EFFECTS OF NURSERY NUTRITIONAL SCHEDULES ON DEVELOPMENT OF WESTERN HEMLOCK SEEDLINGS IN THE FIELD

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Abstract.--Western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) seedlings were cultured with five different nutritional schedules used in the Pacific Northwest. Seedling shoot and root development were compared after the nursery culture period and after the first year in the field. Differences in shoot development were increased whereas differences in root development were decreased during the first year after outplanting.

Résumé.--Des plants de pruche occidentale (*Tsuga heterophylla* [Raf.] Sarg.) ont été cultivés en étant soumis à cinq régimes d'alimentation en usage dans le nord-ouest du Pacifique. La croissance des pousses et des racines de ces plants a été comparée à la fin de la période de culture en pépinières et un an après la plantation. Les différences de développement des pousses se sont accrues tandis que les différences de développement des racines ont diminué au cours de la première année après la transplantation.

INTRODUCTION

Nutritional schedules for the culture of forest tree seedlings have been the subject of much research. Brix and van den Driessche (1974) reviewed this work with regard to the greenhouse culture of tree seedlings in containers. Larson (1974) suggested that application of research knowledge was more of a problem than lack of knowledge in the mineral nutrition of cultured tree seedlings. Inspection of seedlings cultured by many different growers around the Pacific Northwest indicated a surprising diversity of seedling gross morphology which could be attributed in part to differences in nutritional schedules used by these nurseries. The studies reported here were initiated to distinguish quantitatively the differences among the nutritional schedules in common use for the culture of western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) in the Pacific Northwest.

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MATERIALS AND METHODS

Stratified seeds of western hemlock from two seed lots, one from Sekiu, Washington (365 m elevation) and the other from the Seaside, Oregon area (182 m elevation) were sown in mid-February 1977 in 60-cm^3 styroblock-4 quarterblock containers filled with 1:1 peat/vermiculite growing medium. These containers were arranged in 152.4- x 182.9-cm rectangles of 1800 trees each. Half of each rectangle was sown with each seed source. Four greenhouse benches were oriented north-south, each holding five of the seedling blocks 122 cm apart. Each of the five seedling blocks on a particular bench was assigned a nutritional treatment at random. The assigned nutritional schedules included one utilized by the British Columbia Forest Service's (BCFS) Koksilah Forest Nursery at Duncan, B.C., Hoagland's solution, and one utilized by the Crown Zellerbach (CZ) Corporation Nursery near Aurora, Oregon (Table 1). We recognize that managers often alter nutritional schedules during the growing season; therefore, our schedules only approximate those used in any one year.

Table 1. Composition of three liquid nutritional schedules used.

(A) Nutritional schedule based on that of the BCFS

Week	NPK Ratio	Rate (g/1000 L)
5	10-51-16	625
8-24	20-20-20	500
25-26	0-52-34	625
27-34	10-51-16	625
35	0-0-0	
36+	10-51-16	625

(B) Hoagland's Solution

Stock solutions (diluted 1:200 to make final solution). Applied at 6 ml/cavity/ week until midsummer, then as needed.

		mg/gal
(a)	NH_4Cl	244
	KNO_3	458
	KH_2PO_4	124
	$MgSO_4 \cdot 7H_2O$	462
	H_3BO_4	5.2
	$CuCl_2 \cdot 2H_2O$	0.1
	$MnCl_2 \cdot 4H_2O$	3.28
	$Zn(NO_3)_2 \cdot 6H_2O$	0.42
	MoO_3	0.013
(b)	$Ca(NO_3)_2$	848
	Sequestrene	148

(C) CZ 1976 nutritional schedule

Week	NPK Ratio	Rate (ppm)
5-18	1-2-1	25
9-13	1-2-1	50
14	2-1-1	75
15-24	3-1-1	100
25-34	1-2-1	50
35-37	0-0-0	
38+	2-50-25	25

Stock solution used for 1:200 injection into irrigant	NH_3SO_4 g/L	KNO_3 g/L	H_3PO_4 (85%) ml/L
1-2-1 @ 25 ppm	16	11.5	7.9
1-2-1 @ 50 ppm	32	23	15.8
2-1-1 @ 75 ppm	59.5	17	5.95
3-1-1 @ 100 ppm	84.0	15	5.3
2-50-25 @ 25 ppm	0	11.5	7.9

Two other nutritional schedules used were BCFS schedule plus 2.34 kg/m^3 Osmocote 117 (17-5-11) and BCFS schedule plus Scott Progrow (24-9-9) at 1.79 kg/m^3.

