Morphological Development of Field-Planted Western Hemlock Seedlings from Various Dormancy Induction Treatments[1]

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Abstract.—Western hemlock seedlings from four dormancy induction treatments (i.e. long-day dry, bng-day wet, short-day dry, short-day wet) were planted on a coastal reforestation site in British Columbia and monitored for morphological development over two growing seasons. Short-day wet treated seedlings had the greatest incremental height growth and lowest stem units cm over two growing seasons. Short-day treated seedlings had the least needle damage after two years in the field. Seedlings from all treatments had good root development and this was reflected in high survival (i.e. approx. 90%) after two field seasons.

INTRODUCTION

Performance of seedlings planted on a reforestation site is dependent on seedling quality and site environmental conditions (Timmis 1980, Burden 1983 & 1990, Sutton 1988, Puttonen 1989). To quantify the degree of improvement from any particular stocktype requires an assessment of seedling performance both before and after field planting.

Western hemlock (Tsuga heterophylla (Raf.) Sarg.) seedlings were grown under a series of dormancy induction treatments (DIT) and tested with a stock quality assessment procedure that measured seedlings material and performance attributes (Grossnickle et al. 1988, 1990a). Material attributes measured were morphology, pressure-volume analysis and soluble sugars. Performance attributes measured were root growth capacity at high and low root temperature, seedling water movement at high and low root temperature, low root temperature response, drought stress response and frost hardiness. Seedlings from all DIT were in good physiological and morphological condition when tested under optimum environmental conditions, while short-day DIT, particularly short-day wet, showed the best establishment potential under less than ideal environmental conditions (e.g. low soil temperature and drought) (Grossnickle et al. 1988, 1990a).

In the second phase of the research program, partially reported in this paper, seedlings from these DIT were planted on a reforestation site in coastal British Columbia and morphological development monitored over two growing seasons.

MATERIALS AND METHODS

Plant Material

Western hemlock (Tsuga heterophylla (Raf.) Sarg.) seedlings were grown from seed at the Pacific Forestry Centre, Victoria, British Columbia, Canada (Lat. 48° 28" N) in BC/CFS 313A styroblocks. Nursery cultural program is described in Grossnickle et al. (1990a). On July 20, 1987, when seedling population mean shoot height was 15.8 cm, one fourth of the seedling population was treated with one of the following dormancy induction treatments (DIT):

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1) Long-day wet (LDW); seedlings continued to grow under long (16h) photoperiod to prevent bud set and normal watering and fertilization regime.

2) Long-day dry (LDD); seedlings continued to receive an extended photoperiod, but a moisture stress treatment was initiated.

3) Short-day dry (SDD); seedlings had a moisture stress treatment initiated and photoperiod was reduced to 8 hours on August 1, 1987.

4) Short-day wet (SDW); seedlings continued to receive normal watering and fertilization regime, but had the photoperiod reduced to 8 hours on August 1, 1987.

All dormancy induction treatments were concluded on August 29, 1987 after which time fall watering, fertilization, daylength and temperature regimes were implemented. Full details are described in Grossnickle et al. (1990a). Seedlings were placed in cold storage (2°C) on January 11, 1988 and held until field planting on February 24-28, 1988.

During January and February 1988 seedlings were tested with the above mentioned stock quality assessment procedure (Grossnickle et al. 1988, 1990a).

Field Site Conditions

The test site was located at Cowichan Lake on southern Vancouver Island, British Columbia, Canada (Lat. 48° 49' N, Long. 124° 10'W). The site was logged of second growth Douglas-fir (Pseudotsugsa menziesii (Mirb.) Franco) in 1986 with no subsequent site preparation. Elevation is 165 m above sea level. Land is undulating well-drained, gravely, sandy-loam (coarse fragments 30-50-20%), Duric Humo-Ferric Podzol of the Quimper soil association (Jungen 1985). Biogeodlimatic zone is Coastal Western Hemlock and the variant is Vancouver Island Dry Maritime CWHal (Klinka et al. 1984). Vegetative competition was characterized in late June 1988 on sixteen randomly selected 1 x .5 m plots. Mean vegetation cover was 63% and ranged from 95 to 33% with an average maximum vegetation canopy height of 30 cm with a range of 50 to 10 cm. Species composition is described in Grossnickle et al. (1990b).

