First-Year Field Performance of Douglas-fir Seedlings in Relation to Nursery Characteristics[1]

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Abstract.--First-year field performance of 48 Douglasfir seedling samples from six nurseries and nine seed sources was analyzed in relation to nursery measurements of seedling morphology, phenology, and vigor. Height at lifting accounted for 84 percent of the variation in first-year field height, while root dry weight and stem diameter at lifting had the highest correlations with first-year height growth (r^2 = 0.43 for both). A combination of phenological, morphological, and physiological characteristics yielded the best predictions of field performance (e.g., root dry weight at lifting combined with two vigor-test measurements accounted for 63 percent of the variation in first-year height growth). All correlations of nursery characteristics with first-year field survival were non significant. First-year height growth and frequency of multiple leaders in the field were negatively related (r^2 = 0.16).

INTRODUCTION

High-quality seedlings are necessary for successful reforestation. Because morphological characteristics of seedlings are easy to measure, most nurseries grade their seedlings according to those criteria (Ritchie 1984, Thompson 1985). Recently, however, the physiological condition of a seedling has been emphasized as an important determinant of its ability to survive and grow in the field (Duryea 1984, Ritchie 1984, Duryea 1985), and nurseries and reforestation organizations are examining more closely the use of physiological qualities (e.g., root growth potential, frost hardiness, stress response, or vigor) as well as traditional morphological measurements in assessing field performance potential.

The objective of this study was to investigate the relationships of Douglas-fir (*Pseudotsuga menziesii*) first-year field performance to nursery measurements of seedling phenology, morphology, and vigor.

MATERIALS AND METHODS

Data for this study were originally gathered during an investigation of top-pruning effects on the morphology, physiology, and field performance of Douglas-fir (Duryea and Omi, unpublished). In 1983, two-year-old bareroot seedlings were selected at **six** nurseries in central California, Oregon, and southwestern Washington (fig. 1). Four plots (averaging 3.7 x 1.2 m) of unpruned seedlings were selected from each of two seed sources at each nursery. Seed zones ranged in elevation from 305 to 1219 m (table 1). Because one seed source was common to four of the nurseries, nine seed sources were represented in the study. Forty-eight samples were used for comparing seedling characteristics to field

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performance (12 nursery and seed source combinations x 4 plots).

MEASUREMENTS Phenology

Nursery flushing date was defined as the date during the second growing season when 50 percent of the seedlings had initiated growth (needles emerging through bud scales). Approximately six weeks after this date, 20 seedlings per plot were flagged and numbered. The terminal bud of each was rated as growing (flushed) or not actively growing (budset), and was monitored by nursery personnel approximately once a week for 14 weeks and then once every two weeks until late fall. The two phenological measurements derived for each seedling were budset date (Julian date of final budset) and weeks to budset (number of weeks from flushing date to final budset). This second measurement, therefore, assesses growing-season length.

Morphology

Seedlings were lifted during January and February 1984 (table 1) and graded. In contrast to some operational grading procedures, seedlings with multiple leaders were retained if they met all other standards. After grading, seedlings were root-pruned to 25 cm, and approximately 20 seedlings per plot were measured for shoot height, stem diameter, number of branches, terminal bud length, and shoot and root dry weights. Shoot:root ratios were calculated from these dry weights.

