Seed Source Variation for Height and Crown Traits of Fraser Fir Christmas Trees

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ABSTRACT. *Four-year-old open-pollinated progeny of Fraser fir (*Abies fraseri *[Pursh] Poir.) from several elevations on each of five mountains were planted at three locations in western North Carolina. Total height, crown diameter, branch diameter, number of branch buds, number of buds in the terminal cluster, and tree crown density factor all varied significantly by seed source. Low elevation sources (5000–5500 ft) grew taller and had larger crowns than the high elevation seed sources (6000 and 6500 ft). The seed sources collected from Roan Mountain, the area most often used for commercial seed collection, were significantly poorer than the best seed sources for total height, crown diameter, and density factor. Seed source × location interactions were significant for total height, crown diameter, number of buds in the terminal cluster, and branch diameter, but the best seed sources were generally the same in all tests. South. J. Appl. For. 17(1): 5–9.*

The production of Christmas trees and associated products is a significant industry in North Carolina. During the 1990 season, an estimated $65 million worth of trees were harvested in North Carolina; approximately 75% were Fraser fir (*Abies fraseri* [Pursh] Poir.). A combination of form, needle retention, dark blue-green color, excellent shipping characteristics, and pleasant scent has made Fraser fir Christmas trees widely desired by the nation's consumers and is frequently the species against which all others are judged. Fraser fir is a medium-sized tree, usually found on poorly developed, fertile, rocky to sandy loam soils with a pH ranging from 3.5 to 5 5 (Brown 1941, Thor et al. 1962). In plantations, the species grows well at elevations above 3000 ft, but seldom survives or grows well below 2000 ft. In addition to elevation, soil characteristics, slope, and aspect are important determinants of natural occurrence (Thor et al. 1962). The sensitivity of the species to elevation may be the most important limiting factor in establishing large-scale plantations because suitable land at high elevations is often at a premium.

Generally, genetic variation can be expected to be great for species that occur naturally in disjunct populations. Geographic variation is usually explained by genetic drift or varied natural selection pressures on isolated populations. This kind of variation is of key importance for tree breeding, and the success of any tree improvement program depends on a knowledge of variation and its proper utilization. Species that contain the largest racial divergence afford the best opportunity for genetic gains through provenance selection (Zobel and Talbert 1984). In general, provenances from low– to mid elevations at southern latitudes are superior in growth rate to those from high elevations (Callaham and Liddicoet 1961, Fryer and Ledig 1972, Hermann and Lavender 1968, Mirov et al. 1952). In Fraser fir, the low elevation southern mountain provenances tended to be taller than high elevation sources after 1 growing season in the field (Li et al. 1988).

At present, most commercial seed collections of Fraser fir are from natural stands on Roan Mountain, especially at high elevations where the stands are relatively pure and accessible. Although it is easy to obtain seeds from Roan Mountain, there may be economic implications if high elevation sources grow slowly.

The objectives of this study were to determine the magnitude of differences among nine seed sources of Fraser fir and to determine the magnitude of seed source × environment interactions.

Materials And Methods

Seed Sampling

Seeds were collected from five mountains chosen to represent the major populations of Fraser fir (Figure 1). These mountains were chosen because: (1) Roan Mountain is the area most often used for commercial seed collection; (2) Clingman's Dome and Richland Balsam are the most southerly of the major Fraser fir populations; (3) Mount Mitchell is in the central portion of the range; and (4) Mount Rogers is the most northern source of Fraser fir commonly used for seed collection.

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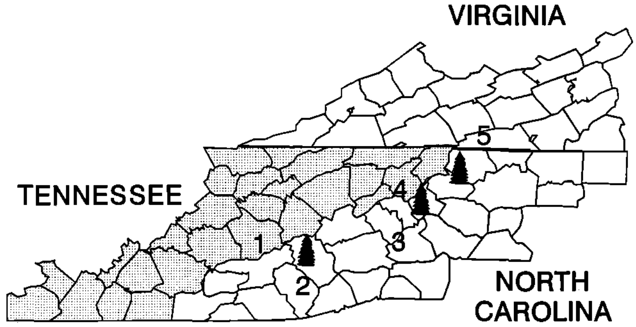

Figure 1. Location of Fraser fir seed sources (indicated by the numbers) and the seed source trials (indicated by tree symbols). Seed source number 1 is Clingman's Dome, 2 is Richland Balsam, 3 is Mt. Mitchell, 4 is Roan Mountain, and 5 is Mt. Rogers.

