Economics of Pitch × Loblolly Pine Hybrids

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(Received April / November 1980)

Abstract

Promising results from developmental testing of pitch × loblolly pine hybrids prompted an evaluation of the economic potential for investment in hybrid seed production. A least-total-cost model was derived to provide guides for cost effective investment in seed orchard and planting phases of hybrid production. The incremental analysis, based on least-cost-plus-loss economic theory, indicates that pitch × loblolly hybrid seed production would yield net gains at interest rates up to 9 percent. The model can be used to find the combination of annual planting area, seed orchard capacity, and expenditure that increased forest yields would justify at different interest rates.

Key words: Pinus rigida × *P. taeda,* hybrid seed orchard, least-cost analysis, investment decisionmaking.

Zusammenfassung

Vielversprechende Ergebnisse aus Versuchen über die Entwicklung von Hybriden zwischen *P. rigida* × *P. taeda* veranlaßten eine Bewertung der wirtschaftlichen Möglichkeiten für Investitionen für die Erzeugung von Hybridsaatgut. Ein Mindestkosten-Modell wurde entwickelt, um einen Weiser für die kostenwirksame Anlage von Samenplantagen und die Pflanzungsphasen der Hybriden zu schaffen. Die Wachstumsanalyse, basierend auf einer Wirtschaftstheorie, die Mindestkosten plus Verlust berücksichtigt, zeigt an, daß die Hybrid-Samen-Produktion bis zu 9% Zinsen ergeben würde. Dieses Modell soll dazu dienen, die besten Kombinationen des jährlichen Pflanzgebietes, Größe der Samenplantage und Kosten zu bestimmen, welche die steigenden Holzerträge bei verschiedenen Zinsen rechtfertigen.

Introduction

Efforts have been underway since 1963 to develop fast growing, winter-hardy, yellow pines for the Eastern United States. This work has focused on pitch × loblolly pine hybrids produced from a selection of phenotypically superior trees. Since 1971, controlled pollinations between the selected clones of pitch and loblolly pine have been test-planted in nine states. Certain of these hybrids combine loblolly pine's rapid growth and good form with pitch pine's winter hardiness (Little and Trew 1979). The tests indicate that, with enough care and effort in selecting parent trees and screening hybrids, rapid growing trees that are well formed and winter hardy can be produced.

The next step appears to be a full-scale program for pitch × loblolly hybrid seed production. But first, it is advisable to determine the costs and economic potentials of investment as a guide to planning this endeavor. How far to go with tree improvement is a matter of choice and a rational choice requires criteria for comparing and evaluating alternatives. Accordingly, this paper estimates the cost of producing pitch × loblolly hybrid seed and indicates the magnitude of expenditure that increased forest yields would justify.

The details of a cost model that would, approximate the expected market price for improved seed have been discribed by Davis (1967). Using this methodology in conjunction with a special adaptation of least-cost-plus-loss economic theory provides one way to pursue maximum effectiveness vis-a-vis investment in forest tree improvement.

Hybrid Seed Production Costs

1. Breeding orchard costs

Hybrids from controlled pollinations between selected clones of pitch and loblolly pines in the New Lisbon, N. J., breeding orchard have been test-planted since 1971. Efforts to establish the experimental breeding orchard and conduct these progeny tests have spanned 15 years. A listing of the activities involved and their cost is given in *Table 1*. The total variable cost for the breeding orchard has amounted to $ 60,978 through 1979. Results from measurement of these experimental plantings will guide the selection of the best trees for subsequent commercial seed production.

2. Mass producing hybrids

One possibility for producing hybrids in quantity is to establish first-generation (F_1) orchards using the best individuals in the best crosses of existing test plantings as sources of scion material and relying on wind pollination. The only known application of this method looks promising (Hyun 1976) but there is little long-term experience to rely on. These Korean orchards have produced viable F_2 seed at a rate similar to that in an orchard of many clones of a single species. And in Hyun's 10 and 11-year-old test plantations the measured growth performance (stem volume) of F_2 hybrids compared favorably with F_1 plantings.

