Superior Parents Produce Superior MCP Families

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Abstract: In 2004, MeadWestvaco planted the first locations of full-sibling loblolly pine (*Pinus taeda*) families bred in a half-diallel design with 12 parents identified as superior for growth. At age five, heights and diameters were measured, fusiform rust infections and forks were tallied, and straightness was assessed. Even among these good parents, there were clear distinctions. Over all of the crosses, one parent was notably superior for growth; a second was reliably rust resistant; and a third yielded families with the best stem quality. For any trait, the best full-sibling families were from parents rated highest for that trait; that is, SCA was not a major factor among this group of families. A rust-adjusted, product-weighted index (RAPWI) is proposed to address various stem degrades that impact the commercial value of a family. The highest RAPWI ratings were achieved by families that included the highest ranking parents. Therefore, the logical first step in developing a Mass Controlled Pollination™ (MCP) production strategy is to identify elite parents for traits of interest.

Keywords: MCP, Mass Controlled Pollination, loblolly pine, *Pinus taeda*

INTRODUCTION

After a 50 plus year history in the Southeast, organized genetic improvement of loblolly pine (*Pinus taeda*) has developed beyond straightforward and easy open-pollinated seed orchards. Landowners increasingly want to exercise greater genetic control to improve returns on their timber investments. Clonal forestry offers the greatest control and potential gains but is not yet available for loblolly pine in volumes great enough or prices low enough to significantly impact Southern regeneration. Between half-sibling and clonal forestry is full-sibling forestry. It is intermediate in availability, price and potential genetic gain. Mass Controlled Pollination™ (MCP) is now practiced by some organizations and is the preferred way of deploying full-sibling families widely.

Full-sibling families are more uniform than half-sibling, open-pollinated families. Full-sibling families also presumably offer some genetic gain because contaminating pollen from outside the seed orchard is reduced or eliminated. The greatest gain, however, comes from the selection of the parents to create the MCPs. Gains are compromised when parental choices are sub par. With so many loblolly parents available in a provenance, it is infeasible to test all combinations to learn which are the best MCP families. Therefore, a logical method is to breed only those with the highest breeding values and assume that the best crosses are among these trees. By design, this will forgo the chance to find the outlier with mediocre parents.

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METHODS AND MATERIALS

MeadWestvaco (MWV) began MCP production on a small scale in 1993, and then expanded in 2002 as the promise became more evident. The company committed to full-scale implementation on one hundred percent of regenerated land. In support of its MCP program, MWV bred a half-diallel of 12 parents considered superior in growth. Following the logic above, MWV wished to learn which few among the many possible crosses were the best MCP candidates. Two locations of field trials were planted in 2004 in Charleston and Colleton counties, S.C. A total of 70 lots were planted. These included 67 full-sibling crosses, a single open-pollinated family from one of the 12 parents, and two unimproved check lots. Each entry was planted as a single tree in each of 25 replications at each location. Due to seedling shortages, six crosses were planted at only one location and were excluded from this paper's consideration (Table 1). Four other crosses were excluded because at least one parent appeared only in a single cross.

Thus, for this paper, 57 full-sibling families, one open-pollinated family and two unimproved check lots are being considered. The 12 parents are members of eight to 11 crosses each. CC3 is the unimproved loblolly check lot for coastal South Carolina used in progeny testing within the NCSU Cooperative Tree Improvement Program. FM2 is an unimproved loblolly collection from the Francis Marion National Forest.

Table 1. Breeding diagram among 12 primary parents, with additional crosses.

