INFLUENCE OF FALL FERTILIZATION AND MOISTURE STRESS ON GROWTH AND FIELD PERFORMANCE OF CONTAINER-GROWN DOUGLAS-FIR SEEDLINGS

Thomas M. Jopson and Jack L. Paul

ABSTRACT: Five fertilizer treatments (+NPK, minus N, minus P, minus K, and tap water) and two wilt treatments (wilt, and non-wilt) were applied to container-grown Douglas-fir seedlings during the fall in the greenhouse. Seedling growth in the nursery was measured. Seedlings were outplanted in mid-winter and growth and performance after planting were evaluated near the beginning and at the end of the growing season. Seedling growth in the nursery and growth and survival after planting were substantially reduced in treatments not receiving nitrogen. Removal of phosphorus or potassium had no discernable effect on growth. The wilting practice was detrimental to seedling growth, both in the nursery and after planting.

INTRODUCTION

The literature does not provide a strong basis for choosing one of the many cultural practices used during the hardening-off and dormant periods of seedling growth in the nursery. Most nurserymen use some form of moisture stress coupled with a reduction or temporary removal of all nitrogen from their liquid feed program to begin hardening-off and achieve budset (Hahn 1982). During the dormant period, many nurserymen feed with high phosphorus nutrient solutions, which are thought to enhance root and caliper development (Van Eerden 1974).

Since the goal of nursery cultural programs is the production of seedlings that perform well in the field after outplanting, alternative nursery practices are best evaluated by comparing the field performance of the resulting seedlings. There are few reports in the literature relating specific nursery practices with field performance. This paper investigates the effects of nitrogen, phosphorus, and potassium fertilization and of a wilting practice during these two critical growth periods by relating specific nursery practices to seedling performance in the field after outplanting.

MATERIALS AND METHODS

The experiment described in this paper was conducted at the Cal Forest nursery in Covelo, California, located in Round Valley in northeastern Mendocino County. Round Valley is an interior valley receiving little coastal climatic influence. Summer highs range from 85 to 105 F (30 to 40 C), but nights are generally cool, 50 to 65 F (10 to 20 C). In the fall, the days are warm, but nights are often quite cold (20 F) because of radiation cooling. Winter highs may reach 60 F (15 C), with lows down to 12.

Seedling Douglas-fir were subjected to different cultural treatments and their responses evaluated during the two-part experiment. The nursery phase, during which fertilizer and wilt treatments were applied, began on September 6, 1982, and ended on February 9, 1983. Wilt treatments were applied during the month of September only, while fertilizer treatments were applied throughout the nursery phase. The outplanting phase, during which seedlings were planted in the field (with no further treatments) and were evaluated for growth and survival, began on February 9, 1983.

Five fertilizer treatments were applied during the nursery phase, including complete NPK, minus nitrogen, minus phosphorus, minus potassium, and a tap water control. A wilt treatment and a non-wilt treatment were applied to each of the 5 fertilizer treatments, giving a total of 10 treatments in the experiment. Measurements of seedling growth and nutrient content were made four times: 1) at budset in the nursery; 2) at the time of outplanting; 3) in the spring about 4 months after outplanting; and 4) at the end of the first growing season on November 27, 1983.

Nursery Phase

Materials-Douglas-fir seedlings were grown from seed from California seed zone 340-25. The seed was sown in late April into #4 styro-quarter blocks filled with commercially prepared 1:1 peat:vermiculite mix (W.R Grace Forestry Mix). Trees were grown outdoors under a nominal 30 percent shade cloth (to give 70 percent of full sun). Fertilization began in early June with 30:10:10 ppm NPK solution increasing to 100:30:30 NPK by the end of June. In the middle of July, the solution was changed to 100:25:150 NPK and remained at that level until the end of August. Tmmediately prior to being removed for the experiment, seedlings were leached with tap water applied for 4 hours through sprinklers.

____

Paper presented at combined meeting of the Western Forest Nursery Council and Intermountain Nurseryman's Association, Coeur d' Alene, ID, August 14-16, 1984.