Understandably, there is some reluctance to base a seed production strategy on F_1 orchards before the method is fully supported by biological information. Nevertheless, its use now could prevent costly delays in hybrid seed availability that would result from waiting until all questions about F_1 orchards are answered. Although the use of F_1 orchards involves a calculated risk, it could prove to be the best choice.

3. Production orchard costs

Given related experience from existing tree improvement programs, the plan of establishment and management requirements for a first-generation (F_1) orchard can be estimated with reasonable certainty. Estimates of expected seed production *(Fig. 1)* follow the general trend reported by Porterfield *et al.* (1975). With thinning and roguing around orchard age 13, seed production is expected to reach about 25 pounds per acre by age 20 and remain steady thereafter. It is estimated that each pound of hybrid seed will yield approximately 15,000 plantable seedlings. At a typical plantation spacing of 6 × 10 feet, each pound of seed is sufficient to plant 20 acres of pitch × loblolly plantation.

There will be an establishment period of about 10 years for the orchard to reach the stage of commercial seed production. Therefore, to determine total annual cost during the period of commercial seed production the base year for analysis is orchard age 10 years. All costs (in-

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cluding the breeding orchard operations) are discounted or compounded to this time. This capital cost is then amortized over a planned 20-year commercial production period to give the annual recovery charge. Finally, annual operating expenses and the cone harvest-seed extraction costs for annual seed production are included to estimate the total annual cost during the commercial production period. Based on the costs in *Tables 1* and *2*, the annual total investment at orchard age 10 is shown below for various size orchards:

Seed orchard size	Avg. capacity: Seed	Avg. capacity: Plantable seedlings	Annual total investment per acre during commercial production period with interest rate at: 7%	10%
(acres)	(lb)	(millions)	(dollars)	
10	210	3.2	3135	4355
40	840	12.6	1235	1665
80	1680	25.2	915	1215
120	2520	37.8	810	1065

The dramatically lower annual cost per acre (and cost per pound of seed) resulting from spreading fixed costs against a large acreage would seem to suggest establishing the largest orchard consistent with seed requirements. However, what must not be overlooked is that any investment in orchard capacity is actually an investment made for forest tree improvement. And it is the potential value of the tree improvement that should justify the amount of investment for orchard capacity.

Gauging Tree Improvement Potential

The area most suitable for pitch × loblolly hybrid planting is conservatively estimated at 840,000 acres *(Table 3)*. This area consists of poorly stocked stands in shortleaf, Virginia, and pitch pine forest types. Only sites capable of producing 50 or more cubic feet of timber per acre per year were included. Lack of specific information about ownership patterns, objectives, tract size, planting conditions, and location of this acreage leads to uncertainty about its availability for planting. But, even if only half of the area could eventually be established to hybrid pine plantations, it still represents a sizeable undertaking. And timber cutting in these forest types will create additional cutover area, tending to sustain the backlog of plantable acreage.

A profile of the total suitable area was used to portray 50,000 acres of this poorly stocked commercial forest land, by forest type and site productivity class. This provides a basis to evaluate alternative seed orchard sizes up to a capacity for planting 50,000 acres per year.

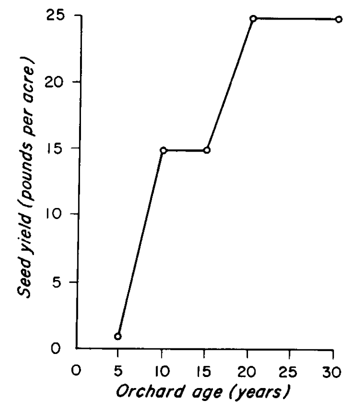

Figure 1. — Estimated seed production per acre of orchard.

Table 1. — Activities and costs associated with the breeding orchard.