Seedlings were planted during late February, 1988 in a randomized block (3) design. Seedlings from each DIT (4) were represented in 10 randomly selected rows for a total of 40 rows per block with 30 seedlings planted per row in a 1 m x 1 m .spacing. A total of 900 seedlings from each DIT were planted.

Morphological Assessment

In each row, selected seedlings (i.e. 1, 5, 10, 15, 20, 25, 30) were reserved for survival and permanent growth measurements. Three randomly selected seedlings in each row were planted in buried cylindrical (25 cm diameter, 30 cm length) porous felt bags. This facilitated removal of twenty seedlings from each DIT at 8 and 20 months (i.e. November 1988 and 1989, respectively) after planting to determine root and shoot development. Further discussion of the root analysis technique can be found in Grossnickle and Reid (1983). Seedling morphological parameters assessed on seedlings excavated at 8 and 20 months were: 1) shoot height, 2) root collar diameter, 3) shoot dry weight, 4) needle damage index, 5) stem units cm^{-1} of new main shoot growth, 6) root dry weight in container plug, 7) root dry weight in soil, 8) total root dry weight, 9) number of new roots, 10) total length of new roots, 11) total shoot to total root ratio (dry wt.) and 12) seedling water balance ratio (shoot dry weight/ [diameter x total root dry weight]). Needle damage index quantified the visual assessment of percent needles where: 1=100%, 2=90-99%, 3=75-89%, 4=50-74%, 5=25-49% and 6=1-24% green needles. Stem unit measurements were taken from the middle of the main shoot tip of new growth. A stem unit is defined as an internode, together with the node and nodal appendages at its distal extremity (Doak 1935). Growth data were subjected to analysis of variance and a mean separation test (p=0.05) (Steel and Tome 1980). Statistical analysis was not conducted on field incremental diameter data because nursery data were used to determine initial field diameters.

RESULTS AND DISCUSSION

Nursery Development

Long-day wet seedlings had the biggest overall shoot system with a greater height and shoot dry weight than any other DIT (Table 1). Both LDW and SDW had a greater root collar diameter than water stressed DIT. Similar studies with western hemlock have also shown greater height growth in LDW treated seedlings and greater diameter growth in non water stressed treatments (Arnott et al. 1988, O'Reilly et al. 1989).

Root dry weight was greater in non water stressed DIT (Table 1). Reduction in root development in water stressed DIT are comparable to a similar study with western hemlock (Arnott et al. 1988). Studies have shown root dry weight to decline with seedling moisture stress (Leshman 1970, Day and MacGilvray 1975, Larson 1980). Root growth in western hemlock is

Table 1.- Morphological development of western hemlock seedlings from different dormancy induction treatments just before planting and at the end of first and second growing season on a reforestation site.

