SELECTING DRY FIBER WEIGHT FOR HIGHER AND BETTER QUALITY JACK PINE FIBER PRODUCTION

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ABSTRACT

Sixteen-year-old half-sib jack pine (*Pinus banksiana* Lamb.) families planted in New Brunswick were evaluated for wood density, growth traits (DBH, tree height, and bole volume), and dry fiber weight (wood density × bole volume). The variation and inheritance of these traits and their relationships were studied. The implications of these genetic parameters for optimum gains in wood quality and wood quantity (bole volume) were discussed. The results indicate that wood density and tree height exhibit considerably less phenotypic variation but a remarkably higher heritability compared to DBH and bole volume. Dry fiber weight shows the largest phenotypic variation but a moderate heritability. There exists a positive genetic correlation between wood density and all growth traits. This suggests that selection for growth traits would not necessarily lead to a reduction in wood density in this species. Compared to traditional selection for bole volume, however, selection for dry fiber weight would result in higher genetic gains not only in dry fiber weight (+12.9% vs. 9.9%), but also in wood density (1.8% vs. 0.8%) and bole volume (9.8% vs. 8.2%). Therefore, this selection strategy would achieve both higher and better quality fiber production compared to traditional selection for volume alone.

Keywords: Jack pine, dry fiber weight, wood density, growth traits, variation, inheritance, correlation.

INTRODUCTION

Over the last few decades, tree breeding programs have aimed at improving volume growth through selection (Zobel and Talbert 1984; Yanchuk and Kiss 1993). With the steadily increasing proportion of improved and intensively managed plantations and the move in forest management to shorter rotations, wood quality has become a major concern in the forest products industry (Bendtsen 1978; Kellogg 1989; Vargas-Hernandez and Adams 1991; Zhang 1995). Tree breeders have realized that wood quantity (volume growth) and wood quality cannot be treated as independent traits and that wood quality improvement should form an integral part of tree breeding programs (van Buijtenen 1986; Keith and Kellogg 1986; Morgenstern and Villeneuve 1986; Magnussen and Keith 1990). Zobel and van

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Buijtenen (1989) suggested that wood quality traits should be included in any tree improvement program where wood is to be the end product, and that wood quality is an important consideration at each of a number of stages defined for a tree improvement program.

Wood quality should be defined in terms of end products or uses (Keith and Kellogg 1986). Of various wood quality characteristics, wood density has been widely studied. This characteristic is closely correlated not only with most wood mechanical properties (Amstrong et al. 1984; Megraw 1985; Zhang 1994), but also with fiber morphology and paper properties (Barefoot et al. 1970; Zhang et al. 1992). This characteristic thus has a major effect on both yield and quality of fibrous and solid wood products (Panshin and deZeeuw 1980; Zobel and van Buijtenen 1989). However, it should be emphasized that in addition to wood density, there are other important wood quality characteristics (e.g., juvenile wood content, fiber quality, compression wood, heartwood content, chemical properties) that should be considered in the future tree improvement programs. In this study, dry fiber weight (wood density × bole volume) was introduced as a relative index of gross fiber yield for individual trees.

In the province of New Brunswick, tree improvement activities are coordinated by the New Brunswick Tree Improvement Council (NBTIC). The Council intended to take wood quality into consideration in its major tree improvement programs (Morgenstern and Villeneuve 1986). Under the Council's initiative, a project was launched in 1993 to deal with the genetics of wood quality in black spruce (*Picea mariana* Mill. B.S.P.). Following the completion of that project (Zhang 1996; Zhang and Morgenstern 1996; Zhang et al. 1996), a similar study was conducted on jack pine (*Pinus banksiana* Lamb.). This species is one of the most important commercial softwood species in eastern Canada. The oldest jack pine family tests were established by the NBTIC in 1979. The objectives of this study are to: 1) provide basic information on major wood quality characteristics in the jack pine family tests; 2) estimate the genetic variation and heritability of wood density and growth traits and their relationships; and 3) explore the implications of these genetic parameters for optimum gains in wood quality and quantity.