1. Location and selection of parent clones $200 per clone x 65 = .. $13,000
2. Orchard (5 acres)

   Site preparation $80 per acre x 5 = ... $400

   (includes land clearing and burning)

   Orchard establishment $1595 per acre x 5 .... $7,975

   (includes scion collection $100/clone x 65 = $6500
   grafting $1.50 each x 650 = $975
   planting $100/acre x 5 = $500)

   Managerial $200 per acre per year x 5 .... $1,000 per year

   (includes fertilizing, mowing, insecticides, supervision)

3. Progeny tests

   Controlled pollinations of available crosses .... $1.00 each

   (includes bagging flowers, pollen collection, pollinating)

   Site preparation .... $25 per acre

   (includes land clearing, burning)

   Establishment .... $75 per acre

   (includes planting, tagging, staking, mapping)

   Measurement of outplanted progeny $100/acre/occasion

   (measure at age 1, 2, 3, 5, 10, 15, 20, and 25 years)

4. Total expenditures through 1979: $60,978

Table 2. — **Activities and costs associated with first-generation (F_1) seed orchard.**

Item		Cost
Site preparation		$100 per acre
(includes land clearing and burning)		
Orchard establishment		$300 per acre
(includes planting stock trees, grafting)		
Managerial (annual)		$250 per acre
(includes fertilizing, mowing, insecticides, supervision)		
Roguing (at age 13)		$50 per acre
Seed harvesting and extraction		$5.25 per pound
Continued progeny tests		
Controlled pollinations	$2.00 each	
Site preparation	$30 per acre	
Establishment	$90 per acre	
Measurement	$150/acre/occasion	
present value at initial commercial seed production (orchard year 10) @ 7% = $144,720		

Table 3. — **Poorly stocked commercial forest land in most suitable zone for pitch-loblolly pine hybrids, by site productivity class.**

State	Total	Growth-per-acre class		
		Low 50-84 ft^3	Medium 85-119 ft^3	High 120+ ft^3
	- - - - - - - - - - Thousand acres- - - - - - - - - -			
NJ	24.7	20.4	1.6	2.7
PA	41.0	23.5	14.2	3.3
OH	32.1	19.9	8.4	3.8
KY	36.3	20.2	12.4	3.7
WV	78.5	39.2	30.7	8.6
TN	95.0	64.0	24.5	6.5
NC	223.4	179.6	36.5	7.3
VA	285.9	248.8	33.3	3.8
MD	23.2	12.4	8.3	2.5
DE	.3	.1	.1	.1
Total	840.4	628.1	170.0	42.3

Potential gain from planting pitch × loblolly hybrids measures what the hybrid would produce versus the native species on a given site. Each species has a separate site index relationship to the three site productivity classes in this analysis:

These site indexes and the corresponding merchantable cubic foot volumes at culmination of mean annual increment for the species quantify their potential by site productivity class.

A weighted blend of pulpwood and sawtimber stumpage prices provides a useful approximation of wood value per cubic foot (Powers *et al.* 1974). Representative prices reported by Sherman (1977), and the sawtimber-cordwood product mix from Smalley and Bailey (1974a, 1974b) gives a 1978 blended price of $ 0.1955 per cubic foot at the stump.

Accumulated evidence indicates a continued real price increase at 1.5 percent per year for southern pine stumpage (Row 1973, Phelps 1975, Mills and Cain 1978). This rate was used in the present-value calculations.

Volumes were converted to valued at the blended price and discounted to the present to adjust for the age-site differences.

It is contemplated that the hybrid growth and form characteristics will be intermediate between pitch and loblolly pine; but as a cautionary measure, loblolly pine was first reduced 20 percent. Accordingly, the potential net gain from the hybrids is expressed as the difference in present value of plantations with these intermediate characteristics compared to the natural-site species. On the basis of these differences in present net value, the appropriate forest types are evaluated for potential gains according to their acreage of poorly stocked area classified as high, medium, or low in site productivity *(Table 4)*.

Site productivity class	Growth-per-acre class (cubic feet)	Midclass site index, by species			
		Loblolly	Shortleaf	Pitch	Virginia
Low	50—84	70(50)[a]	65(45)[a]	65	60
Medium	85—119	85(65)	80(55)	80	70
High	120+	100(75)	95(65)	95	80

a/ Site index at 25 years in parentheses.
Source: North Carolina Forest Survey Field Manual, U. S. Forest Service.

