AN ABSTRACT OF THE THESIS OF

James William Fischer for the degree of Master of Science in Forest Science presented on June 3, 1980.

Title: THE EFFECTS OF SHADE LEVEL AND IRRIGATION REGIME ON CONDITIONING CONTAINER-GROWN ABIES SEEDLINGS FOR FALL PLANTING.

Abstract approved: Signature redacted for privacy.
Peyton W. Owston

First season container-grown noble fir (*Abies procera*) and Shasta red fir (*Abies magnifica* var. *shastensis*) seedlings were given six combinations of shade (0%, 30%, and 50% shade) and irrigation (moist and dry) treatments in the nursery beginning in late July, 1977. To evaluate frost hardiness development, destructive freezing tests were conducted on September 22, October 31, and November 23, 1977 on sample seedlings from all treatments. These seedlings were then examined for survival, foliar browning, cambium condition, bud color, and bud condition. In addition, other sample seedlings were measured for the effects of the treatments on height growth, diameter growth, dry matter production, root regeneration and rate of bud-break after chilling.

Results indicate that full sunlight (0% shade) hastened the development of frost hardiness in the fall and that the effects of the applied irrigation regimes were not significantly different in inducing frost hardiness. Seedling height was not significantly different among the treatments; however, treatments of full sunlight at both moisture levels and moist irrigation at all three shading levels yielded seedlings significantly larger in diameter. No significant differences in seedling dry matter production, root growth,or rate of bud-break following chilling were apparent.

The Effects of Shade Level and Irrigation Regime on Conditioning Container-Grown Abies Seedlings for Fall Planting

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

The Effect of Shade Level and Irrigation Regime on Conditioning Container-Grown *Abies* Seedlings for Fall Planting

INTRODUCTION

Statement of the Problem

Increasing demand for forest products from the Pacific Northwest makes every acre of forest land more valuable for wood fiber production. Furthermore, as old-growth forests are harvested from lower elevation lands, foresters are turning to high elevation forests as a source of raw materials for wood products. This increasing reliance on higher elevation areas commands a need for successful reforestation of these areas after timber harvest.

Reforestation foresters everywhere are concerned with attaining adequate seedling survival and growth following planting. In the Pacific Northwest, the most commonly accepted planting time begins in late winter and continues through spring. During this time seedlings are generally found to attain their deepest state of dormancy and best level of frost hardiness. Also, root growth capacity is usually highest at some time during this period. All of this tends to result in a strong, sturdy seedling potentially able to withstand the shocks of lifting, packing, cold storage, field handling, and planting. Additionally, field conditions at this time are likely to be optimal for seedling survival. Day length is short, decreasing evapo-transpiration demand of the seedling. Temperatures are cool, requiring less transpiration cooling by the plant. Soil moisture is usually at or near field capacity, making water readily available to the seedling.

High elevation forests can present special problems for reforestation foresters in the Pacific Northwest. Shorter planting seasons generally result from much annual snowfall and long, hot, dry summers in the Cascade Range. Snows often begin in October or early November and may not disappear from roadways and planting sites until late June or early July, which drastically limits available planting time. This, coupled with some planting projects that are too large to be accomplished in a single planting season, leave foresters two options:

First, crews can wait until the snows melt, gambling that it is not too late in the planting season for seedling survival and growth. This risk can be compounded by the fact that seedlings are subjected to the stresses caused by long cold storage periods at the nursery.

Second, crews could plant in the fall, after some fall rains, but before heavy snowfall begins. The seedlings out-planted at high elevation sites in the fall often must endure early seasonal low temperatures, frosts and freezes--phenomena not normally encountered at lower elevation nursery sites where most seedlings are produced. Seedlings must, therefore, be cold-hardy at the time of fall outplanting.

Purpose of the Study

The objective of this research was to examine several combinations of shade and irrigation regimes in order to find a combination that will reduce frost susceptibility of fall-planted, container-grown *Abies procera* Rehd., noble fir, and *Abies magnifica* var. *shastensis* Lemm., Shasta red fir seedlings during their first season in the field. The results may be used to reduce losses of higher elevation, fall-planted *Abies* seedlings to early-season frosts.

The null hypotheses under investigation were:

1. The various moisture and light intensity treatments will not have different effects on the time and extent of cold hardiness.
2. The treatments will have no effect on subsequent root growth (i.e., after outplanting) of the seedlings.
3. The treatments will not affect seedling size development.

The scope of the research encompasses three shade levels--0% (no shade) and two degrees of shade provided by commercial shade cloth rated at 30% and 50% shade -- combined in all possible ways with two irrigation regimes--present nursery practice watering and one-half present watering. (These are referred to as "normal" and"one-half normal" in this thesis.) These combinations were examined both for relative effectiveness of each in inducing early cold hardiness and for their effect on seedling growth.

The investigation included a northern Oregon noble fir seed source and a southwestern Oregon Shasta red fir seed source. One thousand nine hundred and sixty (1,960) seedlings from each source were used. The seedlings were container-grown at the USDA Forest Service's Beaver Creek Nursery, fifteen miles southwest of Corvallis, Oregon.

LITERATURE REVIEW

Dormancy and Cold Hardiness

Cold hardiness is the ability of an organism to survive low temperatures. This is an adaptive mechanism found particularly in perennial plants of the temperate regions; it enables them to survive winter seasons when temperatures are frequently below freezing. Sergeev (1964) suggested that the ability and timing for woody plants to develop cold resistance is dependent on morpho-physiological processes that have evolved as a result of climate and soil conditions. Development of cold hardiness usually (although not necessarily) coincides with the development of bud dormancy in a plant. Dormancy is the temporary suspension of growth in healthy plant tissue, even under conditions in which these tissues are furnished with all the chemical and physical requisites for growth (Villiers, 1975). Both dormancy and cold hardiness develop in response to environmental stimuli signalling the coming of winter. The major stimulus for dormancy induction is shortening day length; the signalling for loss of dormancy is the fulfillment of a chilling requirement. Cold hardiness stimuli are less understood (Alden and Hermann, 1971) and are discussed later.

Cold hardiness and dormancy responses enable the plant to overwinter with little or no damage by normal winter environmental conditions. Only dormant trees can develop high degrees of cold resistance (Kozlowski, 1971). Growing trees become somewhat more hardy when exposed to low temperatures, but they will not withstand very low temperatures without injury. Dormancy can be induced by environments unfavorable for good growth -- short photoperiod, changes in light (both quality and intensity), temperature, mineral availability, or water supply (Kozlowski, 1971). Levitt (1966) points to the same factors as enhancing cold hardiness, calling cold hardiness inversely proportional to plant growth rate. Lavender, et al. (1968) found early dormancy to be induced in Douglas-fir seedlings by short photoperiod, low night temperature (3^{o}C),and dry soil. Lavender and Cleary (1974) suggested dormancy may be induced in Douglas-fir seedlings by moderate moisture stress, 8-to 10-hour photoperiod, and low nitrogen-content nutrient solution.

Light and Cold Hardiness

Many more researchers have pointed to a relationship between dormancy and cold hardiness (Alden & Hermann, 1971). Results of research by Aronsson (1975) indicate dormancy and frost hardiness may develop simultaneously under proper conditions. Aronsson said a critical photoperiod (6 to 12 hours) exists for Scots pine and Norway spurce for hardening. Photoperiods shorter than this slowed hardening and longer ones stimulated continuous growth. Van den Driessche (1969 a, 1970) suggested increased photoperiod may increase the rate of hardening in Douglas-fir seedlings indirectly by increasing photosynthesis. He found increasing light intensity to have the same effect on hardiness as light intensity would be expected to have on photosynthesis. So, the rate of hardening was dependent on the photosynthetic rate under constant photoperiods. Under limited light, longer photoperiods increased the rate of hardening, since longer exposure to light permitted more photosynthesis. Once the requirement for photosynthesis was met, decreasing photoperiod hastened hardening. He concluded that under conditions of adequate light intensity a photoperiodic response becomes evident: Short photoperiods hasten hardening and long ones retard it. McGuire and Flint (1962) found hardening to be a similar photoperiodic light response in three-year-old white spruce, Scotch pine, red pine, Douglas-fir, and balsam fir seedlings. They found these seedlings failed to harden in the absence of light even at constant temperatures of 0°C and 5°C. Vovlikova (1963), Tysdal (1933), and Trunova (1965) point to the same light/cold hardiness relationship in winter wheat.

Phases of Cold Hardiness Induction

Vasil'yev (1956), Evert (1968) and van den Driessche (1970) believe there are two phases of cold hardiness development in woody plants: The first phase occurs above 0°C and here light for photosynthesis is essential. The second phase can occur below 0°C and light is non-essential to deepen hardiness. Alden and Hermann (1971) conclude the ability of plants to develop high tolerance to cold may depend on photosynthesis and storage of photosyntates before the dormancy and cold hardening process begins. Tanaka (1974), attempting to affect the second stage of the hardening process, used a two-month, short-day (8-hour)photoperiod to effectively harden high-elevation Douglas-fir seedlings. He obtained substantial cold hardiness without exposure to sub-freezing temperatures. Tanaka (1977) said, however, shortening photoperiod is impractical on a production scale because the tiniest amount of light interrupts the darkness period and is likely to occur in a production facility.

Drought and Cold Hardiness

Development of cold hardiness is also related to desiccation resistance (Kozlowski, 1971). Levitt (1956) stated that water stress will not hasten plant hardiness but that dry conditions enable plants to cold harden more deeply. Tanaka and Timmis (1974) found that increased moisture stress during the growth of low density container-grown Douglas-fir seedlings seemed to advance hardiness by inducing bud-set 25 days earlier than in non-stressed seedlings. They noted the former seedlings were not hardy at the time of bud-set, but that with the proper cold treatment they became dormant. Mild drought, they felt, was a preconditioner for early cold hardiness; however, drought in and of itself is ineffective in inducing frost hardiness (Timmis, 1977).