	SHOOT					ROOT			SHOOT/ROOT RATIOS	
Dormancy Induction Treatment	Height (cm)	Root Collar Diameter cm	Dry Weight (g)	Needle Damage Index[1]	Stem Units (cm^{-1})	Container Plug Dry Wt. (g)	In Soil Dry Wt. (g)	Total Dry Wt. (g)	Total Shoot / Root (by Wt.)	Seedling Water Balance[2]
					FEBRUARY 1988 (Before Planting)					
LDD[3]	27.18±.61b[4]	.27±.01b	1.27±.07bc	1.00[5]	-	.35±.02c	-	.35±.02c	-	14.68±.86b
LDW	31.52±.96a	.32±.01a	1.96±.10a	1.00	-	.49±.04ab	-	.49±.04ab	-	13.65b
SDD	22.18±.57c	.28±.01b	1.00±.03c	1.00	-	.40±.03bc	-	.40±.03bc	-	10.19±.76a
SDW	23.04±.52c	.31±.01a	1.28±.08b	1.00	-	.53±.04a	-	.53±.04a	-	8.69±.55a
					NOVEMBER 1988					
LDD	36.49±1.12a	.433±.016a	3.28±.15ab	3.06±.26ab	12.76±.42bc	1.19±.10a	.673±.082a	1.87±.16a	1.91±.12b	4.59±.42a
LDW	35.07±1.60a	.443±.014a	3.47±.26a	3.44±.18b	13.50±.58c	1.28±.12a	.806±.093a	2.08±.17a	1.73±.10ab	3.97±.25a
SDD	30.71±1.39b	.429±.015a	2.82±.20ab	2.50±.23a	11.68±.50b	1.08±.11a	.813±.108a	1.89±.21a	1.60±.10ab	3.87±.35a
SDW	30.72±1.46b	.425±.017	2.75±.21b	2.89±.21a	8.86±.52a	1.06±.08a	.798±.108a	1.86±.18a	1.57±.11a	3.80±.30a
					NOVEMBER 1989					
LDD	46.14±2.72a	.58±.03a	7.90±1.03a	3.85±.22c	6.15±.53b	1.57±.18b	1.55±.32a	3.12±.48a	2.75±.16b	5.24±.58b
LDW	47.00±2.82a	.60±.03a	7.98±1.00a	3.35±.17c	5.90±.69b	1.95±.21ab	1.46±.30a	3.41±.48a	2.56±.19b	4.54±.49ab
SDD	41.56±2.41a	.61±.03a	7.98±1.12a	2.80±.19b	6.60±.73b	2.62±.40a	1.81±.36a	4.46±.74a	2.01±.18a	3.54±.45a
SDW	46.38±1.86a	.60±.02a	8.65±.89a	1.85±.17a	3.75±.31a	2.06±.25ab	1.63±.29a	3.70±.53a	2.62±.18b	4.52±.38ab

(1) Needle damage index was categorized as: 1=100%, 2=90-99%, 3=75-89%, 4=50-74%, 5=25-49%, and 6=1-24% green needles.

(2) Seedling water balance ratio is: shoot dry weight/(diameter x total root dry weight).

(3) LDD=Long-day dry
LDW = Long-day wet
SDD = Short-day dry
SDW = Short-day wet

(4) Mean and standard error. A difference in the letter for a morphological variable within each harvest date indicates a significant difference between dormancy induction treatment at p = 0.05 as determined by ANOVA and Wailer-Duncan mean separation test.

(5) No statistic analysis due so lack of variation in one or more treatment(s).

seasonal with high root growth normally occurring during early summer (Zaerr and Brown 1976). Water stress DIT, applied during early to mid summer, resulted in reduced root growth.

Short-day DiT had a lower shoot to root ratio and a better (i.e. lower) seedling water balance ratio than long-day DIT (Table 1). In newly planted seedlings, low shoot to root and seedling water balance ratios are important to ensure survival by avoiding the development of high water deficits caused when absorption lags behind transpiration (Kramer and Kozlowski 1979, Thompson *1985).*

First Year Development on the Reforestation Site

Long-day DIT seedlings had the largest shoot height and dry weight, while root collar diameter was similar between all DIT (Table 1). O92Reilly (personal communication) found western hemlock long-day, compared to short-day, DIT seedlings hail larger diameter growth after one field growing, season. Stem units cm^{-1} was lowest to highest in SDW, SDD, LDD and LDW. Lower stem units cm indicates greater cell elongation (O'Reilly et al. 1989) and is probably attributable to reduced stress during growth. Short-day DIT seedlings had lower needle damage index than long-day DIT. Short-day DIT seedlings, and especially SDW, had the greatest seasonal incremental height growth and LDD seedlings the greatest seasonal incremental root collar diameter growth (Fig. 1). Short-day DIT seedlings appear better able to withstand stressful reforestation site environmental conditions. Seedling quality assessment results indicated short-day, compared to long-day, DIT seedlings had a better cold and drought stress performance potential (Grossnickle et al. 1988, 1990a) and had better photosynthetic and stomatal conductance capability during summer environmental conditions on the reforestation site (Grossnickle and Arnott 1990).