In mid-December 12 seedlings were chosen at random from each replicate block and measured for total height, root-collar diameter, shoot dry weight and root dry weight. The number of unsuberized root tips per root system was counted on seedlings sampled from the Sekiu seed source.

The remaining seedlings were then put into storage at 2-4°C until late January 1978 when 100 trees were sampled randomly from each seed source and each nutritional treatment and outplanted. Sekiu source seedlings were planted on a northeast aspect at 365 m elevation near Sekiu, Washington. Seaside source seedlings were planted near 182 m elevation in the Charlie Creek subdrainage of the Necanicum River near Seaside, Oregon. At each site the seedlings were individually tagged and planted in a completely randomized design. At the Charlie Creek site seedlings were protected from animal damage with Vexar tubing.

In January, 1979, total height, height growth and groundline diameter were measured on each seedling. On the Sekiu plantation, 25 trees were randomly sampled for root system structure from each treatment except the BCFS plus Scott Progrow treatment. The trees chosen were marked on the uphill side of the stem at groundline, then excavated 15 cm from the stem and a minimum of 25 cm deep. The excavated seedlings were placed in a 12-zone frame similar to that used by Rischbieter (1978). The number of roots per zone and the diameter of the largest root in each zone were recorded for each of the excavated seedlings. Programs of the Statistical Analysis System (SAS Institute Inc., SAS Circle, Cary, NC. 27511) were used for data analysis.

RESULTS

Seedlings from the various nutritional schedules varied less than 3 cm in mean height at the end of the nursery culture period (Fig. 1). These variations were not strongly related to treatment (a = .2016), but were more related to seed source (a = 0.0848) and position of the replicate within the greenhouse (a = 0.1142). Mean root collar diameter was greatest for seedlings cultured with the BCFS Osmocote 117, and least for seedlings cultured on Hoagland's solution schedule (a = 0.0001) (Fig. 1). The mean weight distribution within seedlings also varied depending on the cultural treatments (Fig. 2). Shoot weight was highest in seedlings cultured with the CZ nutritional schedule, and the other treatments were very similar in weight (overall a = 0.0001). Root weight varied only about 0.14 g and while differences due to treatment were significant (a = 0.0001) the variation due to location in the greenhouse was quite strong (a = 0.0043). Conversely, shoot weight did not vary by greenhouse location (a = 0.9908). Shoot:root ratio was most affected by treatment (a = 0.0001) but was also affected by greenhouse location (a = 0.0043). Over all, seedlings cultured on the CZ schedule had comparatively high shoot:root ratios (Fig. 2).

Nutritional regime had a pronounced effect on the number of active root tips (a = 0.0030) and the number of active root tips per gram dry weight of root (a= 0.0005), although these parameters were also affected by greenhouse location (a = 0.0626 and a = 0.0084, respectively). In general, the BCFS schedule and modifications of it had uniformly high numbers of active root tips per gram dry weight of root while the CZ and Hoagland's solution schedules produced lighter roots with fewer active tips (Fig. 3).

Foliar analysis at the end of the greenhouse culture period indicated that the BCFS nutritional schedule with and without controlled release fertilizer amendments yielded seedlings with higher foliar levels of nitrogen, potassium and phosphorus than the CZ and Hoagland's solution schedules (Table 2).

On the Seaside, Oregon site seedlings from the BCFS plus Osmocote 117 nutritional schedule grew more the first year after outplanting (a= 0.0125) and were also the tallest (a = 0.0192) (Fig. 4). The groundline diameter of these trees was also greater than that of trees from other treatments (a = 0.0001).

Seedling height growth on the Sekiu, Washington test site was not related to nursery cultural treatment (a = 0.7772). Seedlings from BCFS plus Osmocote 117 and Crown Zellerbach nutritional schedules were the tallest (a = 0.0829) because of differences at planting (Fig. 5) and had the largest groundline diameter (a = 0.0147).

