*forests*

MDPI

*Article*

# Ortet Age and Clonal Effects on Growth and Market Value of Fraser Fir (*Abies fraseri*) Grafts as Christmas Trees

**Eric Hinesley [1,*], John Frampton [2], Buddy Deal [3] and Earl Deal [3]**

[1] Department of Horticultural Science, Box 7609, North Carolina State University, Raleigh, NC 27695-7609, USA

[2] Department of Forestry and Environmental Resources, Box 8008, North Carolina State University, Raleigh, NC 27695-8008, USA; john_frampton@ncsu.edu

[3] Smokey Holler Tree Farm, LLC; 3452 Meadowfork Road, Laurel Springs, NC 28644, USA; smokeyholler@skybest.com (B.D.); info@smokeyhollertreefarm.com (E.D.)

* Correspondence: eric_hinesley@ncsu.edu; Tel.: +1-919-539-2707

Received: 14 February 2018; Accepted: 30 March 2018; Published: 3 April 2018

**Abstract:** Grafting provides a means to clonally produce Fraser fir (*Abies fraseri* (Pursh) Poir.) Christmas trees that have desirable traits such as faster growth, greater crown density, increased pest resistance, or more desirable foliage attributes than seedling stock. Grafting Fraser fir to disease resistant rootstocks also provides a means to ameliorate the impact of root rot, predominantly caused by *Phytophthora cinnamomi* Rands. The influence of ortet age on growth and market value of grafts has not been studied for Fraser fir Christmas tree production. A field trial was established in 2004 near Independence, Virginia (USA), with the objectives of assessing (1) the effect of ortet age (stock plants = 6 to 8, 10 to 12, and 18 to 20 years) and (2) shearing regimes (fixed leader length versus variable leader length) on growth, quality, and market value of Fraser fir Christmas trees. Commercial height, Christmas tree grade (based on U. S. Dept. of Agric. standards), and net present value (US dollars) were assessed at the time of harvest. Cone damage to quality was rated after 8 years in the field. Scions from Fraser fir Christmas trees 2 m or taller produced grafts that expressed maturation, resulting in lower tree quality, heavier cone damage, and decreased market value compared to seedling stock. In contrast, the quality and market value of grafts was similar to that of seedlings when scions were collected from young Fraser fir Christmas trees. For Christmas tree production, scions should be collected from the upper whorls of trees no older than 2 to 3 years in the field (6 to 8 years from seed). The effect of age on Fraser fir clones varies so that pre-screening might identify some older selections suitable for use as scion donors. Fixed versus variable shearing regimes had little effect on tree value, although some individual clones responded better to one regime or the other.

**Keywords:** grafting; ortet; ramet; vegetative propagation; shearing; Christmas tree grade; cone crop; scion material

## 1. Introduction

Fraser fir (*Abies fraseri* (Pursh) Poir.) is one of the most important Christmas tree species grown in the United States. The largest Fraser fir production region is in the Southern Appalachians. Commercial plantations occur at elevations well below elevations of the natural range. While commercial plantations usually are established from transplants originating from seed, a small but increasing number of Christmas tree growers in the region have been experimenting with grafted planting stock.

Although there are limitations, grafting currently is the vegetative propagation technique of most interest to Fraser fir Christmas tree growers in the eastern USA because it provides a means to ameliorate the impact of root rot, predominantly caused by *Phytophthora cinnamomi* Rands. This disease has seriously impacted many sites throughout the production region for Fraser fir. Infested sites become unusable for subsequent production of Fraser fir, and treatment methods are prohibitively expensive. Fraser fir, which is highly susceptible to the pathogen [1], can be grafted onto rootstock of a resistant fir species for deployment in areas known to be heavily infested [2–4]. Momi fir (*Abies firma* Sieb. & Zucc.) is the best rootstock species for this purpose [1].

Using disease resistant rootstocks, grafting is the only way to date to clonally produce Fraser fir to be sold as Christmas trees. In addition to exploiting disease resistant rootstock, grafting provides an opportunity to utilize clonal propagation to improve product uniformity, increase growth rate, and improve Christmas tree quality compared to ordinary planting stock derived from open-pollinated seed. Growth rate and crown density are under strong genetic control in Fraser fir [5]. Thus, the use of scion donors identified by phenotypic selection in commercial Christmas tree plantations should potentially result in grafts of higher quality and value compared to standard planting stock. This strategy, however, is complicated by the known effect of maturation on vegetative propagules of coniferous species [6]. For example, grafted scions of loblolly pine (*Pinus taeda* L.) from 1-, 4-, 8-, and 12-year-old ortets decreased in number of growth cycles, height, diameter increment, number of branches, foliar surface area, and total scion biomass with increasing age [7]. The effect of maturation on grafts of Fraser fir has not been investigated, but if present, could negate the potential benefits of clonal Christmas tree production via grafting.

Grafting of stem cuttings or buds, or shoot apices, or even shoot apical meristems, is most often done in connection with genetic improvement programs, clone banks, seed orchards, and clonal forestry. Although there are already publications related to various aspects of grafting Fraser fir [2–4,8], this is the first study to evaluate the operational use of grafting Fraser fir Christmas tree plantations in the field. The objectives were to assess the effect of (1) ortet age; (2) ortet genotype; and (3) two shearing treatments on the growth, quality, and economic value of Fraser fir Christmas trees clonally produced by grafting.