Table 4. -- Potential gains from pitch-loblolly hybrid pantations; a 50,000-acre profile of forest type and site productivity in order by decreasing gains per acre.

Natural-site pine replaced	Site productivity class	Percent of area	Acres	Net gain; present value @ 7% interest	Average annual net gain
			(M)	(M$)	(M ft^3)
Virginia	High	3.1	1.5	23.1	15.3
Shortleaf	High	1.3	.7	7.1	4.7
Pitch	High	.6	.3	3.1	2.0
Virginia	Med.	13.2	6.6	31.7	22.4
Shortleaf	Med	5.6	2.8	11.5	8.1
Pitch	Med	1.5	.8	3.3	2.3
Virginia	Low	47.0	23.5	45.4	35.3
Shortleaf	Low	21.4	10.7	4.2	3.2
Pitch	Low	6.3	3.1	1.2	.9
Total		100.0	50.0	130.6	94.2

Decision-Model

1. *Logic for approach*

For efficient investment in pitch × loblolly pine hybrid development, the scale of application, intensity of development, its cost, and the subsequent physical and economic impacts need to be considered jointly as a system. FREEMAN and others (1973) have extended least-cost-plus-loss economic theory to the management of environmental quality. Their model as modified here to apply to forest tree improvement can be understood as a two-part process:

1. Loss in the flow of forest goods and service (commodities) as a result of not implementing tree improvement efforts characterized according to scale and intensity of operation.
2. Damages to the economy as a result of the dollar values lost from the flow of goods and services foregone.

This process provides the link needed to tie forest tree improvement planning to land management planning.

The value of an increment to the flow of forest goods and services is the maximum amount of money that people would be willing to pay to receive that increment rather than be without. Thus, these dollar values can represent the maximum aggregate willingness to pay to prevent potential loss in foregone goods and services. Benefits are defined as the savings in loss averted, and costs are for the tree improvement activities employed. When the combined cost of loss and tree improvement investment is lowest, the optimum level of tree improvement is reached.

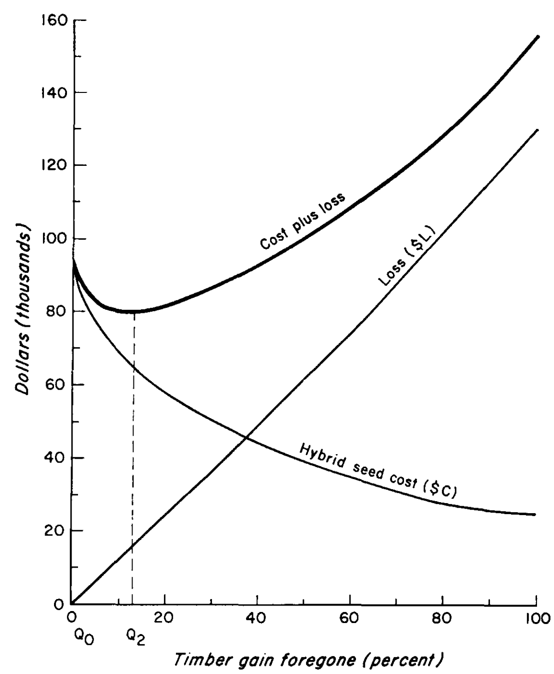

Figure 2. — Total cost-plus-loss related to levels of commodity flow.

2. *Model mechanics*

Figure 2 shows the relationship between willingness to pay or total loss ($L) and increasing impact of tree improvement efforts on commodity flow. Moving to the right along the horizontal axis represents increasing loss in goods and services-foregoing an increased flow of commodities from the management unit and incurring increased loss in value foregone. Conversely, moving to the left represents reduced value foregone and improving commodity flow. Point Q_0 represents the maximum attainable commodity flow that could be sustained from the tree improvement effort.