MATERIALS AND METHODS

Materials and measurements

Jack pine plus trees were selected in 1977 by the NBTIC member agencies from natural stands, based on tree height, stem straightness, and crown and branch characteristics. Seeds collected from selected trees were used to establish seedling seed orchards and family tests. In the spring of 1979, field tests were established at four locations in New Brunswick. Each test consisted of 4-tree row plots with trees spaced at 2 × 2 m, replicated 10 times in a randomized block design. One jack pine family test established by J. D. Irving, Limited, was chosen to provide the samples for this study. This test is located in Dubee Settlement, southeastern New Brunswick. For further information about the test, refer to Park et al. (1989). Four blocks were selected to cover different growth rates. In total, forty-four families were selected based on the diameter at breast height measurements at age 14. At the end of the 1994 growing season, the two most northwestern trees were sampled from each 4-tree plot. The tree height (TH) and diameter at breast height (DBH) of each selected tree were measured and recorded, and bole volume (BV) was calculated based on TH and DBH using a total tree volume equation developed by Honer et al. (1983).

A 6-mm increment borer was used to extract a bark-to-pith core sample from each selected tree at approximately 0.7 m above the stump level. Sampling at this height is as effective as at breast height (Loo-Dinkins and Gonzalez 1991), and it allows 1-2 more growth rings to be obtained. The core samples were extracted with a solution of cyclohexane/ethanol (2:1) for 24 h and then with hot water for another 24 h. After the extraction, the core samples were dried to about 12% in moisture content. The dry samples were sawn into 1.57-mm-thick (longitudinal) strips for X-ray densitometric analysis at the Eastern Laboratory of Forintek Canada Corp. Each strip was scanned from the pith to the bark at air-dry condition. A number of ring characteristics (e.g., average ring density, earlywood density, latewood density, earlywood width, latewood width, total ring width, and latewood percentage) were obtained for each growth ring scanned. Based on these data on individual growth rings, weighted average wood density was computed for each tree. This weighted average wood density (WD) at the 0.7-m height was multiplied by tree volume (DFW = WD·BV) to serve as a relative index of gross fiber yield for individual trees in this study.

Genetic analysis

Analyses of variance and covariance for various wood density and tree growth traits were performed to estimate genetic parameters using SAS statistical package (SAS Institute Inc. 1985). Various variance and covariance components were estimated from the appropriate mean square and mean cross-products using the SAS procedures. The estimated variance components were interpreted in terms of genetic and environmental variance and were used to derive the genetic parameters. Assuming that for half-sib families, the family component of variance equals one quarter of the additive genetic variance (Falconer 1981; Zobel and Talbert 1984), individual-tree and family narrow-sense heritabilities (h^2_f and h^2_i, respectively) were estimated as follows (Becker 1984):

$$h^2_i = \frac{4\sigma^2_f}{\sigma^2_{pi}} = \frac{4\sigma^2_f}{\sigma^2_w + \sigma^2_{bf} + \sigma^2_f}$$

$$h^2_f = \frac{\sigma^2_f}{\sigma^2_{pf}} = \frac{\sigma^2_f}{\sigma^2_w/bt + \sigma^2_{bf}/b + \sigma^2_f}$$

where σ^2_{pi} and σ^2_{pf} are the phenotypic variances based on individual-tree and family means, respectively; σ^2_w, σ^2_{bf} and σ^2_f are the variance components due to error, block × family interaction, and family, respectively; and b and t denote the number of trees/plot and the number of replications, respectively.