Thomas M. Jopson is owner of Cal Forest, Covelo, CA.; Jack L. Paul is Professor of Environmental Horticulture, University of California, Davis

Table 1.--Nutrient solution composition and concentration used for liquid feed fertilizer treatments

Nutrient	Treatment Solutions (mg/liter) CON	-N	+NPK	-P	-K	Nutrient Source
NO_3-N	-	-	70	70	70	NH_4NO_3, $Ca(NO_3)_2$
NH_4-N	-	-	30	30	30	NH_4NO_3
P	-	30	30	-	30	H_3PO_4
K	-	134	134	134	-	K_2SO_4
S	-	54	54	54	40	K_2SO_4, $MgSO_4$
Ca	-	40	57	57	57	$Ca(NO_3)_2$, $CaCl_2$ in -N
Mg	-	30	30	30	30	$MgSO_4$
Fe	-	4	4	4	4	330 Fe chelate
Bc	-	.070	all treatments contained the same micronutrient concen. except the control which contained none.			Peters STEM
Cu	-	.15				"
MN	-	.39				"
Mo	-	.0022				"
Zn	-	.21				"

The fertilizer solutions were prepared as needed by mixing the commercial fertilizers as indicated in table 1 with tap water in 70-liter plastic containers.

Methods--Irrigation was accomplished by immersing the blocks in the appropriate solution until the bubbling of air from the media ceased. Wilt treatment trees were stressed to the wilting point before each of the first three irrigations (about 6 days apart). Trees were considered wilted when the terminals were drooping over slightly. Irrigation with nutrient solutions was continued in both non-wilt and wilt treatments until the beginning of the outplanting phase on 2/9/83.

Data collection--Dates and measurements taken are given in table 2.

Table 2.--Experimental measurements taken at different times during the experiment

Type of Measurement	Date 1/ 9/1/82 A	S	10/23/82 A	S	2/9/83 A	S	5/26/83 A	S	11/27/83 A	S
Stem height	X		X		X			X		X
Stem caliper	X		X		X			X		X
Shoot fresh & dry weight		X		X		X		X		X
Root fresh & dry weight		X		X		X		X		X
N content		X		X		X		X		X
P content		X		X		X		X		X
Number of roots emerging								X		X
Root length								X		X

1/ A = All trees measured
S = Sample of trees measured

Outplanting Phase

The outplanting area was chosen as typical of the many planting sites in the interior Coast Range region of northwestern California. It was on a southeast slope at 2,000 feet (610 meters) on Dingman Ridge just east of Round Valley. Soil type is designated as SITES (depth 2-3 feet [60-90 cm)) on the California soil-vegetation map (43a-3). The surface soil is described as a moderately acid loam with fair timber growing capability. In January, the outplanting area was ripped to a depth of approximately 18 inches (45 cm) with a three-bottom Howard V-Chisel behind a MF 238 tractor. The **area** was then disced twice. A light cover of grass, plus a heavy cover of star thistle in plot #3, developed in the outplanting area despite the discing.

Data collection-Dates and measurements taken are given in table 2.

Tissue analysis methods--Shoot nitrogen was determined by micro-Kjeldahl procedure. Shoot phosphorus was determined by a molydate blue procedure.

RESULTS AND DISCUSSION

The presentation of results is divided into two sections: the first on the nursery phase, the second on the outplanting phase. Reference is made in the text to the following time periods:

Nursery phase

9/6 -10/23 -hardening-off period
10/23- 2/9 -dormant period

Outplanting phase

2/9 - 5/26 -spring period
5/26-11/27 -summer/fall period

Nursery Phase

Treatments resulted in differences in seedling appearance, mortality, time of budset, and seedling growth. Differences in appearance were apparent within 3 weeks after the start of treatments on 9/6 with -N and control seedlings beginning to show chlorosis. This chlorotic condition persisted throughout the nursery phase, although it did not visibly worsen after the first month. During the dormant period, some seedling mortality occurred; wilted trees, particularly those not receiving nitrogen, shoved a greater mortality rate in the nursery.

As indicated by the percent of seedlings with terminal buds on 10/23, there were differences in the average time of budset. The control and minus N seedlings set buds more rapidly on the average than the nitrogen-fertilized seedlings. Wilting had the expected effect of promoting more rapid budset in seedlings supplied with nitrogen, but seemed to slow budset in -N and control seedlings. Despite the differences noted above, all seedlings did eventually set a terminal bud, and no frost damage was observed.