Each mountain was divided into seed sources by elevational increments of 500 ft. Each elevation and mountain combination was considered as a separate seed source (nine total seed sources, Table 1), since there was large elevational variation in climate, soil, and vegetation conditions. Open-pollinated seeds were collected from up to 10 trees per seed source if cones were present on trees in these areas. The sample trees were dominants or codominants and were reasonably straight without forks. The trees chosen were at least 200 ft apart to reduce the possibility of collecting from highly related individuals.

To cover the entire elevational range of the species without leaving large gaps, trees chosen within a mountain were aligned along the same aspect. A lack of cones and absence of Fraser fir at certain elevations resulted in cone collections from a total of only 90 families (Table 1).

Testing Procedures

Seeds for the study were sown by open-pollinated (OP) family in 10 in.^{3} Ray Leach® tubes in a Weyerhaeuser Company greenhouse at Comfort, NC, in December 1980. Some families were lost due to poor seed germination. Seedlings grown in the greenhouse for 1 year were transplanted to a nursery bed at the North Carolina Forest Service nursery in Crossnore, NC, in spring 1982 (cf. Li 1984).

Field trials were established in spring 1984 with 1–2 seedlings at three locations in western North Carolina (Figure 1):

1. Bald Mtn., Watauga Co., NC (36°44'N, 81°39'W), 5118 ft elev.
2. Crossnore, Avery Co., NC (36°0'N, 82°W), 2950 ft elev.
3. Purchase Knob, Haywood Co. (35°30'N, 83°0'W), 4429 ft elev.

Table 1. Seed collection locations and elevations used for Fraser fir seed source analysis.[1]

Elevation (ft)	Clingman's Dome	Richland Balsam	Mt. Mitchell	Roan Mountain	Mt. Rogers
6500	—	—	10	—	—
6000	10	—	10	10	—
5500	10	10	—	10	—
5000	10	—	—	—	10

[1] The numbers shown at each mountain/elevation represents the number of open-pollinated families collected at that location.

A randomized complete block design was used, with six blocks at each location. Five trees per family were randomly assigned to positions within each block (e.g., a noncontiguous plot design) and were planted at a 6 × 6 ft spacing. Each planting received standard Christmas tree fertilization and weed and insect control practices. However, the trees were not sheared at the time of this analysis.

The following traits were measured on each tree after 4 growing seasons: (1) total height; (2) crown diameter, determined by averaging two crown width measurements taken along row and column axes and averaged for each tree; (3) branch diameter—the diameter of the longest branch in the branch whorl nearest the terminal bud, measured just beyond the point of basal swelling; (4) branch bud number—the number of lateral buds on the same branch measured for diameter; (5) terminal bud number—the total number of buds in the terminal cluster of the central stem; and (6) density factor—the product of terminal bud number and branch bud number.

Statistical Procedures

The mean of all measurement trees within a seed source was calculated for each location-block-seed source combination (i.e., plot means). Six of the nine seed sources were represented by trees from ten families; two seed sources had nine families; and one seed source had seven families. Data from block 1 in the Crossnore planting were deleted because block 1 contained a poorly drained area that resulted in numerous trees dying from Phytophthora. Data from the three field plantings were pooled for a combined analysis of variance to determine the significance of seed source and seed source × environment interaction effects (Table 2). Seed sources were considered as fixed effects, and other effects were considered as random. Significant differences among seed sources were determined using Waller-Duncan K-ratio T test (SAS Institute Inc. 1988). For traits with significant seed source × location interactions, stability-variance parameters (Shukla 1972) were estimated using the program written by Kang (1985) to determine which seed sources were contributing significantly to the interaction sums of squares. A probability level of $P \leq 0.05$ was used as the minimum level for determining statistical significance.

Results And Discussion

Seed Source Differences

Significant differences were found among seed source means averaged over the three planting locations for all traits measured in the study (Table 2). The mean total height for seed sources ranged from 2.95 to 3.61 ft after 4 growing seasons in the field (Table 3). The tallest seed source, Richland Balsam-5500, grew more than the two seed sources most frequently used for commercial seed collection, Roan Mountain-5500 and -6000, by 11.6% and 17.6%, respectively. Seed source differences of this magnitude are important, and a large

Table 2. Results of analyses of variance based on seed source-block means for the Fraser fir seed source study after four growing seasons.