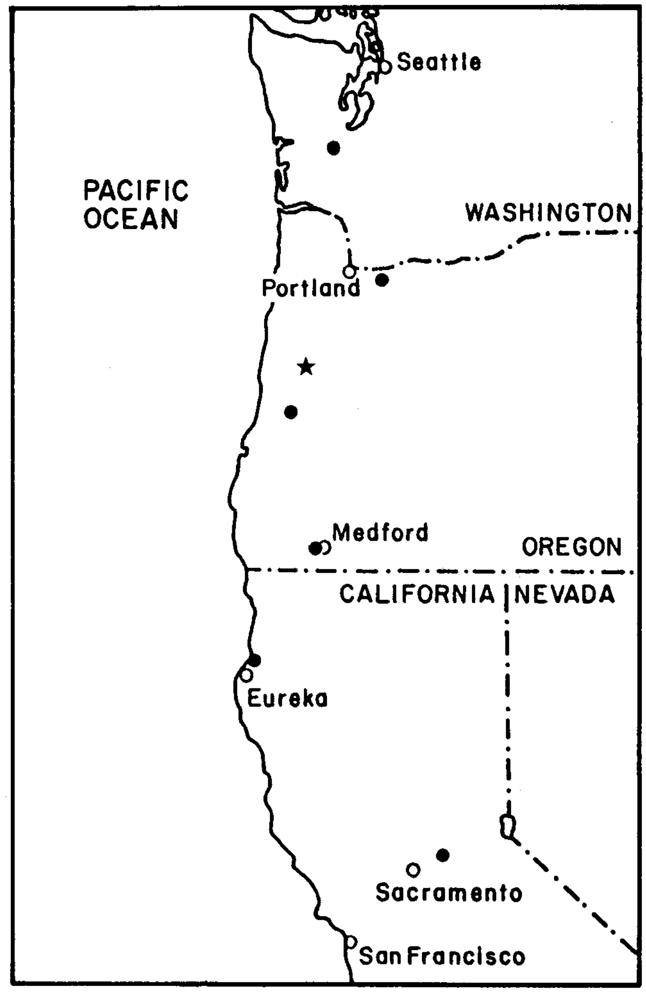

Figure 1. Locations of nurseries (•) and planting site (★).

Table 1. Nursery and seed zone characteristics and lifting and planting dates for the twelve nursery and seed source combinations.

Nursery[1]	Seed zone	Elevation in ft (m)	Owner of stock	Seedbed density in seedlings per ft² (m²)	Lifting date	Planting dates
1	030	1000 (305)	Washington Dept. of	22 (237)	2/7/84	3/14/84 - 3/27/84
	430	1000 (305)	Natural Resources	24 (258)	1/10/84	3/14/84 - 3/27/84
2	270	1500 (457)	International Paper Co.	22 (237)	2/14/84	3/28/84 - 4/11/84
	461	3500 (1067)	Willamette Industries	20 (215)	2/14/84	3/14/84 - 3/27/84
3	270	2000 (610)	Medford District, BLM	30 (323)	1/17/84	3/28/84 - 4/11/84
	062	1500 (457)	Eugene District, BLM	22 (237)	1/17/84	3/14/84 - 3/27/84
4	270	2500 (762)	Medford District, BLM	34 (366)	1/11/84	3/28/84 - 4/11/84
	492	3500 (1067)	Umpqua National Forest	26 (280)	1/11/84	3/14/84 - 3/27/84
5	270	2000 (610)	Medford District, BLM	21 (226)	1/31/84	3/28/84 - 4/11/84
	072	1000 (305)	Coos Bay District, BLM	22 (237)	1/31/84	3/14/84 - 3/27/84
6	525	4000 (1219)	Tahoe National Forest	34 (366)	1/24/84	3/14/84 - 3/27/84
	524	2500 (762)	Plumas National Forest	48 (517)	1/24/84	3/14/84 - 3/27/84

[1] See figure 1 for nursery locations.

OSU Vigor Test

A separate sample of 20 shippable seedlings per plot was used for seedling quality evaluation in the OSU vigor test (McCreary and Duryea 1985). Seedlings were randomly divided into two groups of 10. One group was given a 15-minute stress treatment (root exposure at 30°C and 30% relative humidity), and the other was left unstressed (McCreary and Duryea 1985). Two-month greenhouse survival and the number of seedlings that had broken bud after one month were recorded for both groups.

Field Performance

Seedlings were planted on one site at the OSU McDonald Forest in Corvallis, Oregon (fig. 1) over a one-month period in spring 1984 (table 1). Seedlings from each nursery sample were planted as two randomly assigned 10-tree row plots at 1.2 x 1.2 m spacing (960 seedlings total). Vexar® tubes were placed over all seedlings immediately after planting.

In the fall of 1984 (one season after planting), survival, total height, 2+0 height, and stem condition (multiple or dominant leader) were recorded for each tree. First-year height growth was determined by subtracting 2+0 height from first-year height.

