Seed Source Variation for Growth and Quality Traits of Fraser Fir Christmas Trees: Rotation Age Results

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ABSTRACT. *Open-pollinated Fraser fir* (Abies fraseri *[Pursh] Poir.) progeny from several elevations on each of 5 mountain sources were assessed at 8 yr (rotation age) for growth and quality traits. Seed sources varied significantly in total height, crown diameter, branch diameter, straightness, crown density, USDA Christmas tree grade, and Christmas tree value. Age 8 yr results were very similar to both 1 and 4 yr results; lower elevation, southern sources showed superior performance in most traits including wholesale value. The common commercial seed sources on Roan mountain performed poorly by comparison. Statistically significant seed source × location interaction found for height, crown diameter, branch diameter, and value proved practically unimportant. Top-ranked seed sources overall maintained superiority at all sites. Potential rotation age tree wholesale value gains to Christmas tree growers through changing from the current chief commercial seed source on Roan Mt. to superior seed sources may exceed 7%. South. J. Appl. For. 19(4): 157–161.*

Fraser fir (*Abies fraseri* [Pursch] Poir.) has become widely accepted as the preferred fresh cut Christmas tree species throughout the United States and commands appropriately high prices. An excellent shape, pleasant aroma, strong branches, dark blue-green color, and excellent postharvest needle retention are among its attributes. North Carolina is the leading producer of Fraser fir Christmas trees, and in this state it accounts for 75% of an $80 million a year industry (Cook 1990, Jett et al. 1993).

Fraser fir's natural range is very limited, occurring only in disjunct, isolated mountain stands above 4500 ft in Virginia, western North Carolina, and eastern Tennessee (Brown 1941, Thor et al. 1962). In cultivation, the species displays sensitivity to elevation and soils, typically growing well above 3000 ft but seldom surviving below 2000 ft in North Carolina (Thor et al. 1962).

Large genetic variation can generally be expected for species that occur naturally in disjunct populations (Zobel and Talbert 1984). This tends to develop through genetic drift or differential selection pressures on each isolated population through long periods of time. Knowledge and quantification of such variation is essential for tree breeders to achieve real genetic improvement in a species.

In most forest tree species, seed sources from lower to midelevations at lower latitudes of their natural range tend to grow more rapidly than those from higher elevations, higher latitudes, or both (Callahan and Liddicoet 1961, Fryer and Ledig 1972). Similar patterns for growth with respect to elevational source, at least through age 4 yr (half-rotation), have been found in Fraser fir (Jett et al. 1993).

Despite the species current economic importance, only superficial attention has been given to the relative performance of different seed sources for Christmas tree growth and quality. Higher elevation natural stands on Roan Mountain, the major commercial source, gained favor as a seed collection area due to stand purity, accessibility, and smaller tree size resulting in ease of seed collection. However, more important considerations of this species' genetic value in terms of growth and Christmas tree quality have not been considered to date. Commercial growers may be experiencing substantial economic loss if the Roan Mountain source proves inferior to other seed sources. In addition to the importance of seed source information, understanding its geographic genetic variation will be essential for effective conservation of this important species.

This study reports on both rotation age (typically 8 yr for Fraser fir Christmas trees) differences among 9 seed sources of Fraser fir for growth and Christmas tree quality, and on the magnitude of seed source × environment interactions.

Materials and Methods

A sampling of Fraser fir's natural range provided seeds of 90 open-pollinated families. These represented a total of 9

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separate seed sources covering the species elevational ranges over 5 separate mountains, as described previously by Li et al. (1988) and Jett et al. (1993).

Details covering the greenhouse, nursery, and field establishment phases of this trial, which commenced in 1980, are described by Li et al. (1988) and Jett et al. (1993). Field tests were planted in 1984 at three locations in western North Carolina: Bald Mountain (36°44'N, 81°39'W), Crossnore (36°0'N, 82°0'W), and Purchase Knob (36°44'N, 81°39'W). A randomized complete block design was used, with 5 trees per family randomly positioned in each of 6 blocks (i.e., a noncontiguous plot design). Trees were planted at a 6 ft × 6 ft. spacing. After 4 growing seasons in the field, all trees were pruned and sheared annually following standard Christmas tree cultural practices.