Root development was similar between all DIT (Fig. 2, Table 1). Short-day, compared to long-day, DIT seedlings had a better shoot to root ratio, while all treatments had a similar seedling water balance ratio. Seedlings from all treatments were well established on the reforestation site after one growing season (Fig. 3). This contrasts work with 1+0 western hemlock seedlings planted on a dry south facing clear-cut where a greater shoot to root imbalance occurred after one growing season (Livingston and Black 1988).

Seedling survival at the end of the first growing season was between 95 and 97% for all DIT (Fig. 4). This survival is higher than previously reported for western hemlock seedlings from similar DIT grown for one field season (O'Reilly, personal communication). Non stressful environmental conditions during the first half of the growing season (i.e. moderate mean temperatures) and high monthly precipitation) allowed seedlings from all DIT to grow roots and become well established.

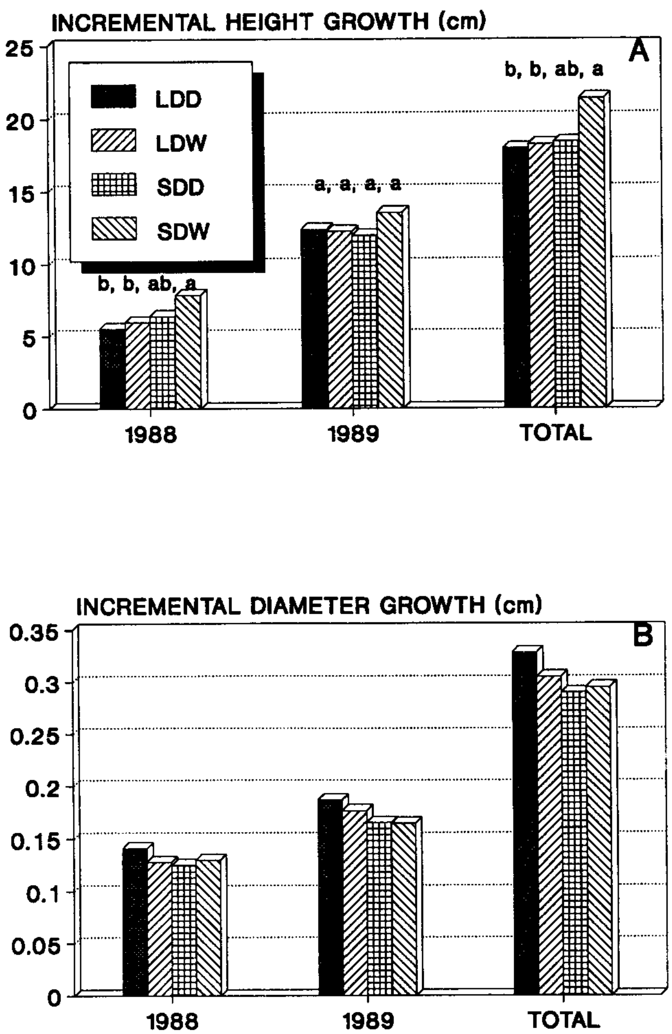

Figure 1-- Incremental height (A) and diameter (B) growth over two growing seasons (1988 & 1989) for western hemlock seedlings from dormancy induction treatments: 1) long-day dry (LDD), 2) long-day wet (LDW), 3) short-day dry (SDD) and 4) short-day wet (SDW). Means covered by the same letter are not significantly different at the *5%* level.