	L	K	J	I	H	G	F	E	D	C	B	T	U	V	W
A	**X**	**X**	**1 loc**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**1 cross**	**1 cross**	**1 cross**	
B	**X**	**X**	**X**	**X**	**X**	**X**	**1 loc**	**X**	**X**	**X**					
C	**1 loc**	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**						
D	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**							
E	**X**	**X**	**1 loc**	**X**	**X**	**X**	**X**								
F		**1 loc**	**X**	**X**	**X**	**X**									
G	**1 loc**	**X**		**X**	**X**										
H	**X**		**X**	**X**											
I	**X**	**X**	**X**												
J	**X**	**X**													
K	**X**														
S															**1 cross**

Both tests were measured at age five. In addition to height and diameter data, fusiform rust infection, stem forking and stem straightness were assessed. Rust infection and forking were noted as either present or absent. Straightness was judged using a scale of one to six, where the straightest trees received a one and the most crooked a six. At the two sites, heights averaged 8.3 meters and 8.9 meters (27.2 ft and 29.2 ft), forking was 19.8 and 24.4 percent, and rust infections were 29.0 and 53.9 percent. A tree volume surrogate was calculated as an index of $\pi r^2 * ht$.

The test data were analyzed using GAREML (D. A. Huber, University of Florida) which employs a mixed model approach where location and block within location are fixed effects and parent, full-sib family and error are random effects. The software produces both parental general combining ability and family specific combining ability values for each trait (height, volume, disease and stem qualities). The family genetic values are the sum of the parental values and the family value.

Parents, full-sibling and check lots were sorted and ranked by volume growth to identify those with the greatest potential for wood production, independent of stem quality. Values for fusiform rust infection, forks and crooked trees (straightness codes five and six to 24 percent of the population) were then considered for each lot. Using results from ten 5- to 12-year-old International Paper progeny tests with 30-52 percent rust infection (Table 2), the rust infection proportion was multiplied by 70 percent to estimate the proportion of trees with stem galls. Multiplying percentages of stems without galls, trees without forks and those not rated as crooked resulted in the portion of each lot with sawtimber quality stems.

Table 2. Fusiform rust infection rates, percent of infected trees with stem galls and percent of stem galls at or below breast height in 10 International Paper progeny tests, aged five to 12.

	Test Rust Infection (%)	Stem Galls (%)	Galls at or Below Breast Ht. (%)
A3449095.TAY	31.1	81.3	
B1328893.CT	40.0	33.0	
LGEL9804.BNR	42.4	46.8	91.8
LGO19403.CED	52.4	78.0	92.0
LGO29403.CED	49.1	79.4	93.5
LGO29403.JSO	30.3	85.8	95.2
LGOP9804.BNR	42.8	49.8	92.0
LOP19303.VRD	45.9	92.9	99.0
UGF19204.H82	36.0	78.0	93.4
UGF19204.MUL	42.6	86.0	91.4
Averages:	41.3	71.1	93.5

NeoLob, a growth and yield model developed by MeadWestvaco, was chosen to develop an estimate of product distributions. Using the range in heights for the various lots, NeoLob runs (one thinning and harvest at age 25) projected a distribution of 24 percent, two percent and 74 percent for pulpwood, chip-and-saw and sawtimber tons. This is a dimension-dependent distribution and does not consider stem degrades.

After accumulating degrades due to rust, forking and poor straightness, each lot's volume index was apportioned into the product categories. Each product was then weighted by prices of eight, 15 and 30 dollars per ton, respectively. This product-weighted index (PWI) was then sorted and lots were ranked again.

A stem infection's impact varies by location on the stem. In the International Paper data set, 94 percent of stem infections were at breast height or below. A major infection below breast height removes the most valuable piece of the tree, but it may be harvested above the gall to obtain a less valuable log. A major infection above breast height will eliminate a large number of potential saw logs.

Using the above judgments, a rust adjustment of 50 percent was assumed for trees with stem galls. That is, 50 percent of the volume in stem galled trees was assumed to remain as saw log volume and 50 percent was shifted into pulpwood.

The PWI was recalculated with the 50 percent rust adjustment factor to arrive at a rust-adjusted index (RAPWI), and the lots were ranked on that.

RESULTS

Even among these selected parents, there are distinct differences in all the traits. Breeding values for volume index ranged from 3.47 to 4.71, rust infection from 21.7 to 89.8 percent, forking from 3.4 to 51.8 percent and straightness from 2.60 to 4.81.