Measurements on each tree were carried out at planting, and after 1, 4, and finally 8 growing seasons. In 1991, after 8 growing seasons, but prior to year 8 shearing and shaping, all trees were assessed for the following traits: (1) total height; (2) crown diameter—maximum crown width was measured along the planting row and column axes and the two measurements were averaged for each tree; (3) branch diameter—the diameter of the longest branch in the whorl nearest the terminal bud was measured just beyond the point of basal swelling; (4) density—scored subjectively on a scale of 1 (best) to 3 (worst) in accordance with USDA Christmas tree grading standards (Anon. 1989); (5) straightness—also scored subjectively on a scale of 1 (best) to 3 (worst) in accordance with USDA grading standards on main stem curvature (Anon. 1989). In addition, following year 8 shearing and shaping, each tree was also measured for Christmas tree height merchandising class and scored for USDA grade. These grades in decreasing order of quality are Premium; No. 1.; No. 2; and Cull, as defined by USDA standards (Anon. 1989). The merchandising height class is the total post shearing height, less a 3 in. stump, rounded down to the nearest whole foot. Together, USDA grade and merchandising height class enabled a wholesale market value to be determined for each tree based on 1991 prices (Table 1). For statistical analyses in this study, USDA grades were assigned numerical values as follows; Premium = 0; No. 1 = 1; No. 2 = 2; and Cull = 3.

Results from after 1 and 4 growing seasons results have already been reported (Li et al. 1988, Jett et al. 1993). This report will focus on the 8 yr final assessment.

The mean of all trees from all families within a seed source were calculated for each location-block-seed source combination (i e , plot means). After 8 growing seasons, 5 of the original 10 seed sources were represented by 10 families. Other seed sources ranged from 6 to 9 families, providing 82 families in total. Block 1 at the Crossnore site was excluded from the analyses due to an unforeseen water drainage problem that had resulted in numerous tree deaths and poor development due to *Phytophthora cinnamomi* Rande root rot.

Table 1. Wholesale prices for fresh cut Fraser fir Christmas trees based on 1991 averages at the western North Carolina Farmers' Market.

Height class (ft)	USDA grade			
	Premium	No. 1	No. 2	Cull
		($)		
4 – 5	9	6	4	2
5 – 6	13	10	8	3
6 – 7	17	14	12	5
7 – 8	25	22	20	9
8 – 9	33	30	28	11

(Source: Pers. Comm., D. Massey, North Carolina Division of Agriculture)

The year 8 data from the 3 field locations was 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 all other effects were considered random. Differences among seed source means were analyzed for significance with Waller-Duncan K-ratio T-tests (SAS Institute Inc. 1988). Shukla's (1972) stability variance parameters (s_i^2) were estimated for traits that displayed a significant seed source × environment interaction using the program developed by Kang (1985). These parameters were used to identify those seed sources that contributed significantly to the interaction.

Results and Discussion

Seed Source Means

All traits assessed at year 8 showed significant differences ($P \geq 0.05$) between seed source means across the 3 test locations (Table 2). Eight year height ranged from 7.73 ft for Clingman's Dome—5500 to 7.21 for Mt. Mitchell—6500 (Table 3). The 5 seed sources from elevations of 5500 or lower all had significantly taller height than those from elevations exceeding 6000 ft with the exception of Mt Mitchell—6000. This apparent anomaly for height performance is likely due to genetic contamination of Mt. Mitchell stands through planting of seedlings from some other source earlier in this century (Claridge 1930, Anon. 1932). These results are in very close agreement with height growth performance at both 1 yr (Li et al. 1989) and 4 yr (Jett et al. 1993). The rank correlation coefficient of seed source mean heights between ages 8 and 4 yr was 0.97, and 0.87 for 8 and 1 yr. The top-ranked seed source for 8 yr height, Richland Balsam—5500, performed consistently with age, also being the tallest at ages 1 and 4 yr. Similarly, the top 3 ranked seed sources as a group performed consistently across the 3 ages.

These strong rank correlations for age–age seed source performance indicate seed source differences for at least height growth are solidly expressed at early ages. Consequently, breeders can identify with confidence Fraser fir seed sources with superior height growth as early as 1 yr in the field.