Analysis of covariance between traits and the calculation of covariance components were necessary for the determination of genetic correlations among various traits. Genetic correlation, $r_g(xy)$, and phenotypic correlation based on family means, $r_p(xy)$, were computed as follows (Falconer 1981):

$$r_g(xy) = \frac{COV_f(xy)}{[\sigma^2_f(x)\sigma^2_f(y)]^{1/2}}$$

$$r_p(xy) = \frac{COV_{pf}(xy)}{[\sigma^2_{pf}(x)\sigma^2_{pf}(y)]^{1/2}}$$

where $COV_f(xy)$ and $COV_{pf}(xy)$ are the family covariance component and the phenotypic covariance (based on family means) between traits x and y, respectively; $\sigma^2_f(x)$ and $\sigma^2_f(y)$ are the family variances for traits x and y, respectively; and $\sigma^2_{pf}(x)$ and $\sigma^2_{pf}(y)$ are the phenotypic variances for traits x and y, respectively (based on family means).

Implications of the genetic relationships between wood density and growth traits were evaluated by estimating the expected genetic gains for these traits in the offspring of a seed orchard. When only one trait is selected, expected genetic gain in the trait (▲G) is estimated using the equation for direct response (Falconer 1981):

$$\blacktriangle G = ih^2\sigma_p$$

where i is the selection intensity; h^2 is the appropriate heritability depending on the selection method (individual or family selection); and σ_p is the corresponding phenotypic standard deviation. Selection for one trait (x), however, will result in a correlated response for other traits. The correlated response of a trait (y) can be estimated using the equation for indirect response (Falconer 1981):

$$\blacktriangle CR = ih(x)h(y)\, r_g(xy)\sigma_p(y)$$

where ▲CR is the correlated response of trait y due to the selection for trait x; h(x) and h(y) are the square roots of appropriate heritabilities for traits x and y, respectively; $r_g(xy)$ is the genetic correlation between traits x and y; $\sigma_p(y)$ is the corresponding phenotypic standard deviation for trait y.

RESULTS AND DISCUSSION

Genetic variation and inheritance

Means, ranges, and coefficients of variation for wood density, growth traits, and dry fiber weight are given in Table 1. Average wood density value (360 kg/m^3) for the 16-year-old jack pine family test is comparable with that reported by Magnussen and Keith (1990) for a 20-year-old jack pine family test, but considerably lower than those documented by Gonzalez (1990) for this species. Table 1 shows that all traits exhibit a wide range among the trees studied. Dry fiber weight, for instance, ranges from 3.33 to 26.17 kg per tree, and wood density from 305 to 442 kg/m^3. Among various traits studied, wood density and tree height display a small phenotypic variation (6.7% and 8.8%, respectively) as indicated by coefficient of variation, followed by DBH (16.6%) and bole volume (36.8%), which exhibit a considerably larger variation than tree height, whereas dry fiber weight exhibits the largest phenotypic variation (37.2%). Similar results have been reported elsewhere for jack pine (Magnussen and Keith 1990) and other species (Zhang and Morgenstern 1996).

The estimated individual variance component, individual-tree and family-mean phenotypic variances, and individual-tree and family narrow-sense heritabilities for wood density, growth traits, and dry fiber weight are presented in Table 2. Although wood density exhibits the smallest phenotypic variation in this species, a remarkable part of the variation is due to family (σ^2_f), which accounts for 11.1% of the variation (Table 2). Therefore, wood density is under strong genetic control (h^2_i = 0.45 and h^2_f = 0.40). Dry fiber weight shows a moderate heritability (h^2_i = 0.21 and h^2_f = 0.25) in spite of its largest phenotypic variation. DBH (h^2_i = 0.13 and h^2_f = 0.16) and bole volume (h^2_i = 0.13 and h^2_f = 0.16), however,

TABLE 1. *Means, ranges, and coefficients of variation (CV) for wood density, growth traits, and dry fiber weight.*