Table 3. Volume index, fusiform rust infection, forks and straightness for 12 parents and two check lots.

Parent	Volume	Rust %	Fork %	Straightness
A	4.709	53.5	50.2	2.951
B	3.469	89.8	3.4	2.604
C	4.119	38.1	31.1	3.064
D	4.454	21.7	17.9	3.044
E	3.941	50.9	44.9	3.484
F	3.899	50.7	35.8	3.223
G	3.617	42.9	35.2	4.361
H	3.985	51.1	13.3	4.155
I	4.036	40.8	51.8	4.110
J	4.486	62.4	15.3	3.425
K	3.889	44.7	47.5	4.809
L	3.843	57.0	19.9	4.518
CC-3	3.104	88.3	21.3	4.475
FM-2	3.103	72.7	29.1	4.594

No single parent excelled in all traits. One dominated in volume growth and was a parent in six of the top 10 families sorted on volume index. Table 4 gives details for those families and the two check lots, which performed worst among the 60 lots on which this paper reports. Cross identifications are given as parental rankings. For example, G1 (parent A) is the highest-ranked of the 12 parents for growth, and g12 is the lowest.

Table 4. Volume indices and ranks for best families and check lots.

Mother	Father	Cross	Volume	Rank
A	D	**G1** x g3	4.685	1
A	H	**G1** x g6	4.609	2
F	J	g8 x g2	4.515	3

A	L	**G1** x g10	4.500	4
D	J	g3 x g2	4.482	5
D	I	g3 x g5	4.468	6
A	C	**G1** x g4	4.415	7
A	OP	**G1** x OP	4.344	8
A	K	**G1** x g9	4.321	9
D	H	g3 x g6	4.320	10
. . .				. . .
CC-3			3.305	59
FM-2			3.305	60

A second (parent D) was superior in rust resistance and was a parent of nine of the top 10 families. Table 5 provides rust infection details of the top 10 families in the same manner as Table 4. In this case, the rust infection value for one parent was worse than the CC3 and FM2 checks. Parent B excelled in straightness and was in five of the top 10 families (Table 6). Nine families and FM2 ranked below the CC3 check. Parent B also rated best in forking and was in five of the top 10 (Table 7). CC3 ranked 21 out of 60, doing much better in forking than in other traits.

Table 5. Rust values and ranks for 11 families and a check lot.

Mother	Father	Cross	Rust %	Rank
C	D	r2 x **R1**	29.9	1
D	I	**R1** x r3	31.2	2
D	G	**R1** x r4	32.3	3
D	K	**R1** x r5	33.2	4
D	F	**R1** x r6	36.2	5
D	E	**R1** x r7	36.3	6
D	H	**R1** x r8	36.4	7
A	D	r9 x **R1**	37.6	8
D	L	**R1** x r10	39.3	9
C	I	r2 x r3	39.4	10
. . .				. . .
CC3			75.8	59
B	J	r12 x r11	76.1	60

Table 6. Straightness values for 12 families and a check lot.

Mother	Father	Cross	Straight	Rank
A	B	s2 x **S1**	2.73	1
B	C	**S1** x s4	2.83	2
B	D	**S1** x s3	2.84	3
B	J	**S1** x s6	2.99	4
B	E	**S1** x s7	2.99	5

A	D	s2 x s3	3.02	6
A	C	s2 x s4	3.04	7
C	D	s4 x s3	3.04	8
D	F	s3 x s5	3.11	9
C	F	s4 x s5	3.12	10
. . .				. . .
CC3			4.16	50
. . .				. . .
G	K	s10 x s12	4.59	59
K	L	s12 x s11	4.61	60

Table 7. Forking values for 12 families and a check lot.