In fir Christmas tree species, consumers generally prefer denser trees with wider crowns (Duncan at al. 1960). Fraser fir crown diameters in this study showed significant seed source affects and ranged from 4.13 ft for Clingman's Dome—5500 to 3.72 ft for Mt. Mitchell—6500 (Table 3). Trees with the greater crown diameter have the best potential to develop perfect Christmas tree form and crown fullness (Jett et al 1993). This occurs through both limb growth alone, and its interaction with cultural shearing and shaping. Wide trees can be reduced to perfect taper, but shearing can not develop

Table 2 Analyses of variance based on seed source-block means for Fraser fir seed source study after 8 growing seasons

		Traits						
Source[1]	df	Total height	Crown diameter	Branch diameter	Straightness	Density grade	USDA value	Wholesale
					Mean squares[2]			
Location	2	6.7221	11.0517	0.007229	0.5971	6.3729	4.937	725.624
Blocks (location)	14	0.3063	0.4766	0.002048	0.3405	0.3075	0.209	11.731
Seed source	8	0.5963**	0.4322*	0.000227**	0.0478*	0.2299**	0.141**	18.382**
Seed source × location	16	0.0695**	0.0422*	0.000123*	0.0229ns	0.0164ns	0.015ns	2.416**
Error	112	0.0247	0.0107	0.000057	0.0161	0.0115	0.016	1.038

1 Significance of Location and Block(location) effects were not tested.
2 *, **; significant at $P < 0.05$ and 0.01 respectively; n.s. nonsignificant.

appealing form on excessively narrow trees. Tree shape and tree fullness have proven to be the first and third most important criteria considered by consumers in tree selection (Hildebrandt 1991).

Significant seed source effects ($P \leq 0.05$) existed for branch diameter. However, the maximum difference of seed source means was 0.011 in. between the thickest, Mt. Mitchell—6000, and the thinnest, Richland Balsam—5500. Despite this being significant ($P \leq 0.05$), these differences are too small to be of practical significance. This concurs with conclusions drawn on branch diameter differences at half rotation (Jett et al. 1993).

The combination of straightness and crown density are very important to tree quality. Both of these traits were significantly ($P \leq 0.05$) affected by seed source. Mean straightness score varied from 1.53 for the straightest, Richland Balsam—5000, to 1.67 for the most crooked, Mt. Mitchell—6000. Clingman's Dome—5500 had the best mean density score at 1.81 and Clingman's Dome-6000 the worst with 2.12. While density is crucial to tree fullness and has been identified as a major concern to consumers (Duncan et al. 1960), density and straightness together are integral in determining USDA grade (Anon. 1989). Using the scoring categories employed in this study, only trees scoring "1" both for straightness and crown density would qualify as USDA Premiums, the most valuable grade of tree.

USDA Christmas tree grades are a recognized and accepted measure of quality; higher tree value is associated with better grades (i.e., numerically lower). Seed source means for USDA grade ranged from 0.65 for the best, Clingman's Dome—5500, to 0.90 for the worst, Mt. Mitchell—6500 (Table 3). The two seed sources from Roan Mountain, which represent commonly used commercial seed sources, had a high average USDA grade. Both averaged 0.68, which was not significantly different from the best seed source (Table 3). Roan Mountain—5500 and —6000 averaged 47.5% and 45.0% Premiums, respectively, and, again, did not differ significantly from the best seed source, Clingman's Dome—5500 with 48.0%.

The combination of merchandising height class and USDA grade determine wholesale value. Seed source means for this trait ranged from \$15.73 per tree for Mt. Mitchell—6500 to \$18.06 for Richland Balsam—5500 (Table 3); a 14.8% difference. The current commercial seed stands seed sources, Roan Mountain—5500 and —6000, had mean wholesale values of \$17.10 and \$16.78 respectively, both significantly lower ($P \leq 0.05$) than the best seed source (Table 3).

Seed source differences for some of the evaluated traits revealed significant geographic trends. Wholesale value and height decreased both for seed sources of equal elevation going from south to north, and for seed sources within individual mountains as elevation increases (Figure 1).

Table 3. Means of traits measured after 8 growing seasons for 9 Fraser fir seed sources.

