops is initially very thin and thereafter limited usually to about 25 cm, as a result of root undercutting. As a consequence, the nursery crops have available only a limited soil water reservoir to respond to demands for evaporation that may reach, even in Ontario, up to 8 mm/day, normally peaking during mid-day. At the same time, due to its water-related characteristics, this limited reservoir cannot receive much water without it going away from the root zone together with dissolved nutrients.

Careful consideration of these main constraints, combined with practical experience, suggest the correct irrigation strategy: to avoid both stressful episodes between rain events and excessive nutrients leaching, the crops have to be supplied often but with not more than the amount of water potentially transferred from the crop of seedlings and soil to atmosphere during a certain interval.

Traditionally, the subject of irrigation rate (IR) calculation has been approached either through

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Supported by COFRDA Project 33505, Canada-Ontario Development Agreement.

soil, by following the depletion of the moisture and irrigating when a set threshold was reached, or through **atmosphere,** by calculating the evapotranspiration rate. Both approaches have specific merits and the current research in irrigation science continues in both directions. The subject of this paper is a brief description of a **computerized system for weather data collection and irrigation rate calculation,** based on the atmospheric approach, that is currently in use in two nurseries of Ontario Ministry of Natural Resources in Ontario, Canada.

The Atmospheric Approach

A large body of agricultural literature has been devoted to the concept of **potential evapotranspiration** (ET_p). In crop physiology and irrigation science, it is both a measure of stress and an essential guide for the irrigation rate calculation. A considerable number of empirical or physically based models have attempted to determine its amount from currently monitored weather parameters. Reviews of models and their performance under variable weather conditions have been presented by McGuiness and Bordne (5) and Jensen (3). Currently, the modern irrigation science in North America-in its quest for standardization-appears to agree on two estimates of ET_p, namely, 'grass' and 'alfalfa.' Both imply the consumptive use of water for crops that completely shade the ground and are not short of water; however, the former has a uniform, extensive surface 8 to 15 cm high (2), while the latter has a rough surface with top growth at 30 to 50 cm (4). For these standards, by means of lysimeter installations, the agrometeorologists have calibrated several models that are currently in use in numerous areas of the world, for both design and operations.

The modern irrigation science has accepted the **energy balance ET_p models** as the most accurate for estimating the actual irrigation needs (1, 2). Unlike empirical models, normally devised for monthly intervals, the models based on energy balance can be used with any time interval. From these models, for the present system, the Penman grass standard model was selected, although the software written has provision also for several other models, such as the Penman alfalfa standard, and standards developed by van Bavel, Blaney-Criddle, and Priestley-Taylor. The Penman alfalfa standard model results in ET_p amounts 15 to 20% higher than the grass standard (2), where as the van Bavel model allows for an explicit definition of crop roughness (5).

Weather Monitoring

The main parameters influencing the energy balance of a green crop are air temperature, solar radiation, air humidity, and wind, for which local measurements have to be obtained. The first two variables are responsible for the so-called heat term in the Penman equation, whereas the latter two constitute the aerodynamic term of the same formula. Additional influences are exerted by the albedo and canopy roughness. However, since these characteristics do not evolve dramatically from one day to another, they can be approximated with functions or coefficients. At the cooperating nurseries the monitoring of the main parameters, plus rainfall and soil temperature, is accomplished using the 21 X micrologger manufactured by Campbell Scientific (Logan, Utah). The microloggers are programmed to store in internal memory 10-minute records of these listed parameters as well as day-of-year and time.

Computer System

The 21 X micrologger can be connected to a telephone line by a modem link for efficient data transfer. The environmental information is downloaded once a day, via the telephone line, into IBM-AT computer clones located in nursery offices, also connected to modems, and operating under the communication package Crosstalk Mk4. A main script (communication program) written in Crosstalk Application Script Language (CASL) acts as a shell and accomplishes, daily, the following routine: (a) transfer weather data, (b) call a compiled QuickBASIC (.EXE) program for data archiving, daily summaries, calculation of ET_p, and irrigation rate, and (c) print a document for operational application of irrigation rate and subsequent filing. These operations are accomplished automatically before office hours. This approach releases the computer for other uses during the day. The system can be implemented in any IBM computer clone operating under MD-DOS version 3 and upwards. If the computer operates under the Microsoft Windows environment or with a multitasking operating system, such as Concurrent DOS or Desqview, the CASL script can be placed in the background partition of the computer.

Another computer program has been written in QuickBASIC version 4.5 for the visual analysis of weather data and calculated parameters for a 24-hour interval. This program can display information on CGA, EGA, and VGA monitors and takes full advantage of color computer screens, if such exist. Graphics are available through a menu-driven program in 10 combinations of measured variables and/or calculated parameters. The graphics allow for determination of times when extreme values for temperature, relative humidity, or wind have occurred. Also, the graphics show the time, duration, and intensity of rain. If the user desires, through a screen dump utility that is part of MS-DOS, the graphics can be copied to dot-matrix printers. In such a case, the computer converts the screen colors to different line shades.

A Real-life Example

The operational information of the computerized irrigation system is exemplified below with 2 days of real data from 1989 at St. Williams nursery. Day 199 (July 18, 1989) was a warm sunny day with low wind; day 216 (August 4, 1989) had an overcast sky, with uniform temperature and higher wind, as well as 6.25 mm of rain. The information for the 2 days is summarized in table 1, and some of the variables and parameters are shown in their hourly variation in figs. 1 and 2.

A comparison of the averages or sums for the weather elements of these days helps with the understanding of their influences on the ET_p daily sums. On day 199, the net radiation was triple that on day 216, which is reflected in the heat effect in the same proportion, although day 216 was warmer. Day 216 had double the wind run but, because the air had been closer to saturation with water vapors, the aerodynamic effects were lower. The magnitude of the four inputs to Penman model controls the proportion between heat and aerodynamic effects. In this respect, the 2 days are remarkably similar, with the aerodynamic effects representing slightly more than one-quarter of ET_p. However, even in the sub-humid climate of Ontario, during days with high winds and sizable saturation deficits, ET_p due to aerodynamic effects may reach up to 45% of total. Under drier climates, the contribution of this factor, which in fact quantifies the energy adverted to crops, can be considerably greater and may desiccate, in a few hours, crops of seedlings poorly supplied with water.