Excavation of seedlings at the Sekiu test site showed that, in all treatments, more roots egressed from the, bottom zone of the plug than from the upper zones (Fig. 6). Seedlings from the BCFS plus Osmocote 117 treatment had more roots in the bottom zone than did those of other treatments (a = 0.0004). The upper zone of the plugs from the Hoagland's solution treatment had more roots than did those from other treatments (a = 0.0353).

While maximum root diameter and the number of roots in each of 12 zones varied with treatment (Table 3), the relative values of these factors between zones was similar among treatments (Fig. 7).

Table 2. Foliar nutrition analysis results at the end of the greenhouse culture period for two seed sources.

Nutritional schedule	N	P	K	S	Ca	Mg	Na	Zn	Mn	Cu	Fe
Hoagland's - 0[a]	1.64	.296	.90	.107	.48	.257	.045	17	222	4.0	168
Hoagland's - W	1.62	.234	.88	.147	.46	.248	.046	17	212	2.9	160
BCFS + Scott Prog - 0	1.72	.449	1.42	.008	.46	.275	.033	40	541	9.0	117
BCFS + Scott Prog - W	2.04	.458	1.61	.008	.41	.283	.037	35	532	6.2	100
Crown Zellerbach - 0	1.66	.292	.87	.214	.36	.174	.023	19	177	3.0	108
Crown Zellerbach - W	1.61	.346	1.05	.290	.40	.211	.021	25	208	3.0	128
BCFS - 0	2.26	.485	1.35	.046	.42	.268	.032	20	429	4.8	61
BCFS - W	1.97	.496	1.37	.007	.37	.266	.035	22	371	4.9	92
BCFS + Osmo 117 - 0	2.16	.508	1.23	.148	.37	.264	.43	21	301	5.4	99
BCFS + Osmo 117 - W	2.00	.463	1.27	.131	.38	.264	.39	19	313	4.9	87

[a]O = Seaside, Oregon seed source
W = Sekiu, Washington seed source

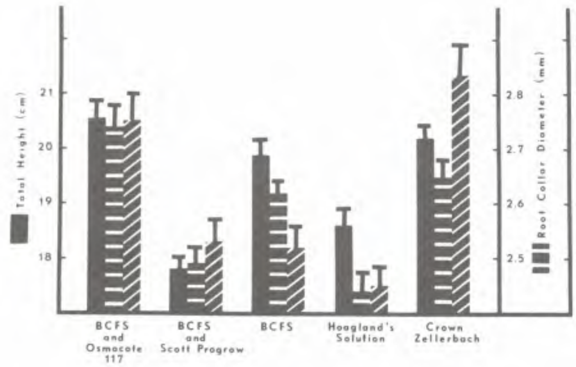

Figure 1. Seedling size parameters for each nutritional schedule. Data were combined for the two seed sources. One standard error of the mean is indicated at the top of each bar.

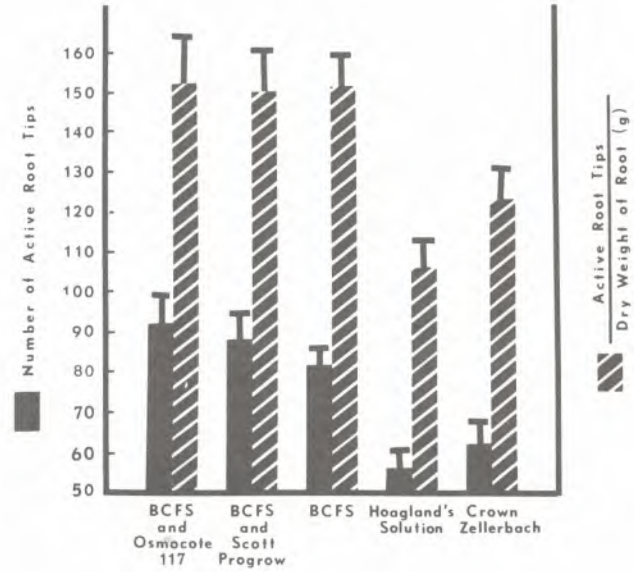

Figure 3. The number of active (unsuberized) root tips per seedling and per gram dry weight of root for seedlings from each nutritional schedule. One standard error of the mean is indicated at the top of each bar.