Mother	Father	Cross	Forks %	Rank
B	H	**F1** x f2	9.3	1
B	J	**F1** x f3	9.6	2
B	D	**F1** x f4	11.0	3
B	L	**F1** x f5	12.2	4
H	J	f2 x f3	14.8	5
D	H	f4 x f2	16.1	6
D	J	f4 x f3	16.5	7
H	L	f2 x f5	16.9	8
B	C	**F1** x f6	16.9	9
J	L	f3 x f5	17.0	10
				. . .
CC3			25.3	21
				. . .
I	K	f12 x f10	51.5	59
A	I	f11 x f12	51.7	60

Cross A x D ranked first among the 60 lots for volume growth. This would be the preferred cross among these 12 parents if stem biomass were the sole objective of an MCP program. However, a breeder must also consider a family's potential to produce sawtimber, which is a major portion of a stand's value. This is especially true in the case of an MCP family. MCP production costs are much higher than for open-pollinated families (McKeand et al., 2008), so increasing the proportion of saw log quality stems is critical. The major factors in downgrading a stem of saw log dimensions to pulpwood are rust galls on the stem, forks and poor straightness.

After a series of degrade steps, A x D loses its top ranking. First, the family's rust infection rate is 37.6 percent. After multiplying this by .7 (Table 2), the estimated portion with stem galls becomes 26.3 percent. Next, the portion of forked stems is 33.3 percent. Finally, 16.0 percent of the stems of A x D were in the bottom two straightness classes and assumed to be too crooked for sawtimber.

Stems without stem galls: (1 - .263) = .737

Stems without forks: (1 - .333) = .667
Straight stems: (1 - .160) = .840

Equation 1. Portion of saw log-potential stems $_{(A \times D)}$: (.737 * .667 * .840) = .413

A saw log-potential rating of 41.3 percent ranks A x D at 14 out of 60 lots tested, a considerable drop from 1. Multiplying this by its top rated volume index brings its ranking back up to eight out of 60. This ranking however, is just as simplistic as the volume index alone because this new rating considers only the volume produced as sawtimber, ignoring any production in pulpwood.

In order to account for the total production of A x D, its volume must be split into the component commercial products. Multiplying its volume index of 4.685 by the 24-2-74 proportions (derived from NeoLob) partitions it into pulpwood, chip-and-saw and sawtimber pieces before culling.

Pulpwood portion = .24 * 4.685 = 1.124
Chip-and-saw portion = .02 * 4.685 = .094
Sawtimber portion = .74 * 4.685 = 3.467

Based on the culling logic above, however, only 41.3 percent of the trees that meet the size standards for chip-and-saw and sawtimber will also meet the quality standards. Culls in these two classes are shifted into pulpwood in order to arrive at a fairer product distribution.

Pulpwood = 1.124 + (1-.413) * (.094 + 3.467) = 3.216
Chip-and-saw = .413 * .094 = .039
Sawtimber = .413 * 3.467 = 1.430

Next, each of these classes is multiplied by the eight, 15 and 30 dollars per ton prices, respectively, to arrive at a product-weighted index.

Equation 2. PWI $_{(A \times D)}$ = (3.216 * 8) + (.039 * 15) + (1.430 * 30) = 69.21

This value is high among this set of lots, but the various degrades in A x D reduced its ranking from number one in the pure volume index to four in this PWI. Even this, though, may not be the final estimate of the worth of A x D. The rust infection portion of the PWI assumes that all of the stem galled trees (i.e., 70 percent of all rust infected trees) are merchandized as pulpwood. This is overly simplistic. In reality, a stem galled tree may end up totally as pulpwood or handled as a saw log with defects. For trees with only a stem gall near the base, the harvester may cut above the infection to get a gall free (but smaller) log. On the other hand, multiple stem galls or a major gall located high on the first log may lead to use only as pulpwood. It is probable that the proportion of stem galled trees that are merchandized as only pulpwood varies. For example, stands with higher rust infection rates will have more multiply galled trees and a higher proportion of volume used as pulpwood. For this paper, the rust adjustment downward to pulpwood is arbitrarily assumed to be 50 percent of the volume of rust galled stems.

