TEN-YEAR RESULTS OF A LIMITED RANGE EASTERN WHITE PINE SEED SOURCE STUDY: VARIATION IN GROWTH AND SPECIFIC GRAVITY

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ABSTRACT.--After ten growing seasons, analysis of a limited range eastern white pine provenance study showed that there were significant differences among provenances for height, dbh, and radial growth. Most provenances from Georgia, North Carolina and Tennessee were superior to other sources including the five from various areas in West Virginia. There were significant positive correlations between height and dbh. Extracted specific gravity differences were slight, but significant among sources. Significant negative correlations were found between extracted specific gravity and height and diameter. Narrow sense heritability for extracted specific gravity was small (.114).

INTRODUCTION

SINCE 1955, there have been several publications concerned with provenance studies in eastern white pine (*Pinus strobus* L.). Most of these were range-wide tests which indicated that trees grown from southern Appalachian seed sources performed better than local sources in more northern areas (Demeritt and Kettlewood 1975; Funk et al 1975; Garrett et al 1973; Genys et al 1978; Wright 1970). Above latitude 42°30'N, however, southern sources tended to be more susceptible to winter injury (Garrett et al 1973).

As an extension of these earlier studies, Wright et al (1978) collected seed from many southern Appalachian locations and outplanted the progeny in several eastern U. S. locations. Early results have shown that progeny from these sources have grown faster than those from northern locations in most test areas and survival has usually been high. For example, in West Virginia these southern sources have usually out-performed most local sources (Wendel and Cech 1976).

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Studies of variation in both growth and wood properties associated with geographic origin of seed, however, are limited (Gilmore and Jokela 1978; Lee 1974). In 1977, an investigation was undertaken to determine the variation in growth and specific gravity among some of the southern Appalachian sources in the West Virginia outplanting (Wright et al 1978). This paper reports on those results.

METHODS

Seed from 32 stands (98 families) were obtained from collections made by cooperators in the locations shown in Table 1 and Figure 1. In 1968, 2-0 seedlings were outplanted on a south-facing cutover mountain site on the Fernow Experimental Forest -pear Parsons, West Virginia. Trees were planted in seven randomized complete blocks with each seedlot represented by **a** four-tree row plot. Sixth-year survival and height growth were reported by Wendel and Cech (1976).

During the summer of 1977, two trees from each row plot in five of the seven blocks were systematically selected for sampling of wood properties. Two 5 mm diameter increment cores were removed from each of 937 trees. The cores were taken at a height of 30.5 cm (1.0 ft) above the ground by boring completely through the trees parallel to the contour--approximately a west to east direction. Where there was a branch whorl or visible injury, the core was taken at least 12.5 cm (5.0 in) above or below it. Cores were placed in plastic drinking straws and labeled to identify the original position in the tree. The samples were frozen in numbered plastic bags for later laboratory determinations.

At the end of the 1977 growing season, the height and dbh of all sampled trees were measured. In the laboratory, increment cores were trimmed to include only the 1973 through 1976 growth increment. One measurement of radial growth to the nearest 0.01 mm was taken on each of the paired cores at 10x magnification with an Ames dual-linear dendrochronometer similar to that devised by Hamilton (1963). Green volume determinations were performed by the water immersion technique.

Alcohol-benzene and alcohol soluble extractives were removed from increment cores using a Soxhlet apparatus (A.S.T.M. 1976; Thor 1964; Thor and Bates 1973). Water soluble extractives were removed with three successive changes of glass distilled boiling water for 1 hour each (A.S.T.M. 1976). Weight determinations were made after the samples were oven dried at 103 + 2°C.

Analysis of Variables was performed using the Statistical Analyses System (SAS) on the IBM 360/370 computer system at West Virginia University.