Table 3.--Seedling stem height during and at the end of the nursery phase

Height in centimeters(cm)

Sample Date	Period	Treatments: Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	seedlings per treat.
9/6	Begin	11.0	11.0	10.8	11.2	11.0	10.5	10.6	10.4	10.6	10.8	0.7	100
10/23	hrdg off	13.5	13.2	14.4	15.0	15.0	12.4	13.0	13.0	13.2	13.7	0.9	100
2/9	dormant	13.5	13.0	14.5	15.0	15.3	12.2	13.0	13.3	13.3	14.0	0.9	100

Table 4.--Seedling stem caliper measured 0.5 cm above the cotyledonary scar during and at the end of the nursery phase

Caliper in millimeters(mm)

Sample Date	Period	Treatments: Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	seedlings per treat.
9/6	Begin	2.0	2.0	2.0	2.0	2.0	2.0	1.9	2.0	1.9	2.0	.07	100
10/23	hrdg off	2.5	2.5	2.9	2.9	3.0	2.2	2.4	2.6	2.5	2.6	.10	100
2/9	Dormant	2.5	2.5	3.1	3.0	3.1	2.2	2.4	2.7	2.7	2.7	.13	100

Height and Caliper--Height and caliper measurements are given in table 3 and table 4.

Dry Weight (table 5)--Shoot dry weight increases during the nursery phase ranged from 0.3 grams (wilt-control) to 0.8 grams (non-wilt+NPK), with 2/3 of the gain occurring during the hardening-off period, and 1/3 during the dormancy period. Root dry weight gains were just about evenly distributed between the hardening off and the dormant period, with total gains ranging from 0.3 grams (wilt-control) to 0.75 grams (non-wilt-K). Nitrogen fertilization did not increase root dry weight over controls during the hardening-off period, but did significantly increase root dry-weight during the dormant period. Compared to the NPK treatments, the -P and -K treatments consistently produced greater root weights in the wilted treatments, but produced the same, or lower weights in the non-wilted treatments. None of these effects was statistically significant, however. During the hardening-off period, wilted seedlings produced only about 1/2 as much root dry weight as non-wilted seedlings, but during the dormant period, average root dry weight production was nearly the same. Thus, by the time of outplanting, roots were growing at the same rate in both groups.

Shoot Nitrogen (table 6)--Seedlings deprived of nitrogen became chlorotic within 4 weeks of the beginning of the treatments, and still appeared chlorotic when outplanted. Nitrogen fertilization resulted in significantly higher shoot nitrogen percent at the end of the nursery phase when compared to -N and controls.

Shoot Phosphorus (table 6)--The phosphorus content was high at the end of the budset period, but declined during the dormant period. However, phosphorus levels iii the minus P treatments remained within the range found in seedling Douglas-fir (0.16 percent to 0.30 percent)(van den Driessche 1969).

Table 5.--Average shoot and root dry weight of seedlings sampled during the nursery phase

Shoots (grams)

Sample Date	Period	Treatments: Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	Seedlings per treat.
9/6	Begin	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40		
10/23	Hrdg-off	0.80	0.90	0.89	1.01	1.04	0.79	0.73	0.79	0.80	C.75	0.21	10
2/9	Dormant	1.12	0.90	1.33	1.39	1.28	0.89	0.90	1.03	1.11	1.19	0.30	10

Roots (grams)

Sample Date	Period	Treatments: Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	Seedlings per treat.
9/6	Begin	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20		
11/23	Hrdg-off	0.43	0.45	0.42	0.46	0.48	0.39	0.33	0.37	0.34	0.38	0.09	10
2/9	Dormant	0.72	0.61	0.96	0.91	0.98	0.57	0.60	0.82	0.90	0.89	0.23	10

Table 6.--Average shoot (needles and stem) tissue nitrogen percent and phosphorus percent of samples taken during the nursery phase

% NITROGEN

Sample Date	Period	Treatment: Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	Seedlings per treat.
9/6	Begin	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6		1/
10/23	Hrdg-off	0.86	0.86	1.87	1.77	1.67	0.80	0.92	1.50	1.67	2.02	.39	4
2/9	Dormant	0.90	0.90	1.67	1.70	1.67	0.97	0.80	1.67	1.57	1.65	.20	4

% PHOSPHORUS

Sample Date	Period	Treatment: Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	Seedlings per treat.
9/6	Begin												1/
10/23	Hrdg-off			0.45	0.36				0.37	0.31		.07	4
2/9	Dormant			0.24	0.18				0.20	0.21		.05	4

1/ Value derived from as sample of ten trees from the same population as the experimental trees.