METHODS

Stock Description

The Forest Service's Beaver Creek Nursery was the site of this study. The noble fir seeds were sown on March 8, 1977, for the Mt. Hood National Forest. The seeds were from Seed Zone 451, elevation 1,067m (3,500 feet). The Shasta red fir seeds were sown on March 7 and 8, 1977, for the Rogue River National Forest. These seeds were from Seed Zone 511, elevation 1,677m (5,500 feet). Both seed lots received pre-sowing stratification consisting of a twenty-four hour water soak followed by cold, moist storage at $1^{o}C$ for six weeks. Sowing was done by hand, two seeds per cell in Ray Leach pine cell containers. This is a container system consisting of two hundred individual 65 cm^3 (4-cubic inch) containers evenly spaced in a 80 cm x 40 cm (24 inches x 12 inches) supporting rack. Individual seedlings may be handled and moved in their containers without disturbing the seedling's root system or other seedlings. The containers were filled with "Lite-Gro", a commercially prepared potting mixture consisting of peat moss and vermiculite in approximately equal proportions. After germination, the seedlings were thinned to one seedling per container. Germination and early growth took place in a greenhouse (Figure 1). On June 6, 1977, 1200 seedlings from each species were consolidated into the same area in a greenhouse. A night lighting regime of five minutes every one-half hour from 11:30 P.M. until 7:00 A.M. was employed to help insure continuous and uniform growth until experimental treatments were started.

Figure 1. Seedling eary growth within the greenhouse at Beaver Creek Nursery (age - 18 weeks).

Seedling Care and Monitoring

Height growth measurements were taken on the following dates in 1977: June 21, July 5 and 19, August 2, 16 and 30, September 13 and 27. These measurements were taken on a 20% random sample of the seedlings. In addition, height measurements were taken on all seedlings following each of three freeze tests (described later) conducted during the project. On June 21, the 20% sample was determined and these seedlings were marked in their containers so that the same seedling sample could be measured on each measurement date. Height measurements were taken from the top of the container to the terminal growing tip on actively growing seedlings and to the tip of the bud on seedlings that had set bud.

On July 19, all seedlings were transferred from the greenhouse to the shadehouse at Beaver Creek as an intermediate step between the greenhouse and the open study area. This acclimation period (July 19-25) was taken to minimize the shock of transferring the seedlings outside the greenhouse for the remainder of the study.

Physical Arrangement for Treatments

On July 26, the seedlings were removed from the shadehouse to an open study area. Table I shows the treatments that were employed and the number of seedlings receiving each treatment.

TABLE I. NUMBER OF SEEDLINGS FROM EACH SPECIES IN EACH TREATMENT COMBINATION.

	NO SHADE	30% SHADE	50% SHADE	TOTAL
Normal Watering	160	160	160	480
Moisture Stress	160	160	160	480
Total	320	320	320	960
TOTAL BOTH SPECIES				1920

Figure 2 is a diagrammatic representation of the split-plot random bench arrangement for the study. Four replicates were employed. Each replicate consisted of a full container rack from each of the three shade treatments. The placement of the racks of containers and the shade treatment were randomly determined.

Each rack was divided into two groups of 40 plants of each species. These four groups were randomly arranged within each rack and separated by an empty row of container spaces so that water from the normally watered groups was less likely to enter groups that were being stressed. Each of the two species within the rack was represented by one group of 40 with a normal watering schedule and another group of 40 with a one-half normal watering schedule. Watering schedules were randomly assigned.

Blocks 13 and 14 were unreplicated sub-samples of the two extreme shade treatments and both moisture levels. These blocks were used in a small field trial described later.

Shade Treatment

Shade for the treatments was provided by commercial shade cloth rated at thirty per cent and fifty per cent shade. Light meter readings were taken near 9 a.m., near 12 p.m., and at 4 p.m. on both July 10, 1977, and October 16, 1977. Near-noon readings showed the shade material provided very close to its rated shade capacity. Morning and afternoon readings showed the material provided more shade, particularly in October (Table II).

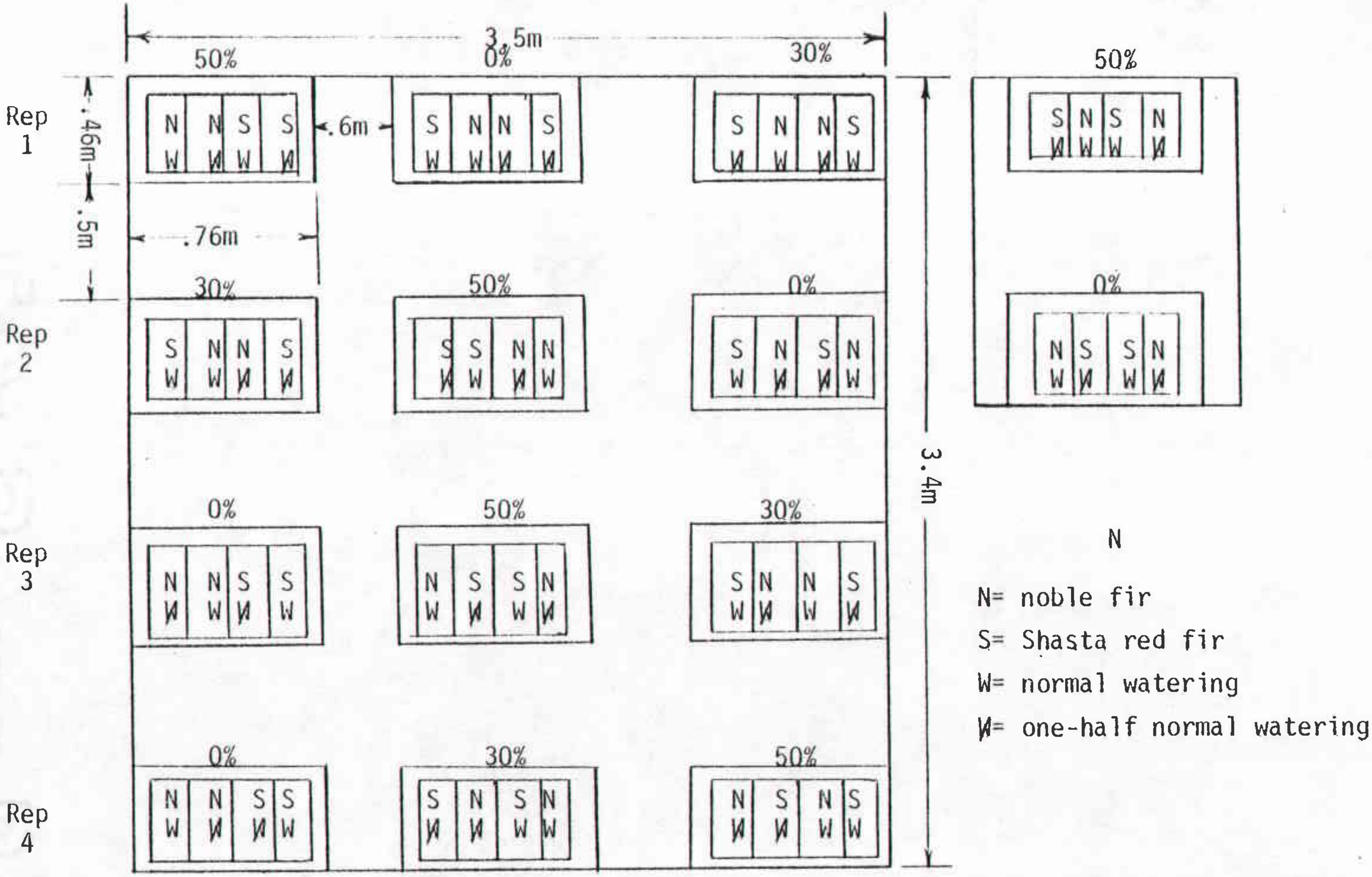

Figure 2. Randomized split-plot bench arrangement of the seedling racks.

TABLE II. LIGHT INTENSITY READINGS UNDER THE SHADECLOTH (IN FOOT-CANDLES) AND PER CENT OF FULL SUNLIGHT.

DATE	TIME	NO SHADE	30% SHADE	50% SHADE
7/10/79	9:00 A.M.	7880 (100%)	4649 (41%)	2837 (64%)
7/10/79	12:00 P.M.	8083 (100%)	5400 (34%)	4250 (47%)
7/10/79	4:00 P.M.	7956 (100%)	5012 (37%)	3501 (56%)
10/16/77	9:00 A.M.	7540 (100%)	4298 (43%)	2639 (65%)
10/16/77	12:00 P.M.	8833 (100%)	6000 (32%)	4900 (45%)
10/16/77	4:00 P.M.	6485 (100%)	3502 (46%)	2140 (67%)

The shade cloth was supported above and around the seedlings on a frame made of three-eighths of an inch diameter bamboo garden stakes. The frames were 0.76 m (30 inches) long, 0.46 m (18 inches) wide, and 0.53 m (21 inches) tall. This was to insure adequate space between seedlings and shade frames (and shade cloth) to help minimize microclimatic influence of the shading device. In addition, the north side of the shade frames and from four to five inches all around the bottom of the frames were left without shade material. This was to help air circulation and to contribute to minimization of microclimatic changes caused by shading material. Figure 3 shows an individual shading device. Figure 4 shows the bench arrangement at the nursery throughout the experimental period.

Figure 3. Individual shading device.

Figure 4. Bench arrangement of seedling racks and shading device.

