RISK ANALYSIS OF LOBLOLLY PINE CONTROLLED MASS POLLINATION PROGRAM

T.D. Byram[1] and F.E. Bridgwater[2]

Abstract: -- The economic success of controlled mass pollination (CMP) depends both upon the value of the genetic gain obtained and the cost per seed. Crossing the best six loblolly pine (*Pinus taeda*) parents currently available in each deployment region of the Western Gulf Forest Tree Improvement' Program will produce seed with an average additional gain in mean annual increment at age 20 of 16.1% compared to seed from open-pollinated seed orchards with 30% pollen contamination. The present value of this additional gain in growth rate is $0.177 per seed, which compares favorably to the estimated production cost of $0.05 per seed.

Three different CMP scenarios were evaluated by varying the number of female strobili per isolation bag, the cost of CMP per isolation bag, and the seed obtained per strobilus pollinated. The distributions for the possible number of strobili per isolation bag and cost of CMP per isolation bag were estimated from two pilot-scale CMP programs. CMP cost per isolation bag included the cost of pollen collection, the installation and removal of the isolation bag, and a single pollen application. Distributions for strobili per isolation bag and the cost per isolation bag were assumed to be the same for all three scenarios. Data from three loblolly pine control-pollination programs were used to estimate the distribution for the average annual seed yield per strobilus pollinated and formed the basis for the three different scenarios. The average annual cost of CMP seed production varied substantially among programs. Where seed yields were high and consistent, the annual CMP cost averaged $0.0535 per seed with a range of $0.0119 to $0.1844. If seed yields were high but twice as variable, the annual CMP cost averaged $0.0594 per seed with a range of $0.0112 to $0.4129. Where seed yields were both lower and less dependable, the annual CMP cost ranged from $0.0096 to $12.120 per seed with an average of $0.1275. However, when CMP seed costs were weighted by seed production across years, all three scenarios were economically attractive. CMP seed production weighted for total seed production was $0.0473, $0.0475 and $0.0555 for the three scenarios. The much larger quantity of cheap seed produced in good years more than offset the expensive seed produced in poor years. The annual expense per seed exceeded the breakeven cost of $0.177 only 0.2, 1.1 and 10.3 percent of the time, respectively.

Kewords: -- mass pollination, risk analysis, *Pinus taeda*, seed production

INTRODUCTION

Controlled mass pollination (CMP) has been shown to be an economically attractive method of increasing genetic gain from loblolly pine (*Pinus taeda* L.) seed orchards (Bridgwater et al. 1998). In the Western Gulf Forest Tree Improvement Program (WGFTIP), crossing the best six individuals in a breeding region would result in an average gain in mean annual increment at age 20 of 16.1% above seed collected from currently producing open-pollinated seed orchards with 30% pollen contamination. Based on the additional stumpage available for harvest at age 25, each CMP seed had a marginal present value in the year of pollination of $0.177 above open-pollinated orchard seed. This value compares favorably to the production cost of $0.05 per CMP seed estimated from pilot-scale studies.

[1] Western Gulf Forest Tree Improvement Program, Texas Forest Service, Forest Science Laboratory, Texas A&M University, College Station, TX 77843-2585

[2] USDA-Forest Service, Forest Science Laboratory, Texas A&M University, College Station, TX 77843-2585

Estimates of CMP production costs are based on limited experience with average costs and seed yields, from pilot-scale studies. CMP production costs depend on the cost per isolation bag, the number of female strobili per bag, and the seed obtained per female strobilus pollinated. Because all of these factors vary, actual production costs of CMP seed will fluctuate and could be quite high in years with crop failures. To properly evaluate the economic return from CMP programs, the variation in production costs and the frequency with which the production costs exceed the present value of the seed need to be understood. Monte Carlo simulation can be used for this type of risk analysis (Law and Kelton 1991, Anonymous 1995) by allowing input variables (cost per isolation bag, etc.) to vary and examining the distribution of the calculated CMP production costs.

CMP cost per isolation bag, which includes the costs of pollen collection, the installation and removal of the isolation bag, and pollen application is to some degree under the control of the operator. Similarly, the number of female strobili per isolation bag varies among clones and from year to year but is also controlled by the operator's selection of limbs for bagging. Because these factors are strongly influenced by operator choices, distributions for these variables can be estimated from pilot-scale studies. However, the number of seed obtained per strobilus pollinated is a complex trait dependent on pollination success, strobilus survival, and seed yields. These factors are in turn affected by clonal selection, pollen viability, timing of pollination, extreme weather events, and insect predation. Pilot-scale studies, which generally are limited to only a few years, may not adequately sample all of these factors. Estimating the probabilities for each factor individually also has limitations. For example, the likelihood of complete crop failure may be estimated by examining weather records to determine the frequency of spring freezes. If worst case scenarios are assumed for all factors, risks are vastly overestimated. Similarly, failure to accurately combine information on multiple factors can lead to an underestimate of risk. The approach used here was to e&mate the distribution for seed yields per strobilus pollinated from the historical records provided by control-pollination programs for progeny test seedling production. These records combine information on pollination success, strobilus survival and seed yields over many years, many different operators, and many different operational conditions.