Outplanting Phase

At the time of the spring evaluation (May 26) seedlings from most of the treatments appeared to be in excellent condition. However, seedlings from both minus N treatments and the wilt control seedlings appeared to be more spindly and had sparser foliage than the others. Seedling survival at this time was excellent (table 11), with all mortality occurring in the wilted seedlings. Growth and survival were also recorded at the end of the growing season on November 27(summer/fall period), when seedlings were dormant and after the fall rains. At that time, large differences between treatments had become apparent.

New Shoot Growth and Caliper--New shoot growth and caliper measurements are given in table 7.

Dry Weight (table 8 and figure 1)--Shoot and root dry weight increases were markedly influenced by nitrogen fertilization in the nursery. Nitrogen-fertilized seedlings accumulated twice the dry weight of the nitrogen-deprived seedlings during the outplanting phase. Shoot dry weight gain was the same in the spring and summer/fall periods,

Table 7.--New shoot growth and stem caliper of seedlings after outplanting

NEW SHOOT GROWTH (cm)

Sample Date	Period	Treatment: Non-wilt					Wilt					LSD .05	Seedlings per treat.
		CON	-N	+NPK	-P	-K	CON	-N	+NPK	-P	-K		
5/26	Spring	1.56	2.27	4.22	3.66	3.68	1.36	2.14	3.26	3.07	3.55	1.39	9
11/27	Sum/fall	3.64	2.87	5.20	4.26	5.33	2.75	*	5.91	4.64	4.85	1.49	9

CALIPER (mm)

Sample Date	Period	Treatment: Non-wilt					Wilt					LSD .05	Seedlings per treat.
		CON	-N	+NPK	-P	-K	CON	-N	+NPK	-P	-K		
5/26	Spring	3.2	3.3	4.2	4.4	4.1	2.9	3.0	3.6	4.0	3.5	0.8	9
11/27	Sum/fall	4.0	4.0	5.5	4.8	5.4	3.2	*	4.6	5.0	5.1	0.3	8

*too few survivors to obtain an adequate sample

while 1/3 of the root dry weight gain was in the spring and 2/3 in the summer/fall. The wilt treatment had very little effect on the accumulation of dry weight during the outplanting phase, but weight reductions from the nursery phase were not regained.

Roots growing from the rootball (table 9)--The influence of fertilization on root growth in the field was apparent in the count of roots emerging from the rootball and in average length of emerged roots. The data show that nitrogen fertilization increases both the number of roots emerging and the average length. Wilting had a significant effect only in the +NPR treatment where it resulted in a significant reduction in the number of roots emerging from the plug.

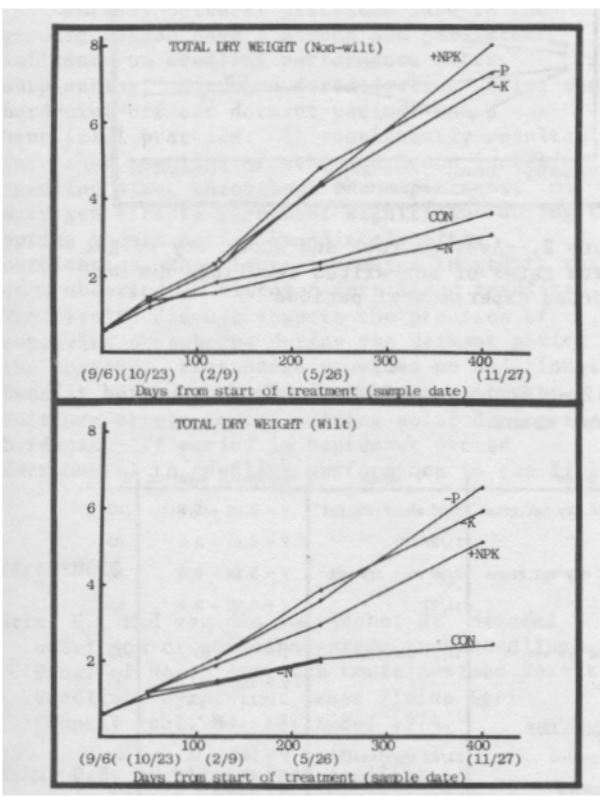

Figure 1.--Total seedling dry weight (root plus shoot) for each non-wilted fertilizer treatment (top) and each wilted fertilizer treatment at the beginning of the experiment and at the end of each experimental period

Table 8.--Average shoot and root dry weight of seedlings dug after the spring growth period and at the end of the first growing season after planting

Shoot (grams)