Irrigation Treatment

The irrigation schedule for seedlings to be watered normally was the usual irrigation schedule for the nursery -- *i.e.*, watering done every other day until August 3, 1977 when, due to hot, dry weather conditions, irrigation was done daily through the rest of August. In September, the every-other-day schedule was resumed.

Seedlings to receive one-half the normal watering regime were watered one-half as often as the others (or every four days) - except for August, when they were watered every other day. Each time any seedlings were watered (whether moist or dry treatment), they were wetted until water dripped from the holes in the bottom of the container cells. This insured all cells were being wetted to their full water-holding capacity.

Freeze Tests

Controlled freeze tests were conducted on three occasions in 1977: September 22, October 31, and November 23. Five seedlings from each treatment-replication of each species were selected at random and tested for cold hardiness on these dates. Freezing tests were conducted to minimums of -6^{o}C, -12^{o}C and -18^{o}C on each respective date. Freezing the seedlings was accomplished by dropping the temperature one degree Fahrenheit[1] every fifteen minutes until the minimum temperature for that date was reached.

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1 Degrees Fahrenheit were used because the control panel of the freezing chamber was so calibrated.

The temperature was held at the minimum for two hours and then raised one degree Fahrenheit every fifteen minutes until reaching $1^{o}C$.

Seedling Examination Following Freeze Tests

Seedlings were then removed from the freezing chamber and permitted to re-acclimate overnight. The next day they were placed in a warm growth chamber ($27^{o}C$ daytime, $18^{o}C$ nighttime temperature) with a 12-hour light, 12-hour dark lighting regime. The seedlings stayed in the growth chamber for one month, at which time cold damage was assessed by determining number of dead seedlings and damage to foliage, cambium, and terminal buds of surviving trees. Seedling root activity was also assessed at this time for each freeze-test group.

Measurements of seedling height, diameter, and dry weight were also made for all seedlings given freeze tests. This was done following the growth chamber period and was intended to characterize the seedlings as well as reveal any effects of the experiments on seedling growth.

Spring Survival Potential

A growth chamber test for spring survival potential was conducted by planting five seedlings per species-treatment replication in 2-gallon containers on November 1, 1977. On December 20, 1977, they were removed from the experiment site at Beaver Creek and placed in cold storage ($3^{o}C$) for six weeks. The seedlings were then transferred to a growth chamber and their responses to simulated summer conditions ($28^{o}C$ day, $18^{o}C$ night with 18-hr light period) were measured. Survival, time until bud break, height growth, and root growth were measured after six weeks.

Outplanting Trials

Concern for first season survival of these container-grown seedlings in the field led to two small sub-sample fall outplanting trials by the method described by Owston and Stein (1974). Noble fir seedlings were outplanted on October 21, 1977, in the area and elevation from which the seed originated. Shasta red firs were outplanted on October 28, 1977, at elevation 1220m (4,000 feet) near the Santiam Pass on the Willamette National Forest. This location was chosen because travel to the Rogue River National Forest, from which the seed originated, was not practical at the time.

Due to a shortage of available seedlings from the seed lots and elevations desired, these sub-samples were not replicated in the nursery and only the 50% and 0% shade were employed along with both irrigation regimes.

Field plantings consisted of four plots (replications), each consisting of one randomly located row of 10 seedlings of each of the four treatments (50% shade, normal irrigation; 50% shade, ½-normal irrigation; 0% shade, normal irrigation; 0% shade, ½-normal irrigation). The Mt. Hood noble firs were checked for survival on May 11, 1978, and the Shasta red firs were checked on June 9, 1978.

Statistical Analysis

Analysis of variance was used as appropriate for a split-plot experimental design (Table III). Shading effects were analyzed using orthogonal contrasts. A significance level of at least 90% was used throughout the study.

TABLE III. ANALYSIS OF VARIANCE TABLE.

Source	df	
Racks	3	
Shade treatments (T)	2	
0 versus 30+50(T)		1
30 versus 50 (T_2)		1
Error (main plot)	6	
Moisture (M)	1	
Species (S)	1	
M X S	1	
T X M	2	
T_1 X M		1
T_2XM		1
T X S	2	
T_1 X S		1
T_2 X S		1
T X M X S	2	
T_1 X M X S		1
T_2 X M X S		1
Error (split plots)	27	
Total	47	

RESULTS

Seedling Size

Height growth of seedlings through the growing season is shown in Figures 5 and 6. Rate of growth did not appear to be affected by the imposed treatments. There was a tendency near the last date of height measurement for noble firs given the normal watering treatment to add additional height. No statistically significant differences in final height occurred within species. There was, however, a tendency within each species for moist-treatment and shade treatment seedlings to be somewhat taller than seedlings receiving the drier water regime. Figure 7 shows final seedling height averages by treatment.

Diameter growth measurements of the seedlings given within species freeze tests in September and November showed seedlings given the 0% shade treatment were significantly larger than seedlings given 30% and 50% shade. Overall, final season diameter measurements showed 0% shade treatment seedlings as well as the seedlings with the normal watering regime had significantly larger diameters than those of the other treatments (Figure 8).

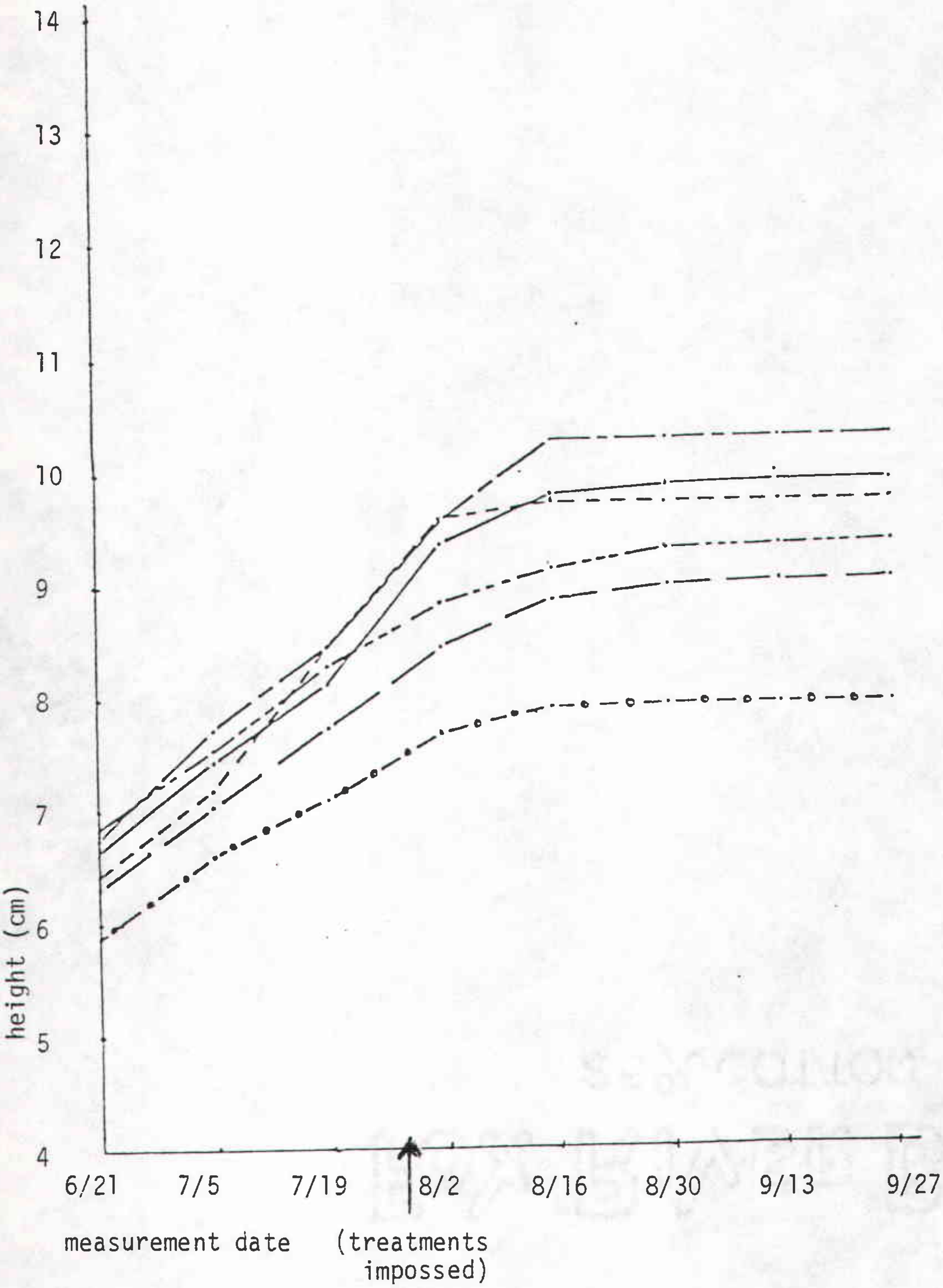

Figure 5. Shasta red fir height growth through the season (averages of a 20% sample of test seedlings).