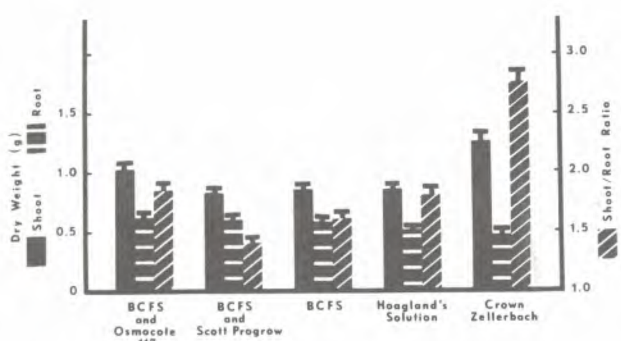

Figure 2. Seedling weight parameters for each nutritional schedule. Data were combined for the two seed sources. One standard error of the mean is indicated at the top of each bar.

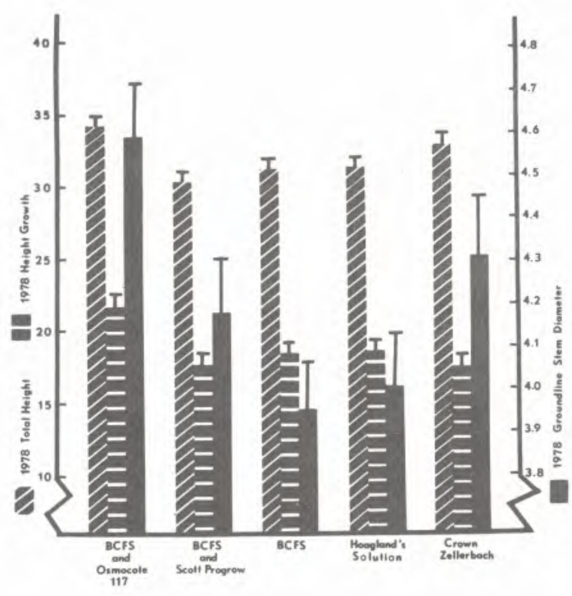

Figure 4. Height, height growth, and groundline diameters one year after outplanting at Seaside, Oregon. One standard error of the mean is indicated at the top of each bar.

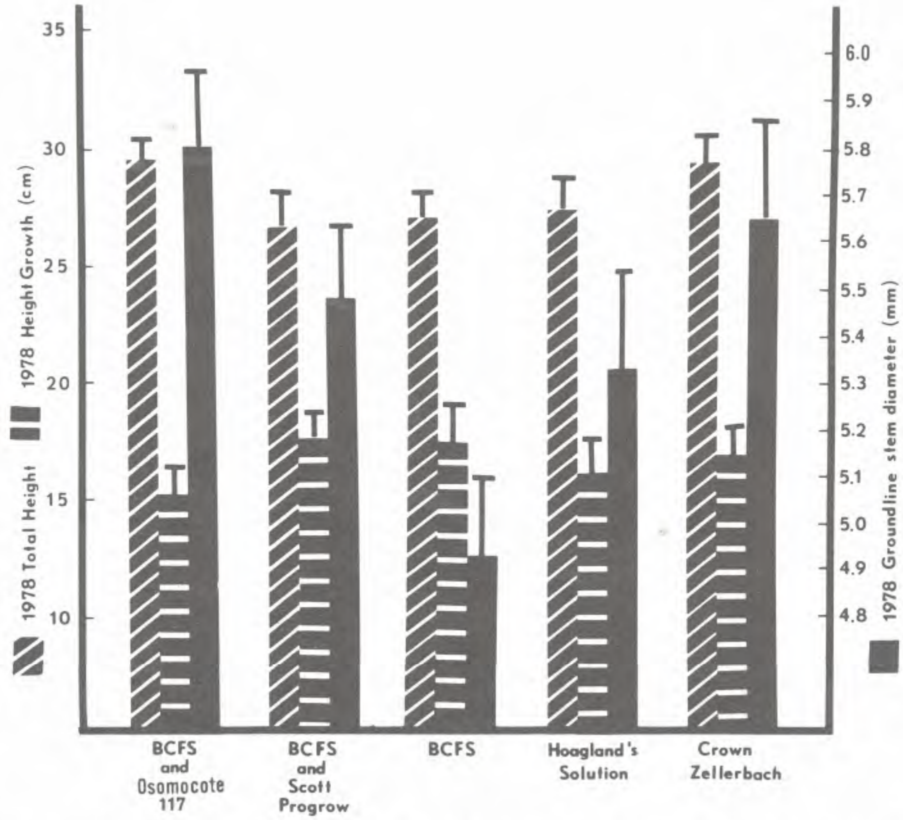

Figure 5. Height, height growth and groundline diameters one year after outplanting at Sekiu, Washington. One standard error of the mean indicated at top of each bar.