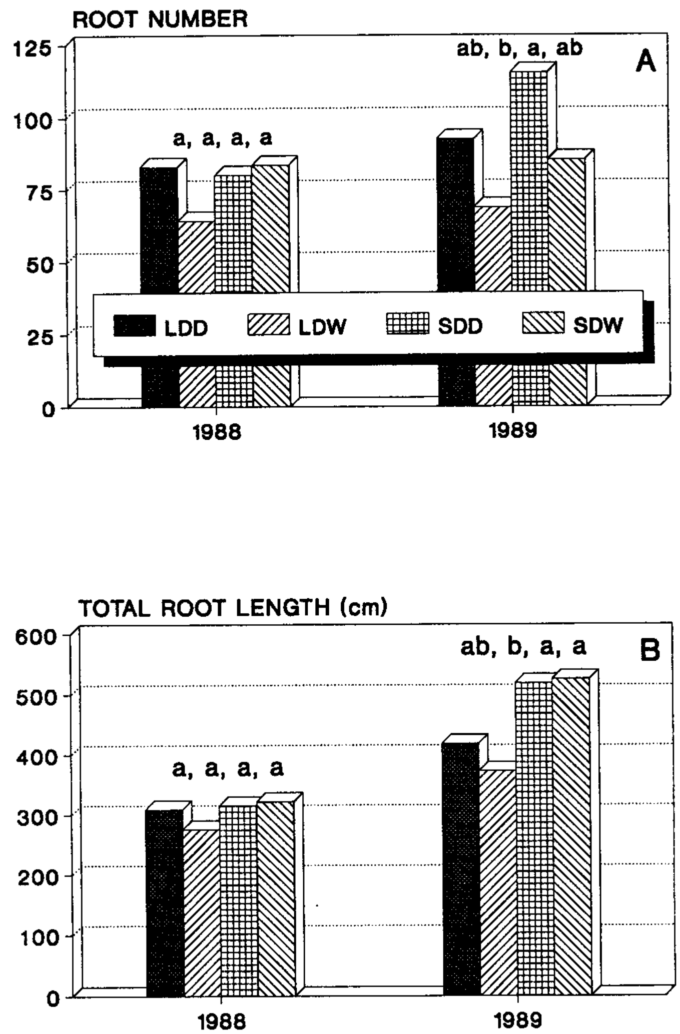

Figure 2.-- Number of roots (A) and total root length (B) development outside the container plug over two growing seasons (1988 & 1989) for western hemlock seedlings from dormancy induction treatments: 1) long-day dry (LDD), 2)long-day wet (LDW), 3) short-day dry (SDD) and short- day wet (SDW). Means covered by the same letter are not significantly different at the 5% level.