Cost data and estimates of strobili per bag from' two pilot-scale CMP programs were combined with estimates of seed production per strobilus pollinated from three different control pollination programs to estimate production cost for CMP seed. Monte Carlo simulation was used to examine three different scenarios: 1) relatively high and reliable annual seed yield, 2) high but more unpredictable annual seed yield, 3) relatively lower and more unpredictable annual seed yields. Average annual cost for CMP seed, the likelihood that the breakeven cost would be exceeded, and CMP cost weighted by annual seed production were calculated for each scenario.

METHODS

Development of Probability Distributions for Costs and Seed Yields

Costs and number of female strobili per bag were obtained from two pilot-scale CMP programs. One program had data from three different years while the other program had data from two years (Table 1). CMP costs included the cost of pollen collection and processing, installation and removal of the pollination bags, and a single pollination application. Equipment rental and wages for both permanent employees and contractors were included. Average CMP cost per bag was calculated by year and used to specify a distribution of possible costs as input into the simulation. CMP costs were normally distributed but truncated at $2 per bag as a minimum level of expense not likely to be surpassed by any

Table 1. Pilot-scale studies used to estimate the distributions for CMP costs and number of strobilus per bag.

	Year	Number of Crosses	Number of Bags
Pilot Program 1			
	1995	4	1,000
	1997	6	2,040.
	1999	5	10,332
Pilot Program 2			
	1997	17	10,072
	1999	13	15,919

CMP program. The maximum cost generated by the simulation was not restricted. Limiting the minimum cost per bag had a negligible impact on the average cost per seed and did not hinder the ability to determine the number of times the breakeven cost was exceeded. The number of female strobili included in each isolation bag at installation was available for only nine crosses as only the strobili present at bag removal were normally recorded. The distribution used to represent the possible values for strobili per bag was truncated at two as it was assumed that the operator would not install bags on limbs with fewer than two strobili. The means, standard deviations, and ranges for the CMP costs and strobili per bag used as input into the simulation are shown in Table 2 and represented graphically in Figures 1 and 2.

Table 2. Average, standard deviation, minimum and maximum values generated by the simulation for use as input to calculate CMP seed costs.

	Mean	Standard Deviation	Minimum	Maximum
Cost/Bag	$3.86	$0.95	$2.00	$7.06
Strobili/Bag	4.38	1.4	2.4	9.9
Seed/Strobilus				
scenario 1	18.62	2.47	11.04	27.06
Scenario 2	18.56	5.33	1.69	35.43
scenario 3	16.01	7.66	0.17	39.38

Seed yields per strobilus pollinated were available from control-pollination programs located in central Arkansas, northern Louisiana and southern Mississippi. The overall average seed yield per strobilus pollinated for all crosses from these three programs was 16.12 (1,140,299 seed / 70,716 female strobili). Females that consistently failed to produce seed would not likely be used in a CMP program and were eliminated from the data to obtain the values in Table 3. The distributions used as input to the simulation are in Table 2 and represented graphically in Figure 3. Scenario 1 represents a situation where the average seed yield is high and predictable. In scenario 2 the average seed yield is only marginally lower than in scenario 1 but the standard deviation is twice as large. Scenario 3 has both lower average seed yields and a higher annual variation.

Table 3. Average seed yields per strobilus pollinated by cross from three loblolly pine control-pollination programs.

	Year	Number of Crosses	Average Number of Seed/Strobilus Pollinated	Minimum	Maximum
Program 1					
	1987	25	19.5	1.8	74.5
	1988	64	16.8	0.0	50.6
	1989	70	19.2	0.0	51.2
	1990	49	14.2	0.0	60.0
	1991	121	19.8	0.0	57.8
	1992	80	22.8	0.0	71.4
	1993	48	20.5	0.0	51.6
	1994	49	17.7	0.0	56.9
	1995	24	17.6	0.0	64.5
Program 2	1985	25	22.8	7.1	62.5
	1987	27	22.8	0.2	66.9
	1988	17	12.5	0.0	37.8
	1989	29	21.7	3.0	76.1
	1990	21	12.9	0.0	59.2
Program 3	1986	34	25.9	0.0	75.3
	1987	121	6.9	0.0	50.0
	1988	228	8.0	0.0	75.8
	1989	246	17.0	0.0	79.4
	1990	138	25.3	0.0	99.5
	1991	129	7.8	0.0	53.7
	1992	159	15.7	0.0	76.2
	1993	142	25.5	0.0	84.1
	1994	105	17.7	0.0	105.2
	1995	17	4.5	0.0	19.8

