of, renovating and cropping these systems for multiple years.

The impending loss of methyl bromide as a soil fumigant is forcing a reevaluation of strawberry production practices. As we research ways to advance or alter strawberry production in North America, we should consciously evaluate the impacts of changes not only on yield and profitability, but also on conserving environmental resources, improving the viability of small-farm strawberry production, and the potential benefits to consumers and society (Nonnecke and Dewitt, 1995; Pritts, 2002). Adaptations of the annual hill or plasticulture system are already being explored to improve the economic sustainability of cold-climate strawberry production. Improvements in the matted row production system may provide an alternative to plasticulture for maintaining profitability while minimizing impact on the environment.

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Genetic Improvement of Virginia Pine Planting Stock for Christmas Tree Production in South Carolina

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ADDITIONAL INDEX WORDS. ***Pinus virginiana*, choose and cut, heritability, gain, correlation, quality, crown density, retail value**

SUMMARY. **Twenty open-pollinated families from a virginia pine (*Pinus virginiana*) seed orchard in South Carolina were planted and managed as Christmas trees at three sites. Retail value and related traits were assessed once the tests reached marketable size (4 years in the field). All traits assessed (except survival) proved to 1) be under a moderate degree of genetic control (family mean heritability = 0.68 for retail value) and 2) have a large range among open-pollinated family means ($11.42/tree to $22.00/tree, retail value) suggesting that they will response well to the traditional tree improvement approach of selection, breeding and testing. The retail value of the best five families tested averaged an increase of $3.47/tree or 20.7% more than the average. At a 6 × 6 ft (1.8 m) spacing [1,210 trees/acre (2,990 trees/ha)], these families would produce an increase in revenue of almost $4,200/acre ($10,387/ha). Much of this increase in value is a result of reducing the cull rate from 14.5% to 8.1%. Survival, height, crown density and straightness of these five families also exceeded the average of the 20 families tested.**

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Table 1. Summary of plot data for three virginia pine progeny tests established and managed as Christmas trees in South Carolina.

Test	County	Date established	Month measured	Management
88	Laurens	10 Mar. 1995	Nov. 1998	Drip line irrigation, mechanical shearing
106	Laurens	24 Feb. 1997	Nov. 2000	Mechanical shearing
108	Saluda	21 Feb. 1997	Nov. 2000	Hand shearing

Virginia pine is cultured for Christmas tree production across the southern U.S. In South Carolina it accounts for about 40 to 60 thousand of the estimated 300,000 real Christmas trees sold annually. Imported cut fraser fir (*Abies fraseri*) and locally produced eastern white pine (*Pinus strobus*), leyland cypress (×*Cupressocyparis leylandii* 'Leighton Green'), eastern redcedar (*Juniperus virginiana*) and other minor species account for the remaining Christmas trees sold in the state.

While virginia pine is capable of producing attractive and marketable Christmas trees, currently available planting stock is highly variable in quality and frequently results in cull rates near 50% at harvest (Frampton, 2001). Due to its relatively poor post-harvest needle retention, it is virtually always marketed on choose and cut farms rather than sold wholesale and shipped to distant markets. For these reasons, the production of virginia pine Christmas trees has declined across the southern U.S. in recent years. However, the production and use of genetically improved planting stock could greatly enhance Christmas tree quality and reverse this trend. The high investment required to grow Christmas trees and their high value warrants the use of the best possible seedlings.

There has been some interest in the genetic improvement of virginia pine for both Christmas trees and pulpwood production (e.g., McKinley, 1987; Talbert et al., 1980). While several studies have investigated genetic control of growth, stem straightness, branches per whorl and even subjective traits like needle color and overall quality (Bailey et al., 1974; Brown, 1979; Brown, 1987; Meier and Goggans, 1977; Talbert et al., 1980; Tauer et al., 1998; Warlick et al., 1985), these studies have largely focused on provenance testing with little or no attention to individual families.