In the present approach, we considered the recommended IR as

Table 1—*Summary weather and ET_p information for day 199 and day 216*

	Day 199	Day 216
Weather elements		
Mean air temperature (°C)	22.62	25.07
Mean air relative humidity (%)	71.29	92.27
Total net radiation (langley)	343.42	115.44
Total daily wind run (km)	102.25	229.78
Total rainfall (mm)	0.00	6.25
Daily potential evapotranspiration (ET_p)		
Heat effects on ET_p (mm)	4.49 (73%)	1.48 (71%)
Aerodynamic effects on ET_p (mm)	1.62 (27%)	0.60 (29%)
Total potential evapotranspiration (mm)	6.11	2.08

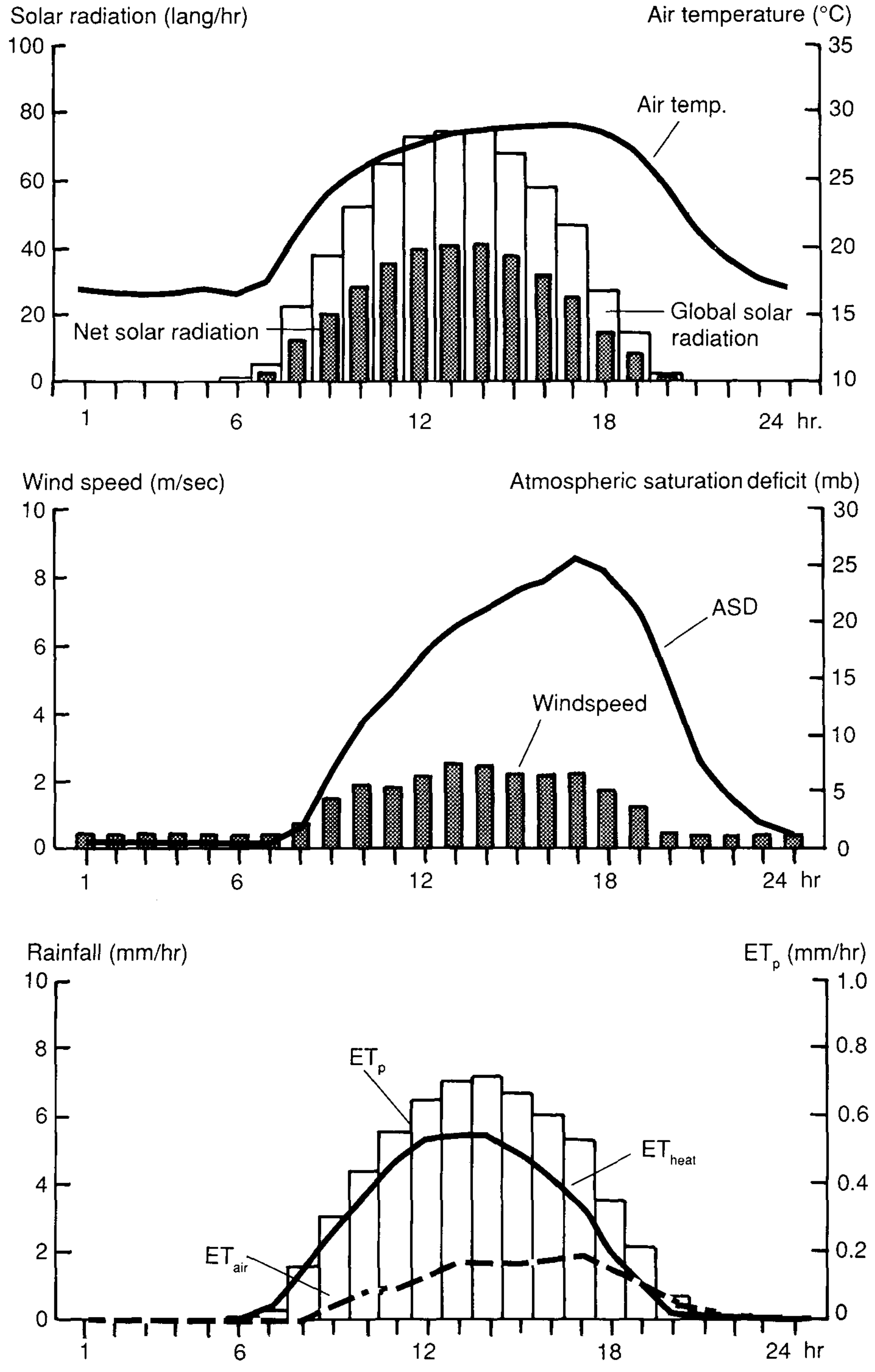

Figure 1—*Atmospheric variables and evapotranspiration (ET) on day 199 (July 18, 1989)*

being equal to 110% of ET_p. The 10% addition is to account for the water lost to evaporation and wind drift, which is estimated at around 8% for open-field sprinkler systems (6) as well as for the time necessary for the whole irrigation lateral to reach the operational pressure. On the basis of these ET_p figures, as well as sprinkler nozzle spacing and operational pressure, the program subsequently calculates the IR in minutes of operation (table 2). These are based on discharge rates given by the manufacturer of the irrigation equipment (7). The sprinkler type and spacing depend on the existing equipment and its allocation to various nursery crops and have to be input to the program at the stage of software implementation. With respect to

Table 2—*Operational sprinkler pressure at the St. Williams Nursery, Ontario for July 18, 1989 (day 199) and August 4, 1989 (day 216)*

Sprinkler nozzle size	Weak pressure	Fair pressure	Good pressure
Day 199			
3/16 by 1/4 inch	37.40	28.89	23.69
3/16 by 7/32 inch	43.99	34.07	27.76
3/16 by 1/8 inch	71.88	53.36	45.42
Day 216			
3/16 by 1/4 inch	12.76	9.85	8.08
3/16 by 7/32 inch	15.00	11.62	9.47
3/16 by 1/8 inch	24.51	18.20	15.49

Sprinklers were spaced at 18 by 18 meters. *Weak* operational pressure measures about 30 pounds per square inch (psi); *fair* pressure, 55 psi; and *good* pressure, 75 psi.