Table 1. Geographic location of eastern white pine parent stands in the southern Appalachian Mountains

MSFG NUMBER	WVU Number [2/]	County & State	Latitude	Longitude
3534-3541	1	Anderson, TN	36 00 N	84 10 W
3487	2	Burke, NC	35 52 N	81 46 W
3545	3	Union, GA	34 43 N	84 06 W
3513-3521	4	Fannin, GA	34 35 N	84 10 W
3495-3502	5	Polk, TN	35 00 N	84 25 W
3544	6	Fannin, GA	34 44 N	84 09 W
3452	7	Graham, NC	35 20 N	83 52 W
3551	8	Madison, NC	35 50 N	82 40 W
3503-3512	9	Monroe, TN	35 20 N	84 10 W
64 (B) [1/]	10	Raleigh, WV	- - N	- - W
3439-3443	11	Henderson, NC	35 00 N	82 50 W
3420	12	Carter, TN	36 20 N	82 04 W
3552 (B)	13	Burke, NC	35 51 N	81 30 W
3423	14	Caldwell, NC	36 00 N	81 30 W
3449	15	Whitley, KY	36 55 N	84 15 W
3416-3417	16	Buncombe, NC	35 30 N	82 30 W
3548	17	Rabun, GA	35 54 N	83 30 W
3422 (B)	18	Burke, NC	35 51 N	81 51 W
3570-68-76	19	Wetzel, WV	39 30 N	80 45 W
67 (B)	20	Raleigh, WV	- - N	- - W
94-98	21	Braxton, WV	38 45 N	80 30 W
3407	22	Montgomery, VA	37 14 N	80 27 W
81-86	23	Pocahontas, WV	38 20 N	79 30 W
3554-87-93	24	Pleasants, WV	39 25 N	81 07 W
66 (B)	25	Greenbrier, WV	- - N	- - W
65 (B)	26	Greenbrier, WV	- - N	- - W
77-80	27	Greenbrier, WV	38 00 N	80 14 W
3522-3531	28	Cherokee, NC	35 10 N	84 10 W
3470	29	Botetourt, VA	37 31 N	79 37 W
3590	30	Pocahontas, WV	38 20 N	79 53 W
3460 3462 3463	31	Greenbrier, WV	37 58 N	80 08 W
3453	32	Pocahontas, WV	38 28 N	79 48 W

