TREE IMPROVEMENT PLAN FOR THE MINNESOTA DNR 1990 UPDATE

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Minnesota Department of Natural Resources
Division of Forestry

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THE PURPOSE OF APPLIED FOREST TREE IMPROVEMENT

To steadily and continuously improve the genetic quality of seeds, stem cuttings, and other regeneration stock used in reforestation programs.

THE PURPOSE OF THE DIVISION OF FORESTRY APPLIED FOREST TREE IMPROVEMENT PROGRAM

The Minnesota Department of Natural Resources (DNR), Division of Forestry is the largest public producer of tree and shrub seedlings in the northeastern United States. The state nurseries provide the majority of planting stock for all forest land ownership classes in Minnesota. As such, the Division of Forestry has the responsibility for distributing genetically improved plant materials to increase the effectiveness of planting programs.

THE PURPOSE OF THE REVISED TREE IMPROVEMENT PLAN

Development of a long term tree improvement plan was initiated by DNR-Forestry personnel and University of Minnesota, College of Forestry scientists in 1978. By 1979, a draft plan was available for interim use. A final version of this plan was published in 1981. In response to legislative direction provided in the Forest Resource Management Act of 1982, the 1981 plan was reviewed and modified. The modified plan was published in 1983, and incorporated changes in the source of program funding and fine tuning of species priorities based on economic analysis.

As in any organizational endeavor, changes in the Division's internal and external environments have lead to a reassessment of the long term goals and objectives of the tree improvement program. The purposes of this revised plan are to:

1. Describe the growth of the tree improvement program.

2. Describe the current tree improvement program.

3. Plan the future direction of the tree improvement program.

The revised plan will set priorites for the Division's applied forest tree improvement program, providing a basis for budgeting and annual work planning.

WHAT IS APPLIED FOREST TREE IMPROVEMENT?

A "combination of <u>all</u> silvicultural and tree breeding skills ... to grow the most valuable forest products as quickly as possible and as inexpensively as possible." [1] The practice of applied tree improvement can be defined by the level of genetic control: Base, intermediate, and high.

Applied forest tree improvement can be as basic as avoiding dysgenic selection (high grading). By favoring the better quality trees in a stand, the forester can maintain, and often improve the genetic quality of the stand.

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[1] Bruce J. Zobel and John Talbert, Applied Forest Tree Improvement (New York: John Wiley and sons, 1984), p. 6.

At an intermediate level, tree improvement is seed source control. Almost without exception, seeds collected from a local source will survive and grow better than non-local sources.

At a higher level, applied forest tree improvement also involves plus tree selection, establishment of seed orchards, progeny testing, selective breeding, and production of superior clones. Considerable genetic improvement can be achieved with these methods.

THE PRODUCTS OF APPLIED FOREST TREE IMPROVEMENT

Applied forest tree improvement programs strive to genetically improve traits of economic importance to the forest products industry. These traits include growth rate, branch and crown conformation, straightness, wood quality, and insect and disease resistance. Genetic improvement of these traits is usually "packaged" in the form of seeds, although the use of rooted cuttings is gaining increased acceptance. Genetically improved seed is processed through the nursery program, resulting in higher quality planting stock. The end result is increased production of high quality wood.

THE HISTORY OF TREE IMPROVEMENT

In the United States, applied forest tree improvement programs were initiated in the early 1950's. Through continuity of purpose and support, and a commitment to excellence, these programs are on the verge of a third generation of genetic improvement. In 1987 alone, members of the North Carolina State University-Industry Tree Improvement Cooperative harvested over 93 tons of genetically improved seed.[2]

The unqualified success of applied forest tree improvement in the South led to the development of commercial tree improvement efforts in Florida, the Texas Gulf Region, the Pacific Northwest, the Inland Empire, and the Lake States. Today, nearly all state forestry agencies in the Northeastern Area have, or are planning tree improvement programs.[3]

TREE IMPROVEMENT BENEFITS AND COSTS

Forest managers have a keen interest in the economics of applied forest tree improvement. A review of the literature reveals, that despite different assumptions and methodology, economic analyses of tree improvement consistently yield strong, positive rates of return. Among a range of forest management options, tree improvement is often the best choice.