	Means[1]						
Seed source-elevation (ft)	Total height (ft)	Crown diam (ft)	Branch diam (in.)	Straightness score[2]	Density score[3]	USDA grade[4]	Wholesale value (\$)
Richland's Baslam—5500	7.73 a	4.12 a	0.298 d	1.53 a	1.53 a	0.67 ad	18.06 a
Clingman's Dome—5500	7.61 bc	4.13 a	0.302 bcd	1.63 bcd	1.81 a	0.65 a	17.99 a
Clingman's Dome—5000	7.63 ab	4.08 a	0.302 bcd	1.59 abcd	1.92 b	0.74 bcd	17.55 ab
Roan Mt.—5500	7.45 d	3.82 c	0.307 ab	1.54 ab	1.82 a	0.68 abc	17.10 bc
Mt. Mitchell—6000	7.52 cd	3.92 b	0.308 a	1.67 d	1.99 c	0.76 d	17.09 bc
Mt. Rogers—5000	7.53 cd	3.88 b	0.298 d	1.67 cd	1.82 a	0.75 cd	16.79 cd
Roan Mt.—6000	7.30 e	3.82 c	0.301 cd	1.62 abcd	1.90 b	0.68 abc	16.78 d
Clingman's Dome—6000	7.22 e	3.74 d	0.305 abc	1.57 abc	2.12 d	0.89 e	15.74 e
Mt. Mitchell—6500	7.21 e	3.72 d	0.302 bcd	1.56 ab	2.08 d	0.90 e	15.73 e

1 Means within a column followed by the same letter are significantly different ($P < 0.05$).
2 Straightness is scored on a scale of 1 to 3 as follows: 1—main stem does not visibly curve more than 4 in. from the vertical; 2—main stem visibly curved more than 4, but less than 6 in. from the vertical; 3—main stem visibly curved more than 6 in. from the vertical.
3 Density is subjectively assessed on a scale of 1, high density; to 3, low density.
4 USDA class has been represented here as a numerical value: Premium = 0; No. 1 = 1; No. 2 = 2; Cull = 3.

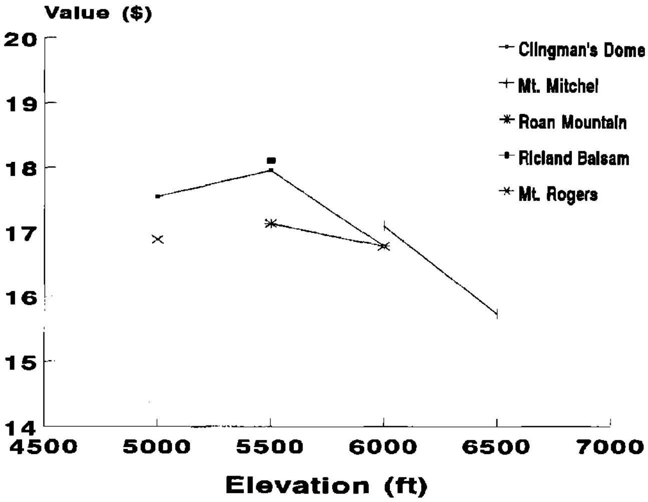

Figure 1. Fraser fir seed source mean wholesale valures plotted by elevation.

Table 4. Stability variances for total height and wholesale value at age 8 yr for 9 Fraser fir seed sources.

Seed source	Rank for 8 yr wholesale value	Stability variance (S_i^2)[1] Total height	Wholesale value
Richland Balsam—5500	1	0.12**	8.63**
Clingman's Dome—5500	2	0.43**	12.41**
Clingman's Dome—5500	3	0.10*	0.18
Roan Mt.—5500	4	0.66**	7.21**
Mt. Mitchell—6000	5	0.02	-0.07
Mt. Rogers—5000	6	0.01	0.12
Roan Mt.—6000	7	0.00	-0.13
Clingman's Dome—6000	8	0.05	6.78**
Mt. Mitchell—6500	9	0.00	6.41**

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

Richland Balsam—5500, the most southern source, had 5.6% greater wholesale value than Roan Mountain—5500. Within Clingman's Dome, a 1000 ft increase in source elevation from 5500 ft to 6500 ft resulted in an 11.5% reduction in value. The reduced height growth with increasing seed source latitude and elevation as shown in these 8 yr results, was evident after only 1 yr in the field (Li et al. 1989). Similar height growth and quality trends with seed source location have been reported for Christmas trees of Douglas fir, *Pseudotsuga menziesii* (Jaynes et al. 1986); Virginia pine, *Pinus virginiana* (Warlick et al. 1985); and for height growth in Christmas trees of the closely related balsam fir, *Abies balsamea* (McCormack 1985).

Seed Source by Location Interactions

Four of the traits evaluated in this study, total height, crown diameter, branch diameter, and wholesale value showed significant seed source by test location (G × E) interaction (Table 2). Since seed source differences in branch diameter are concluded to be of no practical importance, the G × E interaction of this trait has no practical connotations. It might be expected that significant crown diameter G × E interaction would lead to a significant interaction for USDA grade. However, as this was not the case (Table 2), it is apparent that the crown diameter G × E interaction detected is of little practical concern to the stability of aggregate tree quality across environments represented by the random sample of sites in this study.