	Mean	Range	CV (%)
Wood density (kg/m^3)	360	305–442	6.5
DBH (× 100, m)	10.7	6.0–14.9	16.6
Tree height (m)	7.3	5.7–9.0	8.8
Bole volume (× 1000, m^3)	33.44	8.65–70.19	36.8
Dry fiber weight (kg)	12.02	3.33–26.17	37.2

are poorly heritable. This agrees with many studies (cf. Zobel and van Buijtenen 1989) which found that wood quality traits (e.g., wood density) are more heritable than growth traits. However, surprisingly tree height in this species has a much higher heritability (h^2_i = 0.76 and h^2_f = 0.57) than other growth traits, even higher than wood density. This has been rarely reported (cf.Zobel and van Buijtenen 1989). It should be noted that wood density, in addition to a large family component of variance, has a remarkable family-block interaction component (7.4%), which tree height and other traits do not have (Table 2). A higher family heritability (h^2_f) for tree height was also reported by Park et al. (1989) for the same jack pine family test at age 10, but the individual-tree heritability (h^2_i) for tree height is still lower than wood density. Magnussen and Keith (1990) found that wood density in a 20-year-old jack pine family test was more heritable (h^2_f = 0.50) than tree height and other growth traits (h^2_f smaller than 0.18). The individual-tree heritability values (h^2_i) reported by Park et al. (1989) for wood density and growth traits of the same family test at age 10 are mostly comparable with those at age 16 (Table 2). However, the family heritability values (h^2_f) for all traits studied at age 16 appear lower than those at age 10 (Park et al. 1989), but are comparable with those reported for a 20-year-old jack pine family test (Magnussen and Keith 1990).

Correlations between wood density and growth traits

Genetic and phenotypic correlations computed from estimated variance and covariance

TABLE 2. *Estimated individual variance components (σ^2_f, σ^2_{bf} and σ^2_w), individual-tree and family-mean phenotypic variances (σ^2_{pi} and σ^2_{pf}), and individual-tree and family narrow-sense heritabilities (h^2_i and h^2_f) for wood density, growth traits, and dry fiber weight.*

	Wood density	DBH	Tree height	Bole volume	Dry fiber weight
σ^2_f	0.00006	0.0998	0.0762	4,911,652	1,010,464
%	11.1	3.2	19.0	3.3	5.3
σ^2_{bf}	0.00004	0.0000	0.0000	0	0
%	7.4	0.0	0.0	0.0	0.0
σ^2_w	0.00044	2.9908	0.3247	144,178,659	17,952,400
%	81.5	96.8	81.0	96.7	94.7
σ^2_{pi}	0.00054	3.0906	0.4009	149,090,321	18,962,864
h^2_i	0.45	0.13	0.76	0.13	0.21
σ^2_{pf}	0.00015	0.6220	0.1329	30,085,246	4,144,952
h^2_f	0.40	0.16	0.57	0.16	0.25

components are presented in Table 3. Phenotypically, almost no correlation exists between wood density and the three growth traits (−0.08, 0.09, and −0.02). However, the three growth traits (e.g., DBH, TH, and BV) all show a positive genetic correlation with wood density (0.21, 0.16, and 0.35, respectively). This is in contrast with the earlier study on 10-year-old trees (Park et al. 1989). But Magnussen and Keith (1990) also found that wood density showed a positive genetic correlation with tree height and DBH for a 20-year-old jack pine family test. The present result implies that selection for growth will not result in a decrease in wood density in this species. It is also noted that correlation of wood density with either tree height (TH) or DBH is significantly lower than that reported by Park et al. (1989) for year 10 data. These discrepancies may be explained by the inaccuracy in measuring wood density using the Pilodyn method in the year 10 study. In addition, dry fiber weight in this species shows a strong genetic correlation with wood density (0.62), DBH (0.84), tree height (0.59), and bole volume (0.96).