Model Implementation

Monte Carlo simulation implemented in an Excel® spreadsheet with @Risk@ software was used to evaluate the distribution of cost for CMP seed. The distributions for the numbers of strobili per isolation bag and the cost of CMP per isolation bag were assumed to be the same for all three scenarios. The numbers of seed obtained per strobili pollinated were varied as described above to produce three scenarios. All three variables were uncorrelated. Each scenario was sampled 500 times and CMP seed costs were calculated according to the following formula:

CMP cost per seed = (Cost per bag)/[(Strobili per bag)*(Seed per strobilus)]

Annual CMP seed costs, probabilities of exceeding the breakeven cost and CMP seed costs weighted by annual seed production were calculated.

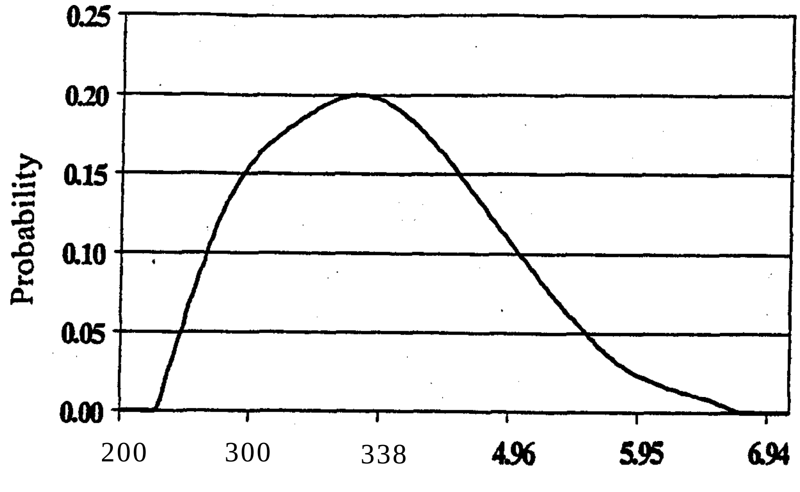

Figure 1. Distribution of CMP costs per pollination bag.

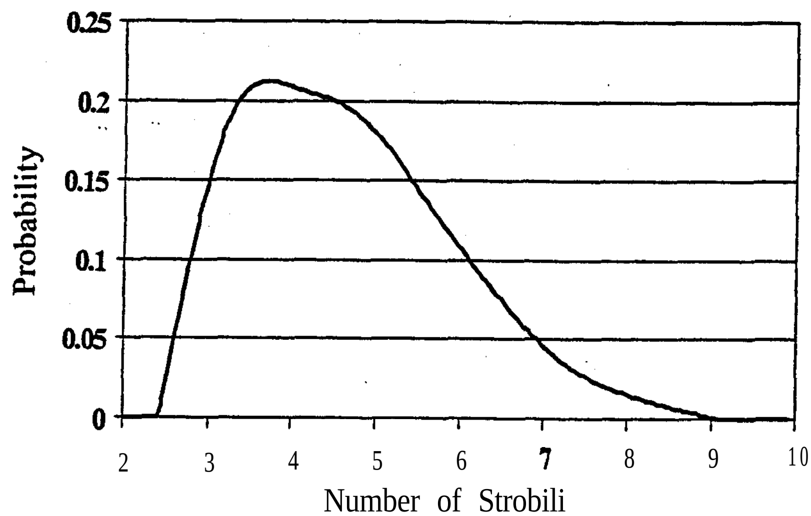

Figure 2. Distribution of the number of strobili per pollination bag

RESULTS AND DISCUSION

Annual CMP costs per seed differed substantially among the three scenarios (Table 4). Scenario 1, in which seed yields were relatively high and reliable, had an average annual CMP seed production cost of $0.0535 per seed with a range from $0.0119 to $0.1844. The breakeven cost of $0.177 per seed was exceeded in only 0.2% of the simulations. Scenario 2, which had very similar average seed yields per strobilus pollinated but where the standard deviation among years was almost twice as large, had a very