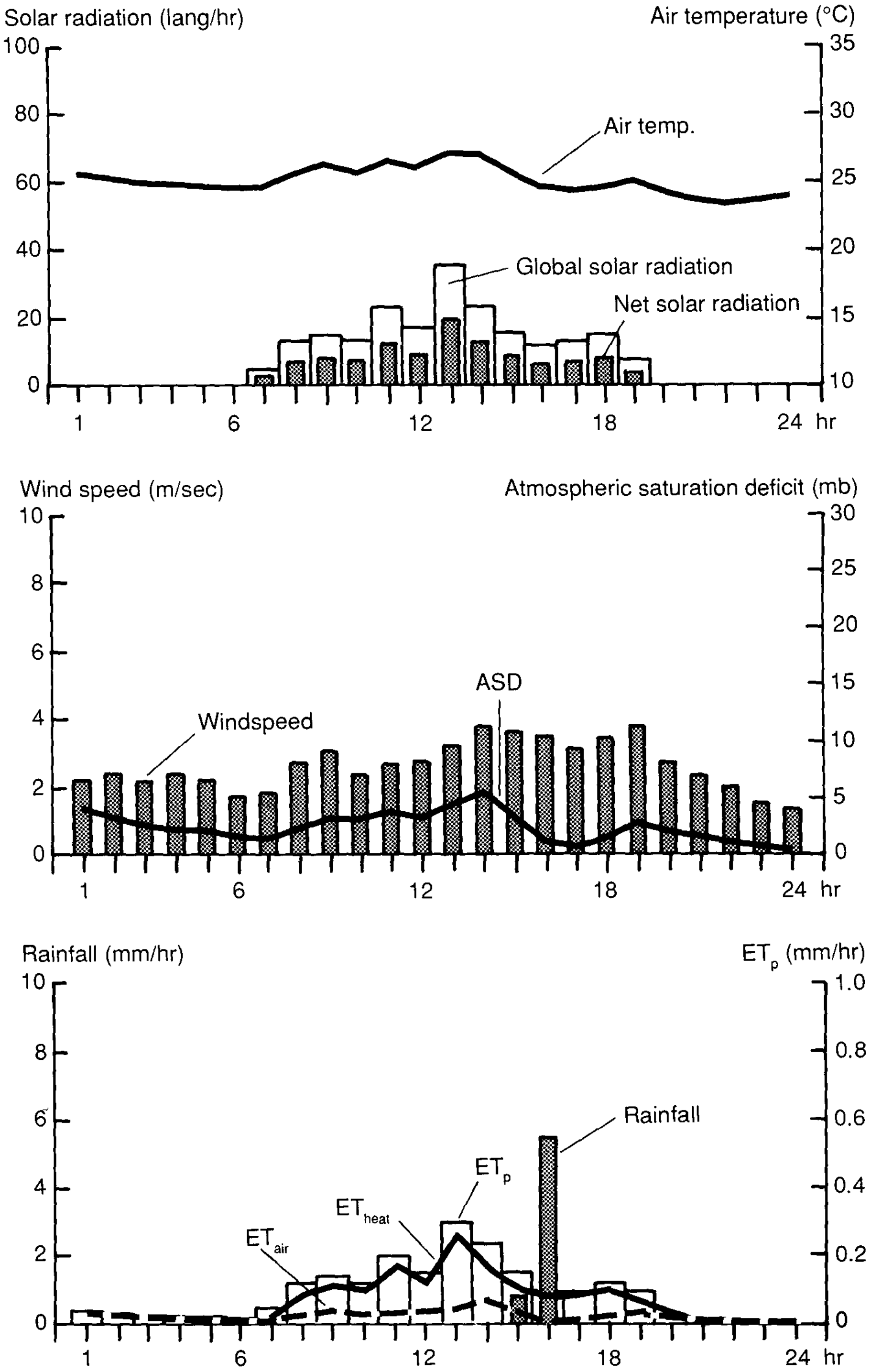

Figure 2—*Atmospheric variables and evapotranspiration (ET) for day 216 (August 4, 1989)*

operational pressure, which normally is not measured at the sprinkler, we opted for qualifiers (that is, weak, etc.). However, these correspond to the pounds per square inch (psi) values given in parentheses. Experienced irrigation operators can assess in a fairly correct manner the pressure from the 'throw' radius and dispersion of the jet.

A comparison of IR for the 2 days shows that if we were to apply the rates corresponding to day 216, in some cases, some of the application times would have been less than 10 minutes. In fact, such times are too short for achieving a good application uniformity. Therefore, judgment has to be exercised to determine whether such low rates should be applied or not. In the concrete case of day 216, however, this application should not be made because, as we have noticed in table 1, there was already a rainfall amounting to 6.25 mm.

An Irrigation Strategy

The development of the computer software is aimed at the operation use of the system in real life situations. The cornerstone of this approach remains the replenishment of the soil water reservoir in the next day with an amount equal to the ET$_p$ of the previous 24 hours. Although it is very important to know how much to apply in order to resupply the soil before the daily consumption peak, the decision whether to irrigate or not has to be made at the beginning of the next working day. This must be done because in the sub-humid climate of the Province of Ontario the weather changes frequently. Therefore, it is necessary to consider the overnight weather evolution and the latest rain forecast transmitted by media. If such a forecast, or at least cloudiness, exists, then no application is to be made because either the replenishment will be natural or the demand will be very low anyway. If no such forecast, exists then the application has to go on with the known amount. This decision is helped by setting the time for the data downloading at 7 AM of the current day. In case of overnight rain, the document would show how much of the demand corresponding to the previous day has already been replenished. At this point in time, it appears that this is the most flexible way to avoid crop water stress during dry spells while suppressing the irrigation during clusters of wet days. Of course, this approach corresponds more to the sub-humid climate of Ontario, as well as the northeast United States, where water is abundant, rains are frequent, and over irrigation has to be avoided mostly in order to curb nutrient leaching. However, application of the same operational principles in drier climates is likely to result in even more important savings of water and pumping energy.

The application time of IR has considerable importance. Since the ET_p is strongly influenced by the incoming solar radiation, which peaks at noon, it is important to replenish the soil water reservoir before the peak demand. Application of the irrigation in the afternoon allows for a long time before the next demand peak. Given the high permeability of typical nursery soils, in this interval much of the water moves out of the root zone.

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Reducing Pesticide Use Without Reducing Yield

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Because of concern about environmental, human, and seedling health, the University of Idaho Forest Research Nursery has reduced the number of pesticide applications and the amount of pesticide applied by 80%, while maintaining a high level of productivity. Sanitation and modifications of cultural practices have successfully reduced dependence on preventative pesticide applications. Tree Planters' Notes 41(4):28-32; 1990.

Nursery managers have long been concerned with overuse of pesticides because of the potential development of pest resistance (1, 2). However, with increasing risks to groundwater quality and human health (7), nursery pesticide programs will continue to come under closer scrutiny. Inevitably, nursery operations will have to wean themselves from chemical pesticide applications as the availability of these chemicals decreases because of stricter environmental laws (13) and increasing public pressure (14).

A primary concern of nursery managers is that reduced availability of chemical pesticides will lead to a reduction in seedling production. However, this concern may be unwarranted.

The University of Idaho has produced container seedlings since 1980. An aggressive spraying program evolved during the first five growing seasons. These first crops at the University of Idaho Forest Research Nursery were grown from seed obtained from cooperators or bought on the open market that was often of poor quality. Seedlings became diseased. Damping off was an annual problem in many seedlots; *Fusarium* root disease caused problems in Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco); and Botrytis ran rampant in western larch (*Larix occidentalis* Nutt), true firs (*Abies* spp.) and spruces (*Picea* spp.). Approximately 80% of the pesticides used were fungicides; the remaining 20% were insecticides.

From 1983 until 1986, the research nursery annually grew 10 species of conifers in containers, about 500,000 cells, in two fiberglass greenhouses. In 1986, the addition of a double-polyethylene greenhouse and rolling benches in all greenhouses increased annual production to 12 species and 830,000 cells (table 1). Seedlings are grown in Ray Leach pine cells® (66 cm^3, 100 seedlings per square foot) and watered with an overhead, traveling boom irrigation sys-

Table 1—*Total cells sown and species mix at the Idaho Forest Research Nursery between 1983 and 1990*

	1983-1986		1987-1990	
Species	Total cells (× 10^3)	Percentage of total	Total cells (× 10^3)	Percentage of total
Western white pine (*Pinus monticola* Dougl. ex D. Don)	125	25	240	29
Ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.)	125	25	275	33
Other *Pinus* spp.	20	4	30	4
Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]	60	12	60	7
Western redcedar (*Thuja plicata* Donn ex D. Don)	15	3	15	2
Western larch (*Larix occidentalis* Nutt.)	70	14	105	12
Grand fir [*Abies grandis* (Dougl. ex D. Don) Lindl.]	40	8	40	5
Spruces [*Picea abies* (L.) Karst.; *P. engelmannii* Parry ex Engelm.; *P. pungens* Engelm.]	35	7	50	6
Other conifers	—	—	15	2
Total	500	100	830	100

The authors thank Dr. R. L. James, USDA Forest Service, Coeur d'Alene, ID, and Dr. T. D. Landis, USDA Forest Service, Portland, OR, for their technical reviews and helpful comments.

tem. Air circulation and heat are provided via under-the-bench polyethylene tubes and fans. One full-time staff person is responsible for all cultural practices.