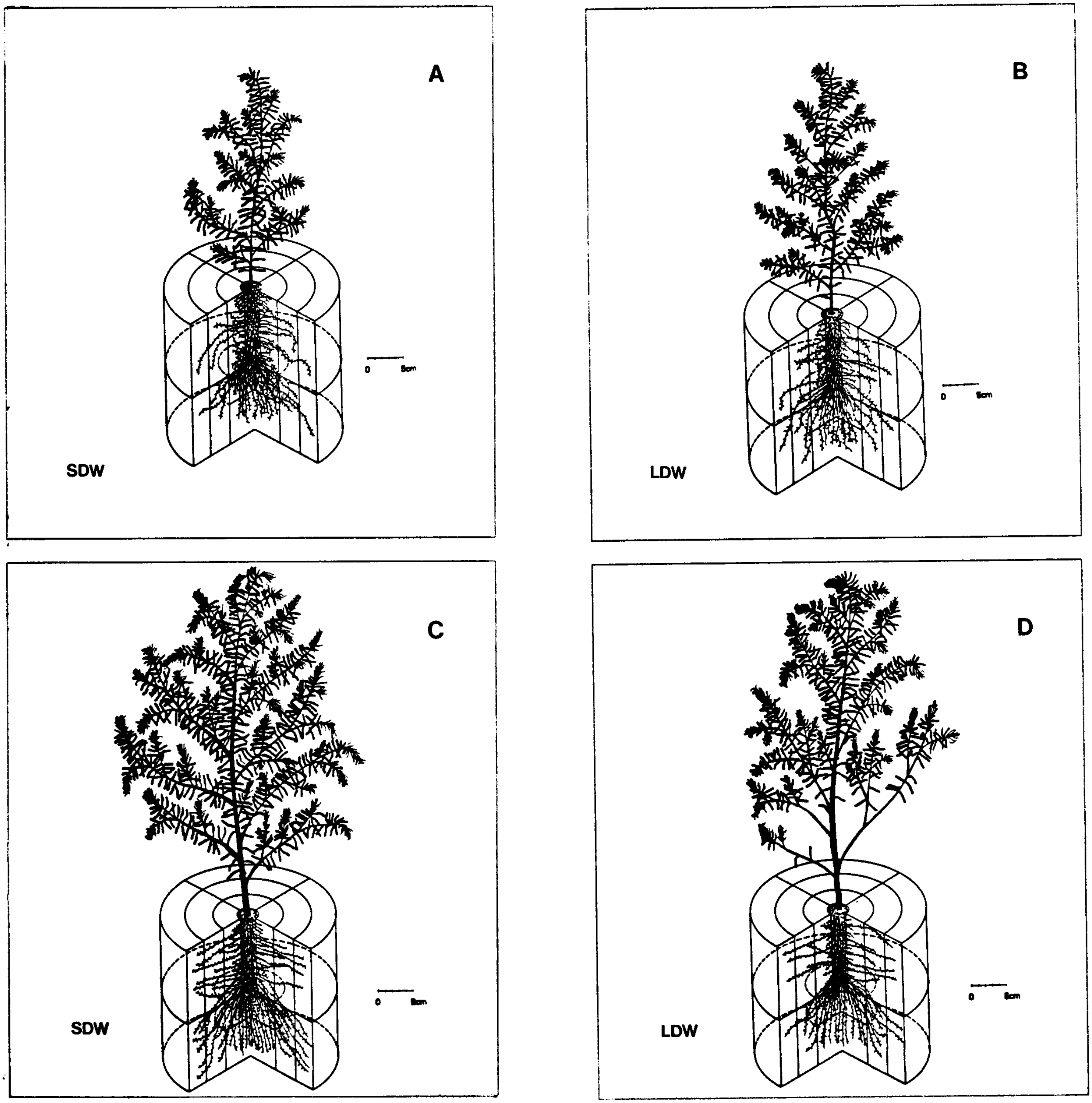

Figure 3.— Diagrammatic representation of western hemlock seedling shoot and root development (n=20) form short-day wet (SDW) and long- day wet (LDW) dormancy induction treatments at eight (A and B) and twenty (C and D) months after planting on a reforestation site

(Table 1 & Fig. 3). Thus, when drought or high evaporative demand occurred during the summer, seedlings did not experience severe levels of water stress (Grossnickle et al. 1990b, Grossnickle and Arnott 1990) because adequate root development provided the capability to extract water from a large soil volume. Previous western hemlock reforestation trials have found seedling mortality to be high when root development is restricted (Arnott 1975, Livingston and Black 1988).

Second Year Development on the Reforestation Site

Shoot height, root collar diameter and dry weight were similar between all DIT (Table 1). Short-day wet seedlings had the lowest number of stem units cm^{-1}, plus the greatest incremental height growth in 1989 and total over two growing seasons (Fig. 1). Seedlings from all DIT at least doubled their incremental shoot height growth during the second growing season. Once established in the field, western hemlock seedlings have the capability to grow very rapidly (Arnott 1975, 1976, Arnott and Burdett 1988). Incremental diameter growth was similar between DIT. SDW seedlings had the lowest needle damage index of all DIT (Table 1) and SDW, compared to LDW, seedlings showed better shoot form and less needle drop (Fig. 3). Stock quality assessment procedures predicted SDW seedlings to have the best field performance potential to adverse environmental conditions (Grossnickle et al. 1988, 1990a), and two years later in the field their shoot systems still seem to be in the best overall morphological condition.