Without tree improvement, level of value foregone (loss) depends on the nature of the natural-site species in terms of inherent adaptability to such things as soil, site, and weather. For our planning unit, the natural state of loss from not implementing tree improvement is at Q_1 level of goods and services *(Fig. 2)*. By investing in forest tree improvement, the timber gain foregone and the corresponding loss can be driven from Q_1 toward zero. A curve ($ C) sloping upward to the left from Q_1 represents the total cost of tree improvement activities including research and development. In this case, "cost" is a shorthand term for a least-cost series of technologically possible options for supplying alternative quantities of improved tree seed.

The optimum level of tree improvement is achieved when the total cost of value foregone and tree improvement investment is at a minimum. Vertical summation of the loss curve and tree improvement cost curve is shown by the heavy line in *Figure 2.* This total cost curve has its minimum at point Q_2. The optimum level of forest productivity expressed as commodity flow. The criterion compares the value of reductions in the level of loss with the cost of achieving them.

Predicted gains from planting pitch ×loblolly hybrids range from negligible to substantial (0.3 to 10.2 ft^3 average net gain per acre per year) depending on forest type and site productivity class. From *Table 4,* the relationship between area that could be planted to pitch × loblolly hybrids and the resulting physical impact on the commodities produced from a land management unit is expressed graphically by a curve representing intensity of the tree improvement effort. For each unit of acreage that could be planted, the intensity transformation function indicates the cumulative impact on the commodity flow *(Fig. 3).*

Likewise, a diagram of the relationship between annual total investment and the capacity to produce improved tree seed represents the cost-efficient frontier of seed orchard alternatives from among those technologically possible *(Fig. 4).*

3. Four-quadrant model

A combined diagram can now be formed to show the interaction among potential plantation area, intensity of tree improvement effort, physical gains, dollar benefits, and costs *(Fig. 5).* The upper right-hand quadrant shows the loss and cost-plus-loss curves. The lower right-hand quadrant shows the curve that relates planting area and intensity of tree improvement effort to potential timber gains. The lower left-hand quadrant shows the relationship between potential plantation acreage and the seedling capacity it would require. And the upper left-hand curve is a mirror image of the relationship between the cost and capacity of improved tree seed orchards.

As implied earlier, the shape of the loss curve is dependent on the public's willingness to pay for forest goods and services. The shape of the cost-plus-loss curve, however, is highly dependent on the transform functions in the other quadrants. The cost-plus-loss curve is obtained by tracing various levels of expenditure counterclockwise through the transforms and summing the cost and loss curves in quadrant I. Once the shape of the cost-plus-loss curve has been found, it is relatively simple to identify the low point and trace back (dotted line) to find the optimum annual seedling capacity and expenditure.

This model should be considered from the standpoint that the curves reflect the average planting situation and represent expected values. The transform functions are specific to the 50,000-acre planning unit illustrated. In this case, however, the planning unit was constructed to represent a cross section of the total area considered most suitable for pitch × loblolly hybrids.

Results

Tracing the point of least cost-plus-loss through the

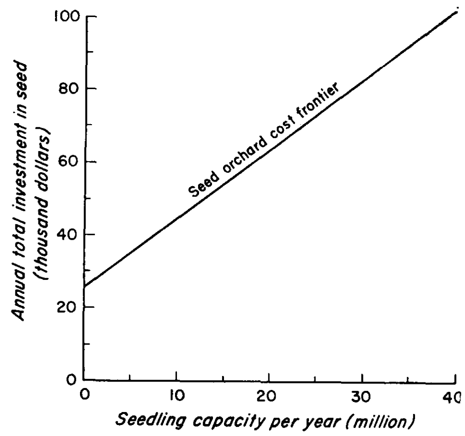

Figure 4. — Relationship between capacity to produce pitch-loblolly hybrid seed and annual total investment at 7-percent interest rate.