Data Analyses

Sample means for all field traits were calculated by averaging over the two 10-tree row plots (20 seedlings). Coefficients of simple determination (r^2) were computed on nursery and field means for all samples (N = 48). In addition, a stepwise regression procedure (SAS Institute, Inc. 1985) was used to develop relationships between the independent (i.e., nursery phenology and morphology, OSU vigor test) and dependent (i.e., field performance) variables, and for these a coefficient of multiple determination (R^2) was calculated. To remain in the model, independent variables had to cause a reduction in the sums of squares of the dependent variable at the 0.05 level of significance. Before analysis, all proportions were transformed to arcsine square-root values (Steel and Torrie 1980).

RESULTS

First-year Field Survival

Correlations of all independent variables with first-year field survival were nonsignificant ($P > 0.05$, table 2). Uniformly high survival among all samples made it difficult to detect significant relationships. Mean survival was 90 percent (s.e. = 1%) and ranged from 70 to 100 percent. Because survival varied little among sample means, no adequate regression model could be derived.

First-year Height

First-year height was significantly correlated ($P < 0.01$) with several independent variables (table 2). Coefficients of determination ranged from 0.14 (budbreak of unstressed seedlings) to 0.84 (height at lifting); budset date and weeks to budset were also significantly correlated with first-year height (r^2 = 0.35 and 0.64, respectively). Average first-year height was 43 cm (range 29 to 62 cm, s.e. = 1.34 cm).

The best regression equation for predicting first-year height included height at lifting, shoot:root ratio, and weeks to budset, and accounted for 90 percent of the variation in first-year height. However, variation in height at lifting alone could account for 84 percent of the variation in first-year height.

First-year Height Growth

Nine of the 14 independent variables were significantly correlated with first-year height growth (table 2); root weight and stem diameter at lifting had the highest correlations (r^2 = 0.43 for both; fig. 2). Again, weeks to budset had a higher correlation ($r^2 = 0.18$, $P < 0.01$) than budset date ($r^2 = 0.02$, $P > 0.05$).

The best regression equation for predicting first-year height growth accounted for 78 percent of the variation and included root weight, stem diameter, survival and budbreak of unstressed seedlings (OSU vigor test), shoot weight, weeks to budset, and frequency of multiple leaders at lifting. Root weight combined with unstressed vigor-test survival and budbreak accounted for 63 percent of this variation; stem diameter in the same combination accounted for 57 percent.

Because weeks to budset only accounted for an additional three percent of the variation in first-year height growth when entered into the model, we deleted this variable to explore the relationships among the others; and, because the remaining variables could be classified as either physiological (OSU vigor test) or morphological, we investigated each class of independent variables separately. When only morphological variables were considered, the best regression equation involved root weight alone and accounted for 43 percent of the variation in height growth. When only physiological traits were analyzed, both budbreak and survival of unstressed seedlings contributed significantly to reducing the sums of squares ($R^2 = 0.32$).

First-year height and height growth were positively correlated ($r^2 = 0.26$, $P < 0.01$). First-year height growth averaged 7 cm (s.e. _ 0.3 cm) and ranged from 3 to 12 cm.

Frequency of Multiple Tops After One Year

After one year in the field, only four independent variables were significantly correlated with the proportion of multiple-leader seedlings (table 2); first-year height growth , and multiple-leader frequency in the field were negatively related ($r^2 = 0.16$, $P < 0.01$). Mean frequency of seedlings with multiple leaders in the field was 21 percent (s.e. = 2%) and ranged from 0 to 61 percent.

The best predictive regression equation included the proportion of multiple-leader seedlings at lifting, weeks to budset, and height at lifting, and accounted for 46 percent of the observed variation in multipleleader frequency in the field.

DISCUSSION

Significant correlations between nursery characteristics and field performance suggest that a variety of phenological, morphological, and physiological nursery characteristics could be used for predicting seedling quality for the samples in this study. Several of these relationships previously have been confirmed. Thompson (1985) indicated that morphological characteristics such as seedling height, stem diameter, dry weight, and bud length are significantly correlated with the field performance of many conifer species. McCreary and Duryea (1985) reported significant correlations between the OSU vigor test and field performance.