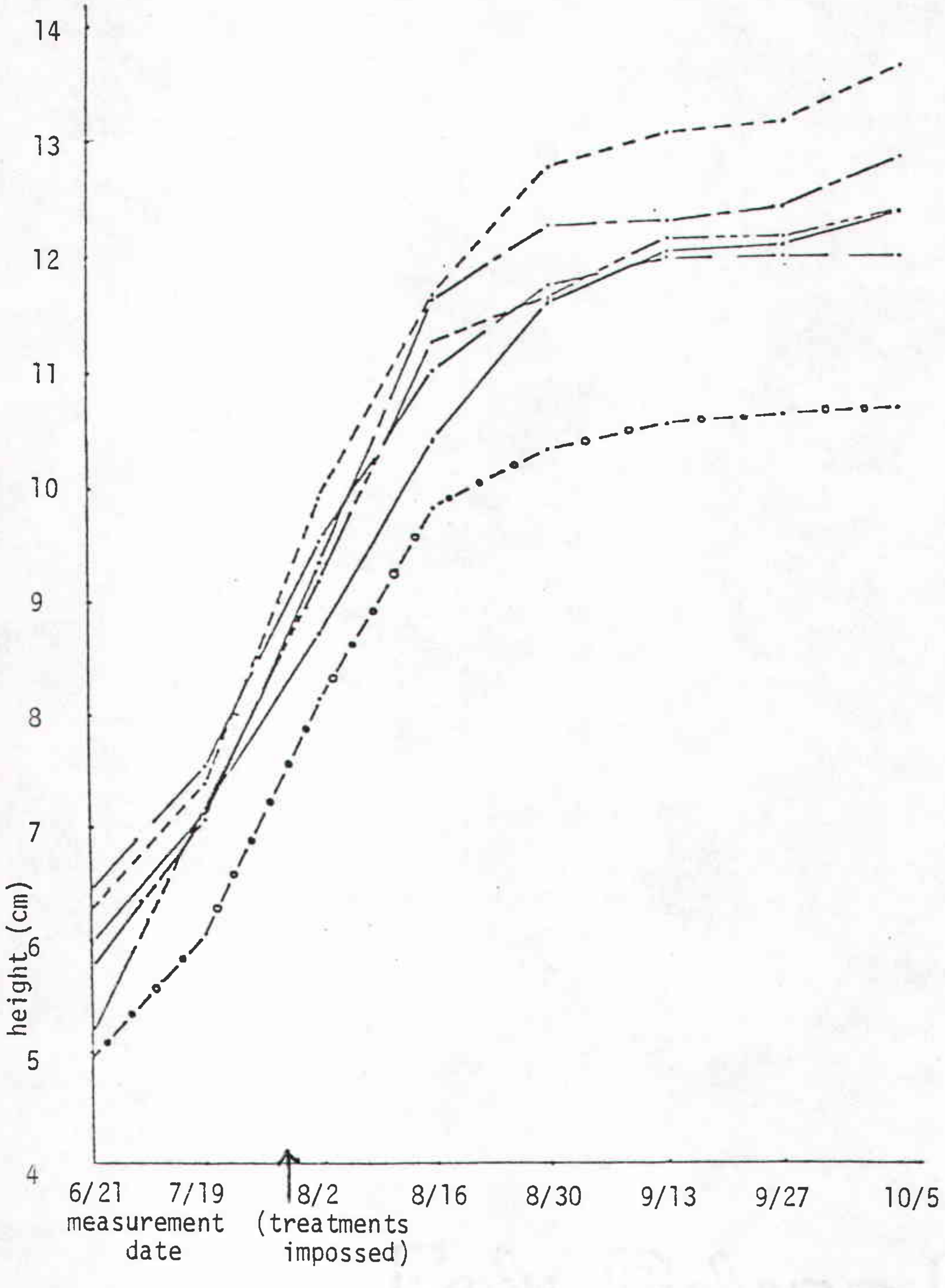

Figure 6. Noble fir height growth through the season (average of a 20% sample of test seedlings).

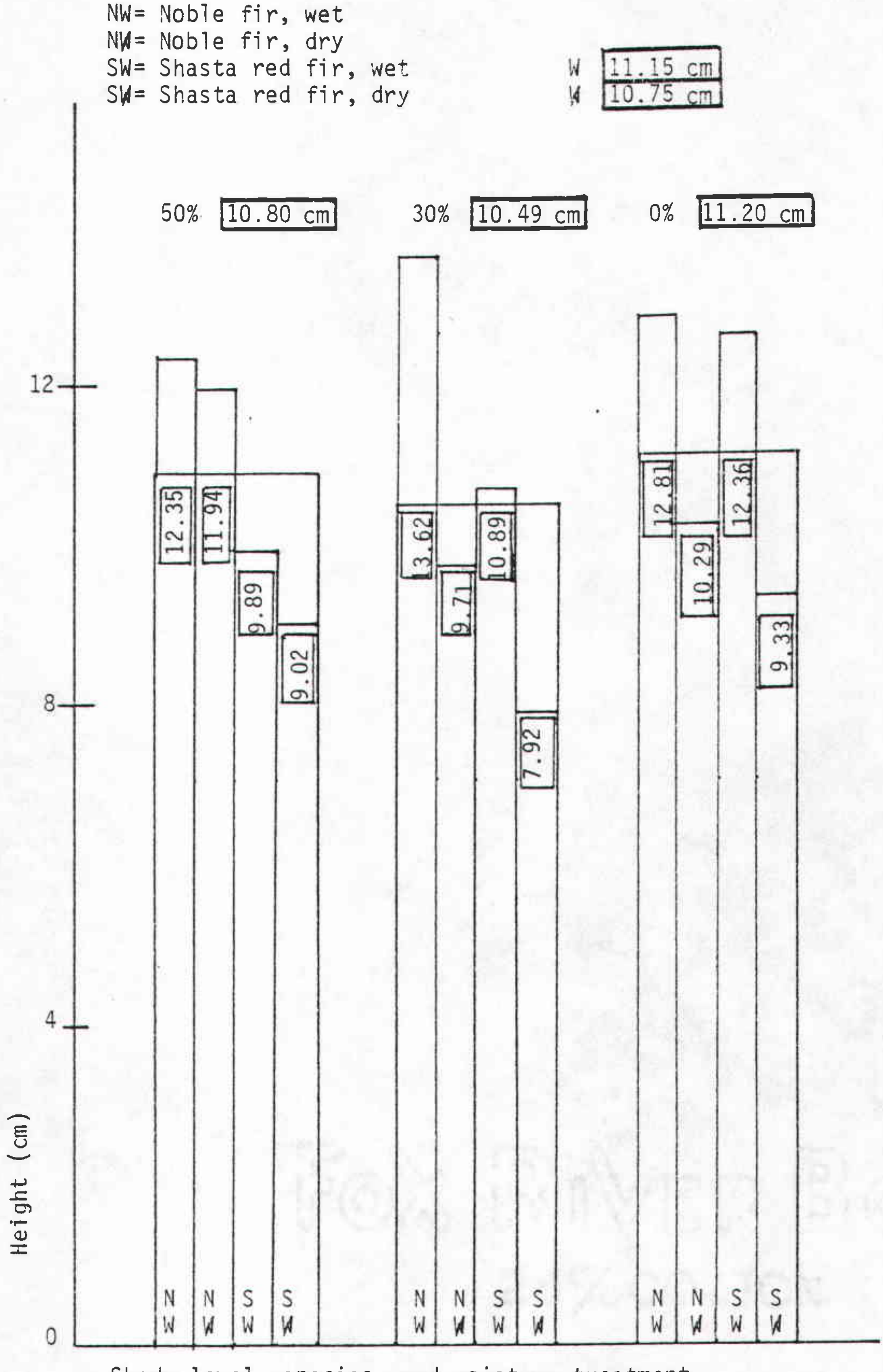

Figure 7. Final seedling height averages by species and treatment (numerical values shown in boxes).

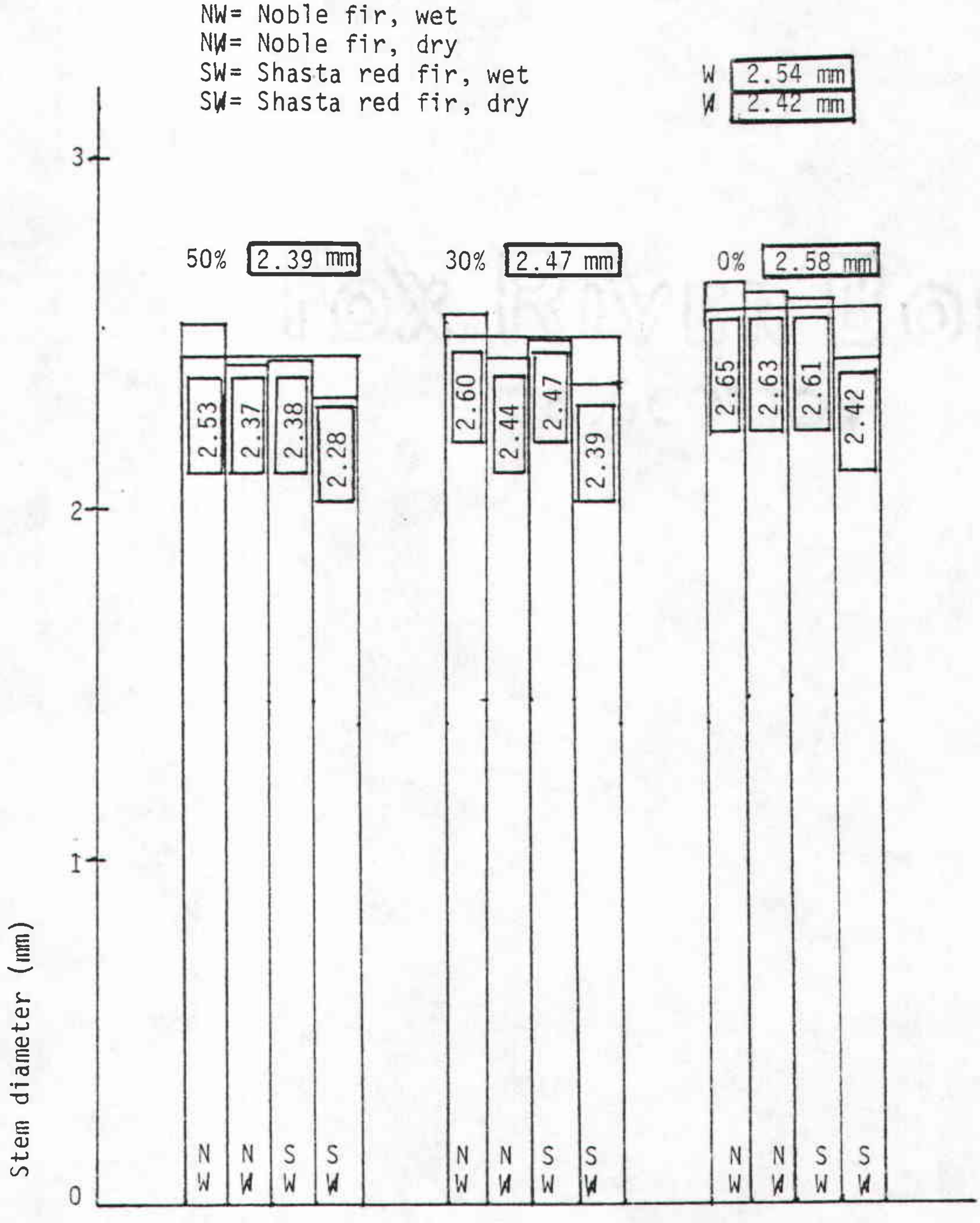

Figure 8. Final seedling diameter averages by species and treatment (numerical values shown in boxes).