## 2. Materials and Methods

### *2.1. Field Site*

The site was located in a Fraser fir Christmas tree plantation near Independence, Virginia, USA (36°36′33″ N, 81°07′30″ W), approximately 790 m elevation. The soil series was a Glenelg loam, 15% to 25% slopes (fine-loamy, mixed, semiactive, mesic typic hapludults) [9]. The site is in U. S. Department of Agriculture 2012 Plant Hardiness Zone 6b, indicating an average annual extreme minimum temperature between −20.6 and −17.8 °C [10].

The study was established in a Fraser fir plantation that had completed one year in the field. The seed source of these plants was Roan Mountain, located on the North Carolina/Tennessee border in Avery County, NC (USA) (36°5′35″ N, 82°8′45″ W). Smokey Holler Tree Farm acquired 3-year-old seedlings from a forest tree nursery in Pennsylvania (USA), and grew them 2 more years outdoors to produce 3 + 2 transplants. When the field experiment was initiated in 2004, average plant height was 46 to 61 cm aboveground. The field layout covered an area approximately 20 rows × 40 columns (0.18 ha), with a tree spacing of 1.5 × 1.5 m. Initially, stock plants for the study were selected to be uniform in size and vigor. In the allocation of treatments, trees were excluded if they were too large or too small, or had an obvious defect. Six hundred trees were used in the experiment.

### *2.2. Experimental Design*

The experimental design was a randomized complete block with 30 blocks, and 20 treatments per block. Each of the 20 treatments (10 plant sources × 2 shearing methods) was randomly assigned to one tree in each block. Individual blocks consisted of 20 plants (excluding non-study trees) in adjacent rows along the landscape contour. When a row within a block (7–9 trees) ended before all treatments in a block were assigned, the block was continued in a serpentine manner in the next row lower on the hillside. Treatments are described below in the section for "*Scion Material*". Two of the 20 treatments (seedlings) consisted of non-grafted plants in the field planting and were included for comparisons with grafted treatments. All rootstocks and seedlings were the same age (one year in the field).

### *2.3. Scion Material*

Scions from three selections of Fraser fir were collected from a clone bank (managed by the NC Forest Service) at Rattlesnake Knob in Macon County, NC, USA (35°05′54″ N, 83°13′31″ W, elevation = 1260 m). The clone bank was established in 1993 from grafts of selections from a provenance/progeny study conducted by North Carolina State University [5]. For the present study, two clones (NCSU 023 and NCSU 032) were elected from the families ranked second and third based on wholesale value ($, USD) after 8 years in the field. For contrast, another clone (NCSU 173) was selected from the 17th ranked family (out of 90) for wholesale value. At the time of scion collection, the grafts were 5 to 7 m tall, and 24 years from seed.

On 30 March 2004, scion material (tips of first-order laterals) from the Macon Co. clone bank trees was collected from branches on the lower half of the crown. Shoots were clipped to a length of about 20 cm, bundled by selection, placed in plastic bags in a cooler, and covered with ice. A wet paper towel was placed next to the base of the cut shoots inside each bag to prevent desiccation and maintain high relative humidity.

Scion material from three additional Fraser fir grafted clones was collected 31 March 2004 at Smokey Holler Christmas Trees in Laurel Springs, NC (36°24′40″ N, 81°12′32″ W, elevation = 945 m). One selection (Deal 001) originally was selected because it exhibited very rapid growth and high branch density. The other two selections (Deal 002 and Deal 003) had good growth and foliage color, including one that had a bluish tint, similar to blue spruce (*Picea pungens* Engelm.). Estimated age of these clonal stock plants was 20 to 23 years from seed.

Additional scion material was collected on 31 March 2004 from open-pollinated Christmas trees at Smokey Holler to represent two control treatments: medium-age grafts and older grafts. Scions for the medium-age grafts came from sheared Christmas trees with a commercial height of 1.8 to 2.1 m (age = 10 to 12 years from seed). Scions for the older grafts came from sheared Christmas trees about 3.6 m tall (18 to 20 years from seed). For both age classes, scions were first-order laterals from second and third whorls below the leader. Collection and transport procedures were similar to those previously described. Scion material was transported on ice back to North Carolina State University the evening of 31 March 2004 and placed in a −2 °C cold room pending grafting.

A third control treatment (young grafts) consisted of vigorous first-order laterals taken from the top whorl of plants that were on the experimental site but not used in the experiment. Those scions were collected on the day of grafting.

### *2.4. Grafting and Shearing*

Grafting was carried out 14 and 15 April 2004 more than one month prior to budbreak of the rootstocks. To minimize errors, scions of each selection were color coded in the storage bags, and ribbons of appropriate color were tied on each experimental plant in the field during the layout phase.