To produce seeds and planting stock for the Christmas tree industry, the South Carolina Forestry Commission (SCFC) established a 2-acre (0.81-ha) virginia pine clonal seed orchard near Columbia, S.C., during 1979–80. Fast growing selections from several forestry tree improvement programs were chosen as orchard parent trees on the basis of their height performance evaluations across a series of progeny tests. Currently, the SCFC produces 50 to 100 thousand virginia pine seedlings annually from this orchard.

To evaluate these orchard trees for Christmas tree production, a three-site progeny test series was established, and managed as Christmas trees in collaboration with the South Carolina Christmas Tree Association (SCCTA). Using Christmas tree retail values and related traits assessed in these tests, the objectives of this paper are to rank open-pollinated families from the seed orchard, determine the importance of site and site × family interactions, and estimate the degree of genetic control.

Materials and methods

FIELD ESTABLISHMENT AND DESIGN. In 1994, 20 open-pollinated families derived from the SCFC virginia pine seed orchard were grown in 7-inch^3 (115-cm^3) Ray-Leach Super Stubby Cone-tainer cells (Stuewe and Sons, Inc., Corvallis, Ore.) at the SCFC greenhouse near Creech, S.C. Seedlings were sown in the fall and field-planted the following spring. The field sites were two locations provided by members of the SCCTA in Spring 1995. One test was later destroyed by fire. Two additional test sites were planted in February 1997. The families were planted in single-tree plots with 28 replications per test. The use of single-tree plots and the large number of small replications was used to 1) account for highly irregular site shapes, 2) minimize within replicate variation, and 3) minimize any bias by the grower or field crews. Tests were planted on 6 × 6 ft (1.8 m) spacing, and each occupied about 0.6 acre (0.24 ha). Individual replications were about 1,000 ft^2 (93 m^2) in size and fairly uniform. After the SCFC planted each test, the growers managed them as operational Christmas tree farms. Each grower was allowed to manage the trees as he saw fit, but was requested to apply management activities equally across the entire test (Table 1).

MEASUREMENTS. Height, crown density, and stem straightness were measured at age 4 years (rotation age) in each test. Height was measured to the nearest tenth of a foot (3.05 cm). Crown density was recorded using a 0 to 9 subjective scale where 9 = densest. Straightness was recorded using a 1 to 5 subjective scale where 1 = straightest. Also, two or three Christmas tree graders assessed the merchantable retail value of each tree. Trees deemed marketable by the grader were assigned a retail value while trees that were not marketable or that had been previously removed by the grower due to exceptionally poor growth or pest damage were classified as culls and given a value of $0/tree. Values averaged across graders were analyzed to eliminate error from the bias of a single grader. Trees that had some value but may not have been salable during the assessment year were given intermediate values. This included trees that were mediocre for the current season but were likely to develop into marketable trees the following year.

STATISTICAL ANALYSES. Significant differences were determined using analyses of variance from the general linear model procedure (GLM) of the Statistical Analysis System 8.1 (SAS Institute, 1999) with site, replication (site), families, and site × family as sources of variation. All effects were considered random except site. Site means were separated using pair-wise *t* tests with Tukey-Kramer experiment-wise error rate adjustments. Variance components were estimated using SAS's restricted maximum likelihood (REML) method in Proc VarComp (SAS Institute, 1999). To estimate the degree of genetic control for each trait, narrow-sense individual tree (h^2_I) and family mean (h^2_F) heritabilities were calculated as follows: $h^2_I = 4\sigma^2_F/\sigma^2_{Pi}$ $h^2_F =$

Table 2. Results of analysis of variance for survival, height, crown density, straightness, retail value and cull of 20 virginia pine open-pollinated families at age 4 years managed as Christmas trees.