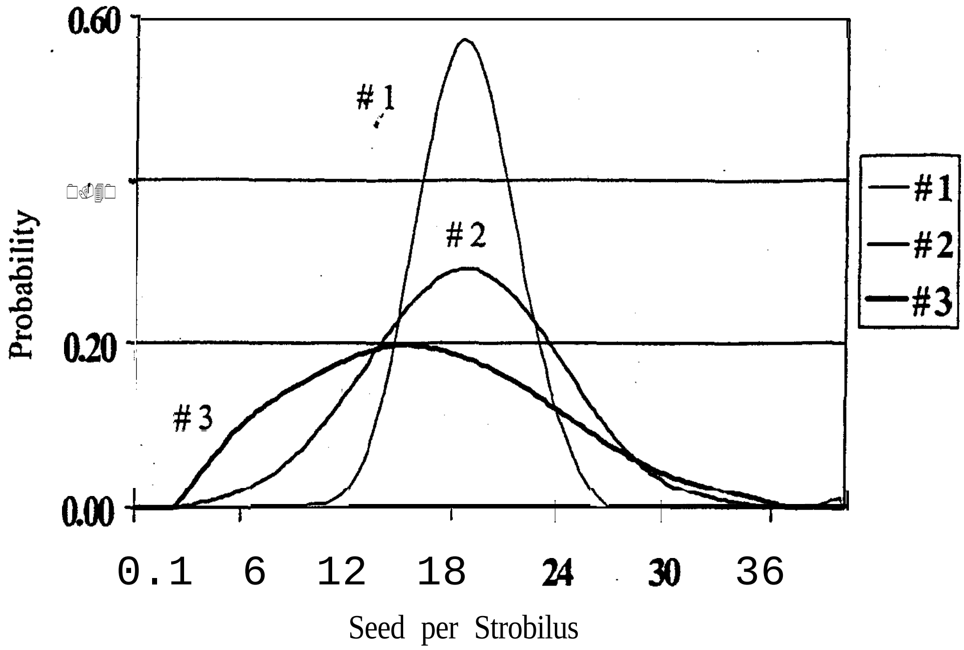

Figure 3. The distribution of average number of seed obtained per strobilus pollinated for three scenarios: 1) High average and low variability, 2) High average and high variability and 3) Low average and high variability.

similar average annual CMP seed production cost of $0.0594. The range of annual CMP seed production cost was larger, as high as $0.41 per seed in some simulations. Even so, the breakeven cost was exceeded in only 1 .1% of the simulations. In Scenario 3, where the seed yields per strobilus pollinated were both lower and more variable, average annual CMP seed production was more costly. The average annual cost of CMP seed was over twice as large as the average annual CMP cost predicted for the other two scenarios. Nevertheless, Scenario 3 was predicted to exceed the breakeven cost in only 1 year in 10 (10.3%).

Table 4. CMP costs per seed for three different scenarios.

Scenario	CMP cost Weighted for Total Seed Production	Annual CMP Costs Per Seed			Probability of Exceeding $0.177 (%)
		Average	Minimum	Maximum	
1	$0.0473	$0.0535	$0.0119	$0.1844	0.2
2	$0.0475	$0.0594	$0.0112	$0.4129	1.1
3	$0.0555	$0.1275	$0.0096	$12.120	10.3

A more appropriate criterion for evaluating the economic attractiveness of a CMP program is likely to be the mean CMP cost weighted for annual seed production. By this standard, all three scenarios are well below the breakeven costs with weighted CMP costs of $0.0473, $0.0475, and $0.0555 per seed (Table 4). In other words, the much larger quantity of cheap seed produced in good years more than offset the expensive seed produced in crop poor years. Under the conditions described in Scenario 3, the seed orchard manager must be willing to accept that CMP seed will be very expensive in some years. However, if seed costs are distributed across years, a CMP program would still. be profitable.