Four or five people did the grafting, using care to ensure that differences among grafters were not confounded with treatments. Cleft grafting was done in place in the field. Leaders were clipped, leaving sufficient stub (8 to 13 cm) for a cleft graft. Scions were cut to a length of 8 to 10 cm, stripped of needles on the proximal 3 to 4 cm, tapered to a V-shape, inserted into a cut in the leader stub of the rootstock, and wrapped with a grafting rubber (Forestry Suppliers, Jackson, MS, USA). Next, they were coated with hot paraffin (Royal Oak Enterprises, Roswell, GA, USA) to prevent desiccation.

At the time of grafting (2004), the terminal buds of first-order lateral branches (second-order axes) were removed to encourage growth of the grafted scion. No additional pruning occurred the first growing season. After two growing seasons, the larger side branches were tipped on 8 August 2005, but leaders were left intact. In addition, any orthotropic shoots in the nodes just below the graft union were removed to prevent competition with the graft scion.

Shearing treatments (once annually) began the third growing season after grafting, using two systems: (1) variable shearing, and (2) fixed leader length. Traditionally, leaders were shortened to a fixed length of 30 to 35 cm (12 to 14 inches). Based on observations in another shearing experiment [11], a leader length of 41 cm was selected as the fixed length for this experiment. With variable shearing, leader length was discretionary depending upon the density, vigor, budset, and branch configuration of each tree. Residual leader length ranged from 30 to 55 cm but was mostly 40 to 48 cm. Shearing was carried out in late July or August each year using hand clippers and knives.

### 2.5. Data and Measurements

After 2 years in the field, tree height was measured to the nearest centimeter with a ruler. In addition, branches were counted on the 2005 internode of each tree, and branch density was calculated by dividing total branches by internode length.

In the eighth year after grafting, trees produced a heavy cone crop, which strongly impacted tree quality. Cones were concentrated in the upper crown. The usual practice in such situations is to send workers into the field to manually remove the cones early in the growing season to minimize the effect on growth and appearance. Consequently, when the shearing and measuring crew arrived in July, the cones already had been removed. Because no cones were present on the trees at the time of evaluation, it was necessary to estimate the cone crop based on the appearance of the trees. The rating was based on a subjective scale of cone damage to tree quality, with a value of 1 representing few cones (little noticeable impact to the upper crown) and a value of 4 representing a heavy cone crop (extensive impact to the upper crown). With this system, the lowest numerical rating was assigned to trees that showed little or no visible damage in the upper crown, and presumably had produced the fewest cones.

Harvesting began in 2009 and continued each year thereafter. At first, a small number of non-treatment trees were removed to prevent crowding of experimental trees. As trees matured, more experimental trees were removed. There was no systematic method for harvesting. Each year, the decision to leave a tree was based on a subjective evaluation of two questions. First, "Would the quality of a tree be negatively impacted by leaving it an additional year?" Second, "Would leaving the tree an additional year negatively affect the quality of one or more neighboring trees?" After about 30% to 40% of the trees were harvested, there was more flexibility in deciding whether to leave a tree an additional year.

Height of a tree at the time of harvest was taken as the mid-point of its 0.3-m commercial height class. The market quality of each tree was also assessed by assigning a U. S. Department of Agriculture grade [12]. In addition to the standard grades (Premium, No. 1, No. 2, and Cull), an additional grade (No. 3) was included for trees that were lower quality than Grade 2, yet still salable as cut trees. In the analysis, values for grade were entered as follows: Premium = 0, Grade 1 = 1, Grade 2 = 2, Grade 3 = 3, and Cull = 4. Thus, trees of the best quality had the lowest numerical values for grade.

The wholesale value of each tree was recorded at the time of harvest using the growers' pricing schedule. Because trees were harvested over a span of 5 years, the value of a tree in 2013 was adjusted to net present value (NPV) by compounding with a 5% interest rate (10-year average) for the appropriate number of years. For example, if a tree harvested in 2013 had a wholesale value of $20.00, another tree of similar size and quality that was harvested 3 years earlier would have a net present value of $23.15.

### 2.6. Data Analysis

All data were analyzed using the general linear model procedure of version 9.3 of SAS [13] (SAS Inst. Inc., Cary, NC, USA). Separate analyses were conducted to investigate the effect of ortet age (at the time of grafting) and clone on assessed traits. Differences were considered significant at $\rho \leq 0.05$ for all statistical tests.

### 2.6.1. Ortet Age Effect Analyses

This analysis included four categories of trees: seedlings, young grafts, middle-age grafts, and older grafts. A fixed-effect analysis of variance (ANOVA) was conducted with block, shearing treatment, ortet age, and the "shearing treatment × ortet age" interaction as sources of variation. Since the year of harvest varied, "year cut" was included as a covariate in the ANOVAs for height and grade. Least squares means were evaluated using Tukey-Kramer pair-wise comparisons.

### 2.6.2. Clonal Effects Analyses

Only the seedlings and six old clones were included in these analyses. A fixed-effect analysis of variance (ANOVA) was conducted with block, shearing treatment, clone, and the "shearing treatment × clone" interaction as sources of variation. Since the year of harvest varied, "year cut" was included as a covariate for the ANOVAs for height and grade. Clonal least squares means were compared to the seedling least squares mean using a Dunnett-Hsu test. In the case of height at harvest, the "shearing treatment × clone" interaction was significant, so that a slice or simple-effects test was carried out. Thus, the effect of shearing treatment was tested separately for each clone using the model mean square error as the denominator in the F statistic.