A rust-adjusted product-weighted index (RAPWI) differs from the PWI through changing the first factor in Equation 1. For A x D, this is:

Volume not degraded by rust: (1 - .263 * .5) = .868

Inserting this into Equation 1 results in:

Portion of saw log-potential volume $_{(A \times D)}$: (.868 * .667 * .840) = .486

Carrying this through product volume calculations gives:

Pulpwood = 1.124 + (1-.486) * (.094 + 3.467) = 2.953
Chip-and-saw = .486 * .094 = .046
Sawtimber = .486 * 3.467 = 1.686

And finally:

Equation 3. RAPWI $_{(A \times D)}$ = (2.953 * 8) + (.046 * 15) + (1.686 * 30) = 74.88

This value ranks A x D at fourth out of 60. It is clearly one of the most preferred full-siblings in this group, but bringing stem quality traits into consideration has reduced its ranking by three positions. Ahead of it in RAPWI (and in PWI as well) are D x J, D x H and C x D, ranked five, 10 and 13, respectively, for volume index. Parent D is common to all four of the top crosses. This is reasonable since, as a parent, it never ranks below fourth for any of the traits considered here. One major reason that D x J, D x H and C x D outrank A x D in RAPWI and PWI is because their forking rates are much lower – half as much for the first two.

Significant rank changes from the volume index through the RAPWI were common (Table 8). Crosses of parent B, which was the best of the 12 for both straightness and forking but poorest in rust and growth, moved up from two to 45 positions (the latter when crossed with parent D). Conversely, crosses of parent K, poorest in straightness and tenth in forking, changed by a +2 (when crossed with parent B) down to a -34 rank positions. The two unimproved check lots, CC3 and FM2, were consistent across all indices. They ranked 59th and 60th for volume index and 58th and 60th for RAPWI.

If the RAPWI is a reasonable tool to judge commercial value of these 60 lots, then it is clear that the best MCP families are produced by the best parents – a common sense and expected conclusion. Of the top 10 RAPWI crosses, nine include parents that rank the best for at least one of the four traits considered in this paper: growth, rust resistance, forking and straightness. Both parents of the tenth cross, C x J, rank second of 12 for either growth or rust. Parent D is present in seven of the 10 top crosses. It ranks no lower than fourth for any of the traits, by far the best overall ratings among the 12 parents. Parent B is present in three crosses, a clear result of its superior forking and straightness scores. Interestingly, parent A was in only one cross among the RAPWI top 10, despite being the best grower by a good margin. Cumbie et al. (2008) reported a similar result in a population of Lower Gulf elites. Only two of the top 10 elite families for volume growth were also in the top 10 for monetary value.

Table 8. Volume, product-weighted and rust-adjusted product-weighted indices for 60 lots.