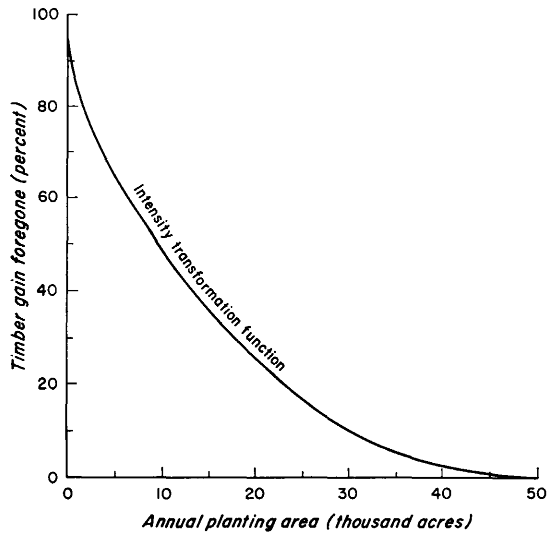

Figure 3. — Relationship between area planted to pitch-loblolly hybrids and commodity flow foregone.

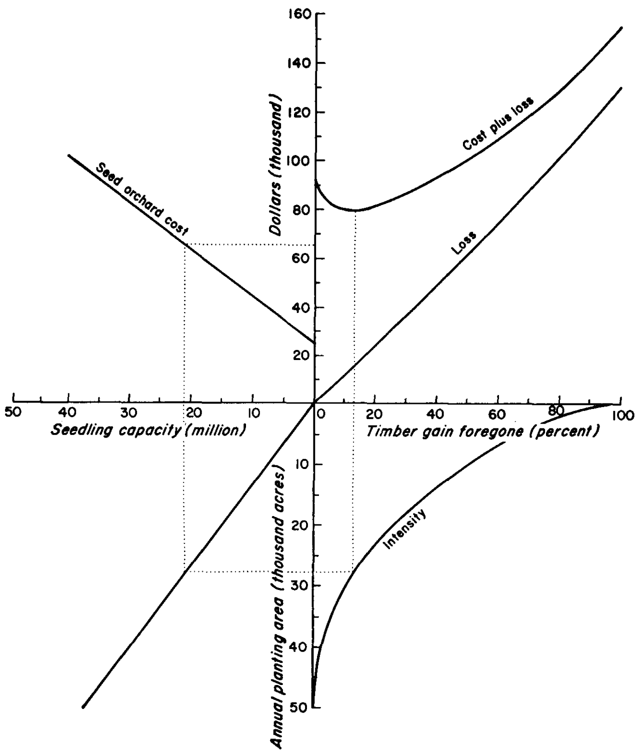

Figure 5. — Relationship among planting area, intensity, physical gains, dollar losses, seed orchard capacity, and costs at 7-percent interest rate.

four-quadrant model for pitch × loblolly hybrid development (Fig. 5) indicates the following:

Optimum planting level	28,000 acres per year
Optimum orchard capacity	21,000,000 seedlings per year
Optimum orchard investment ...	$ 65,000 per seed-producing year
Loss averted	$ 115,600 (net present value)
Net gain	$ 50,300 (net present value)

Results are based on a 7-percent interest rate. This approximates the current "nominal" rate of return on long-term government bonds that is commonly used to rank competition for natural resource program funds. The results translate to establishing 66.7 acres of seed orchard capable of producing 1,400 pounds of hybrid seed per year. This seed orchard acreage would require an initial capital outlay of $ 26,680 (exclusive of land costs) and operating costs of $ 24,025 per year, plus the costs of further progeny testing.

1. Hybridity adjustment

The level of hybridity to expect from these F_1 orchards is unknown. The model as constructed assumes 15,000 hybrid seed per pound. If hybridity was 80 percent of this figure (12,000 hybrids per pound of seed) it would take 20 percent more seed production to yield enough hybrids to plant any given acreage. With a 7-percent interest rate the optimum planting level remains at 28,000 acres per year. But the 20-percent decrease in hybridity would require increasing the seed orchard acreage (by 20 percent) to 80.0 acres, capable of producing 25,200,000 seedlings per year. The corresponding optimum orchard investment would amount to $ 73,250 per seed production year (up 12 percent), for a net gain of $ 42,350 (down 16 percent) due to this reduced hybridity.