Dry weight measurements of the seedlings showed no significant differences within species, although seedlings given the 0% shade treatment averaged somewhat greater mass. Figure 9 summarizes average seedling dry weight measurements.

Freeze Tests

Data for the two species were combined in the tables presented because there were no significant species interactions.

The number of seedlings surviving the September freeze test from the 0% shade treatment was significantly larger than that of seedlings given either the 30% or 50% shade treatment (Table IV).

Survival within shade treatments increased from September through November, and there were no observed significant differences among shading treatments in either the October or in the November freeze tests. This occurred in spite of the fact that freezing temperatures were lowered with each successive test.

TABLE IV. PER CENT OF SEEDLINGS SURVIVING FREEZE TESTS BY TEST DATES AND SHADE TREATMENT (SPECIES COMBINED).

Date	Lowest Temp. (^oC)	0% Shade	30% Shade	50% Shade
September	-6	85.3%[a]	81.3%[b]	77.5%[b]
October	-12	93.4%[c]	95.0%[c]	87.5%[c]
November	-18	98.7%[d]	100.0%[d]	100.0%[d]
All dates combined	---	95.0%[e]	92.1%[f]	88.3%[f]

a is significantly different from b at the 95% level
e is significantly different from f at the 95% level

No significant differences in seedling survival were apparent with respect to the two irrigation regimes following the September freeze test.

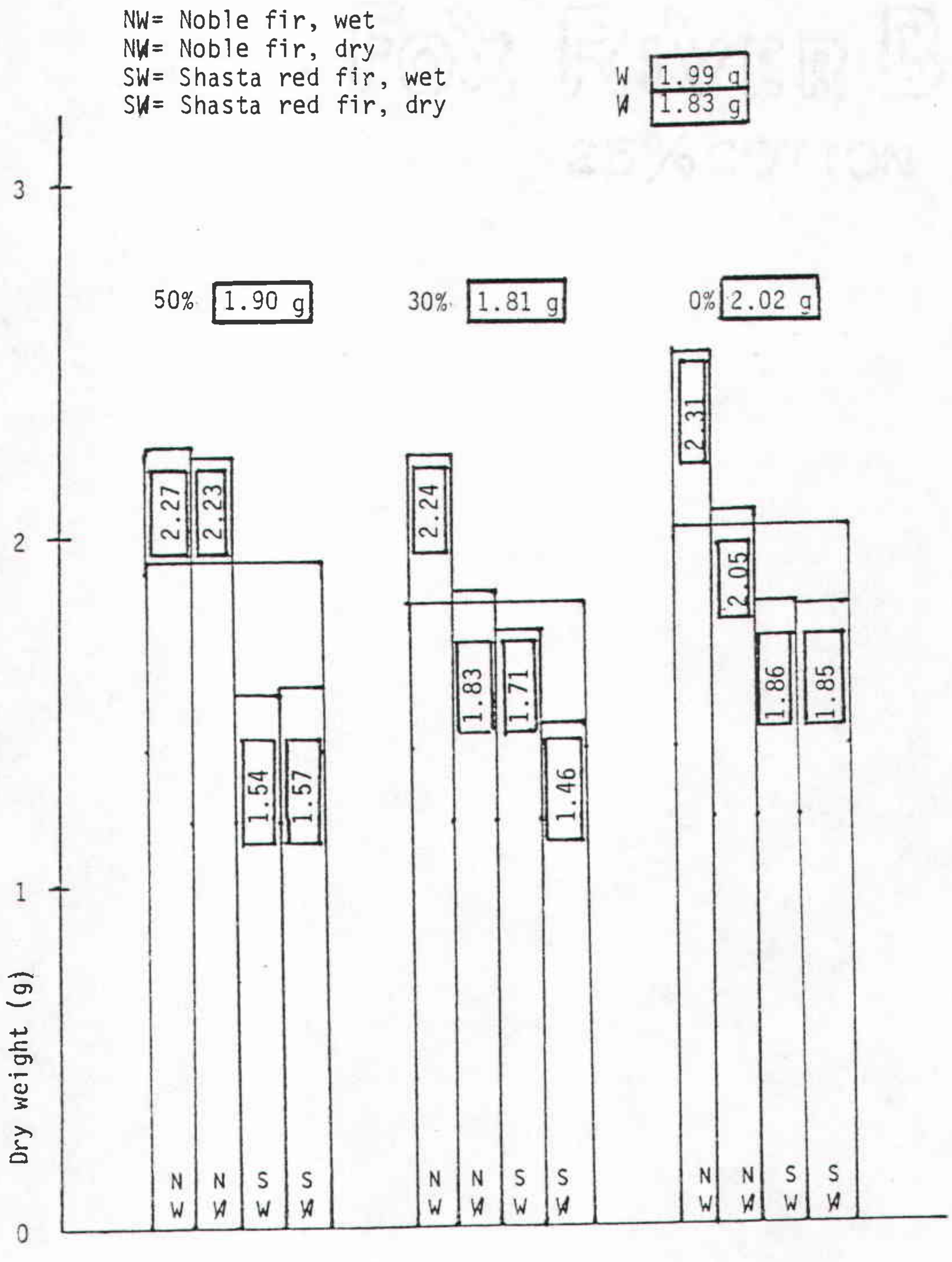

Figure 9. Seedling dry weight averages by species and treatment (numerical values shown in boxes).

Survival increased under both irrigation regimes from September through November (Table V).

TABLE V. PER CENT OF SEEDLINGS SURVIVING FREEZE TESTS BY TEST DATES AND IRRIGATION REGIME (SPECIES COMBINED).

Date	Lowest Temp. (^oC)	Normal Irrigation regime	One half Normal regime
September	-6	81.7%[a]	85.8%[a]
October	-12	92.5%[b]	91.7%[b]
November	-18	100.0%[c]	99.2%[c]
All dates combined	---	91.4%[d]	92.2%[d]

No statistically significant differences

<u>Foliar damage</u> was assessed in terms of five classes:

Class 1: fully green--no visible needle browning.
Class 2: less than one-third of the needles brown.
Class 3: between one-third and two-thirds of the needles brown.
Class 4: two-thirds or more of the needles brown but not fully brown.
Class 5: all needles brown.

Table VI gives the per cent of seedlings in each foliar damage class and identifies those with statistically significant differences. The September freeze test showed significantly more Class 1 seedlings from the 0% shade treatment than from the other shade treatments. This trend diminished rapidly through the October and November freeze tests to insignificant levels.

TABLE VI. FOLIAR DAMAGE BY SHADE TREATMENT (SPECIES COMBINED).

	Numerical Damage Class and Per Cent Shading														
Date	1			2			3			4			5		
	0%	30%	50%	0%	30%	50%	0%	30%	50%	0%	30%	50%	0%	30%	50%
September	40.0[a]	17.5[b]	22.5[b]	28.7[c]	33.7[c]	22.5[c]	15.0[d]	16.3[d]	22.5[d]	8.7[e]	3.8[e]	8.7[e]	8.8[f]	25.0[g]	25.0[g]
October	43.8[h]	35.0[h]	37.5[h]	20.0[i]	28.8[j]	28.7[j]	11.3[k]	21.2[k]	11.2[k]	18.8[l]	8.8[l]	12.5[l]	6.3[m]	6.3[m]	10.0[m]
November	31.3[n]	30.0[n]	36.3[n]	52.5[o]	66.3[o]	55.0[o]	8.8[p]	3.8[p]	7.5[p]	3.7[q]	0.0[q]	1.2[q]	1.3[r]	0.0[r]	0.0[r]
All Dates Combined	38.3[s]	27.5[s]	32.1[s]	33.7[t]	42.9[t]	35.4[t]	11.7[u]	13.8[u]	13.7[u]	10.4[v]	4.2[w]	7.9[w]	5.4[x]	10.4[y]	11.7[y]

a is significantly different from b at 90% level

f is significantly different from g at 90% level

i is significantly different from j at 90% level

v is significantly different from w at 99% level

x is significantly different from y at 90% level

Figures 10 and 11 are photographs of the seedlings following the September freeze test. The rack in Figure 10 contains most of the shaded seedlings and most of the foliar damage.