Source	df[z]	Survival	Ht	Crown density	Straightness	Retail value	Cull
Site	2	**	**	**	**	**	**
Replication (site)	81	**	**	**	**	**	NS
Family	19	NS	**	**	**	**	**
Site × family	38	---	NS	**	*	**	**

[z]Total df = 1,105 for crown density and straightness and 1,309 for retail value and cull.
[NS,*,**]Nonsignificant or significantly different at $P < 0.05$ or 0.01.

Table 3. Summary of traits assessed at three virginia pine progeny test sites managed as Christmas trees in South Carolina.

	Site[z]			
Trait	88	106	108	Overall
Survival (%)	82.4 b	93.01 a	90.5 a	88.6
Height (ft)[y]	6.74 a	6.27 b	6.10 b	6.40
Crown density (0–9 scale)	6.24 a	7.06 b	5.88 c	6.42
Straightness (1–5 scale)	3.78 a	3.56 b	3.03 c	3.45
Cull (%)	13.9 a	21.7 b	8.00 c	14.5
Retail value ($/tree)	18.51 a	16.55 b	15.19 c	16.81

[z]Column values are least squares means. Site means followed by different letters are significantly different at the $P < 0.05$ level according to pair-wise t tests with Tukey-Kramer experiment-wise error rate adjustments.
[y]1.00 ft = 0.305 m.

σ^2_F/MS(F)/r, where, σ^2_{Pi} = phenotypic variance = $\sigma^2_E + \sigma^2_{RF} + \sigma^2_F$, σ^2_F = family variance, σ^2_{RF} = replication × family interaction variance, σ^2_E = error variance, MS(F) = family mean squares, r = number of replications.

Results

Differences among sites were highly significant for all measured traits (Table 2). The irrigated Laurens Co. site (test 88) had significantly lower survival (82.4%) and taller height [6.74 ft (2.05 m)] than the other two sites, which were not different from each other (Table 3). Each site was statistically different from the other two sites for the other four traits measured (Table 3). Site mean retail values ranged from $15.19/tree at the Saluda County site (test 108) to $18.51/tree at the irrigated Laurens County site (test 88) (Table 3).

Except for survival, differences among families were also highly significant for all traits measured (Table 2). The ranges of overall family means were 5.89 to 7.08 ft (1.79 to 2.22 m) for height, 5.73 to 7.27 for crown density, 2.94 to 4.13 for straightness and $11.42/tree to $22.00/tree for retail value (Table 4). The best five open-pollinated families averaged $3.47/tree or 20.7% more for retail value than the overall average.

Most individual tree and family mean correlations among traits were significant. For individual tree correlations, only the following correlations were not significant: straightness with height, straightness with cull, and height with cull (Table 5). In addition, the family mean correlations between height and crown density was not significant. Retail value was most strongly correlated with percent cull (-0.69 for individual and –0.82 for family mean correlation), crown density (0.64 individual tree and 0.87 for family mean correlation), and height (0.34 for individual tree and 0.56 for family mean correlation).

For all traits, overall individual tree heritabilities were relatively low (0.09 to 0.21) while family mean heritabilities were moderate (0.39 to 0.68) (Table 6). Estimated overall heritabilities were highest for retail value. Both individual and family mean heritabilities were variable across sites for all traits assessed.

Statistically significant site × family interactions were detected for all assessed traits except survival and height (Table 2) and their effects are apparent in the site heritability estimates (Table 6).

Table 4. Comparison of the overall mean and range of 20 open-pollinated family means from a virginia pine Christmas tree seed orchard with the performance of the best five families.