Mother	Father	Cross with Parental Rankings	Volume Index	Vol. Index Rank	PWI	PWI Rank	RAPWI	RAPWI Rank
D	J	g3-R1-s3-f4 x g2-r11-s6-f3	4.482	5	73.79	1	81.70	1
D	H	g3-R1-s3-f4 x g6-r8-s9-f2	4.320	10	71.52	2	77.84	2
C	D	g4-r2-s4-f6 x g3-R1-s3-f4	4.213	13	71.48	3	76.47	3
A	D	G1-r9-s2-f11 x g3-R1-s3-f4	4.685	1	69.21	4	74.88	4
C	J	g4-r2-s4-f6 x g2-r11-s6-f3	4.101	28	64.85	8	73.54	5
B	J	g12-r12-S1-F1 x g2-r11-s6-f3	3.987	37	58.39	21	73.50	6
D	E	g3-R1-s3-f4 x g7-r7-s7-f9	4.213	14	67.61	5	73.38	7
B	D	g12-r12-S1-F1 x g3-R1-s3-f4	3.666	53	61.25	11	71.46	8
B	C	g12-r12-S1-F1 x g4-r2-s4-f6	3.875	45	59.38	18	70.89	9
D	F	g3-R1-s3-f4 x g8-r6-s5-f8	4.136	23	65.22	7	70.67	10
F	J	g8-r6-s5-f8 x g2-r11-s6-f3	4.515	3	62.05	9	70.54	11
D	I	g3-R1-s3-f4 x g5-r3-s8-f12	4.468	6	66.26	6	70.52	12
A	B	G1-r9-s2-f11 x g12-r12-S1-F1	4.108	27	57.10	23	69.29	13
A	H	G1-r9-s2-f11 x g6-r8-s9-f2	4.609	2	61.05	13	68.03	14
D	L	g3-R1-s3-f4 x g10-r10-s11-f5	4.174	17	61.88	10	67.30	15
A	C	G1-r9-s2-f11 x g4-r2-s4-f6	4.415	7	61.15	12	67.24	16
C	F	g4-r2-s4-f6 x g8-r6-s5-f8	4.021	34	60.52	16	66.91	17
H	J	g6-r8-s9-f2 x g2-r11-s6-f3	4.150	22	58.50	20	66.84	18
C	H	g4-r2-s4-f6 x g6-r8-s9-f2	4.111	25	60.48	17	66.74	19
C	G	g4-r2-s4-f6 x g11-r4-s10-f7	4.018	36	60.87	15	66.56	20
A	L	G1-r9-s2-f11 x g10-r10-s11-f5	4.500	4	58.93	19	66.15	21
D	G	g3-R1-s3-f4 x g11-r4-s10-f7	4.109	26	61.03	14	65.14	22
B	H	g12-r12-S1-F1 x g6-r8-s9-f2	3.902	42	53.86	32	64.88	23
F	H	g8-r6-s5-f8 x g6-r8-s9-f2	3.890	43	56.72	24	63.80	24
C	E	g4-r2-s4-f6 x g7-r7-s7-f9	3.930	40	57.20	22	63.02	25
B	E	g12-r12-S1-F1 x g7-r7-s7-f9	3.659	54	51.97	40	62.98	26
A	F	G1-r9-s2-f11 x g8-r6-s5-f8	4.295	11	56.58	26	62.96	27
A	OP	G1-r9-s2-f11 x OP	4.344	8	54.99	29	61.99	28
I	J	g5-r3-s8-f12 x g2-r11-s6-f3	4.291	12	55.86	28	61.94	29
C	I	g4-r2-s4-f6 x g5-r3-s8-f12	4.090	29	56.02	27	60.47	30
E	F	g7-r7-s7-f9 x g8-r6-s5-f8	4.133	24	54.54	30	60.45	31
D	K	g3-R1-s3-f4 x g9-r5-s12-f10	4.163	20	56.71	25	60.25	32
E	H	g7-r7-s7-f9 x g6-r8-s9-f2	3.838	46	53.76	33	60.16	33
J	L	g2-r11-s6-f3 x g10-r10-s11-f5	4.174	18	52.97	36	60.00	34
E	I	g7-r7-s7-f9 x g5-r3-s8-f12	3.946	38	54.35	31	59.73	35
A	E	G1-r9-s2-f11 x g7-r7-s7-f9	4.178	16	53.36	34	59.10	36
B	G	g12-r12-S1-F1 x g11-r4-s10-f7	3.584	55	49.45	46	58.46	37
B	I	g12-r12-S1-F1 x g5-r3-s8-f12	3.810	48	50.07	45	58.32	38