Our Integrated Pest Management Program

In an attempt to curb pesticide use while continuing to reduce disease losses, the nursery began a modest two-point program in 1985 based on sanitation and growing regimes.

Sanitation. Sanitation is the foundation of our program. Sanitation begins during seed harvest and processing. We brief our cooperators on the importance of seed quality and seed testing. Many disease problems can be circumvented by using high-quality seed. We routinely use a 10-minute soak in an agitated bleach solution-2 parts bleach (5.25% sodium hypochlorite) to 3 parts water-followed by a thorough rinse in running water to reduce microorganism levels on Douglas fir and pine seed before stratification (11).

Before sowing, all used cells are emptied, then rinsed with a high-power hose to remove any remaining medium, broken pieces of roots, salt accumulation, and superficial growth of algae and fungi. Blocks are rotated so the high-pressure stream is directed toward cells from all directions. Blocks are then placed on their sides so their bottoms can also be treated. We pay close attention to cleaning the cell bottoms because most *Fusarium* root disease and other pathogen inocula are found there (3). This treatment has resulted in very low levels of potential pathogens (4). Previously used cells are dipped in a 1:10 bleach-water solution before they are filled. Disease-susceptible species such as Douglas-fir, western larch, and spruces are sown in new cells, lessening the chance of infection by container-borne inocula.

Blocks are filled with a Gleason® flat filler with medium return. Any medium that falls on the floor and is trampled is discarded. Before filled blocks are put inside the greenhouse, the facility is thoroughly swept out, hosed down, and washed with a 1:10 bleach solution (including the walls, roof, and benches). Any algal buildup on our concrete floors is sprayed with a copper sulfate solution (20 pounds copper sulfate per 100 gallons of water).

Once sowing is complete, the crop is monitored daily for problems. Diseased seedlings are immediately rogued and tallied by species and seedlot. If the incidence of damping-off passes our damage threshold level (at least 15% of the blocks within the seedlot have at least 5% of their cells with disease), fungicide is applied to the problem seedlot. Thinning crews also rogue diseased seedlings and help with monitoring. The process of rogueing dead or dying seedlings continues until the seedlings are extracted. We use rolling benches so that all trays are easily accessible. We believe that rogueing is especially important in removing potential hosts for Botrytis and for minimizing build up of *Fusarium* and other pathogen spores in our containers. Weeds, algae, and moss are not tolerated anywhere in the facility, and their presence is kept to a minimum by spraying them with 100% bleach (5.25% sodium hypocholorite) through a hand spray bottle. A weed-free, clutter-free buffer zone is maintained around the greenhouse perimeter to reduce breeding and hiding grounds for pests, including mice.

Growing regimes. Growing regimes have an impact on the occurrence of disease and insects. At the research nursery, western larch provides a fine example of how growing regimes influence pesticide applications. Since 1984, we have modified our western larch growing regime to decrease height, which has also decreased needle length and promoted earlier hardening-off (12). Because smaller seedlings require less water, the frequency of irrigation and the time foliage is wet are decreased; our larch seedlings are 50% smaller (15 cm tall with 2.5-mm root collar diameter) and pesticide applications have been reduced 60%.

Because of reduced seedling size, irrigation frequency, rogueing of dead seedlings, and under-the-bench ventilation, no pesticides have been necessary to control *Botrytis* infection during the last three growing seasons. Users of our western larch are very pleased with stock size and outplanting performance.

Ventilation. We use under-the-bench ventilation. It improves aeration and decreases humidity around seedlings, reduces algal build-up on floors, and aids airpruning of roots. We have also concluded good air circulation is effective in reducing the incidence of *Botrytis* infection, an observation supported by recent research (9).

Pesticide use philosophy. Our philosophy for chemical pesticide use takes the curative, rather than preventive, approach. That is, chemical pesticides are used only after all other environmental and cultural control techniques have been examined or used, not as the sole means of preventing the pest from occurring (6). Streu (10) and Linquist (8) discuss the advantages and disadvantages of a curative approach, but for our operation, the advantage is reduced pesticide use and reduced exposure of employees, students, and visitors to these pesticides.

For a curative approach to be successful, pests must be identified early, before damage becomes significant. Initially, the main disadvantage of our curative spraying approach was an increased effort to monitor the crop for pests. We

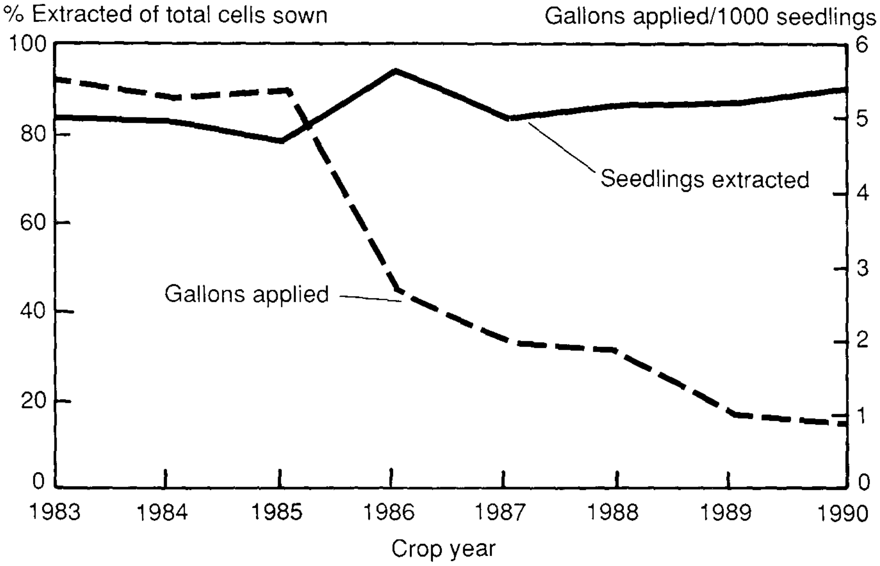

Figure 1—*Percentage of extractable seedlings for crop years 1983 through 1990 and associated gallons of pesticide applied per 1,000 seedling cells sown.*

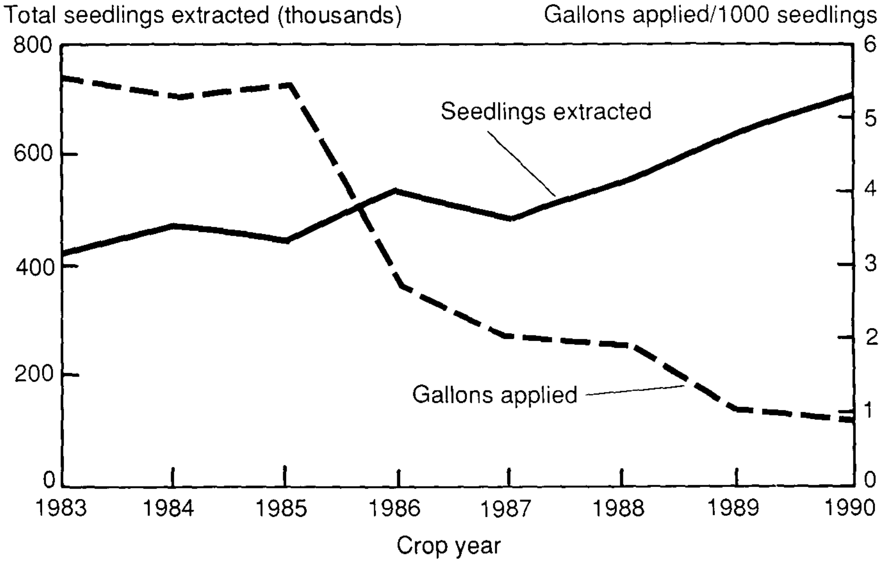

Figure 2—*Total seedlings extracted for crop years 1983 through 1990 and associated gallons of pesticide applied per 1,000 seedling cells sown.*