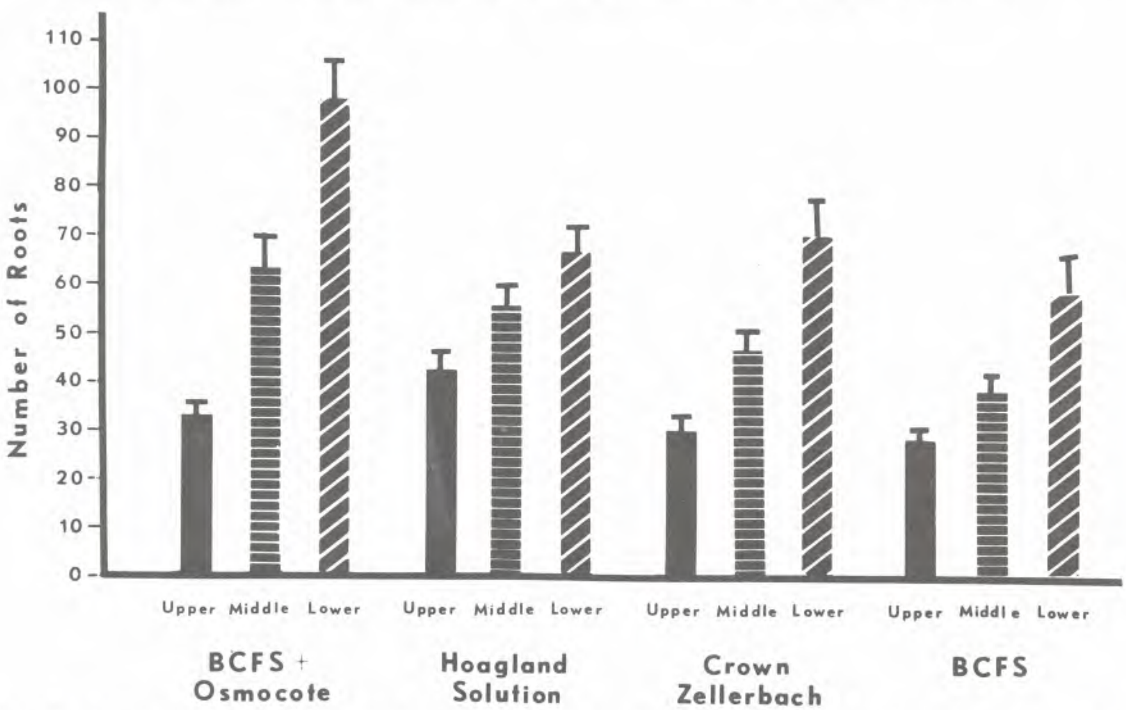

Figure 6. Number of roots egressed from the upper, middle and lower third of the original plug root mass one year after outplanting. One standard error of the mean indicated at top of each bar.

Table 3. Analysis of variance of number of roots per zone and the maximum root diameter (cm) in each zone by treatment.

	Number of roots in zone		Average maximum root diameter in zone	
	Mean square by source*		Mean square by source*	
Root zone	Treatment**	Error	Treatment**	Error
1	$47.87^{0.1204}$	24.20	$0.2744^{0.1885}$	0.1697
2	$67.33^{0.0789}$	29.07	$0.3561^{0.0427}$	0.1268
3	$47.42^{0.1254}$	25.18	$0.2597^{0.0671}$	0.1062
4	$54.51^{0.1697}$	32.02	$0.7212^{0.0431}$	0.2576
5	$54.57^{0.4352}$	59.22	$0.3217^{0.1066}$	0.1550
6	$59.20^{0.4118}$	61.08	$0.0699^{0.6388}$	0.1222
7	$366.35^{0.0011}$	62.52	$0.1553^{0.4727}$	0.1830
8	$498.81^{0.0006}$	78.55	$0.7311^{0.0095}$	0.1814
9	$612.81^{0.0017}$	111.67	$0.2258^{0.4044}$	0.2292
10	$317.34^{0.0422}$	112.64	$0.3048^{0.1196}$	0.1537
11	$794.93^{0.0097}$	198.20	$0.4388^{0.0783}$	0.1890
12	$1110.67^{0.0001}$	137.29	$0.7499^{0.0206}$	0.2192

*There were three degrees of freedom for treatment and 102 for error.
**The superscript on the mean square is the probability of a type I error.