## 3. Results

Two percent of the 540 grafts died or showed signs of incompatibility after the first growing season, and virtually all leaders were orthotropic. By the end of the second year in the field, most leaders had developed radial bud symmetry that is characteristic of normal leaders on Fraser fir.

After two growing seasons in the field, the height of seedling and control grafts was not affected by shearing treatment or ortet age (Table 1). Older grafts and middle-age grafts, however, had significantly higher branch density than seedlings (64 vs. 53 branches per meter) (Tables 1 and 2).

Branch density 2 years after grafting was strongly affected by clone (Table 1). The two clones with highest branch density were Deal 001 (71 branches per meter) and Deal 002 (65 branches per meter) (Table 3). Seedlings averaged 53 branches per meter on the leader. In addition, middle-age and older grafts had greater branch density than seedlings and young grafts (Table 2).

Cone damage increased with ortet age (Tables 1 and 2). Based on the subjective rating previously described, trees derived from young grafts had the lowest cone damage (1.6) compared to 2.1 for middle-age grafts (Table 2). Older grafts had a significantly higher cone damage (3.0) than middle-age grafts (2.1) (Table 2). All clones, with one exception, had significantly higher cone damage than seedlings (Table 3). Clone NCSU 031 had significantly less cone damage (Rating = 1.4) than seedlings (Rating = 1.9) (Table 3).

For trees derived from seedlings and the three age classes of controls, there was no significant difference between the two shearing treatments for any measured variables (Table 1). In addition, there were no significant interactions ($\rho \leq 0.05$) for "ortet age × shearing treatment". Height at harvest averaged 2.9 m for seedlings compared to a range of 2.8 to 3.0 m for young, middle-age, and older grafts (Table 2). None of these differences in height were significant.

Among clones, however, there was a highly significant interaction of "clone × shearing treatment" for the variable "Height at harvest" (Table 1). Three clones (Deal 001, Deal 002, NCSU 031) were taller with variable shearing, one clone (Deal 003) was similar in both shearing treatments, and two clones (NCSU 125 and NCSU 173) were taller in the fixed shearing treatment (Table 4). However, height differences between shearing treatments were significant for only two clones (Deal 002 and NCSU 031), both of which grew taller under the variable shearing treatment.

**Table 1.** Analysis of variance for Fraser fir Christmas trees derived from grafts and open-pollinated seedlings, and cultured with two shearing regimes.

| Source of Variation | Df [1] | Height [1] | Branch Density [1] | Height at Harvest [1] | Tree Grade [1] | Cone Damage [1] | NPV [1] |
|---|---|---|---|---|---|---|---|
| | | (2 years) | (2 years) | (5 to 9 years) | (5 to 9 years) | (8 years) | (5 to 9 years) |
| Seedlings and Control Grafts [2] | | | | | | | |
| Year Cut | 1 | -- | -- | <0.0001 [3] | <0.0001 | --- | --- |
| Block | 29 | 0.004 | 0.016 | 0.33 | 0.19 | 0.63 | 0.22 |
| Shear Tmt | 1 | 0.51 | 0.95 | 0.77 | 0.67 | 0.69 | 0.59 |
| Age | 3 | 0.13 | 0.01 | 0.15 | <0.0001 | <0.0001 | <0.0001 |
| Shear × Age | 3 | 0.42 | 0.06 | 0.28 | 0.90 | 0.86 | 0.99 |
| Clones and Seedlings [2] | | | | | | | |
| Year Cut | 1 | -- | -- | <0.0001 | <0.0001 | --- | --- |
| Block | 29 | 0.004 | 0.008 | 0.03 | 0.02 | 0.35 | 0.44 |
| Shear Tmt | 1 | 0.51 | 0.38 | 0.004 | 0.49 | 0.054 | 0.82 |
| Clone | 6 | 0.13 | <0.0001 | 0.002 | <0.0001 | <0.0001 | <0.0001 |
| Shear × Clone | 6 | 0.42 | 1.00 | 0.003 | 0.88 | 1.00 | 0.61 |

[1] df = degrees of freedom; Branch density = branches per meter on the 2nd-year internode (2005); height at harvest is in meters; tree grade is based on U. S. Department of Agriculture grades for Christmas trees: Premium = 0 (best), No. 1 = 1, No. 2 = 2, market grade (saleable, but lower quality than No. 2) = 3, and Cull = 4; cone damage is based on a subjective rating of visible damage to the crown as a result of prior removal of cones: scale = 1 (little noticeable impact) to 4 (extensive impact); NPV = net present value ($, USD); age is the number of growing seasons following grafting in April 2004. [2] First analysis includes seedlings and young, medium-age, and older grafts; second analysis includes six clones as well as open-pollinated seedlings; year cut is a co-variable. [3] Values are probability levels for a Type 1 error ($0 < \rho < 1.00$).