Table 2—*Pesticide applications and amount applied per 1,000 conifer seedlings grown at the University of Idaho Forest Research Nursery (1983–1990)*

Year	No. of applications*	Gallons per 1,000 seedlings
1983	30	5.5
1984	26	5.3
1985	28	5.4
1986	12	2.7
1987	11	2.0
1988	9	1.9
1989	10	1.0
1990	6	0.9

*An application is defined as the event of applying a fungicide or insecticide to any or all of the crop within a single greenhouse.

have found, however, that the quality of our crop has improved over the years because our staff members, in looking for problems, have spent more time observing seedlings. A greater awareness of the condition of the seedlings has aided our "fine-tuning" of growing regimes and pest management.

Some species, such as ponderosa pine and western redcedar, are generally problem free and rarely need pesticides. Species that are more disease-susceptible, such as western larch, spruce, and Douglas-fir, must be watched more carefully. However, even in these species, it is possible to apply pesticides only to problem seedlots (that is, those showing poor germination, low vigor, past history of disease problems), further reducing the total amount of pesticide applied.

The Resultant Decrease in Pesticide Use

From crop history records for the past 8 crops, the magnitude of reductions in pesticide usage is apparent. Plotting the percentage of extractable seedlings from cells sown (fig. 1) and total seedlings produced (fig. 2) against gallons of pesticide solution applied per 1,000 cells sown shows the positive effects of sanitation and growing regime manipulation on pesticide use. Gallons of pesticide solution per 1,000 cells sown has decreased from 5.5 (20.8 liters) in 1983 to less than 1 (3.8 liters) in 1990 (table 2). This decrease occurred even though the species mix of the nursery remained fairly constant but total cells sown increased more than 60% (table 1). Furthermore, the percentage of extractable seedlings has remained nearly constant over time and the total number of seedlings produced has steadily increased.

Conclusions

As Jarvis (5) concludes, we now have a comprehensive assortment of control methods for crop production. Proper use of these pest management tools is a decision making process. Integrating pesticides and environmental and cultural controls is a necessity for seedling production. Balancing the economic and environmental concerns can be accomplished only by monitoring the production system and keeping concise records of growing regimes. Placing an emphasis on using these pesticide reducing techniques can effectively control pests while maintaining a high level of productivity.

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A Precision Seed Sower for Longleaf Pine Bareroot Nursery Seedlings

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Commercial vacuum precision seed sowers were modified to obtain satisfactory density, row alignment, and spacing of longleaf pine (Pinus palustris Mill.) seed in two southern bareroot forest tree nurseries. Satisfactory seedling density and spacing for production of top-quality seedlings can be obtained with the modified sower if seed purity is at least 95 % and germination potential is at least 70%. Potential limiting factors encountered and suggestions for improvements are discussed. Tree Planters' Notes 41(4):33-38; 1990.

Longleaf pine (*Pinus palustris* Mill.) was previously the dominant tree species on approximately 60 million acres of virgin forests on the southern Coastal Plain and Sandhills of Georgia and North and South Carolina (3). The longleaf pine is well adapted to deep, sandy sites with good drainage. It is comparatively resistant to the fusiform rust fungus [*Cronartium quercuum* (Berk.) Miyabe ex Schirai f. sp. *fusiforme*], grows to a large size, and produces wood of excellent quality for a variety of forest products (8). However, there are only about 5 million acres presently forested in longleaf pine, and the species accounts for only about 2.5% (approximately 50 million seedlings) of the annual production of southern pine seedlings.

Outplanted longleaf pine seedlings have a recurrent history of failures, primarily resulting from inferior seedling quality, protracted slow growth in the characteristic "grass stage," and the extreme susceptibility of seedlings to the brown-spot foliage blight [caused by *Mycosphaerella dearnessii* Barr., synonym *Scirrhia acicola* (Dearness) Siggers] during the grass stage (1).

Recently, reforestation with longleaf pine has received considerable attention because many plantings of slash (*P. elliottii* Engelm.) and loblolly (*P. taeda* L.) pines on the deep sandy soils have either stagnated or succumbed to fusiform rust. More recently, key components of longleaf pine seedling quality have been identified and Wakeley's (9) seedling grading rules for this species have been expanded. Morphological characteristics of seedlings have been used in developing nursery management procedures for the consistent production of high-quality seedlings that show increased field survival, reduced disease hazard, and increased growth (2). Desirable characteristics associated with high-quality bareroot seedlings of longleaf pine include a root collar diameter of at least 10 mm (0.4 inch), at least 6 primary lateral roots that are 2 mm or more in diameter, a highly fibrous root system, and at least 25% of the feeder roots being ectomycorrhizal (2).

Close control of seedling and row spacing is needed to produce a high proportion of seedlings with the above characteristics (4). In addition to producing seedlings of uniform size, uniform spacing facilitates lateral root pruning, which significantly increases root fibrousness and ectomycorrhizal development. The standard bareroot nursery drill on row spacing of 15 cm (6 inches) permits scheduled root pruning to promote maximum development of roots and ectomycorrhizae. Controlled spacing between seedlings also promotes the development of larger root collar diameters and better quality seedlings (2, 6, 7, 10).

Precise sowing of longleaf pine seed has been a problem in southern nurseries because the seed shape is irregular and its accompanying wing is very difficult to separate completely from the seed. Longleaf seed has been sown by a variety of methods, including both hand and machine broadcasting. At the USDA Forest Service nursery, in Ashe, MS, a number of other methods were used to sow longleaf pine seed during the 1980's; these included custom-built and modified commercial seeders. However, none of these seeders or methods has provided the desired seedling density or spacing in nursery beds.

A cooperative project was established by the USDA Forest Service, Southern Region-the National Forests in Mississippi, Forest Pest Management, and the Savannah River Forest Station; the USDA Forest Service Missoula Technology Development Center; and the South Carolina Commission of Forestry to develop the system that was needed.

Methods

Only recently have precision seed sowers become available to forest tree nurseries in the United States. These machines pull a partial vacuum through specifically sized and spaced holes on a rotating drum or disc, which picks up and then drops individual seeds. A wide range of precise sowing rates can be obtained by adjusting the speed of the tractor, the rotation speed of the drum or disc, and the vacuum pressure. Very precise spacing and density are possible with small to medium-sized seeds of high purity and germination capability (5). However, irregular shapes caused by incomplete wing removal, low seed purity, and poor germination of longleaf pine seeds can complicate seed sowing with a standard Summit precision sower.