A	G	G1-r9-s2-f11 x g11-r4-s10-f7	4.168	19	53.13	35	58.17	39
J	K	g2-r11-s6-f3 x g9-r5-s12-f10	4.199	15	52.24	39	57.83	40
H	L	g6-r8-s9-f2 x g10-r10-s11-f5	3.911	41	51.34	43	57.44	41
A	I	G1-r9-s2-f11 x g5-r3-s8-f12	4.153	21	52.55	37	57.31	42
A	K	G1-r9-s2-f11 x g9-r5-s12-f10	4.321	9	52.49	38	57.18	43
E	L	g7-r7-s7-f9 x g10-r10-s11-f5	4.025	33	51.31	44	57.10	44
B	K	g12-r12-S1-F1 x g9-r5-s12-f10	3.832	47	48.28	49	56.12	45
F	I	g8-r6-s5-f8 x g5-r3-s8-f12	4.038	32	51.51	42	56.03	46
C	K	g4-r2-s4-f6 x g9-r5-s12-f10	4.071	30	51.75	41	55.66	47
B	L	g12-r12-S1-F1 x g10-r10-s11-f5	3.576	57	46.14	52	55.41	48
F	G	g8-r6-s5-f8 x g11-r4-s10-f7	3.555	58	49.32	47	54.41	49
G	H	g11-r4-s10-f7 x g6-r8-s9-f2	3.757	51	49.20	48	53.90	50
I	L	g5-r3-s8-f12 x g10-r10-s11-f5	3.942	39	47.27	50	51.36	51
E	G	g7-r7-s7-f9 x g11-r4-s10-f7	3.777	49	46.17	51	50.07	52
E	K	g7-r7-s7-f9 x g9-r5-s12-f10	4.018	35	44.61	54	47.74	53
I	K	g5-r3-s8-f12 x g9-r5-s12-f10	4.066	31	45.06	53	47.73	54
H	I	g6-r8-s9-f2 x g5-r3-s8-f12	3.762	50	44.20	55	47.53	55
K	L	g9-r5-s12-f10 x g10-r10-s11-f5	3.581	56	43.05	57	47.03	56
G	I	g11-r4-s10-f7 x g5-r3-s8-f12	3.884	44	44.15	56	46.86	57
CC3			3.305	59	36.79	59	42.64	58
G	K	g11-r4-s10-f7 x g9-r5-s12-f10	3.708	52	39.39	58	41.54	59
FM2			3.305	60	36.49	60	41.05	60

DISCUSSION

More than 50 years into improvement of loblolly pine, breeders have a large collection of tested parents for all of the recognized provenances. Cooperative tree improvement programs have selected and tested more than 7,000 first-generation trees from natural stands and plantations. Additionally, there are breeding values for more than 1,100 advanced-generation selections. When making decisions for grafting new seed orchards, a breeder can ensure high genetic gain for traits of interest by selecting only the very best trees among this very large population.

As forest managers try to get more returns from their plantations, full-sibling forestry technology, in the form of Mass Controlled Pollination, is on the increase in the Southeast. The reason is that MCP plantations provide higher value than open-pollinated alternatives (McKeand, et al., 2008). But it is only with the proper choice of parents that MCPs improve gain. What are the proper choices? Even when a breeder restricts his production population to a fairly small number of parents, making all of the possible crosses to test as MCP candidates can be burdensome. For example, there are (20 * 19)/2 = 190 potential MCP families among 20 parent clones (ignoring reciprocals). This number goes up rapidly, such that 25 parents produce 300 crosses and 30 parents produce 435.

Making all possible crosses in order to find the best full-sibling families is necessary if those families can't be well predicted from their breeding values (e.g. where SCA is a major factor). Doing so is costly, though, and wasteful if breeding values are useful. The results of this test group show that the breeding value of the parent dominates the results of full-sibling families. Among the 57 crosses, the best parent produced six, nine, five and five of the top 10 families in four traits. The index that combines those four (RAPWI) favors crosses with top-ranked parents. The first step, then, in choosing MCP parents should be to select those with high breeding values for traits of interest. This is the procedure recommended by Jansson and Li (2004) based on their analysis of the Atlantic Coastal loblolly population.

There is no surprise in this conclusion. It agrees with basic genetic principles that tree breeders use regularly in practice. It also argues strongly against making major efforts to breed and test large numbers of full-sibling families in order to identify that rare and special case from a mediocre parent. This paper does not suggest that these cases cannot occur. Rather, it implies that an effective MCP operation focuses on superior parents. Discovery of special MCPs from lesser parents may happen accidentally but is not part of an efficient program.

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