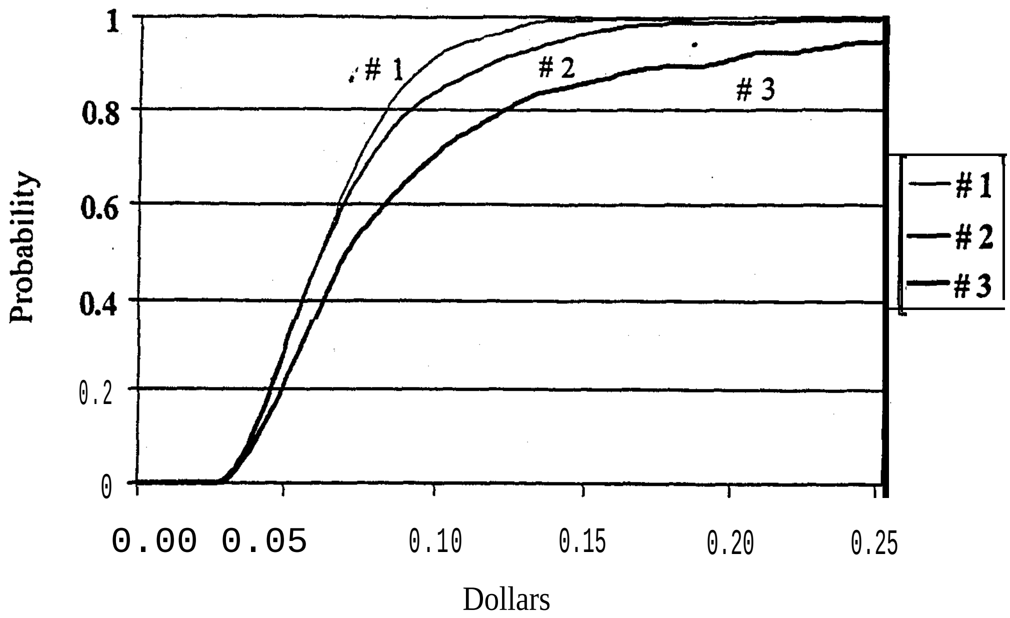

Figure 4. Cumulative probabilities for the likelihood that yearly CMP production costs will be below values on the X axis for three scenarios.

Cumulative probabilities for the three scenarios can be used to estimate the likelihood of being below specific CMP seed production cost values in a given year (Figure 4). For example, the probabilities of CMP seed production cost being less than $.10 are 95.7%, 88.8%, and 76.3% for Scenarios 1, 2, and 3, respectively. This is a slightly different parameter than the weighted CMP cost used to predict expenses adjusted for seed production over multiple years.

Caution should be exercised when using simulations to make decisions, as they are only as reliable as the underlying assumptions. As stated earlier, the economic success of CMP seed production depends on both the value of the genetic gain obtained and the cost of seed production. In this paper, the present value of CMP seed was based on the assumption that each percent gain in mean annual increment at age 20 had a value of $0.011 per seed and that CMP seed had a marginal genetic gain of 16.1% above the next best source of planting material. Changes in stumpage value or marginal genetic gain of CMP seed will change the breakeven cost of CMP seed production and alter the decision criteria

Seed yields per strobilus pollinated have a large impact on the cost per seed. For this paper, seed yields were estimated from control-pollination programs for genetic testing that differ in important ways from operational CMP programs. Control-pollination programs for genetic testing generally use a different type of isolation bag, frequently involve multiple pollen applications per bag, and are likely performed by more experienced applicators. Presumably, all of these factors may lead to higher seed yields. On the other hand, control-pollination programs for genetic testing are performed on many clones with a range of seed production capacities and may be performed in scion banks with less than optimal insect protection. Also, no rare weather events such as the region wide freeze experienced in the spring of 1996 were represented in the control-pollination data.

Because high and reliable seed production per strobilus pollinated is important to the economic success' of CMP efforts, selecting female parents for seed production as well as genetic gain is critical. Strobilus survival, seed yield per cone, and viability of extracted seed can vary dramatically among female parents making it desirable to use certain parents only as males or to exclude them entirely from CMP programs.

CONCLUSIONS

CMP seed production is an economical& attractive method of capturing genetic gain in loblolly pine production programs under the conditions examined in this paper. The high probability that CMP production costs will be below 'the breakeven value under a range of assumptions makes it likely that small inaccuracies in the assumptions underlying this simulation will not change this conclusion. Failure to account for variation in seed yields per strobilus pollinated will result in substantially underestimating production costs where annual variation in this trait is large. However, even with some poor seed crop years, CMP seed cost weighted for annual seed production were well below the present value for the improvement available in genetic gain.

ACKNOWLEDGMENTS

We wish to thank the members of the Western Gulf Forest Tree Improvement Program for supporting this work. Boise Cascade and Champion International provided cost figures from pilot-scale CMP projects. The Arkansas Forestry Commission, The Mississippi Forestry Commission, and the Timber Company provided records from their control-pollination programs.

LITERATURE CITED

Anonymous. 1995. @Risk: Advanced risk analysis for spreadsheets. Palisade Corp. Newfield, NY. 321 p.

Bridgwater, F.E., D.L. Bramlett, T.D. Byram, and W. J. Lowe. 1998. Controlled mass pollination in loblolly pine to increase genetic gains. The Forestry Chronicle 74(2):185-189.

Law, A.M. and W.D. Kelton. 1991. Simulation modeling and analysis. McGraw-Hill, New York, NY. 759 p.