Family	Survival (%)	Height (ft)[z]	Crown density (0–9)	Cull (%)	Straightness (1–5)	Retail value ($/tree)
Overall mean	88.6	6.40	6.42	14.5	3.45	16.81
Range of family means	80.0–96.1	5.89–7.08	5.73–7.27	5.10–32.60	2.94–4.13	11.42–22.00
			Best five families for retail value			
43727	90.5	6.84	7.27	8.8	3.06	22.00
3-62	93.4	6.37	7.10	5.1	3.13	20.74
43738	91.9	7.08	6.60	11.3	3.28	20.12
73740	88.6	6.77	6.52	12.2	3.32	19.58
18-501	91.2	5.89	7.00	3.3	2.94	18.76
Mean	91.1	6.59	6.90	8.1	3.15	20.24
Improvement	2.5	0.20	0.50	–6.4[y]	–0.28[y]	3.47
Gain (%)	2.8	3.1	7.8	–43.9[y]	–8.3[y]	20.7

[z]1.00 ft = 0.305 m.
[y]Negative values are desirable for these traits.

Table 5. Individual tree correlations (bottom) and family mean correlations (top) for virginia pine traits measured at 4 years of age.

Trait	Ht	Crown density	Straightness	Retail value	Cull
Height		0.34NS	0.018NS	0.56**	–0.22NS
Crown density	0.12**		–0.64**	0.87**	–0.73**
Straightness	–0.020NS	–0.34**		–0.47*	0.39NS
Retail value	0.34**	0.64**	–0.27**		–0.82**
Cull	0.00NS	0.11**	0.05NS	–0.69**	

NS,*,**Nonsignificant or significantly different at $P < 0.05$ or 0.01.

Table 6. Narrow-sense individual and family heritability estimates for 4-year-old virginia pine managed as Christmas trees at three South Carolina sites.

	Individual				Family			
Trait	88	106	108	Overall	88	106	108	Overall
Height	0.66	0.04	0.40	0.09	0.82	0.16	0.80	0.58
Crown density	0.13	0.48	0.28	0.14	0.42	0.73	0.69	0.60
Straightness	0.29	0.10	0.45	0.16	0.60	0.35	0.78	0.64
Cull	0.058	0.23	0.21	0.057	0.25	0.61	0.58	0.39
Retail value	0.14	0.64	0.35	0.21	0.48	0.83	0. 83	0.68

Discussion

Market value of virginia pine Christmas trees at age 4 years averaged $16.81/tree across the three South Carolina sites in this study. This average included cull trees ($0/tree) and so is less than the average that growers realize per tree sold. The market value of virginia pine Christmas trees is under moderately strong genetic control (h^2_{family} = 0.68) (Table 6) so that the use of the best families could significantly enhance profits for growers.

By bulking seeds and marketing seedlings from the best five clones in their seed orchard, the SCFC could offer virginia pine planting stock of considerably improved value to growers. These five families averaged $3.47/tree or 20.7% more than the orchard average. At a 6 × 6 ft spacing (1,210 trees/acre), these families would produce additional revenue of almost $4,200/acre, largely as a result of reducing the cull rate from 14.5% to 8.1%. Due to positive inter-trait correlations, survival, height, crown density and straightness of these five families exceeded the orchard average. It should be noted that the clones in the SCFC orchard have previously been selected for growth and straightness, so that the improvements stated above would be in addition to past improvements.

There were significant site × family interactions for most assessed traits. Site effects were confounded with cultural practices, thus, making it impossible to recommend families for specific site types or grower regimes. In addition, the small number of virginia pine Christmas trees planted relative to forest tree crops would make developing planting stock adapted to specific site types economically unfeasible. For these reasons, the families performing best across all three sites will be selected for future use as improved Christmas tree planting stock.

The moderately strong family heritabilities and large range in family means for the traits assessed (except survival) suggest that these traits should respond well to a traditional selection/breeding/testing tree improvement program. Further, virginia pine's early and precocious flowering, coupled with short Christmas tree rotations, makes it amenable to advanced generation improvement efforts.

This cooperative endeavor between SCFC and SCCTA should be extended to Christmas tree associations and state forestry agencies in other southern states where virginia pine Christmas trees are produced. These results indicate that such efforts would enhance the economic feasibility of virginia pine Christmas tree production in the southern U.S.

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