Sample Date	Period	Treatment: Non-wilt					Wilt					LSD .05	Seedlings per treat.
		CON	-N	+NPK	-P	-K	CON	-N	+NPK	-P	-K		
5/26	Spring	1.20	1.28	2.39	2.63	2.49	1.11	1.07	1.54	1.76	2.00	.44	9
11/27	Sum/Fall	1.55	1.33	3.50	3.44	3.08	0.95	*	2.28	2.53	2.96	.98	8

Root (grams)

Sample Date	Period	Treatment: Non-wilt					Wilt					LSD .05	Seedlings per treat.
		CON	-N	+NPK	-P	-K	CON	-N	+NPK	-P	-K		
5/26	Spring	1.12	0.98	2.06	2.18	1.97	0.90	0.90	1.33	1.54	1.55	.46	9
22/27	Sum/Fall	2.10	1.73	4.53	3.91	4.02	1.49	*	2.84	3.44	3.57	1.17	8

*too few survivors to obtain an adequate sample

Tissue analysis (table 10)--Shoot nitrogen percent was more variable after outplanting than in the nursery. Seedlings from nitrogen-fertilized treatments generally had a higher nitrogen content than seedlings deprived of nitrogen, but differences were not significant in most cases. Observed nitrogen levels were similar to other observations of Douglas-fir in the field (Lavender and Carmichael 1966; Smith and others, 1981). Shoot phosphorus declined after outplanting; the final levels were slightly lower than observed elsewhere (Lavender and Carmichael 1966)

Table 9.--New root growth from the root ball into the soil after outplanting

Number of New Roots Per Seedling

Sample Date	Period	Treatment: Non-wilt					Wilt					LSD .05	Seedlings per treat.
		CON	-N	+NPK	-P	-K	CON	-N	+NPK	-P	-K		
5/26	Spring	34	20	65	41	48	20	22	35	41	59	18	9
11/27	Sum/Fall	37	26	64	45	52	31	*	36	45	53	19	8

Average Length of New Roots (cm)

Sample Date	Period	Treatment: Non-wilt					Wilt					LSD .05	Seedlings per treat.
		CON	-N	+NPK	-P	-K	CON	-N	+NPK	-P	-K		
5/26	Spring	1.9	2.9	3.5	2.9	2.9	1.9	2.1	2.1	3.2	3.2	1.2	9
11/27	Sum/Fall	3.9	5.2	6.9	7.5	6.8	4.0	*	4.2	6.5	5.5	2.0	8

Average Root Extension (Length x number) (cm)

Sample Date	Period	Treatment: Non-wilt					Wilt					LSD .05	Seedlings per treat.
		CON	-N	+NPK	-P	-K	CON	-N	+NPK	-P	-K		
5/26	Spring	76	58	225	184	154	50	55	107	157	196	87	9
11/27	Sum/Fall	189	136	465	362	372	127	*	188	311	375	171	8

*too few survivors to obtain an adequate sample

Table 10.--Shoot (needles and stem) tissue nitrogen percent and phosphorus percent in seedlings dug during and after the first growing season after planting

Nitrogen (%)

Sample Date	Period	Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	Seedlings per treat.
5/26	Spring	0.75	0.95	1.15	1.27	1.20	1.12	1.00	1.27	1.02	1.12	.37	4
11/27	Sum/Fall	1.17	0.97	1.50	1.07	1.20	0.96	1.00	1.22	1.22	1.55	.33	4

Phosphorus (%)

Sample Date	Period	Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K	LSD .05	Seedlings per treat.
5/26	Spring			0.14	0.13				0.15	0.13		.02	4
11/27	Sum/Fall			0.16	0.13				0.12	0.11		.02	4

Survival (table 11)--Seedling survival after ouplanting was improved by nitrogen fertilization in the nursery. Wilting reduced survival in all treatments except +NPK.

DISCUSSION

Growth and survival after outplanting were clearly enhanced by nitrogen fertilization during the hardening-off and dormant periods in the nursery. The correlations between root and shoot dry weights at the end of the nursery phase and root and shoot dry weight at end of both the spring and summer/fall periods in the field demonstrate that good seedling growth in the field is strongly related to cultural practices which enhance growth in the nursery (table 12). Good correlations between survival and root and shoot dry weights at the end of the nursery phase indicate a relationship between seedling growth, as enhanced by nitrogen fertilization, and seedling survival (table 12).