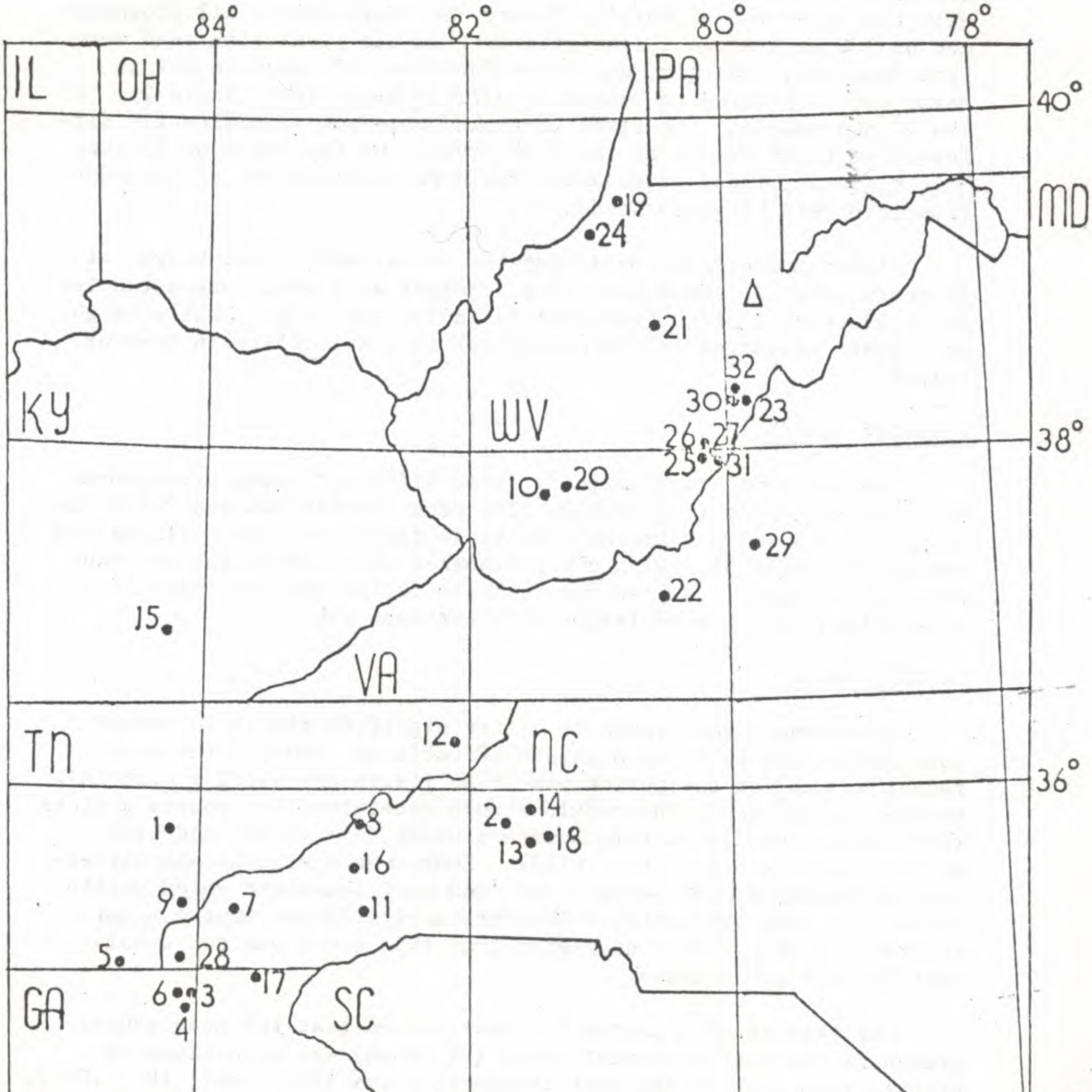

Fig. 1 Approximate location of eastern white pine parent stands whose progeny were evaluated in the present study (numbered dots) and planting site (triangle).

RESULTS AND DISCUSSION

Height Growth

Significant differences in total height were found among the 32 provenances by a general linear models (GLM) procedure (P .0001) (Table 2). The mean 10-year height was 5.6 + 1.1 m (18.4 + 3.6 ft). With the exception of Whitley County, Ky (MSFG 3449), all provenances having an average height greater than the plantation mean were from Tennessee, Georgia, and North Carolina. Provenance height means were subjected to Duncan's Multiple Range Test (Table 2). Of the 32 provenances, the first 21 ranked were not significantly different in total height at the 0.05 level. On the basis on 10-year height growth, these provenances would be recommended for introuluction into West Virginia stands.

Linear regressions were computed to estimate total height at 10 years using 2- and 6-year data. Height at 6 years accounted for about 92 percent of the variability in 10-year height, while height at 2 years accounted for 78 percent of the variability in 10-year height.

Diameter Growth

Dbh was found to be significantly different among provenances by a GLM procedure (P < .0001). The mean 10-year dbh was 7.9 + 2.4 cm (3.1 + 0.9 in). A Duncan's multiple range test was performed on dbh means (Table 3). Although provenance rank for height and dbh were not identical, all sources ranking taller than the mean 10-year height also ranked larger than the mean dbh.

Radial Growth

Provenances were found to differ significantly in increment core radial growth by an analysis of variance (ANOV). The mean radial growth for the period was 25.86 + 9.58 mm (1.02 + 0.38 in). However, significant interactions were determined for source x block (P = .0023), seedlot within source x block (P = .0004) and tree within source x block (P = .0210). There was a significant difference in radial growth between west and east increment cores within trees (P <,.0001 by a GLM). However, a significant source x core interaction (P < .0001) suggested that this trend was not consistent for all provenances.

The results of a paired t - test showed that the mean radial growth of the east increment cores (26.48 mm) was significantly greater than that of the west increment cores (25.24 mm) (P < .001). Olessen (1973) explained within tree differences in radial growth of Norway spruce (*Picea abies* L.) by reference to the direction of the prevailing winds. Bole radial growth on the leeward side was found to be significantly greater than that of the windward side. Since