There are indications, however, that reduced hybridity might be offset somewhat by much higher fertility in F_2 hybrid seed than in F_1 seed. Hyun (1976) reported that F_2 seed gave 22 percent higher mean fertile seed yield than the F_1 did. Overall, at the 7-percent interest rate it is unlikely that seed orchard area requirement will be better or worse than the 66.7-acre or 80.00-acre extremes, respectively.

2. Planting strategy

The model also gives important information for planning pitch × loblolly pine hybrid planting operations. Data for this least-cost-plus-loss analysis represent a hierarchy of potential timber gains. Each potential gain is associated with certain conditions identified by forest type and site productivity class. The sequence from greatest to least potential gain per acre, given in *Table 4,* corresponds with the cumulative acreage plotted on the lower axis of *Figure* 5. Therefore, it is possible to specify the order in which areas should be planted (or left unplanted) for the greatest net gain from a planting program. Planting should follow the "best first" sequence of type-site classes in *Table 4* but stop when 15,300 acres are planted on low site productive areas in the Virginia pine type. At 7-percent interest, this strategy would emphasize planting the kind and amount of forest land where pitch × loblolly hybrids could contribute most to timber gain in the planning unit.

3. Sensitivity to interest rate

Higher interest rates shift the minimum cost-plus-loss to the right, indicating that less acreage should be planted and a smaller seed orchard should be established. In short, at a higher interest rate less of the area suitable for the hybrid is capable of earning a minimum net gain equal to the higher rate of interest. At 8 percent, for example, planting 21,600 acres per year (16,200,000 seedlings) is feasible, and this would require 48.4 acres of seed orchard. Compared to the 7-percent interest rate answers, this amounts to annually planting 13 percent less of the planning unit area and decreasing seed orchard acreage by about 23 percent.

A seed orchard with sufficient capacity to plant the entire 50,000-acre planning unit would be justified at 4 percent. On the other hand, at 9 percent the costs nullify potential gains in timber value and no pitch × loblolly hybrid seed orchard expenditure would be justified.

The cut-off rate of interest (where a net gain is possible) can reach 9 percent if past development costs are removed from the calculations. With development costs excluded, the solution framework retains its same relative shape; expenditures decrease, but the corresponding loss-averted remains unchanged. Consequently, the only effect is an increase in potential net gain. At 9 percent, 30.5 acres of seed orchard providing hybrids to plant 12,750 acres per year could yield a net gain if recovery of past development costs is disregarded.

Conclusions

This study illustrates one approach to subjecting a forest tree improvement program to economic analysis. The model as applied to pitch × loblolly pine hybrid development provides useful guides for cost-effective investment in both the seed orchard and planting phases of tree improvement. A target level for annual planting and the corresponding seed orchard capacity justified by potential timber value gains have been identified—at 7-percent interest, 28,000 acres and 21 million seedlings per year (66.7 acres of seed orchard), respectively. Consequently, the best level of investment for pitch × loblolly hybrid development work can be tailored to the amount of expenditure that increased forest yields would justify. In addition, the forest type-site class sequence is specified for a planting strategy that would contribute most to timber gain in the planning unit.

Developmental testing has shown promising results for pitch × loblolly pine hybrids. This analysis has explored the costs and economic potential of investment to guide planning for a full-scale hybrid seed production program. Even with gain estimates thought to be conservative, there is adequate economic justification for tree improvement work with pitch × loblolly hybrids.

No benefits were included for other favorable characteristics such as adaption to droughty or disturbed sites, resistance to winter injury, top dieback, and fusiform rust. As data accumulate, the value of attributes other than timber gain can be incorporated into the model to broaden the area of application. For now, the analysis focuses on the area thought most suitable for planting pitch × loblolly hybrids, simply weighing the benefit of timber gains versus the cost of achieving them. By comparing incremental levels of expenditure and focusing on relative effectiveness, the model can help the decisionmaker see his alternatives in quantitative terms likely to identify the best one.