**Table 2.** Least squares means for height, branch density, grade, cone rating, and net present value for Fraser fir Christmas trees derived from open-pollinated seedlings or scion material of various ages.

| Source [1] | Height [2] (2 Years) | | Branch Density [2] (2 Years) | | | Height at Harvest [2] (5 to 9 Years) | | Tree Grade [2] (5 to 9 Years) | | Cone Damage [2] (8 Years) | | NPV [2] (5 to 9 Years) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean [3] (m) | SE [3] | Mean | | SE | Mean (m) | SE | Mean | SE | Mean | SE | Mean ($, USD) | SE |
| Seedlings | 1.13 a | 0.029 | 53.2 | b | 2.68 | 2.9 a | 0.04 | 1.6 c | 0.119 | 1.9 b | 0.14 | 43.86 a | 4.45 |
| Young grafts | 1.10 a | 0.030 | 61.9 | ab | 2.79 | 2.9 a | 0.04 | 1.3 c | 0.120 | 1.6 b | 0.15 | 44.99 a | 4.70 |
| Middle-age grafts | 1.12 a | 0.027 | 64.1 | a | 2.71 | 3.0 a | 0.04 | 2.0 b | 0.123 | 2.1 b | 0.15 | 39.48 a | 4.45 |
| Older grafts | 1.04 a | 0.029 | 64.4 | a | 2.68 | 2.8 a | 0.04 | 3.0 a | 0.119 | 3.0 a | 0.14 | 19.38 b | 4.06 |

[1] $n$ = 60 for each source. [2] Branch density = branches per meter on the 2nd-year internode (2005) of primary stem; tree grade is based on U. S. Department of Agriculture grades for Christmas trees: Premium = 0 (best), No. 1 = 1, No. 2 = 2, market grade (saleable, but lower quality than No. 2) = 3, and Cull = 4; cone damage is based on a subjective rating of visible damage to the crown as a result of prior removal of cones: scale = 1(little noticeable impact) to 4 (extensive impact); NPV = net present value ($, USD). [3] Least squares means within the same column and followed by the same letter are not significantly different ($\rho \leq 0.05$) according to Tukey-Kramer pair-wise comparisons; SE = standard error of the mean.

**Table 3.** Least squares means for height, grade, cone rating, and net present value of Fraser fir Christmas trees derived from open-pollinated seedlings or clones.

| Source [1] | Tree Height [2] (2 Years) | | | Branch Density [2] (2 Years) | | | Tree Grade [2] (5 to 9 Years) | | | Cone Damage [2] (8 Years) | | | NPV ($, USD) [2] (5 to 9 Years) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | SE [3] | $\rho$ [3] | Mean | SE | $\rho$ [3] | Mean | SE | $\rho$ [3] | Mean | SE | $\rho$ [3] | Mean | SE | $\rho$ [3] |
| Seedlings | 1.12 | 0.030 | – | 53.2 | 2.70 | – | 1.6 | 0.12 | – | 1.9 | 0.13 | – | 44.14 | 3.492 | – |
| Deal 001 | 1.09 | 0.029 | 0.89 | 70.7 | 2.73 | <0.0001 | 2.2 | 0.12 | 0.004 | 2.3 | 0.13 | 0.23 | 32.20 | 3.303 | 0.06 |
| Deal 002 | 1.14 | 0.029 | 1.00 | 65.3 | 2.73 | 0.01 | 2.4 | 0.12 | <0.0001 | 2.5 | 0.13 | 0.02 | 26.59 | 3.559 | 0.0027 |
| Deal 003 | 1.05 | 0.029 | 0.34 | 64.4 | 2.73 | 0.02 | 2.5 | 0.12 | <0.0001 | 2.8 | 0.13 | <0.0001 | 23.13 | 3.378 | 0.0001 |
| NCSU 025 | 1.18 | 0.030 | 0.60 | 56.3 | 2.70 | 0.92 | 2.7 | 0.12 | <0.0001 | 2.6 | 0.13 | 0.0031 | 22.13 | 3.203 | <0.0001 |
| NCSU 031 | 1.09 | 0.030 | 0.95 | 62.8 | 2.73 | 0.06 | 1.6 | 0.12 | 1.00 | 1.4 | 0.13 | 0.02 | 43.57 | 3.569 | 1.00 |
| NCSU 173 | 1.19 | 0.030 | 0.35 | 41.8 | 2.70 | 0.02 | 3.2 | 0.12 | <0.0001 | 3.0 | 0.13 | <0.0001 | 16.14 | 3.232 | <0.0001 |

[1] $n$ = 60 for each source. [2] Height at 2 years is in meters; branch density = branches per meter on the 2nd-year internode (2005); tree grade is based on U. S. Department of Agriculture grades for Christmas trees: Premium = 0 (best), No. 1 = 1, No. 2 = 2, market grade (saleable, but lower quality than No. 2) = 3, and Cull = 4; cone damage is based on a subjective rating of visible damage to the crown as a result of prior removal of cones: scale = 1 (little noticeable impact) to 4 (extensive impact); NPV = net present value ($, USD); [3] SE = standard error of mean; $\rho$ = probability of a Type-1 error in a Dunnett-Hsu test with $H_0$: Least squares mean = the seedling mean in the same column.