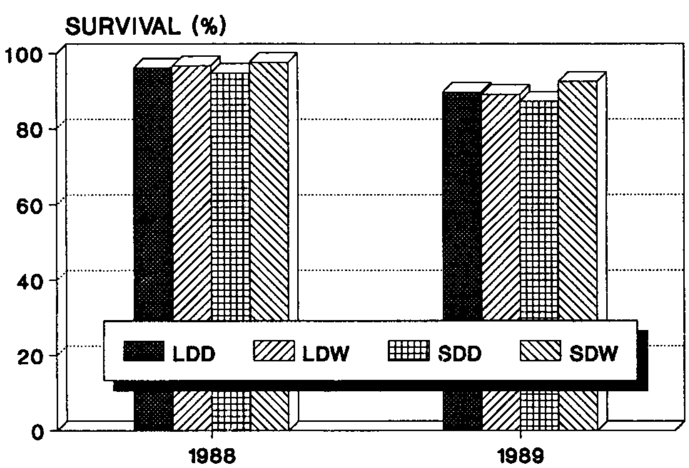

Figure 4.-- Percent survival after the first (1988) and second (1989) growing seasons for western hemlock seedlings from dormancy induction treatments: 1) long-day dry (LDD), 2) long-day wet (LDW), 3) short-day dry (SDD) and 4)short-day wet (SDW).

Root dry weight measurements were similar between all DIT (Table 1). Seedlings from all DIT showed root development characteristic of an established styro-plug western hemlock seedling (Arnott 1976, 1978) with large masses of fibrous roots symmetrically distributed around the original root plug and no indication of a taproot (Fig. 3). Long (1978) found that less than 20% of planted western hemlock seedlings had well developed taproots. Long-day wet, compared to other DIT, seedlings had the least number of roots and total root length for roots developed outside the container plug (Fig. 2) and this is shown diagrammatically in figure 3. Seedlings in all DIT had more roots extend from the bottom third of the plug than from upper zones and this is comparable to previous work with styro-plug western hemlock seedlings (Long 1978, Carlson and Shaw 1981).

SDD seedlings had the lowest total shoot to total root and seedling water balance ratios (Table 1). Carlson (1981) reported comparable shoot to root ratios for 1+0 styro-plug western nemlock seedlings after two field seasons. Interestingly, shoot to root ratios for seedlings in all DIT increased by the end of the second growing season. Western hemlock is known for increase-ing its shoot to root ratio as tree size increases (Eis 1974) and this also occurs during seedling establishment (Long 1978). This inherent growth strategy, coupled with optimal environmental conditions over much of both growing seasons resulted in greater shoot development at the expense of root development.

Seedling survival at the end of the second growing season was between 87 and 92% with SDW treatment having the highest survival rating (Fig. 4). This second year survival is higher than reported in earlier western hemlock field trials (Arnott 1974, 1975, 1976).

SUMMARY AND CONCLUSION

Morphological development of western hemlock seedlings from a series of DIT was monitored over two growing seasons on a reforestation site. Previous stock quality assessment found seedlings from all DIT in equivalent physiological condition when exposed to optimum environmental conditions, while short-day DIT, and especially SDW, had a better capability to respond to limiting (i.e. low temperature and drought) environ-mental conditions (Grossnickle et al. 1988, 1990a). At the time of planting, LDW seedlings had the largest shoot system and short-day DIT had the best shoot to root balance. After two growing seasons in the field all DIT had equal height, diameter and shoot dry weight indicating that SDW, SDD and LDD seedlings grew more than LDW. Short-day wet seedlings had the greatest incremental shoot height growth and the least number of stem units cm^{-1} over two field growing seasons. Short-day treatments also suffered less needle damage indicating that their shoot systems were better conditioned to site environmental conditions. Root development over two growing seasons was equal between DIT. Root growth was sufficient to reduce stress that occurs during seedling establishment and this was indicated by the high rate of seedling survival in all DIT.

The combination of stock quality assessment results and subsequent field trial performance provided a comprehensive information base to select the best performing stocktypes for specific reforestation site conditions. In this program, western hemlock seedlings from short-day, and especially SDW, DIT had the best performance capability in both stock quality assessment testing and field performance over two growing seasons on a coastal reforestation site.

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