Acknowledgment

The author sincerely thanks Dr. Silas Little for providing much of the material in this study and for his helpful criticism.

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Study of the pollination pattern in a Scots pine seed Orchard by means of Isozyme Analysis

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(Received July / November 1980)

Summary

A genotype analysis of three loci — LAP B, GOT A and B, using some two thousand seeds originating from three ramets of a marker clone and ten grafts from surrounding clones was carried out in a seed orchard close to Umeå. A significant difference with regard to frequency of genotypes from seeds derived from the three ramets was found, and there was variation among sectors at different levels of a crown within a ramet due to differences in the fertilizing pollen cloud. Pollen dispersal seems to be dependent on the coincidence of the time of flowering of male and female trees, the distance from a pollen tree to a mother tree as well as wind direction during flowering. A neighbouring tree with all favourable conditions received 31 per cent of the fertilizing pollen from the marker ramet. The average frequency of self-pollinated seeds from the marker clone was roughly estimated at 6 per cent with the lowest frequency at the top of the crown.

Key words: Pinus sylvestris, isozymes, selfing, genetic marker, clone, fertilization, pollen dispersal

Zusammenfassung

Isozymatische Untersuchungen über die Befruchtungsverhältnisse in einer Kiefernplantage.

An den Samen einer Kiefernplantage in der Nähe von Umeå wurden Isozymanalysen für drei Loci: LAP B, GOT A und GOT B durchgeführt. Drei Pfropflinge eines Markörklons und umgebene Propflinge anderer Klone wurden untersucht.

In verschiedenen Höhenzonen und Richtungssektoren der Krone konnten signifikante Unterschiede in der Frequenz verschiedener Isozymmuster festgestellt werden. Diese Unterschiede sind auf unterschiedliche Zusammensetzung des Pollenangebotes während der Blütenperiode zurückzuführen. Die Pollendispersion des Markörklons wurde näher untersucht: Der Pollenbeitrag ist abhängig vom gleichzeitigen Blühtermin männlicher und weiblicher Blüten, dem Abstand zwischen Vater- und Mutterbaum und der Windrichtung zum Blühtermin.

Unter günstigen Verhältnissen konnten 31% der befruchtungsfähigen Pollen auf eine direkte (unmittelbare) Nachbarschaft des Vaterklones zurückgeführt werden.

Die Rate der Selbstungen wird an Hand des Markörklons auf durchschnittlich 6% geschätzt. Sie ist im obersten Kronenteil am niedrigsten.

Introduction

The establishment of seed orchards based on selected trees has become common all over the world during the last twenty years. In many countries they are now the essential way of supplying genetically improved forest seeds. In order to obtain a greater genetic gain it is important to know whether the original prerequisites for the seed orchards are really fulfilled. Some of the main principles for the establishment and function of seed orchards are the following:

1. Selection of the best phenotypes within a homogeneous climatic region
2. Grafting and random plantation in a seed orchard
3. Localization of the seed-orchards in site with favourable climate and soil which encourage flowering and seed-ripening
4. Isolation against dominating pollen from outside the seed-orchard
5. No clones to dominate the pollen production and fertilization
6. The frequency of selfing to be kept at a minimum level

The three first prerequisites are in many cases fulfilled today. However, until recently it has been very difficult to get hold of good information about the last three.

By analysing differences in empty seed frequencies between selfed, outcrossed and open pollinated seeds from a Scots pine seed orchard, Johnsson (1972) found that less than 1 per cent of the viable seeds were due to selfing. Biochemical markers such as isozymes and monoterpenes now make it much easier to study these questions. The perspectives opened up by these methods for research into seed orchards were pointed out by Rudin and Lindgren (1977). Müller (1976). Gregorius and Müller (1975) discussed methods to calculate the pattern of pollination in seed orchards. Müller-Starck (1979) found a selfing frequency as high as 12-14% in a 12-15-year-old Scots pine seed orchard containing 36 clones (with 25 ramets from

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