There was considerable variation in net present value (NPV) of specific selections (Table 3). Among the three selections supplied by the grower, the best (Deal 001) had an average value of $32; the other two were $23 and $27. The best overall selection was NCSU 031 ($44); the two worst were NCSU 025 ($23) and NCSU 173 ($15). Selection NCSU 031 was the only selection with NPV similar to that of trees derived from seedlings ($45), and all other selections had much less value.

**Table 4.** Least squares means for height at harvest of Fraser fir Christmas trees derived from open-pollinated seedlings or clones, and cultured with two shearing regimes. No pair-wise comparisons.

| Source [1] | Fixed Shearing [2] | | Variable Shearing [2] | | Pr > F [4] |
|---|---|---|---|---|---|
| | Mean (m) [3] | SE [3] | Mean (m) | SE | |
| Seedlings | 2.86 | 0.059 | 2.98 | 0.058 | 0.142 |
| Deal 001 | 2.92 | 0.059 | 3.00 | 0.059 | 0.324 |
| Deal 002 | 2.76 | 0.060 | 3.12 | 0.058 | <0.0001 |
| Deal 003 | 2.78 | 0.060 | 2.81 | 0.059 | 0.743 |
| NCSU 025 | 3.08 | 0.058 | 3.01 | 0.060 | 0.400 |
| NCSU 031 | 2.91 | 0.058 | 3.10 | 0.060 | 0.027 |
| NCSU 173 | 3.04 | 0.059 | 2.96 | 0.060 | 0.358 |

[1] $n$ = 60 for each source. [2] Fixed shearing = 41-cm residual leader each year; variable shearing = variable residual leader length. [3] Measured 5 to 9 years after grafting; SE = standard error of mean. There was a significant interaction for "Shearing treatment × Clone", i.e., two clones were tallest with the fixed shearing treatment, one clone was similar, and three clones were tallest with the variable shearing treatment. [4] Results of slice analysis of the significant "Shear × Clone" interaction.

Ortet age strongly influenced the proportion of trees in each commercial grade (Table 5). Fourteen percent of the trees derived from seedlings graded as "Premium" compared to 24% for young grafts. Middle-age grafts and older grafts yielded only 7% and 2% premium trees, respectively.

Approximately one-third (29% to 32%) of the seedlings and young grafts were Grade 1, compared to 16% for middle-age grafts, and 7% for older grafts (Table 5). About one-third of the seedlings (37%) and young grafts (32%) were Grade 2. Half the trees produced from middle-age grafts were Grade 2 compared to 20% for trees that originated from older grafts. Finally, 14% to 17% of trees derived from seedlings and young grafts were in the No. 3 and cull categories combined, whereas 71% of the trees from older grafts were in those two grades (Table 5).

**Table 5.** Grade yield at the time of harvest of Fraser fir Christmas trees produced from open-pollinated seedlings and scion material of varying age.

| Source [2] | Commercial Christmas Tree Grade at Harvest [1] | | | | |
|---|---|---|---|---|---|
| | Premium (%) | No. 1 (%) | No. 2 (%) | No. 3 (%) | Cull (%) |
| Seedlings | 14 | 32 | 37 | 15 | 2 |
| Young grafts | 24 | 29 | 33 | 12 | 2 |
| Middle-age grafts | 7 | 16 | 50 | 20 | 7 |
| Older grafts | 2 | 7 | 20 | 41 | 30 |

[1] Based on U. S. Department of Agriculture grades for Christmas trees. [2] $n$ = 60 for each source; the age of ortets for young, middle-age, and older scion material was 6 to 8, 10 to 12, and 18 to 20 years, Respectively.

## 4. Discussion

Two shearing systems were used in this study, but with little difference. The fixed leader length of 41 cm (16 inches) was based on another long-term shearing experiment involving various leader lengths [11]. In that work, 35- to 41-cm leaders yielded the largest and most valuable trees in a long rotation. Historically, it was common in the culture of Fraser fir Christmas trees to use leader lengths of 30 to 35 cm (12 to 14 inches). In practice, a leader length longer than 45 cm typically yields trees that are not as dense compared to trees with shorter leaders. Under ideal conditions, including optimum soil fertility, long leaders have some advantages, but they also carry significant risks owing to issues such as late frosts, hail storms, and heavy cone crops. Injuries resulting from such events are more difficult to correct when trees have long residual leaders, especially as they approach market age. Injuries affect crown density, which is a major determinant of tree grade. In fact, if density varies sharply within the crown, or if the tree has a tiered appearance, it can be classified as a cull in the USA [12].

In a stand of Fraser fir Christmas trees, some trees have lower branch density than others owing to weak lateral budset on leaders and secondary shoots. During shearing, the usual procedure with those trees is to shorten the leaders to increase crown density. Trees with heavy lateral budset on the leader can be sheared with longer leaders while still maintaining dense crowns. The negative impact of a heavy cone crop can also require shortening of the leader to increase crown density.

The increase in branch density with ortet age after 2 years (Table 2) was somewhat unexpected because loblolly pine grafts from ortets of increasing age tend to produce fewer branches than young plants [6]. However, this trend had likely reversed by harvest time based on the tree grades and cone damage ratings of the control age groups.