Consequently, the Summit seed sower was modified to accommodate the irregularities of longleaf pine seeds. The first requirement was to obtain high-quality seeds. Those used in seeding trials con-

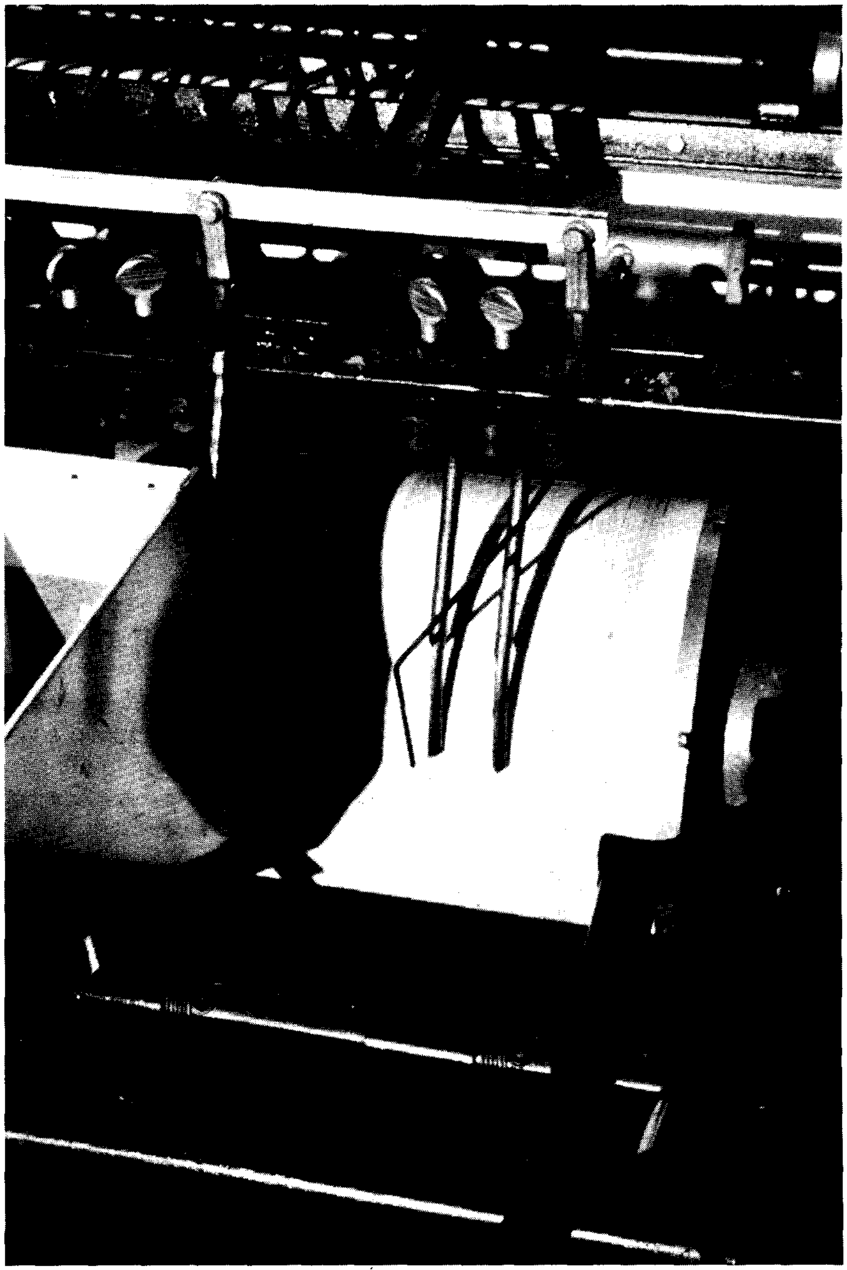

Figure 1—*Modified longleaf pine seeder showing added agitator in each seed hopper.*

Figure 2—*Longleaf pine seeder with custom-built vacuum seed drum (**A**) designed for precision sowing of 8 offset double rows per seedbed (**B**).*

ducted at the Taylor State Nursery in 1988 and 1989 had greater than 95% purity and greater than 70% germination potential. Modifications to the Summit machine included the addition of an agitator in each seed hopper to minimize the "bridging" effect of large, partially winged, and irregularly shaped longleaf seed (fig. 1). The agitator also minimized seed "doubles" by promoting the attachment of a single seed at each seed hole on the drum. A second modification involved custom-built seed drums to either sow 8 double offset rows per seedbed (fig. 2) at the Taylor Nursery or 15 single rows per seed bed (fig. 3) at the Ashe Nursery. A third modification at the Taylor Nursery involved the addition of a computer system for controlling seeding rates (fig. 4). This machine was purchased by the United States Department of Energy for the production of high-quality longleaf pine seedlings at the Taylor Nursery as part of a cooperative 5-year contract for forestation at the Savannah River Site, Aiken, SC. The supplemental modifications were made by the manufacturer in 1988.

Results

The modified Summit sowers provided acceptable seeding results for longleaf pine at two southern nurseries. At the Taylor Nursery, effective results were obtained in both 1988 and 1989. When seed

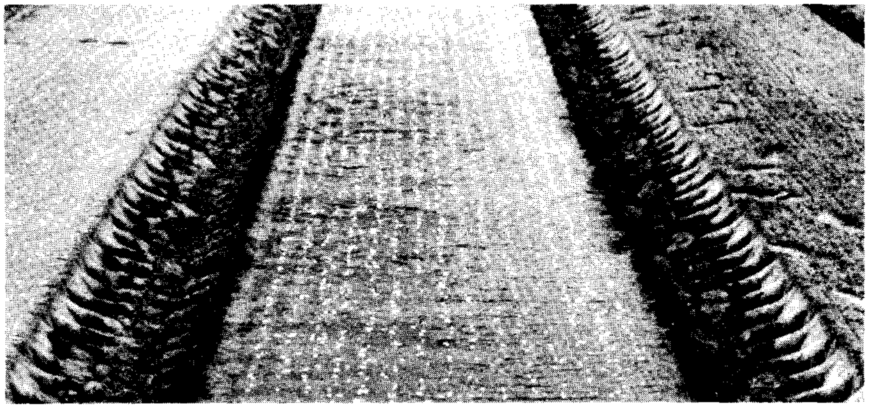

Figure 3—*Precision sowing of 15 evenly spaced single rows per seedbed with longleaf pine seeder with custom-built vacuum seed drum.*