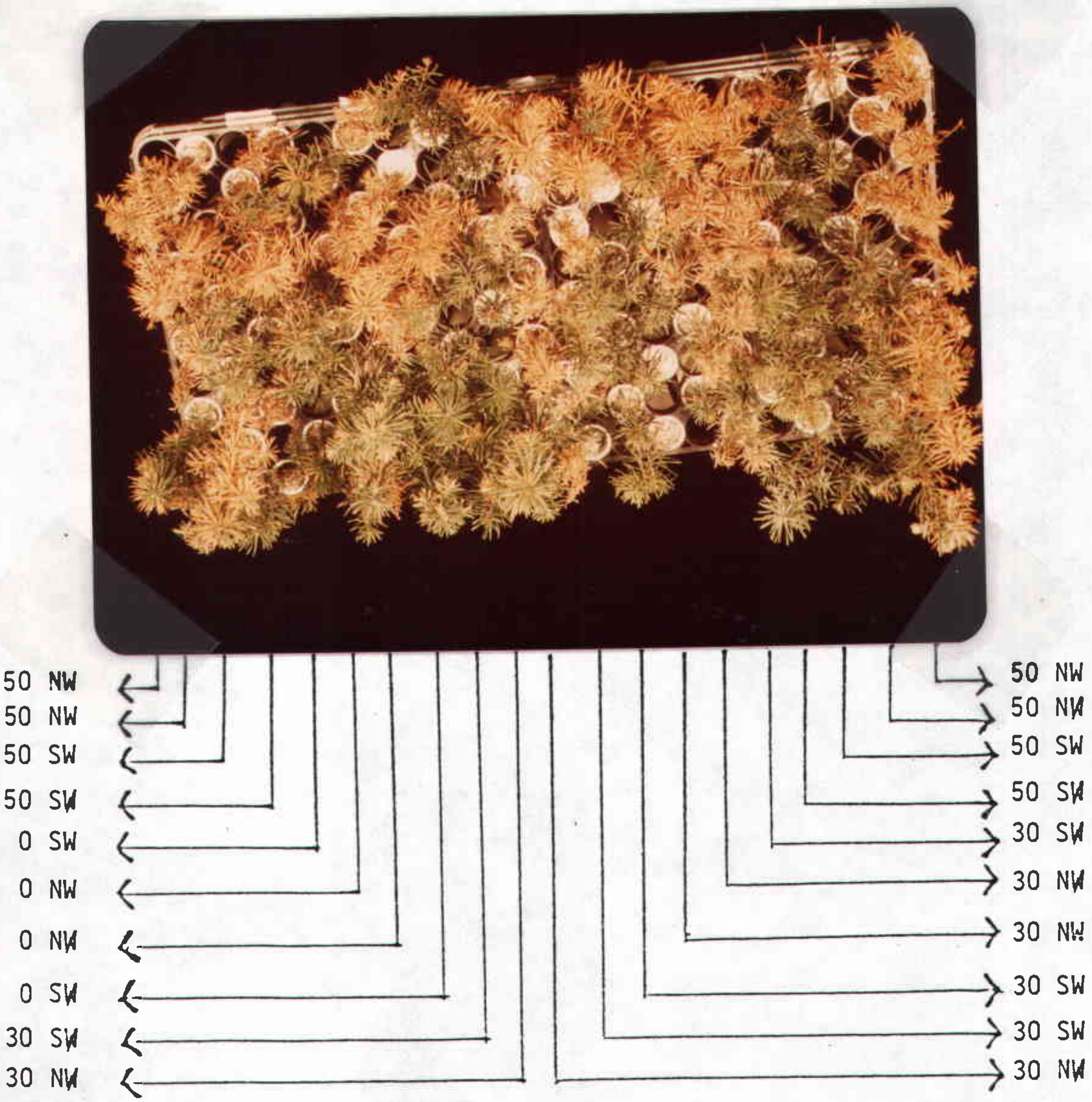

Figure 10. Foliar damage 4 weeks following September freeze test (Group A).

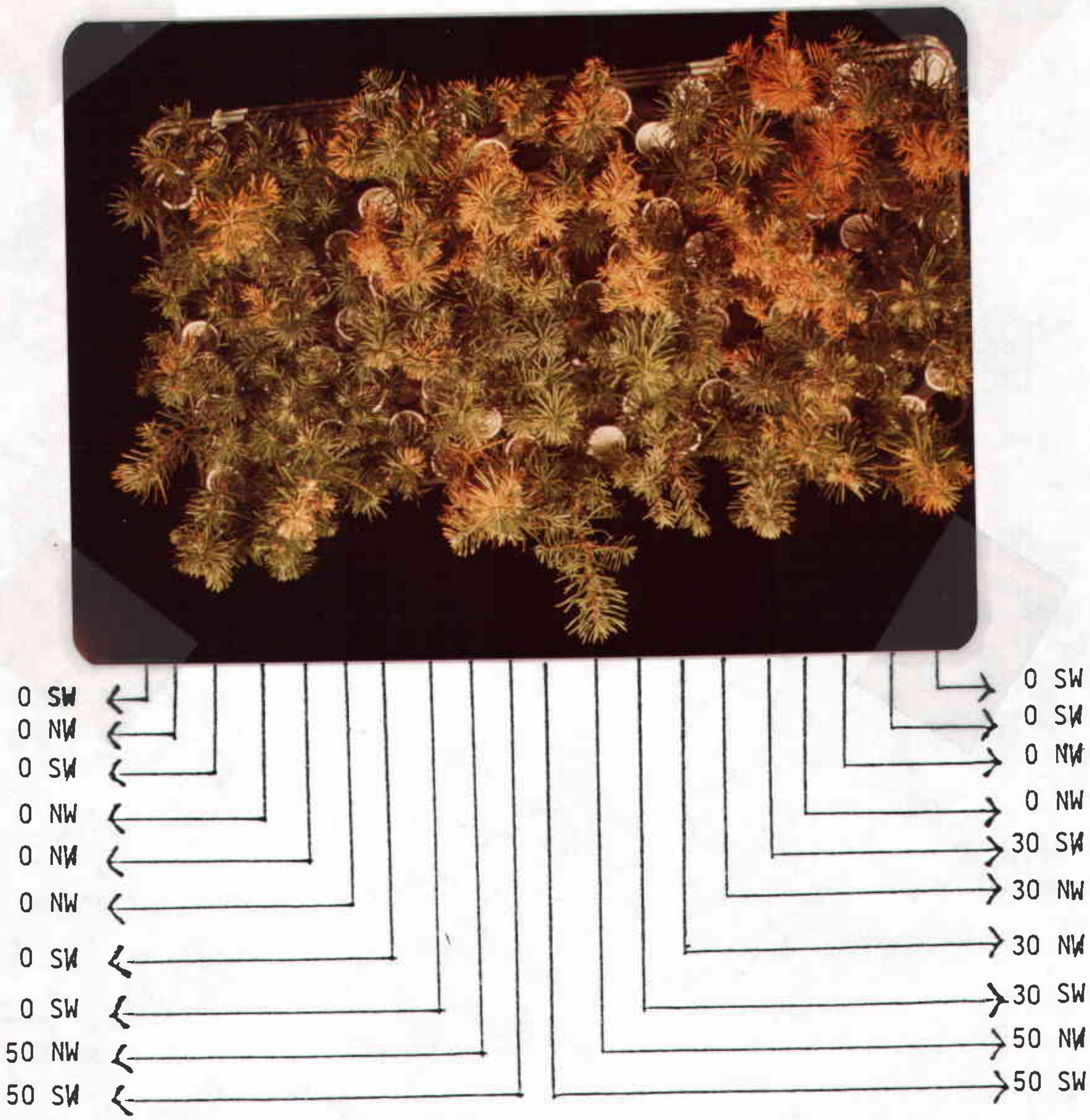

Figure 11. Foliar damage 4 weeks following september freeze test (Group B).

Irrigation regime showed no significant effect on foliar damage following the freeze tests.

Cambial damage was assessed in terms of five categories:

Class 1: 75-100% green, normal healthy tissue.
Class 2: 50-74% green.
Class 3: 25-49% green.
Class 4: 1-24% green.
Class 5: appears dead, no green in cambial tissue.

(Per cent is of circumference of the stem at 1 cm above ground line.)

Again, in respect to the significant differences in seedling survival in the September freeze test, cambial damage Class 5 shows significantly less seedlings from the 0% shade treatment than from the 30% and 50% shade treatments. This trend diminished to an insignificant level by the October and November freeze tests. Table VII summarizes cambial damage by classes and identifies those that showed significant differences by class, shade treatment, and freezing date. Irrigation regime had no significant effect on cambial damage following the freeze tests.

Terminal bud damage was assessed as either:

1. green, apparently living buds; or
2. brown, apparently dead buds.

Terminal bud freeze test results correlated well with the number of surviving seedlings, even though there were generally more dead terminal buds than there were dead seedlings. Table VIII summarizes the results of the terminal bud examination.

TABLE VII. CAMBIAL DAMAGE BY SHADE TREATMENT (SPECIES COMBINED).