Changes in performance that do not parallel the pattern for the mean response across sites can be a major concern to both growers and breeders. Such changes are represented in Shukla's (1972) s_i^2 values. Richland Balsam—5500, Clingman's Dome—5500, Clingman's Dome—5000 and Roan Mt.—5500 each showed significant G × E interaction for total height by Shukla's statistic (Table 4). In total, 5 of the 9 seed sources showed such instability (i.e., significant s_i^2's). Two of these, Clingman's Dome—6000 and Mt. Mitchell—6500, which were the poorest ranked for overall value, accounted for 32% of the G × E interaction sum of squares. Also, some seed sources including Mt. Rogers—5000, showed large contribution to the interaction sum of squares but proved to be stable by Shukla's s_i^2 values. This indicates that the performance of these sources did approximately parallel the mean of all sources across sites, despite their contribution to the G × E sum of squares. Consequently adjustment for variation in site mean performance proved important to reveal the truly stable sources.

The age 4 results revealed similar source instabilities to the 8 yr results presented above (Jett et al. 1993). Seed sources with the greatest height growth, all from the lower altitudes of 5500 ft or less, showed the greatest instability at both ages.

Statistically significant interactions alone are not sufficient to determine the potential practical importance of interactions. Although the top two overall ranked seed sources for value proved to have significant instability, their performance was consistent at all locations (Table 5). Seed source rank changes which manifested in the greatest value differences between locations occurred primarily with seed sources ranked poorly for value overall. This mirrors 4 yr height growth stability. Despite statistically significant rank changes, the best performing seed sources did maintain superiority at each of the 3 locations (Jett et al. 1993).

Though the G × E interaction observed in this study is of little practical importance, it must be emphasized that this applies only for the range of sites represented by the random sample involved in this study (i.e., western North Carolina). Fraser fir is now being grown in many other states and countries with suitable cool climate sites. Greater variation in environmental factors across more diverse locations may result in more substantial G × E interactions and the manifestation of performance instability. Growers in other regions should carefully evaluate Fraser fir seed sources under their own environmental conditions. When grown in other regions, the relative performance of these seed sources may vary from that reported in this study.

Table 5. Rankings for seed source mean 8 yr wholesale values and heights at each of the test sites and overall

Seed source-Elevation (ft)	Rank for 8 yr mean wholesale value and (height) Bald Mt. Knob	Purchase	Crossnore	Overall
Richland Balsam—5500	1 (2)	1 (1)	1 (1)	1 (1)
Clingman's Dome—5500	4 (5)	2 (2)	2 (3)	2 (3)
Clingman's Dome—5000	2 (1)	5 (3)	3 (4)	3 (2)
Roan Mt.—5500	3 (3)	4 (8)	5 (6)	4 (6)
Mt. Mitchell—6000	6 (6)	7 (4)	4 (5)	5 (5)
Mt. Rogers—5500	5 (4)	3 (5)	7 (2)	6 (4)
Roan Mt.—6000	7 (7)	6 (6)	6 (7)	7 (7)
Clingman's Dome—6000	8 (9)	9 (7)	8 (9)	8 (8)
Mt. Mitchell—6500	9 (8)	8 (9)	9 (8)	9 (9)

Conclusions

Significant differences exist for Fraser fir seed sources grown as Christmas trees in North Carolina. Height growth and wholesale value both declined with increased elevation of the seed source, and with increasing seed source latitude. The best 3 seed sources were significantly superior to the 2 more northerly ones, Roan Mt.—5500 and Roan Mt.—6000, commonly used for commercial seed collections. Roan Mt.—6000 performed particularly poorly, being one of the bottom three ranked seed sources for height and value. The results of this study's 8 yr full rotation analyses were consistent with the both 1 and 4 yr results. Seed source selection can offer immediate gains for both breeding and for commercial plantations. A shift to seed sources other than Roan Mt. would materially improve tree value and returns to growers.

The three sites used for this study represent a random sample of the current environments used for commercial cultivation of Fraser fir Christmas trees in North Carolina and encompass most of the species range. Consequently the consistent performance of the better seed sources across these environments, for both wholesale value and height, indicates selection and breeding for this state can be focused in a single program minimizing complexity and costs.

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