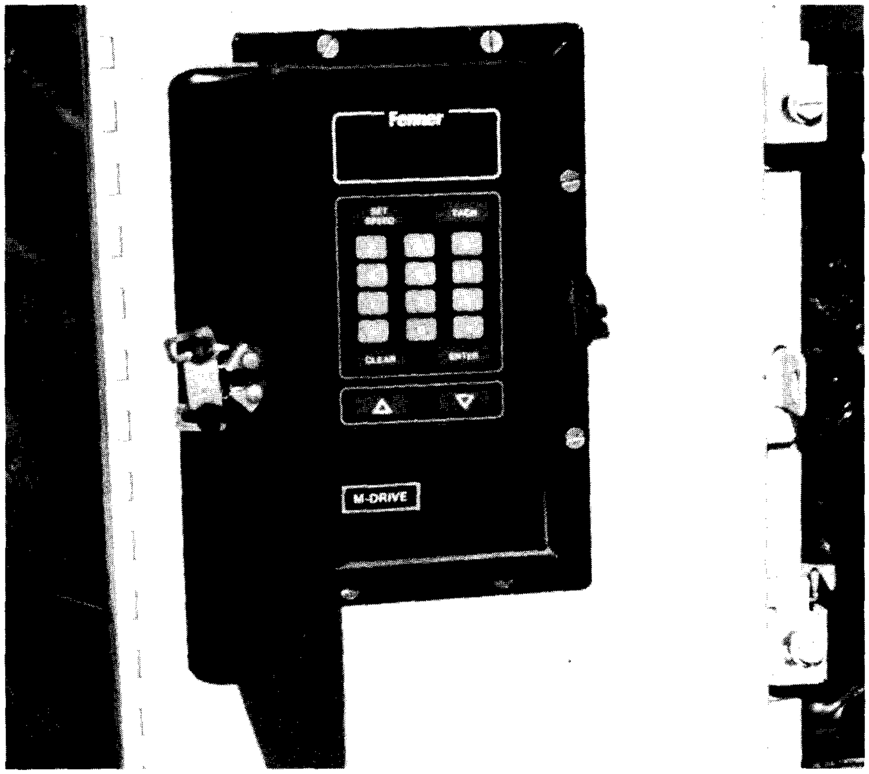

Figure 4—*Longleaf pine seeder showing synchronized computer system designed to maximize the effectiveness and flexibility of desired seed sowing densities.*

had a 70% germination potential, the actual seedbed density in 1988 and 1989 was 14 and 13 seedlings per square foot, respectively. Seed spacing within the offset double seed drill rows was also satisfactory. Single seeds were sown in >75% of the planting spots. At the Ashe Nursery, all 15 seed rows were equally spaced at 3 inches apart, and seed spacing within rows was sufficient to obtain the desired spacing within rows more than 75% of the time.

Using these two machines, seeds for approximately 10 million longleaf pine seedlings were sown operationally at these two nurseries during each of the 1988 and 1989 growing seasons.

Observations and detailed measurements showed that more than 90% of these custom-grown longleaf seedlings had root collar diameters greater than 10 mm (>.4 inch) at harvest time. In addition, the modified broadcast seeding at the Ashe Nursery eliminated the need for the expensive seedling thinning practices as routinely employed in previous years. Spring and fall sowing dates were utilized at the Taylor and Ashe Nurseries, respectively.

Discussion and Conclusions

Along with the observed improvements in longleaf pine seedling quality, improvements in seed efficiency were also observed in association with the vacuum sowers. Significantly less seed was used at both nurseries in 1988 and 1989 than in previous years, when other seeding equipment and procedures were used. This apparently resulted from the observed improvements in both between-row and within-row seed spacing that increased the available growing space for the developing seedlings.

Although the modified Summit vacuum seeders were considered successful in controlling the density and spacing of longleaf pine seedlings in two bareroot nurseries, several factors must be considered for their operational application in southern nurseries.

First, the sowing must be done at low speeds: best success has been achieved at speeds of 0.75 and 1.0 mile per hour. Speeds in excess of 1.0 mile per hour may cause seeds to be thrown forward off the seed drum and then bounce on the ground. Because the rotational speed of the vacuum seeding drum may be varied relative to the tractor's ground speed, the drum's rotational speed must be carefully calibrated and maintained, with the most effective seeding at 20 to 25 revolutions per minute. If the drum rotates too slowly, there is insufficient agitation in the hoppers and seeds often are not picked up by the vacuum drum. If the drum rotates too fast, seeds may be thrown over the drum onto the ground by momentum rather than being picked up singly by the holes in the drum. This is a highly significant factor when the seeder is moving down a slope greater than 1%. As with all vacuum precision seeders, the operator must concentrate on seed placement (quality) rather than sowing speed (quantity).

Second, seed agitation in the hoppers is required for precision sowing of longleaf pine with a vacuum seeder. Unlike loblolly and slash seeds, longleaf seed will not be picked up by the vacuum drum without agitation. Because of their odd shape and the partial wings, longleaf pine seeds tend to interlock and bridge in the hopper. Efforts to sow longleaf seeds precisely without agitation have always failed. Agitation in the seed hoppers has also been found to be the most effective when the vacuum drum is running between 20 and 25 revolutions per minute and with the oscillating agitators extended about 2.5 mm (1 inch) deep into the seeds.

Third, vacuum pressure must be adjusted and monitored to consistently pick up single longleaf seeds on the vacuum drum. If the pressure is too low, the seeds will not be picked up. If the pressure is too high, more than one seed will be picked up by each vacuum hole, and two or more seeds will fall at each seed location on the bed. Whenever the rotational speed of the seeding drum is changed, the vacuum must also be checked and adjusted as needed. The desired vacuum may also change with different seed lots with different seed sizes and shapes.

Fourth, the seeds must be as clean and have as high a germination rate as possible. Debris and trash are picked up by the vacuum seeder and sown just like the seeds. Because longleaf seeds cannot be totally dewinged, they should be rescalped just before sowing to remove any newly broken wings. Seed germination potential should be at least 70% to obtain satisfactory sowing results. Attempting to sow seeds at high rates to compensate for poor germination potential generally results in poor seedling spacing.

Although the longleaf pine seeding results were generally satisfactory, there are opportunities for additional improvements. A consistent supply of longleaf seed from the proper source and with high purity (>95%) and seed germination potential of >70% is urgently needed and may be the most limiting factor in future artificial forestation programs with this species. Without quality seeds, it is virtually impossible to obtain correct spacing of longleaf pine seedlings. Additional modifications are also needed to the vacuum seed drum, including attachments to improve the seed pickup and singulation on the holes.

Finally, a more effective and less destructive method of dewinging longleaf pine seeds would be highly beneficial in obtaining even more precise seed sowing results.

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Tree Planter's Notes, Volume 41, No. 4 (1990)

Short-Term Effect of Three Mechanical Site Preparation Methods on Species Diversity

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Three mechanical site preparation methods were compared for their effects on species diversity, as measured by Shannon's index of diversity. Diversity of frequency and of density both increased as the intensity of site preparation increased. A high-intensity site preparation resulted in the occurrence of more herbaceous species than were observed with low-intensity site preparation. The results obtained are discussed in relation to the control of competing vegetation during the establishment phase of planted tree seedlings. Tree Planters' Notes 41(4):39-42; 1990.

Clearcutting alters both biotic and abiotic ecosystem characteristics to varying extents. In most instances, one objective of clearcutting is to establish a seral (that is, successional) tree species as the next crop. Thus, it becomes desirable to create biotic and abiotic conditions favoring the establishment and growth of that species. This requires the creation of appropriate microclimatic conditions, minimal invasion of competing species, and optimal conditions of the soil on the forest floor. Clearcutting may achieve, at least partially, the first two conditions, whereas mechanical site preparation may achieve the second and third. In many instances, site preparation is required to partially control competing species (8) and obtain adequate survival of conifer stock (10). Walstad and others (18) recently reviewed the principal advantages and disadvantages of different site preparation methods. However, there are very few published reports on the short-term and long-term effects of site preparation on plant species richness (that is, the abundance of each species) and diversity (the number of species), notably for eastern North America.