In our study, morphological variables were consistently the best predictors of field performance. Although the best regression .model for predicting first-year height included other variables, height at lifting accounted for 84 percent of the variation. Similarly, combining root weight or stem diameter with OSU vigor test measurements yielded significant regression equations for first year height growth. However, of the important seedling-quality indicators in this study, stem diameter appeared to be one of the most practical because of its ease of measurement.

Height at lifting was not significantly related to first-year height growth ($r^2 = 0.05$). Because it is reasonable to expect

Table 2. Coefficients of determination (r^2) relating first-year field performance with nursery budset and with morphology and OSU vigor test at lifting.

Nursery variable	First-year field performance: Survival (%)	Height (cm)	Height growth (cm)	Multiple leader (%)
Weeks to budset	0.04	0.64**	0.18**	0.01
Morphology at lifting				
Root weight (gm)	0	0.26**	0.43**	0
Shoot weight (gm)	0	0.59**	0.25**	0.02
Total weight (gm)	0	0.50**	0.32**	0
Height (cm)	0.05	0.84**	0.05	0.10*
Stem diameter (mm)	0	0.42**	0.43**	0
Number of branches	0.01	0.21**	0.01	0.06
Terminal bud length (mm)	0.01	0.18**	0.13*	0.04
Shoot:root ratio	0	0.20**	0.08*	0.23**
Multiple leader (%)	0	0.03	0	0.21**
OSU vigor test at lifting				
Unstressed seedlings				
Survival (%)	0.06	0.05	0.10*	0.07
Budbreak (%)	0	0.14**	0.08*	0.02
Stressed seedlings				
Survival (%)	0.01	0.02	0.03	0.19**
Budbreak (%)	0.01	0.08*	0	0.08

* Significant at $P < 0.05$
** Significant at $P < 0.01$

that future growth potential is more closely related to first-year height growth than to height at lifting, the latter seemed relatively unimportant for assessing the field growth potential of seedlings in this study. If superior first-year height growth translates into growth superiority in later years, the seedling traits most important to consider for long-term performance are those which, either alone or in combination, best predict first-year height growth.

Although weeks to budset (length of growing season) was correlated with first year height (r^2 = 0.64) and height growth (r^2 0.18), it may not be useful as an indicator of seedling quality because of the time required for measurement. In addition, when combined with the other independent variables in the best models, weeks to budset only accounted for 2 to 3 percent of the variation in firstyear height and height growth. However, weeks to budset was consistently a better predictor of field performance than budset date, probably because budset date is strongly influenced by the nursery environment. The nurseries in this study were geographically distant; seedlings in nurseries farther north would naturally have earlier budset dates because of climate and cultural practices that induce earlier seedling dormancy. Weeks to budset is less influenced by differences in nursery environment because it is essentially a measure of growing season length, and, although growing season length also varies somewhat among nurseries, the predictive ability of this variable appeared to be better than that of budset date.

As with phenological characteristics, OSU vigor test variables require more time for measurement than do morphological characteristics; and, in contrast to previous reports (HcCreary and Duryea 1985), we found poor relationships between OSU vigor test variables and field performance. This may be due to confounding effects of planting dates and storage intervals for the twelve nursery and seed source combinations; the time interval between stress tests and actual planting date must be minimized (McCreary and Duryea 1985), and that interval ranged from one to three months in this study. Another possible explanation is the lack of variability in vigortest means. For example, average growth-room survival of unstressed seedlings was consist-