Table 2. 10-Year Mean Total Height

Grouping	MSFG or WVU No.	County and State	No. Trees	Total (ft)	Height (m)	Percent of mean height
A	3452	Graham, NC	10	21.69	6.61	118
	3534-3541	Anderson, TN	60	21.09	6.43	115
	3495-3502	Polk, TN	59	20.70	6.31	113
B	3551	Madison, NC	9	20.52	6.26	112
	3513-3521	Fannin, GA	79	20.42	6.23	111
C	3420	Carter, TN	9	19.84	6.05	108
	3503-3512	Monroe, TN	95	19.66	5.99	107
	3487	Burke, NC	10	19.63	5.98	107
	3416-3417	Buncombe, NC	19	19.41	5.92	106
D	3544	Fannin, GA	10	19.30	5.88	105
	3545	Union, GA	10	19.10	5.82	104
	3439-3443	Henderson, NC	47	19.06	5.81	104
E	3423	Caldwell, NC	9	18.83	5.74	103
	3449	Whitley, KY	10	18.51	5.64	101
	3548	Rabun, GA	10	18.11	5.52	99
	3552 (B)	Burke, NC	10	17.96	5.48	98
	3422 (B)	Burke, NC	8	17.93	5.47	98
	94-98	Braxton, WV	49	17.91	5.46	98
	67 (B)	Raleigh, WV	10	17.87	5.45	97
	64 (B)	Raleight, WV	10	17.62	5.37	96
A	3570,68-76	Wetzel, WV	96	17.57	5.36	96
	81-86	Pocahontas, WV	58	16.89	5.15	92
	3554,87-93	Pleasants, WV	75	16.86	5.14	92
	77-80	Greenbrier, WV	40	16.60	5.06	90
	65 (B)	Greenbrier, WV	10	16.41	5.00	89
	3522-3531	Cherokee, NC	57	16.35	4.98	89
	3407	Montgomery, VA	9	16.33	4.98	89
B	3470	Botetourt, BA	8	16.29	4.97	89
	3460,3462, 3463	Greenbrier, WV	26	15.40	4.70	84
C	66 (B)	Greenbrier, WV	8	15.26	4.65	83
D	3590	Pocahontas, WV	10	13.76	4.20	75
E	3453	Pocahontas, WV	6	12.43	3.79	68

(B) indicates bulked seedlot.
Means with the same letter are not significantly different.
Alpha level = 0.05   DF = 66   MS = 26.6752

Table 3. 10-Year Mean Dbh

Grouping	MSFG or WVU No.	County and State	Dbh (Inches)	Dbh (Centimeters)	Percent of mean dbh
A	3452	Graham, NC	3.94	10.01	127
B	3551	Madison, NC	3.72	9.45	120
	3544	Fannin, GA	3.66	9.30	118
	3495-3502	Polk, TN	3.64	9.25	117
	3420	Carter, TN	3.60	9.14	116
	3534-3541	Anderson, TN	3.60	9.14	116
	3545	Union, GA	3.58	9.09	115
	3487	Burke, NC	3.53	8.97	114
C	3423	Caldwell, NC	3.48	8.84	112
	3503-3512	Monroe, TN	3.42	8.69	110
	3513-3521	Fannin, GA	3.38	8.59	109
	3416-3417	Buncombe, NC	3.26	8.28	105
	3422(B)	Burke, NC	3.23	8.20	104
	3439-3443	Henderson, NC	3.20	8.13	103
	3449	Whitley, KY	3.20	8.13	103
	3552(B)	Burke, NC	3.17	8.05	102
	94-98	Braxton, WV	3.16	8.03	102
	3407	Montgomery, VA	3.11	7.90	100
	64(B)	Raleigh, WV	3.00	7.62	96
	67(B)	Raleigh, WV	2.93	7.44	94
A	3554,87-93	Pleasants, WV	2.87	7.29	92
	81-86	Pocahontas, WV	2.82	7.16	91
	3570,68-76	Wetzel, WV	2.81	7.14	90
	3470	Botetourt, VA	2.79	7.09	90
	77-80	Greenbrier, WV	2.73	6.93	88
	3548	Rabun, GA	2.71	6.88	87
	3522-3531	Cherokee, NC	2.65	6.73	85
	65(B)	Greenbrier, WV	2.64	6.71	85
	3460,3462 3463	Greenbrier, WV	2.48	6.30	80
B	66(B)	Greenbrier, WV	2.39	6.07	77
	3590	Pocahontas, WV	2.05	5.21	66
C	3453	Pocahontas, WV	1.92	4.88	62

(B) indicates bulked provenance.