Implications for optimum gains in both wood quality and volume growth

The implications of the above genetic parameters for tree breeding were evaluated by estimating the expected genetic gains for wood density, bole volume, and dry fiber weight in the offspring of a seed orchard. The expected genetic gains in wood density, bole volume, and dry fiber weight due to different selection criteria were calculated based on family selection at selection intensity i = 1.386 (Table 4). Selection for wood density (criterion 1 in Table 4) would achieve a +3.6% gain in wood density. The genetic gain in wood density is not substantial because this trait shows very limited phenotypic variation. Since wood density is positively correlated with bole volume and dry fiber weight, selection for wood density would thus result in a simultaneous increase in bole volume (+4.5%) and dry fiber weight (+10.1%). Although this option is able to increase wood density, very limited gain in bole volume would be achieved. Therefore, it seems unlikely that this option would be adopted. Compared to selection for wood density, selection for DBH (criterion 2) in this species would improve the genetic gain in bole vol-

TABLE 3. *Genetic (upper triangle) and phenotypic (lower triangle) correlations between wood density, growth traits, and dry fiber weight.*

	Wood density	DBH	Tree height	Bole volume	Dry fiber weight
Wood density		0.21	0.16	0.35	0.62
DBH	−0.08		0.55	0.91	0.84
Tree height	0.09	0.41		0.67	0.59
Bole volume	−0.02	0.97	0.61		0.96
Dry fiber weight	0.19	0.93	0.62	0.97	

TABLE 4. *Expected response in wood density, bole volume, and dry fiber weight when different selection criteria are used.*

Selection criterion	Response (%)[1]		
	Wood density	Bole volume	Dry fiber weight
1. Wood density	+3.6	+4.5	+10.1
2. DBH	+0.5	+7.4	+8.7
3. Tree height	+0.7	+10.3	+11.5
4. Bole volume	+0.8	+8.2	+9.9
5. Dry fiber weight	+1.8	+9.8	+12.9

[1] Response based on family selection at selection intensity i = 1.386.

ume, but would achieve less gain in wood density (+0.5%) and dry fiber weight (+8.7%). Selection for tree height (criterion 3) would achieve higher gains in bole volume (+10.3%) and dry fiber weight (+11.5%) than either selection for wood density or selection for DBH. Even traditional selection for bole volume (criterion 4) cannot achieve as much gain in bole volume as selection for tree height does. This uncommon case is obviously due to a much higher heritability for tree height than for bole volume in this species (Table 2). As shown in Table 4, traditional selection for bole volume (criterion 4) would achieve +0.8% gain in wood density, +8.2% gain in bole volume, and +9.9% gain in dry fiber weight. Compared to traditional selection for bole volume (criterion 4), selection for dry fiber weight (criterion 5) could achieve a higher gain in bole volume (+9.8%) as well. Furthermore, this option would achieve the highest gain in dry fiber weight (+12.9%), namely maximum fiber production. This selection strategy appears to be attractive and economically important. For instance, assuming that wood production of a 40-year-old jack pine plantation is 200 m^3/ha and average wood density is 360 kg/m^3, selection for dry fiber weight (criterion 5) would result in an increase of 9,288 kg of dry fiber per hectare, while selection for bole volume (criterion 4) would result in an increase of 7,128 kg of dry fiber per hectare. Consequently, selection for dry fiber weight would provide over 2,000 kg more fiber per hectare. A similar finding was reported for black spruce by Zhang and Morgenstern (1996). Moreover, selection for dry fiber weight would produce higher density wood (+1.8%) and thus, better quality fiber for lumber and other solid products. Therefore, selection for dry fiber weight would achieve not only higher but also better quality fiber production compared to the traditional selection for bole volume alone.

CONCLUSIONS

Based on the results from this study, it seems reasonable to conclude that:

1. Wood density and tree height display considerably less phenotypic variation than DBH and bole volume, whereas dry fiber weight exhibits the largest phenotypic variation.
2. Wood density and dry fiber weight are more heritable than DBH and bole volume, but tree height in this species shows a much higher heritability than other growth traits, even higher than wood density.
3. Wood density shows a positive genetic correlation with growth traits. Therefore, it is possible to achieve simultaneous gains in both wood density and bole volume.
4. Selection for dry fiber weight would result in the highest gain in fiber yield, and higher gain in wood density and bole volume compared to traditional selection for bole volume.

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