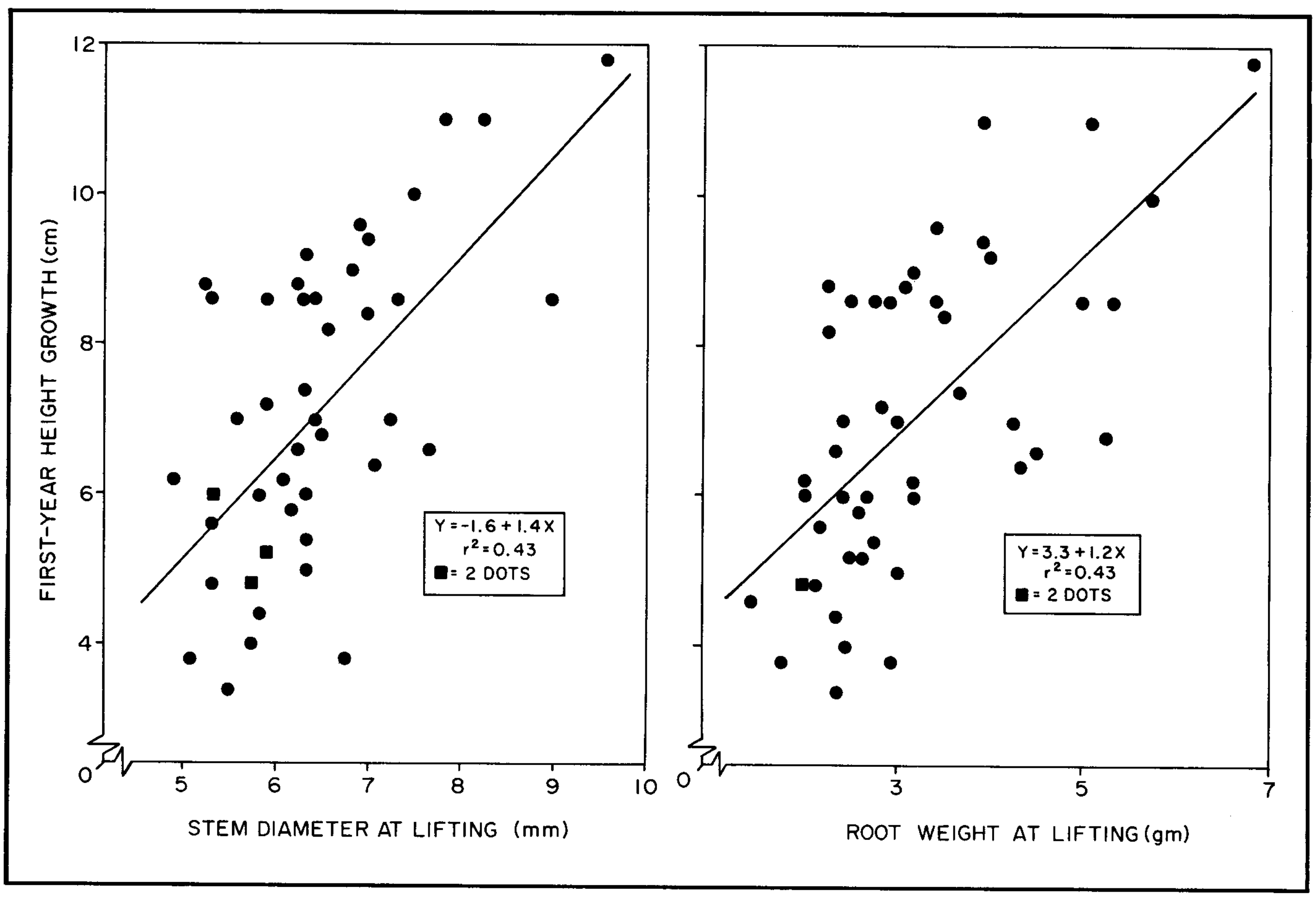

Figure 2. Relationship of first-year height growth to stem diameter and root weight at lifting.

ently high (average 97%, range 50 to 100%), which made it difficult to develop strong relationships with the dependent variables (McCreary and Duryea 1985).

The significance of multiple leaders as an indicator of seedling quality is largely unknown. Reports in the literature suggest that apical dominance is apparent in multipleleader seedlings after two growing seasons in the field (Lanquist 1966, Dierauf 1976, Webb and Reese 1984). Three years after outplanting, survival of white spruce (Picea glauca), black spruce (Picea mariana), and jack pine (Pinus banksiana) differed little between trees with single leaders and those with multiple leaders at lifting (Webb and Reese 1984). Webb and Reese (1984) also indicated that multiple-leader trees may have field height growth similar to that of single-leader trees. In our study, the nursery multipleleader condition was positively correlated, and first-year height growth was negatively correlated, with the occurrence of multiple leaders after the first growing season in the field. The long-term retention of multiple leaders and its effect on field performance remain to be investigated.

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