Utilizing the relatively large supply of nitrogen in the shoot, and perhaps the roots, nitrogen-fertilized seedlings were able to attain shoot growth rates 10 times greater and root growth rates almost 3 times greater than nitrogen-deprived seedlings during the spring period of the outplanting phase (figure 2).

The root dry weight increases derived from increases in both the number and average length of new roots and resulted in significantly greater total average root extension (table 9). Nitrogen-fertilized seedlings had much greater root contact with the soil, and hence greater access to soil water and nutrients. Heiner and Lavender (1972) obtained a correlation between early root growth and Douglas-fir seedling survival. They also found a correlation between early budburst in the spring and survival, and suggested that early budburst is indicative of early root growth. In the current study, early root and shoot growth, as indicated by growth rates during the spring period, were well correlated with survival (table 12), while correlation between growth rate and survival for the other experimental period is relatively poor.

Table 11.--Percentage of seedling surviving in the spring and at the end of the first growing season after outplanting

Percent(%)

Sample Date	Period	Non-wilt CON	Non-wilt -N	Non-wilt +NPK	Non-wilt -P	Non-wilt -K	Wilt CON	Wilt -N	Wilt +NPK	Wilt -P	Wilt -K		Seedlings per treat.
5/8	Spring	100	100	100	100	100	96	98	95	100	98		56
11/27	Sum/Fall	20	11	31	47	47	13	5	29	27	24		47

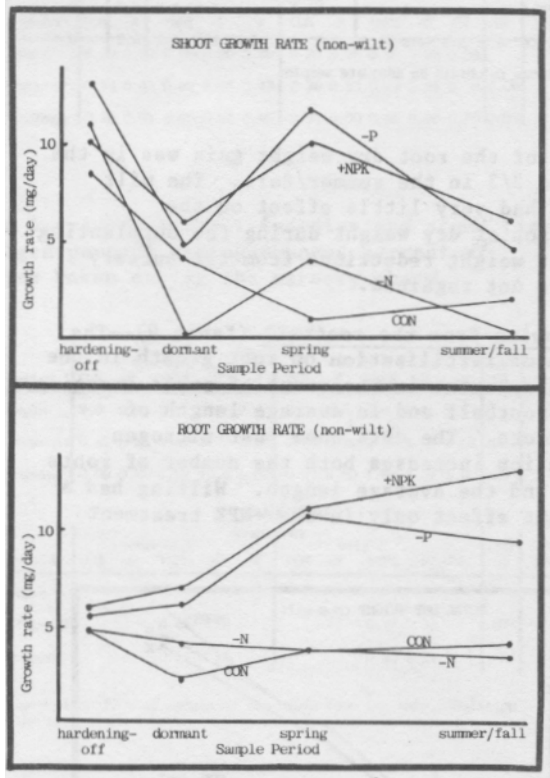

Figure 2.--Average root and shoot dry weight growth rates of non-wilted seedlings during selected experimental periods

Table 12.--Linear regression analysis of treatment means

"X" Means	"Y" Means	Regression equation	R^2
2/9 shoot dry wgt,grams	5/26 shoot dry wgt	Y = 3.0X - 1.7	.87
"	11/27 " " "	Y = 4.6x - 2.9	.86
2/9 root dry wgt,grams	5/26 root dry wgt	Y = 2.9X - 0.8	.85
"	11/27 " " "	Y = 6.9X - 2.5	.95
2/9 shoot dry weight	11/27 survival(%)	Y = 67X - 50	.77
" root " "	"	Y = 78X - 36	.75
shoot growth rate (mg/day)			
Dormant period	11/27 survival(%)	Y = .40X + 12	.27
Spring period	"	Y + .31X + 7	.78
root growth rate (mg/day)			
Dormant period	"	Y = .52X - 1	.51
Spring period	"	Y = .40x + 2	.79

These results emphasize the importance of early, vigorous seedling growth after outplanting, a characteristic which is greatly enhanced by nitrogen fertilization during the hardening-off and dormant periods in the nursery.

The use of high phosphorus levels to improve root development in the nursery during the dormant period as recommended in many cultural programs (Brix and van den Dreissche 1974, van Eerden 1974) is unnecessary. Removal of phosphorus from the nutrient solution did not reduce growth of roots or shoots. Nitrogen was the primary element controlling root growth rates in the current experiment. Philipson and Coutts (1977) obtained the same result for root growth in Sitka spruce using split-root techniques. They found that phosphorus played only a secondary role.