In some ecological systems, logging operations and site preparation often increase species richness and diversity (1, 16). A direct consequence of such increases are that crop species (in many instances, planted tree seedlings) will need to compete against invading and opportunistic species. Therefore adequate mechanical site preparation should help ensure minimal invasion by species that compete with the seral tree species forming the next crop.

The objective of this study was to compare the effect of three intensities of mechanical site preparation on species richness and diversity in a clearcut site in eastern Quebec.

Materials and Methods

The experimental site, 4.5 ha in size, is located in eastern Quebec; it is characterized by flat terrain and a clay-loam soil (pH 4.1; organic matter 4.3%, sand 36%, silt 33%, and clay 31 %). The site was clearcut in 1985 and divided into three experimental blocks. The first block was prepared with V-blade, which formed bands of exposed mineral soil of about 3 m between piles of woody debris (high-intensity site preparation, SP1). The second block was prepared with a toothed brush rake (minimal or no exposition of the mineral soil), which formed areas about 40 m wide between piles of woody debris (medium-intensity preparation, SP2). The third block was prepared by disking (low-intensity site preparation, SP3). These site preparation operations took place in August and September 1987.

The vegetation was surveyed in August 1988. A total of forty 1-m^2 plots were randomly selected in each of the three blocks. In one plot, the trees, shrubs, grasses, and ferns were recorded by species. The average number of individual species per square meter was taken as a measure of species density. The proportion of plots on which the species occurred at least once was taken as a measure of the frequency of that species *(2).*

Characterization of the composition of a plant community is usually described by assessments of species richness and diversity *(12).* The variations in species composition induced by various site

Table 1—*Plant species density and frequency after high-intensity (SP1), medium-intensity (SP2), and low-intensity (SP3) site preparation in balsam fir–spruce forests of eastern Quebec (forty 1-m^2 plots per site preparation)*

	V-blade (SP1)		Brush-rake (SP2)		Disk (SP3)	
Species	Density (sp/m^2)	Frequency (%)	Density (sp/m^2)	Frequency (%)	Density (sp/m^2)	Frequency (%)
Trees and Shrubs						
Red maple (*Acer rubrum* L.)	—	—	0.03	2.5	—	—
Sugar maple (*A. saccharum* Marsh)	0.03	2.5	—	—	—	—
Mountain maple (*A. spicatum* Lam.)	0.2	10.0	—	—	—	—
Speckled alder (*Alnus rugosa* [Du Roi] Spreng.)	—	—	0.2	5.0	—	—
Paper birch (*Betula papyrifera* Marsh.)	0.3	2.5	—	—	—	—
Pin cherry (*Prunus pensylvanica* L.)	—	—	—	—	0.1	7.5
Red raspberry (*Rubus idaeus* L.)	7.4	60.0	16.2	92.5	33.9	100.0
Willows (*Salix spp.*)	0.1	10.0	—	—	—	—
Scarlet elder (*Sambucus pubens* Michx.)	0.2	12.5	0.1	2.5	0.03	2.5
Forbs						
Actaea sp.	—	—	0.1	2.5	—	—
Anaphalis margaritacea (L.) Benth.	0.2	5.0	—	—	—	—
Aralia nudicaulis L.	0.8	22.5	0.2	7.5	0.2	2.5
Cornus canadensis L.	3.2	22.5	0.3	7.5	1.0	22.5
Epilobium angustifolium	9.6	77.5	7.4	82.5	1.3	30.0
Epilobium spp.	7.6	40.0	13.9	65.0	0.03	2.5
Hieracium sp.	0.6	5.0	0.2	15.0	—	—
Impatiens capensis	0.1	10.0	—	—	—	—
Maienthemum canadense	0.6	10.0	—	—	—	—
Nemopanthus mucronatus	0.1	2.5	—	—	—	—
Prenanthes spp.	0.3	10.0	—	—	—	—
Grasses	6.3	70.0	0.8	22.5	0.6	7.5
Ferns						
Osmunda cinnamoma L.	0.03	2.5	—	—	0.1	5.0
All plants	37.7	375.0	39.43	305.0	37.29	180.0
No. of species	18	—	11	—	9	—
Diversity	1.93	2.35	1.28	1.75	0.44	1.43
Standard deviation of H′	0.13	0.10	0.15	0.13	0.04	0.11

$(H' = - \sum_{j} p_j \log p)$

preparation methods, therefore, may be assessed using these statistics (16). Pielou (12) pointed out that indexes of diversity are applicable to various measures of abundance, such as numbers of individuals and frequency. The most widely applied measure of species diversity-for example, that used by Conde et al. (3)-is that of Shannon (14), namely, the negative sum over all species of the product of the proportion, p_j, of the j^{th} species and the logarithm of p_j, that is:

$$H' = - \underset{j}{S} P_j \log p_j$$

This index gives a measure of diversity of density and a measure of frequency diversity for each treatment applied.

Results and Discussion

Shannon's measures of diversity of density and frequency diversity both increased with the intensity of soil-site preparation (table 1). Frequency diversity was 1.43 for the site prepared by disking (low intensity) and reached 2.35 for the site prepared with a V-blade (high intensity). There were 34.03 individual tree and shrub species per square meter on block SP3, as compared to 8.23 on block SPI. Inversely, there were 2.53 and 23.1 individual herbaceous species per square meter on block SP3 and SP1, respectively (table 1).

This is in accordance with previous reports, which indicated that soil site preparation creates modifications that stimulate germination of buried seeds (9, 13, 18, 19). The increase in diversity observed could be attributed mainly to the occurrence of a higher number of herbaceous species on the SP2 and SP1 blocks. Tree and shrub species, on the other hand, formed the principal species on block SP3. This agrees with Oliver (11), who found that the intensity of disturbances determined species composition through its relationship to the reproductive strategy of the various species. The results obtained in this study confirmed those previously reported by Burger and Pritchett (1). They found that woody vegetation made up the largest proportion of the total biomass on the chopped plots (low-intensity site preparation), followed by grass and forbs. Inversely, intensively prepared sites restricted the occurrence of woody vegetation (1).

If residual vegetation capable of sprouting is not uprooted (low-intensity site preparation), it will quickly reoccupy the site. On the other hand, if the site is extensively scarified, an ideal seedbed is created for a host of invading herbaceous species. Site preparation by disking seems to disturb the forest floor soil conditions to such an extent that seral tree species recover more rapidly. The two other site preparation techniques used in this experiment appeared to favor the establishment of early successional species. When required, control of competing vegetation is generally made during the first few years after site preparation and plantation, to ensure maximum tree seedling survival and growth. The choice of a vegetation control treatment, if required, is obviously determined by the composition of the plant community. So, an appropriate choice of site preparation treatment could greatly influence the following:

1. The need of future vegetation control treatment during the establishment phase of the plantation.
2. The choice of a treatment (mechanical, chemical, or manual) to control competing species, notably in regard to new treatment strategies now under study (4, 5, 7).
3. The export of nutrients, especially NO_3-N, from the site (6, 17).

From the results obtained in this study, it is evident that intensive disturbance of the forest-floor soil conditions in eastern Quebec can modify biotic and abiotic conditions, which in turn favor the establishment of early transitional species. The choice of the intensity of a site preparation treatment should take into account variations expected in a plant community as part of a management strategy for tree plantations.

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