Classification of a tree as "cull" can be controversial. Many trees that are classified as "cull" according to USDA standards (e.g., they have uneven density) can still be sold as cut trees, although at reduced prices, in many markets. In this study, trees classified as "cull" were assigned a wholesale value of $4.00 for the greenery they contained that was usable in wreaths and roping. In practice, if such trees were owned by the person who produced the wreaths, their value would be greater.

The selection NCSU 173 gave poor results for grade and value. That selection was one of the lower quality trees of select trees from an earlier genetics study [5] and was included in this study, along with the higher quality selections, with the assumption that it might respond differently to shearing treatments. Compared to other selections, branch density on NC 173 was relatively sparse (Table 3), which reduced crown density. In addition, the distribution of buds on the lateral shoots was not ideal, and large numbers of shoots grew upward and/or inward into the crown rather than outward toward the periphery and shearing line. These shoots—commonly called "horns"—should be removed each year during shearing. If these branches represent a significant percentage of the total branches, as with NCSU 173, removing them causes further reduction in crown density. Observations suggested that selection NCSU 173 would have been a more attractive tree and of higher quality if not sheared at all, but that option is not common in the culture of Christmas trees in the American retail market.

One question of interest was the potential effect(s) of ortet age on growth, quality, and value of Fraser fir Christmas trees. In this study, results were similar for seedlings and for trees derived from young material (1 year in the field, 5 to 6 years from seed). Unfortunately, trees of that size are too immature to reliably select on the basis of phenotype. Trees derived from middle-age (6 to 8 years in the field, 10 to 12 years from seed) ortets had a small decrease in average value ($39 vs. $45) (Table 2), mostly because the average grade was lower. Stock plants for middle-age grafts were first-rotation trees 1.8 to 2.1 m tall in the field, the most common market size. In North Carolina, trees of that size and age have been the basis for prior selection of superior Fraser fir phenotypes.

Trees derived from older ortets (18 to 23 years) had an average net present value (NPV) less than half that of seedlings and young grafts ($19 vs. $45). This outcome was, in part, the result of maturation effects in which the older material produced cone crops that were more frequent and also heavier, compared to seedlings and young grafts. When Fraser fir develops a cone crop, tree quality is affected in two ways. Cones, which might number in the hundreds in the upper crown of a single tree, represent a huge "sink" in terms of the allocation of water and nutrients. This tends to reduce the quantity, distribution, and quality of foliage on the shoots. Christmas trees can be regarded as a foliage crop because the quality and value of a tree depends largely on the amount of foliage, its distribution in the crown, and its appearance. Second, removal of the cones damages the branches, and residual effects remain visible for a long time. Barring further improvements, it appears that using scion material from older ortets would not be economically feasible owing to the low quality of resulting trees. More than 70% of the trees from older ortets were in the No. 3 and Cull categories (Table 5).

Given the negative impact of cones on the USDA grade and net present value (NPV) of trees derived from older stock plants (Table 3), it appears that NCSU 031 had the least propensity to produce cones (cone rating = 1.6) compared to seedlings (1.9) and other selections of similar age (2.6 to 3.1). This suggest that clones mature at different rates; the NCSU clones had all been selected at the same age. Also, some clones inherently produce fewer cones than others. If the objective were to graft scions from more mature trees, then cone production (frequency and amount) is a trait that might demand some priority in selection of ortets to serve as stock plants. In recent years, coning in Fraser fir Christmas tree plantations has become more frequent and severe so that growers have become interested in selecting for delayed coning. This strategy is being pursued in the Lake States region where selection against coning is possible at a relatively young age (2 to 3 years in the field).

The lower economic value of grafts from older ortets is in no way a negative reflection on traditional tree improvement programs in which superior phenotypes are preserved and used to produce seed for future generations. The reduced value was simply a reflection of the maturity of the scion material; in contrast, trees derived from seed are juvenile in their growth and morphology.

## 5. Conclusions

Scions from older Fraser fir Christmas trees produce grafts that express maturation resulting in lower quality USDA grades, increased cone damage, and decreased economic value compared to seedling stock. Growth of sheared Christmas trees was similar for grafted trees and seedling stock. The value of grafts relative to seedlings was similar when scions were collected from young Fraser fir Christmas trees. Scions should be collected from the upper whorls of trees no older than 2 to 3 years in the field. The effect of age on Fraser fir clones varies so that pre-screening might identify some old selections suitable for scion donors. Using scion material from older trees to establish commercial plantations of Christmas trees appears not to be a viable option unless (1) some method(s) could be identified (e.g., growth regulators) to avoid coning and/or other maturation effects; or (2) ortets with low coning potential could be used as sources of scion material. Grafting Fraser fir scions to disease resistant rootstocks of more resistant *Abies* species is the only method currently available to sustain production of Fraser fir Christmas trees on sites that otherwise would be lost as a result of Phytophthora root rot.

## 6. Recommendations for Future Research

Further research is needed to better understand the maturation process in conifers and to develop markers (morphological, biochemical, genetic) that could be used to measure the rate/degree of maturation in a clone. For example, certain proteins are present in juvenile shoot apices of giant sequoia (*Sequoiadendron giganteum* (Lindl.) Buchh.) but not in mature shoots [14]. Research might be warranted to identify some method(s) (e.g., growth regulators) to avoid coning and other negative maturation effects associated with scion material from older ortets. In addition, it might be useful to favor Christmas tree selections that produce fewer cones compared to the general population.