DISCUSSION

Western hemlock seedlings cultured under different but commonly used nutritional schedules generally differed more at the end of the nursery culture period (1 year) than at the end of the first field season. Small differences in height at the end of the nursery culture period were, however, increased slightly after planting on the Seaside plot where seedlings from the BCFS plus Osmocote 117 nutritional schedule were tallest. Anderson and Gessel (1966) and Smith et al. (1966) presented data indicating that in Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) plantations such small differences can become much larger as seedlings develop to 5 years of age.

Osmocote 117 is a resin-coated 17-5-11 NPK controlled release fertilizer (Oertli and Lunt 1962) that can effect increased height growth in both the first and second years after application (Carlson and Preisig 1981). The availability of additional NPK to seedlings in this treatment was thereby extended through the first field season. Carlson (1982) has shown that western hemlock responds to higher levels of this fertilizer applied at planting. The height growth response in this treatment was probably due to the combined effects of initially taller seedlings and residual Osmocote 117.

Late season fertilization of bare-root stock in the nursery has improved the survival and growth of Douglas-fir and western hemlock after outplanting (Anderson and Gessel 1966, Smith et al. 1966, Benzian and Freeman 1967). Benzian and Freeman (1967) noted that such nursery treatments raised the foliar nitrogen level of western hemlock from 0.8% to 1.6% in 2-yr-old stock and to 2.0% in 1-yr-old stock. In the study reported here, late season foliar nitrogen levels ranged from 1.61 to 2.26% and hence were all in the range found by Benzian and Freeman (1967) to give better survival, frost hardiness, height and diameter growth than a 0.8% level found in unfertilized stock. It is apparent that all of the nutritional schedules tested here provide foliar nitrogen adequate to support the type of initial growth observed in the field following late season nursery fertilization of bare-root stock.

The root regeneration potential of trees under controlled conditions has often been used as a basis for estimating bare-root seedling quality (Stone 1955). Containerized seedlings have root systems that are less disturbed at planting and can elongate rapidly to produce a greater length of roots on the seedling than is common for bare-root stock (Hahn and Hutchison 1978). It seems reasonable to assume that a major factor in rapid enlargement of containerized seedling root systems following outplanting is the presence of unsuberized root tips. The initiation of new lateral root primordia is more sensitive to physiological stress than is elongation of existing roots (Ritchie and Dunlap 1980).

Our results suggest that the number of unsuberized root tips does not predict the number of roots that will develop after planting under moist forest conditions in western hemlock. Seedlings cultured on Hoagland's solution had fewer unsuberized root tips at the end of the nursery culture period than did those of other treatments, but these seedlings were second only to seedlings cultured with the BCFS and Osmocote 117 nutritional schedule in number of elongated roots after outplanting. This suggests that new root initiation or elongation of lateral root tips not apparent as unsuberized tips is potentially as important as elongation of unsuberized tips to root system enlargement after outplanting.

Seedlings from all treatments had more roots extending from the bottom third of the plug than from upper zones. This agrees with the findings of Long (1978) for western hemlock. Air pruning at the bottom of the container causes many new roots to form in that area of the plug, possibly because of hormonal changes associated with the injury (Carlson and Larson 1977).

The average root systems of hemlock seedlings cultured with any of the nutritional schedules in this study were symmetrical with respect to numbers of roots and the diameter of the largest root in each of the 12 root zones. Arnott (1978) noted that root system structure of containerized western hemlock seedling roots was oriented in a configuration similar to that of naturally seeded trees.

Results reported here support the conclusion that hemlock seedlings grown in styroblock-4 containers with any one of the nutritional schedules tested will develop an adequate root system after outplanting.

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