		Mean squares[1]					
Source[2]	df	Total ht	Crown diam	Density factor	No. terminal buds	No. branch	Branch diam
L	2	26.61	5.94	3085	1.09	182.34	0.03580
B(L)	14	0.28	0.15	389	0.16	11.12	0.00303
S	8	1.12**	0.23**	912**	0.43**	25.72**	0.00138**
S × L	16	0.13**	0.03**	29ns	0.12**	0.39ns	0.00013*
Error	112	0.02	0.01	22	0.03	0.55	0.00007

[1] *, ** Significant at $P \leq 0.05$ and 0.01 respectively; ns = Nonsignificant.
[2] Significance of location effect and block (location) effect were not tested. L = location, B(L) = blocks within locations, S = seed sources, S × L = seed source × location interaction.

gain for height growth can be expected from choosing the best seed sources.

In general, seed sources from elevations of 5000 and 5500 ft were taller than those from 6000 and 6500 ft. The interactions between mountains and elevations could not be studied since the sample of elevations was different among mountains. Only collections from Clingman's Dome, Roan Mountain, and Mount Mitchell could be compared for elevational effects. There was little difference in height growth between Clingman's Dome-5000 and -5500, but trees from these two lower elevations were significantly taller (18.9% and 19.2%, respectively) than the trees from Clingman's Dome-6000. Mean total height of Roan Mountain-5500 was only 5.5% greater than that of Roan Mountain-6000. The trees from Mount Mitchell-6000 were 8.5% taller than those of Mount Mitchell-6500. Based on the results from these three mountains, the trend is for increasing height growth with decreasing elevation. This same pattern was found in this trial after the first growing season in the field (Li et al. 1988). Similar results have been reported for several other conifer species (Jaquish 1990, Orlic and Ocvirek 1990, Fryer and Ledig 1972, and Callaham and Liddicoet 1961).

Low elevation seed sources (5000–5500 ft) tended to have larger crown diameters than those from 6000 and 6500 ft (Table 3). Clingman's Dome-5000 had a mean crown diameter that was 13.8% larger than the Clingman's Dome-6000 seed source. Compared to the commercial seed collection areas on Roan Mountain, the Clingman's Dome-5000 was 5 8% and 6.4% larger than the Roan Mountain-5500 and -6000 seed sources, respectively. Seed source differences in crown size were reported by Warlick et al. (1985) for Virginia pine (*Pinus virginiana* Mill.) Christmas trees. They viewed crown width as a measure of growth potential of lateral branches that in turn indicated the potential to mask flaws in the crown. If crown size is a measure of the vigor or potential of the trees to respond to cultural practices such as Christmas tree shearing, then the low elevation sources would be advantageous to the Fraser fir Christmas tree producer.

Branch diameter is important to Christmas tree growers since trees with large branches are more difficult to bale for shipment and are especially difficult to box for mail order sales. Although seed sources differed significantly in mean branch diameter (Table 2), the differences were very small (Table 3). The Mt. Rogers-5000 seed source had the largest branch diameter and differed from the seed sources with the smallest branch diameter by 0.03 in. (Table 3). There seems to be a trend for higher elevation sources to possess reduced branch diameters.

While there were significant differences among seed sources in the number of terminal buds, the means only ranged from 5.00 to 5.52 (Table 3). This narrow range in the number of terminal buds, which represents the number of first order lateral branches in a whorl, offers little possibility for selection and breeding. There were no apparent trends in terminal bud number between high and low elevation seed sources.

Seed sources differed significantly for the mean number of branch buds (Table 2). The Mt. Rogers-5000 seed source was very different from the other seed sources averaging 12.3 buds per branch compared to 9.6 for the next best seed source, Richlands Balsam-5500 (Table 3). Again, there were no

Table 3. Mean total height, crown diameter, buds in terminal whorl, branch buds, branch diameter, and density factor for nine Fraser fir seed sources.[1]

Seed source	Total ht (ft)	Crown diam (ft)	No. buds in terminal whorl	No. branch buds	Branch diam (in.)	Density factor[2]
Richland Balsam—5500	3.61a	2.51a	5.52a	9.63b	0.227bc	54.05b
Clingman's Dome—5500	3.53a	2.53a	5.37abc	9.17cd	0.227cd	50.35c
Clingman's Dome—5000	3.52a	2.55a	5.13cd	8.79de	0.226cd	46.50def
Mt Rogers—5000	3.44ab	2.48ab	5.47ab	12.34a	0.242a	68.26a
Roan Mt.—5500	3.24bc	2.41ab	5.22bcd	9.35b	0.235ab	49.58cd
Mt Mitchell—6000	3.20bc	2.44ab	5.35abc	8.83de	0.215e	48.32cde
Roan Mt.—6000	3.07cde	2.35bc	5.36abc	8.69e	0.223cd	47.29cde
Clingman's Dome—6000	2.97cde	2.24c	5.35abc	8.16f	0.219de	44.81ef
Mt Mitchell—6500	2.95de	2.24c	5.00d	8.52ef	0.214e	43.49f

[1] Means within a column followed by the same letter are not significantly different ($P \leq 0.05$).
[2] Density factor is an estimate of crown density based on the product of the number of buds in the terminal whorl and branch bud number.