**Acknowledgments:** This research was funded in part by the North Carolina Agricultural Research Service (NCARS), Raleigh, NC 27695-7643, via the Christmas Tree Genetics Program. The North Carolina Christmas Tree Association (Boone, NC, USA) also provided nominal support. This research was discussed in abridged form in a presentation at the 11th International Christmas Tree Research and Extension Conference in Truro, Nova Scotia [15]. Use of trade names in this publication does not imply endorsement by the NCARS of products named nor criticism of similar ones not mentioned.

**Author Contributions:** Eric Hinesley and John Frampton participated in all phases of the work including experimental design, collection of scion material, installation, grafting, maintenance, data collection, analysis, and writing. Buddy Deal and Earl Deal donated land and Christmas trees for the study, provided scion material from selected Fraser fir ortets, maintained and sheared trees, participated in data collection, provided market valuations for harvested trees, and gave other support as needed. Anne Margaret Braham and Jianfeng Li

(Dept. of Forestry and Environmental Resources, NC State University) provided technical assistance especially during the grafting phase.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## References

1. Frampton, J.; Benson, D.M. Seedling resistance to *Phytophthora cinnamomi* in the genus *Abies*. *Ann. For. Sci.* **2012**, *60*, 805–812. [CrossRef]
2. Hibbert-Frey, H.; Frampton, J.; Blazich, F.A.; Hinesley, L.E. Grafting Fraser fir (*Abies fraseri*): Effect of grafting date, shade, and irrigation. *HortScience* **2010**, *45*, 617–620.
3. Hibbert-Frey, H.; Frampton, J.; Blazich, F.A.; Hundley, D.; Hinesley, E. Grafting Fraser fir: Effect of scion origin (crown position and branch order). *HortScience* **2011**, *46*, 91–94.
4. Hinesley, E.; Frampton, J. Grafting Fraser fir onto rootstock of selected *Abies* Species. *HortScience* **2002**, *37*, 815–818.
5. Arnold, R.J.; Jett, J.B.; McKeand, S.E. Natural variation and genetic parameters in Fraser fir for growth and Christmas tree traits. *Can. J. For. Res.* **1994**, *24*, 1480–1486. [CrossRef]
6. Frampton, L.J., Jr.; Foster, G.S. Field testing vegetative propagules. In *Clonal Forestry I: Genetics and Biotechnology*; Ahuja, M.R., Libby, W.J., Eds.; Springer: New York, NY, USA, 1993; pp. 110–134.
7. Greenwood, M.S. Phase change in loblolly pine: Shoot development as a function of age. *Physiol. Plant.* **1984**, *61*, 518–522. [CrossRef]
8. Garlo, A.S. Vegetative Propagation of Fraser Fir Seed Orchard Trees by Rooted Cuttings and Grafting. Master's Thesis, North Carolina State University, Raleigh, NC, USA, 1982.
9. U.S. Department of Agriculture (USDA). *Web Soil Survey*; USDA, Natural Resources Conservation Service, Soil Survey Staff: Washington, DC, USA, 2018. Available online: https://websoilsurvey.sc.egov.usda.gov/ (accessed on 19 March 2018).
10. U.S. Department of Agriculture (USDA). *2012 Plant Hardiness Zone Map*; USDA, Agriculture Research Service: Washington, DC, USA, 2012. Available online: http://planthardiness.ars.usda.gov/PHZMWeb (accessed on 19 March 2018).
11. Hinesley, E. Growth, quality, and economic value of Fraser fir sheared with varying leader lengths in North Carolina, USA. In Proceedings of the 9th International Christmas Tree Research Extension Conference, Corvallis, OR, USA; Puyallup, WA, USA, 13–18 September 2009; Oregon State University, Washington State University, and Pacific Northwest Christmas Tree Growers' Association; IUFRO Working Unit 2.02.09–Christmas Trees. Hart, J., Landgren, C., Chastagner, G., Eds.; pp. 98–102.
12. U.S. Department of Agriculture (USDA). *United States Standards for Grades of Christmas Trees: Revised, Effective 30 October 1989*; USDA, Agricultural Marketing Service: Washington, DC, USA, 1989; FR Doc. 89-23043.
13. SAS Institute Inc. *SAS OnlineDoc®*, Version 9; SAS Institute Inc.: Cary, NC, USA, 2003.
14. Bon, M.-C. An apex protein associated with juvenility of *Sequoiadendron giganteum*. *Tree Physiol.* **1988**, *4*, 381–387. [CrossRef] [PubMed]
15. Hinesley, E.; Deal, B.; Braham, A.M.; Frampton, J. Effect of scion age on the marketability of Fraser fir grafts as Christmas trees (Abstract). In Proceedings of the 11th International Christmas Tree Research and Extension Conference, Truro, Nova Scotia, 10–14 August 2013; MacDonald, M., Ed.; Dalhousie University: Truro, Nova Scotia, 2013; p. 10.