Date	Numerical Damage Class and Per Cent Shading														
	1			2			3			4			5		
	0%	30%	50%	0%	30%	50%	0%	30%	50%	0%	30%	50%	0%	30%	50%
September	91.2^{a}	75.0^{a}	75.0^{a}	0.0^{b}	1.3^{b}	0.0^{b}	0.0^{c}	0.0^{c}	2.5^{c}	1.3^{d}	3.7^{d}	1.2^{d}	8.8^{e}	16.3^{f}	23.7^{f}
October	93.8^{g}	80.0^{h}	76.2^{h}	0.0^{i}	0.0^{i}	0.0^{i}	3.7^{j}	6.2^{j}	2.5^{j}	2.5^{k}	7.5^{l}	12.5^{l}	0.0^{m}	5.0^{m}	6.3^{m}
November	88.7^{n}	95.0^{o}	97.5^{o}	0.0^{p}	0.0^{p}	0.0^{p}	3.7^{q}	3.7^{q}	1.2^{q}	6.2^{r}	1.2^{s}	1.2^{s}	1.3^{t}	0.0^{t}	0.0^{t}
All Dates Combined	91.2^{u}	80.4^{v}	81.2^{v}	0.0^{w}	0.8^{w}	0.8^{w}	2.5^{x}	3.3^{x}	2.1^{x}	3.3^{y}	4.2^{y}	5.0^{y}	3.3^{z}	7.1^{aa}	10.0^{aa}

a is significantly different from b at 95% level

h is significantly different from i at 90% level

l is significantly different from m at 90% level

o is significantly different from p at 90% level

s is significantly different from t at 95% level

u is significantly different from v at 99% level

z is significantly different from aa at 95% level

TABLE VIII. PER CENT OF TERMINAL BUDS SURVIVING THE FREEZE TESTS BY DATE AND SHADE TREATMENT.

	Per Cent of Shade		
Date	0	30	50
September	92.5[a]	90.0[b]	82.5[c]
October	85.0[d]	73.8[e]	72.5[e]
November	97.5[f]	98.7[f]	98.7[f]
All dates combined	92.1[g]	87.5[h]	84.2[h]

a is significantly different from b at the 95% level
b is significantly different from c at the 90% level
d is significantly different from c at the 90% level
g is significantly different from h at the 99% level

Root Activity Following Freeze Tests

A concern of many researchers has been the ability of fall-planted seedlings to respond with new root growth quickly enough to become established before winter. Although not particularly related to cold hardiness, an attempt to quantify seedling root system response was made by counting the number of white root tips over 0.5 cm long. These, then were divided into four classes:

Class 1: Five or more white root tips.
Class 2: One to four white root tips.
Class 3: Roots appeared alive, but no white root tips.
Class 4: All roots dead.

Results indicate that no one imposed treatment was significantly better than any other at inducing more root growth following the freeze tests and 4-week growth chamber period. Indeed, as Table IX indicates, root growth capacity may be of some concern when dealing with fall-processed container-grown *Abies spp.* In this study, seedlings "lifted" in October showed the most potential to produce new roots.

TABLE IX. PER CENT OF SEEDLINGS IN EACH ROOT GROWTH CLASS BY DATE AND TREATMENT (SPECIES COMBINED).

		PER CENT SHADE			IRRIGATION REGIME	
		0%	30%	50%	W	W̸
	Class	- - - - - - - -	- - Per Cent	- - - - - - - -		
September	1	9 [a]	14 [b]	21 [c]	17	13
	2	45	39	37	42	39
	3	44	40	39	38	44
	4	2	7	3	3	4
October	1	6	6	7	7	6
	2	29	31	25	26	31
	3	45	45	43	45	43
	4	20	18	25	21	20
November	1	5	5	0	0	2
	2	56	54	50	55	52
	3	30	34	40	34	35
	4	9	7	10	11	13
All dates combined	1	5[d]	7[e]	10[f]	8	7
	2	43	41	38	41	41
	3	30	40	40	39	40
	4	22	12	12	12	12

a significantly different from b at 90% level.
b significantly different from c at 90% level.
d significantly different from e at 99% level.
e significantly different from f at 95% level.

Spring Survival Potential

The various treatments had no significant effects on the seedlings' responses to simulated spring growth conditions. Survival was 99% + for seedlings from all shade treatments, 100% for those from the moist treatment, and 98% for those from the dry treatment.

Per Cent Daily Average Rate of Development (DARD) was measured as described by Campbell (1974): DARDS = $\frac{100}{X}$

X = The number of days until budburst.

100 = Constant to convert to per cent.

For example, if it took 20 days from the time the seedling were placed in the growth chamber for a particular seedling to break bud, then $\frac{100}{20}$ = 5% = DARD. All three groups of shade treatmented seedlings averaged just under 5 DARD. The seedlings given the moist treatment averaged 4.9 DARD and the wet-treated seedlings averaged 5.0 DARD.

Height growth within species of seedlings following the spring survival potential test showed no statistically significant differences among treatments. Measurements of both new growth length and new growth dry weight were taken.

Root growth was measured by determining the dry weight of the fine roots[2] from the entire root system, which included first season growth. There were no significant differences among treatments within species.

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2 The tap roots and large lateral roots that function primarily for conduction of materials and support were not included.

Outplanting Tests

Survival was excellent in all cases with the fall-planted seedlings. The noble fir given 50% shade and the wet moisture treatment had 95% survival and the other 3 treatments outplanted (50% dry, 0% wet, 0% dry) had 100% survival when checked on May 11, 1978, the spring after planting. Most had either broken or swollen buds.

The Shasta red fir given the 50% shade wet moisture treatment had 80% survival, while the other three treatments outplanted (50% dry, 0% wet, and 0% dry) had 90% survival when checked (June 9, 1978). All Shasta red fir seedlings surviving had broken buds and were growing.

In general, the fall and winter of 1977/78 that followed the outplanting was slightly milder than normal with temperatures averaging one to two degrees Fahrenheit above the 30-year average for both areas. Winter precipitation was lower than normal by nearly one-half; however, early fall (prior to planting) precipitation averaged slightly above normal (8.5 inches for Fall 1977 vs 8.0 inches for 30-year average). (Climatalogical Data, Oregon 1977, 1978, and Summary, 1940-1970).

DISCUSSION

Results of this research indicate that full sunlight hastens fall cold hardiness in container-grown, high elevation Abies seedlings. This is supported by findings of other researchers on other species (van den Driessche, 1969 a and b and 1970 on Douglas-fir and McGuire and Flint, 1962 on white spurce, Scotch pine, red pine, Douglas-fir, and balsam fir). Cultural techniques at nursery facilities growing containerized, high elevation true firs for fall planting may be able to stimulate cold hardiness induction earlier in the season if seedlings are allowed access to full sunlight beginning in mid-to-late July, and thus increasing photosynthesis as compared with shaded seedlings. This would affect the first phase of cold hardiness induction when, as van den Driessche (1970) states, photosynthesis is essential. This is probably related to the findings of many researchers that during the initial states of cold hardiness induction, there is an increase in sugars within the plant (Kramer & Kozlowski, 1979).

The fact that this research was conducted outside the greenhouse may have had an unmeasured effect on both phases of hardening. Plant moisture stress (PMS) occuring in the afternoons may have been higher in the seedlings given no shade because they are under higher evapotranspiration stress. This effect will be discussed later. The cool night temperatures that are characteristic of the Beaver Creek area in late summer and early fall may have helped the unshaded seedlings to reach the level of cold hardiness found in the September freeze test by affecting the second phase of hardening. No record of outside air temperatures was kept, but it is suspected that one could well enhance the light intensity effect by giving seedlings exposure to cool night time temperatures.

Blake, et al. (1979) found moderate moisture stress (-5 to -10 bars) significantly improved cold hardiness of Douglas-fir seedlings. They found this stress effective if applied during the first phase of cold hardiness induction, before short days. Although there were no consistently significant differences in the moisture stress portion of this experiment, the means indicate that this stress enhanced the early levels of cold hardiness, especially for the unshaded seedlings, since, as mentioned earlier, daytime PMS was probably higher among these seedlings. Due to the limited number of seedlings available for this research, no destructive PMS readings were taken and therefore a quantitative measure of the stress level is not known. An indirect measure of moisture stress was attempted by weighing individual containers to measure water loss, but this proved too cumbersome and time consuming. It is felt that moisture stress levels reached by the dry treatment were not very severe (probably not as low as -5 bars), since the normal irrigation regime at the Beaver Creek Nursery provides abundant quantities of water; most likely only the unshaded seedlings approached -5 to -10 bars. Further investigation of the effect of controlled moisture stress on Abies seedlings seems appropriate.

The good results from the spring growth potential test and the outplanting trial indicate that imposed treatments did not harm the seedlings' potential for survival and growth after outplanting. It would be expected that seedlings given the full sunlight and mild moisture stress treatment to encourage early cold hardiness would experience no detrimental effects on growth from the treatment after outplanting.

Root growth did not appear to be affected by any of the treatments. It should be noted, however, that root growth reached a peak following the October freeze test and 4-week growth chamber period. Possible explanations for this include the likelihood that container-grown Abies seedlings reach a peak in their root growth potential in October or November. This would be quite helpful to fall planting programs. Another explanation may be the fact that the freezing temperatures were consecutively lower (-6^{o}, -12^{o}, and -18^{o}C) for the three freeze tests; thus the root systems may have been affected differently, giving different responses to both different freezing temperatures and different lifting time periods. Work done by Stone and Norberg (1979) indicates there may be a potential for the roots of container-grown Ponderosa pine seedlings to grow in the fall. Further study of this root growth potential may be of interest.

Lack of significant differences in height growth among seedlings of all imposed treatments, combined with increased diameter growth of the seedlings given only the full sunlight treatment indicate that one would not expect to sacrifice seedling size in order to obtain earlier cold hardiness of high elevation true firs. In fact, larger diameter seedlings should result. The larger diameter is possibly the result of more photosynthesis afforded unshaded seedlings during late summer/early fall, when seedlings tend to grow in diameter. Lack of significant differences in height growth may be the result of the later date in which the treatments were imposed, since by mid-July a large portion of the seedlings' height growth had been completed.

Other observations are:

1. Seedlings given full sunlight and open-air experienced less foliar and stem damage by *Botrytis cinerea* than did shaded seedlings. This is probably due to the faster drying effect of full sunlight and open, circulating air currents. This would be an advantage to any container nursery cultural program.