Table 4. Stability variances[1] for total height, crown diameter, number of buds in the terminal whorl, and branch diameter of nine Fraser fir seed sources.

Seed source	Total ht	Crown diam	No. buds in terminal whorl	Branch diam
	Adjusted Sigma-square[2]			
Clingman's Dome—5000	0.04	0.04*	0.03	0.009
Clingman's Dome—5500	0.19**	0.07**	0.45**	0
Clingman's Dome—6000	0.01	0.01	0	0.011
Richland Balsam—5500	0.13**	0.04*	0	0.024*
Roan Mountain—5500	0.14**	0.05**	0	0.013
Roan Mountain—6000	0	0	0	0
Mt. Rogers—5000	0.01	0.03*	0.28**	0.002
Mt. Mitchell—6000	0	0.01	0.01	0
Mt. Mitchell—6500	0.01	0	0.04	0.008

[1] Stability variance (Shukla 1972) for each seed source after adjustment for site-mean.
[2] *, ** = significant stability variance value (Si^2) at $P \leq 0.05$, and $P \leq 0.01$, respectively. A significant stability-variance indicates instability in seed-source performance over locations.

apparent trends associated with elevation of the seed source because Clingman's Dome-5000, at the same elevation as Mt. Rogers-5000, had 40% fewer branch buds.

Foliage density is an important trait affecting Christmas tree quality. Crown density is a consideration for the current United States Christmas tree grades (USDA 1989). Density is affected by the number of first-order branches per unit length of bole, and the number of second-order branches per unit length of first-order branch. In this study terminal bud number was used as a measure of the number of limbs in a whorl, and the branch bud number was used to estimate the potential number of second-order branches. The product of the number of terminal buds and the number of branch buds was used to estimate crown density. There were significant differences among seed sources for the density factor (Table 2). The very high mean branch bud number of the Mt. Rogers-5000 seed source resulted in a density factor score that was 26% greater than the next best score for the Richland Balsam-5500 seed source. The two seed sources that are used most often for commercial seed collection, Roan Mountain-5500 and -6000, had density factors that were 36% and 44% lower than the Mt. Rogers-5000 seed source. The density factor of the low elevation seed sources tended to be greater than those from the high elevation sources (Table 3). Given the importance of crown density in determining Christmas tree grades, the seed source differences for crown density factor may be extremely important in choosing seed sources for use in Christmas tree production.

Seed Source × Location Interaction

Significant seed source × location interactions were found for total height, crown diameter, branch diameter, and terminal bud number, but not for density factor and branch bud number (Table 2). If these interactions arose from seed source rank changes among sites, it could mean that different seed sources would be best for different sites. A stability-variance analysis (Shukla 1972) indicated that the Clingman's Dome-5500, Richland Balsam-5500, and Roan Mt.-5500 seed sources contributed significantly to the seed source × location interaction for total height (Table 4). Rank change seems to be most often associated with the lower (5000 and 5500 ft) elevation seed sources which also displayed the tendency for the greatest height growth (Table 5). A general trend of increased instability with increased performance potential has also been reported for Douglas-fir in Europe by Breidenstein et al. (1990) and in northwestern California by Kitzmiller (1990). Even with these statistically significant rank changes, the tallest seed sources tended to be tallest at all three locations (Table 5).

Clingman's Dome-5000, Clingman's Dome-5500, Richland Balsam-5500, Roan Mountain-5500, and Mt. Rogers-5000 contributed significantly to the seed source × location

Table 5. Mean total height (ft) and rank (in parentheses) at three planting locations and over all locations for nine Fraser fir seed sources.