Means with the same letter are not significantly different.

Alpha level = 0.05 DF = 66 MS = 1.7006

the prevailing winds for the planting site are from the west, this may partly explain the within tree differences in radial growth found here.

Specific Gravity

Significant differences in specific gravity after removal of extractives were found among provenances by a GLM procedure (P = .0093). More variation existed among sources than within sources. Significant interactions were detected for source x block (P c .0001), seedlot within source x block (P < .0001) and tree within block x source (P < .0001), suggesting that this property, like radial growth, is highly site sensitive. Specific gravity ranged from 0.288 to 0.329 and averaged 0.312 + 0.031 for the 6- to 9-year increment. A Duncan's multiple range test at the 0.05 level did not detect differences in specific gravity among provenances.

This range in specific gravity is similar to that reported by Gilmore and Jokela (1978) and may have some practical significance. For example, in the southern yellow pines, each 0.01 unit of specific gravity corresponds to a difference of 50 pounds per cord in dry pulp.

Correlation Analysis

A linear correlation analysis was used to determine the existence of relationships between 10-year height, 10-year dbh, and extracted 6- to 9-year increment core specific gravity for sampled trees (Table 4).

Table 4. Linear Correlation Coefficients

	r Values	
Characteristic	Dbh	Specific Gravity
Height	0.92633	- 0.42204
Dbh		- 0.47864

P< .0001 for these values

The strong relationship between 10-year height and diameter suggests that either of these variables could be used for selecting sources for outplanting.

The weak but significant negative correlations between extracted specific gravity and height and dbh agree with results reported by Thor (1965) and are different from those reported by Lee (1974). Thor found significant negative correlations between radial increment and extracted specific gravity. Lee reported a significant positive correlation between 15-year total height and extracted specific gravity of 9-year growth increment.

It would appear that because of a significant relationship between diameter growth and specific gravity, within tree differences found in specific gravity may be partly due to differences in radial growth found within grees.

Heritability of Specific Gravity

Narrow-sense heritability estimates for extracted increment core specific gravity were obtained by considering this planting as a half-sib progeny test of those seedlots or provenances which shared a single mother tree origin. The mean squares from the ANOV were apportioned into variance components used in the computation of single-tree heritability (Table 5) by the formula (Thayne 1978):

$$h^2 = \frac{4\ \mathrm{Var\ (Source)}}{\mathrm{E\ Var\ (i)}}$$

where Var (i) represent variances due to

Var (Block)
Var (Source)
Var (Block x Source)
Var (Lot (Source))
Var (Block x Lot (Source))
Var (Error)

Work is in progress to determine estimates of expected gains in specific gravity from selection among provenances, among families, and within families.

Table 5. Estimates of components of variance and heritability for 6- to 9-year extracted specific gravity.

Variance component	Estimate	Heritability h^2
Var (Block)	.00001830	
Var (Source)	.00002941	
Var (Block x Source)	.00006273	
Var (Lot (Source))	.00003310	
Var (Block x Lot (Source))	-.00003648	
Var (Error)	.00091764	
		.11476

CONCLUSIONS

The objectives of this research were to evaluate various aspects of the growth and wood properties in the West Virginia outplanting of the Wright et al (1978) limited-range eastern white pine provenance study. After ten growing seasons, significant differences were found among provenances for height, dbh, and radial growth. Most provenances from Georgia, Tennessee, and North Carolina exhibited above average height growth and were superior to the majority of the other sources.

Significant linear regressions were estimated to predict total height at 10 years from both 2-year and 6-year data. The provenances exhibiting above average total height also had dbh means above the plantation average. Significant within-tree differences in radial growth were detected.

Extracted specific gravity differences although significant among sources were slight. Some provenances were found which combined above average height and dbh with above average extracted specific gravity such that simultaneous improvement in these traits could be achieved.

Linear correlation analysis demonstrated a significant positive correlation between height and dbh. Significant negative correlations were found between extracted specific gravity and both height and diameter.

A narrow-sense single tree heritability was estimated for extracted specific gravity. Work is in progress to compute genetic gains by three selection techniques.

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