Application of moisture stress up to -15 bars late in the growing season had the anticipated but unimportant effect of increasing the rate of budset, but was detrimental to growth and survival in the field. The major effect of wilting was reduction of spring growth rates, particularly spring root growth rates.

Non-wilted seedlings showed substantial growth rate increases during the same time period (figure 3). No explanation of this effect is suggested by the data collected in this experiment.

CONCLUSIONS

Nursery cultural practices late in the growing season have a strong and persistent influence on seedling performance after outplanting. Nitrogen fertilization during the hardening-off and dormant periods was a beneficial practice. It consistently resulted in increased seedling growth, and hence increased seedling size, throughout the experiment. Nitrogen effects were most significant during the spring growth period immediately after outplanting, when large increases in growth rate were observed in nitrogen-fertilized seedlings. The results did not support the practice of supplying phosphorus during the dormant period in the nursery. Phosphorus provided no additional benefit beyond that attributable to nitrogen. Moisture stress to the wilting point during the hardening-off period in September proved detrimental to seedling performance in the field.

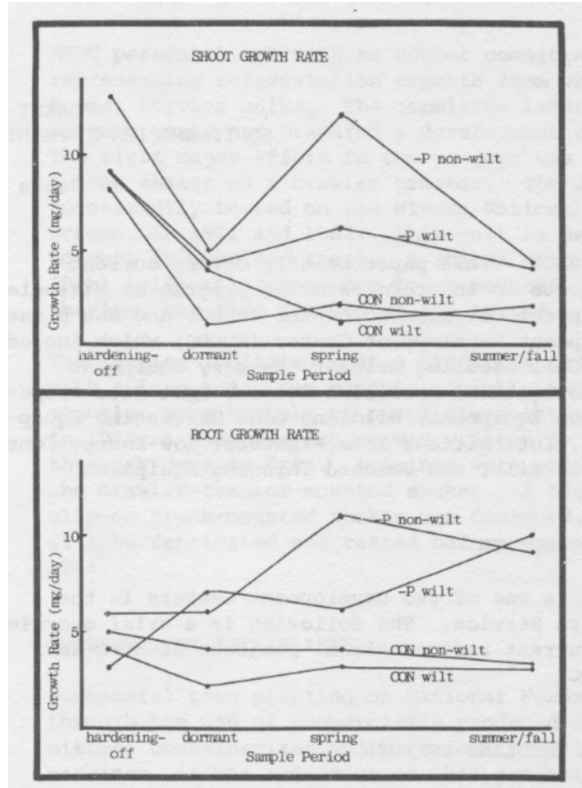

Figure 3.--Average root and shoot dry weight growth rates of wilted and non-wilted seedlings for minus-P and Control fertilizer treatments

REFERENCES

Brix, H., and van den Driessche, R. Mineral nutrition of container-grown tree seedlings. Proc. of North American Containerized Forest Seedlings Symposium. Great Plains Agric. Council Publ. No. 58:77-84; 1974.

Hahn, P.E. Containerized seedling production in a shelterhouse system, p. 110-128. In: Proc. of the 1982 Western Nurserymen's Conference, Western Forest Nursery Council; 1982. 211 p.

Heiner, T.C. and Lavender, D.P. Early growth and drought avoidance in Douglas-fir seedlings. Res. Paper 14, Forest Res. Lab., School of Forestry, Ore. St. Univ., Corvallis; 1972.

Lavender, D.P. and Carmichael, R.L. Effect of three variables on mineral concentrations in Douglas-fir needles. Forest Sci. 12(4):441-446; 1966.

Philipson, J.J. and Coutts, M.P. The influence of mineral nutrition on the root development of trees. II. The effect of specific nutrient elements on the growth of individual roots of sitka spruce. J. Exp. Bot. 20(105):864-871; 1977.

Smith, R.B., Wareing, R.H., and Perry, D.H. Interpreting foliar analysis from Douglas-fir as weight per unit of leaf area. Can. J. For. Research 11(3):593-98; 1981.

van den Driessche, R. Tissue nutrient concentration of Douglas-fir and sitka spruce. B. C. Forest Serv. Res. Note No. 47, 42 p; 1969.

van Eerden, E. Growing season production of western conifers, p. 93-103. In: Proc. of the No. Amer. Containerized Forest Seedlings Symposium. Great Plains Agric. Publ. 68; 1974.