Seed source	Planting location[1] Bald Mountain	Purchase Knob	Crossnore	Overall
Richland Balsam—5500	3.03(3)	3.35(1)	4.62(3)	3.61(1)
Clingman's Dome—5500	2.88(5)	3.26(2)	4.63(2)	3.53(2)
Clingman's Dome—5000	3.04(2)	3.07(4)	4.64(1)	3.52(3)
Mt. Rogers—5000	3.05(1)	3.22(3)	4.18(4)	3.44(4)
Roan Mt.—5500	2.97(4)	2.88(5)	3.98(6)	3.24(5)
Mt. Mitchell—6000	2.80(6)	2.82(6)	4.13(5)	3.20(6)
Roan Mt.—6000	2.67(7)	2.76(7)	3.92(8)	3.07(7)
Clingman's Dome—6000	2.51(9)	2.59(9)	3.97(7)	2.97(8)
Mt. Mitchell—6500	2.61(8)	2.71(8)	3.64(9)	2.95(9)

[1] Bald Mountain, 5118 ft elevation, Watauga County, NC.; Purchase Knob, 4429 ft elevation, Haywood County, NC.; Crossnore, 3297 ft elevation, Avery County, NC.

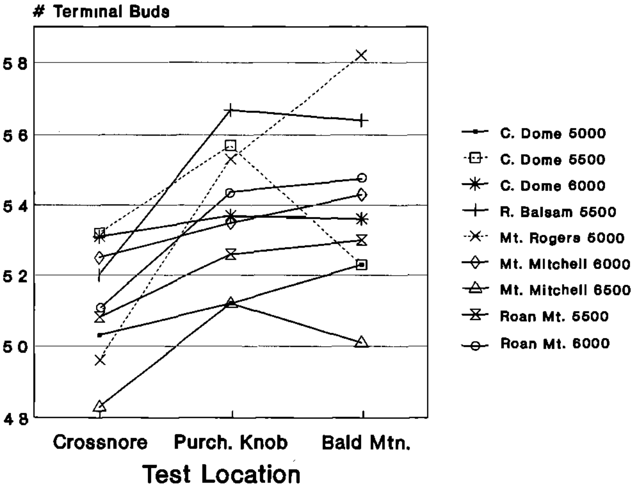

Figure 2. Seed source means for terminal bud number at each test site. The Clingman's Dome 5500 and Mt. Rogers 5000 seed sources (dashed lines) contributed significantly to the location by seed source interaction sums of squares (e.g., significant stability variances in Table 4).

interaction for crown diameter (Table 4). The same general pattern was found for total height; low elevation seed sources contributed more to the seed source × location interaction, but rank changes among the top seed sources were negligible.

Only two seed sources, Clingman's Dome-5500 and Mt. Rogers-5000, were significant contributors to the seed source × location interaction term for the number of terminal buds (Table 4). The elevation of the planting site has been previously observed to significantly influence the number of branches produced by Ponderosa pine (*Pinus ponderosa* Laws.) (Callaham and Liddicoet 1961). While the rank changes across the three sites for the Clingman's Dome-5500 and Mt. Rogers-5000 seed sources are very large (Figure 2), given the small differences in the number of terminal buds, there is little practical importance in the seed source × location interaction for this trait to a Fraser fir breeding program.

Although there was a significant seed source x location interaction for branch diameter (Table 2), only the Richland Balsam-5500 seed source contributed significantly to the interaction term (Table 4). Additionally, in view of the small differences in branch diameter between seed sources, the seed source × location interaction for branch diameter would have no bearing on an applied tree improvement program.

Conclusions

The significant differences found among seed sources of Fraser fir in total height, crown diameter, crown density factor, branch diameter, branch bud number, and terminal bud number after 4 growing seasons in the field indicate that seed source selection is of key importance to Christmas tree growers and tree breeders. The two seed sources currently used most often for commercial seed collections, Roan Mountain-5500 and -6000, were the poorest seed sources for many traits evaluated in this study. As a result, large gains can be expected by selecting seed sources other than the high elevation source from Roan Mountain for the Fraser fir breeding and operational planting programs.

Significant seed source × location interactions have the potential to increase the complexity of applied breeding programs. In our study, five of nine seed sources displayed a significant seed source × location interaction, and most of the interaction seemed to occur in the seed sources with the greatest growth potential from low elevations. In North Carolina, the bulk of commercial Fraser fir Christmas tree plantations occur at elevations less than 4000 ft.[1] The environment of these low elevation plantations should be more compatible with the low elevation seed sources and less likely to result in seed source instability. Consequently, seed source × location interactions are not expected to be important to the Fraser fir breeding and the operational planting programs, provided that low elevation seed sources are used.

[1] Personal communication, Mr. Richard Woodie, President of the North Carolina Christmas Tree Association 1991.

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