2. There has been much discussion in the past as to whether or not high elevation seedlings can be hardened adequately at low elevation nurseries. Results of this research show hardiness to $-18^{o}C$ by late November regardless of treatment. At this time ambiant night time air temperatures at Beaver Creek were not much lower than freezing. This indicates high elevation seedlings are quite capable of hardening well beyond the temperature exposure they received at this low elevation nursery.

3. Bud-set occurred earlier in unshaded seedlings. This was probably due to increased daytime evapotranspirational stress on the seedlings.

SUMMARY

In summarizing, with respect to the null hypotheses:

1. Full sunlight treatment resulted in higher cold resistance in seedlings of both species lifted and freeze-tested in September. These differences diminished to insignificant levels by the final freeze test in November.
2. There was no observed effect on either seedling species root growth by the treatments.
3. Within species, there were no significant differences in seedling height growth among the treatments; however, the full sunlight treatment significantly enhanced seedling diameter growth of both species.

RECOMMENDATIONS FOR NURSERY MANAGEMENT

Many benefits to *Abies* seedlings destined for fall planting could be gained with a minimum amount of effort at container nursery facilities. This effort would be to move *Abies* seedlings from enclosed structures (greenhouses, growth rooms, or shadehouses) by mid-to-late July to open areas such as parking losts or shadehouses with the covering removed. In general, nursery practice has been not to remove the covering at all, or wait until late fall before removing it.

The benefits derived from such a program would include:

1. Seedlings reach a dormant, frost hardy state earlier in the season, decreasing damage and loss in the field from early fall frost. Since they would set bud earlier, they would be more able to withstand the shock of fall lifting, packing, shipping, and outplanting than seedlings not given this treatment.
2. The treatment should help to increase seedling diameter and thus increase seedling quality.
3. *Botrytis cinerea* problems caused by water lingering on foliage inside greenhouses may also decrease.

It seems there is much to be gained with a small amount of effort.

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APPENDIX

ANALYSIS OF VARIANCE FOR NUMBER OF DEAD SEEDLINGS - SEPTEMBER FREEZE TEST

SOURCE	SS	DF	MS	F	P LESS THAN
Error 1	4.125	6	.688		
Replications	11.562	3	3.854	5.606	.036
Shade - 0% vs. 30% and 50%	4.594	1	4.594	6.682	.041
Shade - 30% vs. 50%	.281	1	.281	.409	.546
Error 2	18.562	27	.687		
Irrigation - Normal vs. ½ Normal	.521	1	.521	.758	.392
Species - Shasta Red Fir vs. Noble Fir	22.687	1	22.687	33.000	.001
Interaction - Moisture, Species	.187	1	.187	.273	.606
Interaction - Shade (0 vs. 30, 50), Moisture	.010	1	.010	.015	.903
Interaction - Shade (30 vs. 50), Moisture	2.531	1	2.531	3.682	.066
Interaction - Shade (0 vs. 30, 50), Species	2.344	1	2.344	3.409	.076
Interaction - Shade (30 vs. 50), Species	.281	1	.281	.409	.528
Interaction - Shade (0 vs. 30, 50), Moisture, Species	.094	1	.094	.136	.715
Interaction - Shade (30 vs. 50), Moisture, Species	1.531	1	1.531	2.227	.147

ANALYSIS OF VARIANCE FOR NUMBER OF DEAD SEEDLINGS - OCTOBER FREEZE TEST

SOURCE	SS	DF	MS	F	P LESS THAN
Error 1	1.542	6	.257		
Replications	5.996	3	1.965	7.649	.018
Shade - 0% vs. 30% and 50%	.167	1	.167	.649	.451
Shade - 30% vs. 50%	1.125	1	1.125	4.378	.081
Error 2	23.312	27	.863		
Irrigation - Normal vs ½ Normal	.021	1	.021	.024	.878
Species - Shasta Red Fir vs. Noble Fir	4.687	1	4.687	5.429	.028
Interaction - Moisture, Species	.521	1	.521	.603	.444
Interaction - Shade (0 vs. 30, 50), Moisture	1.042	1	1.042	1.206	.282
Interaction - Shade (30 vs. 50), Moisture	.500	1	.500	.579	.453
Interaction - Shade (0 vs. 30, 50), Species	.375	1	.375	.434	.515
Interaction - Shade (30 vs. 50), Species	.500	1	.500	.579	.453
Interaction - Shade (0 vs. 30, 50) Moisture, Species	.667	1	.667	.772	.387
Interaction - Shade (30 vs. 50), Moisture, Species	1.125	1	1.125	1.303	.264

ANALYSIS OF VARIANCE FOR NUMBER OF DEAD SEEDLINGS - NOVEMBER FREEZE TEST

SOURCE	SS	DF	MS	F	P LESS THAN
Error 1	.125	6	.021		
Replications	.062	3	.021	1.000	.455
Shade - 0% vs. 30% and 50%	.042	1	.042	2.000	.207
Shade - 30% vs. 50%	.000	1	.000	.000	1.000
Error 2	.562	27	.021		
Irrigation - Normal vs. ½ Normal	.021	1	.021	1.000	.326
Species - Shasta Red Fir vs. Noble Fir	.021	1	.021	1.000	.326
Interaction - Moisture, Species	.021	1	.021	1.000	.326
Interaction - Shade (0 vs. 30, 50) Moisture	.042	1	.042	2.000	.169
Interaction - Shade (30 vs. 50), Moisture	.000	1	.000	.000	1.000
Interaction - Shade (0 vs. 30, 50), Species	.042	1	.042	2.000	.169
Interaction - Shade (30 vs. 50), Species	.000	1	.000	.000	1.000
Interaction - Shade (0 vs. 30, 50), Moisture, Species	.042	1	.042	2.000	.169
Interaction - Shade (30 vs. 50), Moisture, Species	.000	1	.000	.000	1.000

ANALYSIS OF VARIANCE FOR NUMBER OF DEAD SEEDLINGS-- ALL FREEZE TEST DATES COMBINED

SOURCE	SS	DF	MS	F	P LESS THAN
Error 1	1.875	6	.312		
Replications	3.687	3	1.229	3.933	.072
Shade - 0% vs. 30% and 50%	1.837	1	1.837	5.878	.052
Shade - 30% vs. 50%	.844	1	.844	2.700	.151
Error 2	8.854	27	.328		
Irrigation - Normal vs. ½ Normal	.162	1	.062	.191	.666
Species - Shasta Red Fir vs. Noble Fir	15.348	1	15.348	46.779	.881
Interaction - Moisture, Species	.087	1	.087	.021	.885
Interaction - Shade (0 vs. 30, 50) Moisture	.291	1	.291	.858	.363
Interaction - Shade (30 vs. 50), Moisture	.268	1	.268	.394	.381
Interaction - Shade (0 vs. 30, 50), Species	1.837	1	1.837	5.631	.025
Interaction - Shade (30 vs. 50), Species	.012	1	.012	.032	.868
Interaction - Shade (0 vs. 30, 50), Moisture, Species	.587	1	.587	1.789	.192
Interaction - Shade (30 vs. 50), Moisture, Species	.010	1	.010	.032	.860

ANALYSIS OF VARIANCE FOR SEEDLING DIAMETER - ALL FREEZE TEST DATES COMBINED

SOURCE	SS	DF	MS	F	P LESS THAN
Error 1	.455	6	.074		
Replications	.639	3	.813	.173	.911
Shade - 0% vs. 30% and 50%	.674	1	.674	9.081	.024
Shade - 30% vs. 50%	.161	1	.161	2.168	.191
Error 2	1.351	27	.050		
Irrigation - Normal vs. ½Normal	.527	1	.527	1.529	.083
Species - Shasta Red Fir vs. Noble Fir	.464	1	.464	9.264	.095
Interaction - Moisture, Species	.608	1	.000	.000	.985
Interaction - Shade (0 vs. 30, 50), Moisture	.003	1	.003	.065	.820
Interaction - Shade (30 vs. 50), Moisture	.604	1	.008	.000	.996
Interaction - Shade (0 vs. 30, 50), Species	.085	1	.085	.098	.756
Interaction - Shade (30 vs. 50), Species	.006	1	.006	.111	.742
Interaction - Shade (0 vs. 30, 50), Moisture, Species	.118	1	.118	2.359	.136
Interaction - Shade (30 vs. 50), Moisture, Species	.000	1	.000	.006	.939

ANALYSIS OF VARIANCE FOR SEEDLING HEIGHT - ALL FREEZE TEST DATES COMBINED

SOURCE	SS	DF	MS	F	P LESS THAN
Error 1	24.043	6	4.007		
Replications	7.001	3	2.334	.582	.648
Shade - 0% vs. 30% and 50%	.147	1	.147	.037	.855
Shade - 30% vs. 50%	.718	1	.718	.179	.687
Error 2	154.708	27	5.730		
Irrigation - Normal vs. ½ Normal	5.720	1	5.720	.998	.327
Species - Shasta Red Fir vs. Noble Fir	277.500	1	277.500	48.430	.001
Interaction - Moisture, Species	5.962	1	5.962	1.040	.317
Interaction - Shade (0 vs. 30, 50), Moisture	4.181	1	4.181	.730	.401
Interaction - Shade (30 vs. 50), Moisture	11.138	1	11.138	1.944	.175
Interaction - Shade (0 vs. 30, 50), Species	.010	1	.010	.002	.967
Interaction - Shade (30 vs. 50), Species	2.190	1	2.190	.382	.542
Interaction - Shade (0 vs. 30, 50), Moisture, Species	.900	1	.900	.157	.695
Interaction - Shade (30 vs. 50), Moisture, Species	.980	1	.980	.171	.682