In a study of the Minnesota DNR program, Ford et al (1983) reported a range of benefit-cost ratios, from 0.4 to 17.6 depending on species and program intensity. In 1986, Risbrudt and McDonald found a benefit-cost ratio of 8.8 at the four percent discount rate for programs in the North Central Region. A more recent analysis by Helmburger (Bureau of Real Estate Management) concluded that the increased cost of genetically improved seedlings resulted in steadily increasing internal rate of return.

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[2] Thirty-second Annual Report. N. C. State University-Industry Cooperative Tree Improvement Program, 1988. p. 38.

[3] Leroy C. Johnson and Ronald P. Overton, Tree Improvement Plan for Northeastern Area State and Private Forestry, USDA Forest Service 1984, p. 29.

Specific tree improvement benefits include:

- -use of properly adapted seed sources
- -increased plantation survival
- -increased volume production
- -reduced rotation length
- -increased product uniformity
- -improved wood quality
- -increased pest resistance
- -more consistent seed supply
- -sales of genetically improved seedlings
- -sales of genetically improved seed
- -tangential improvements in silvicultural practices

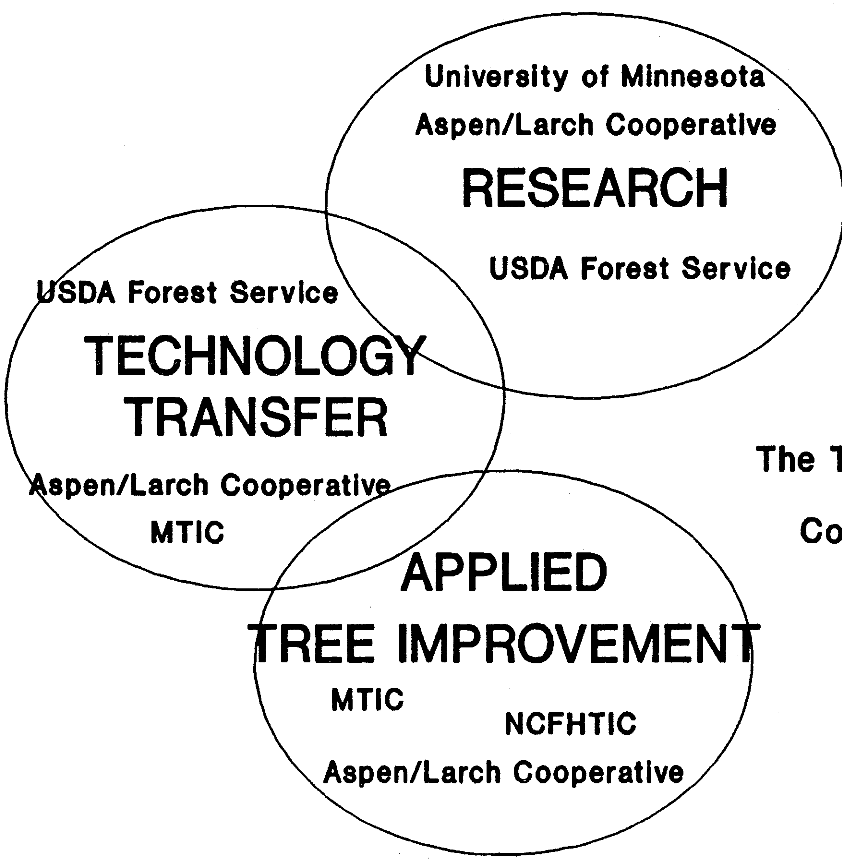
Specific tree improvement costs include:

- -seed source control
- -plus tree selection
- -collection of scion material and cones
- -grafting
- -establishment of seed orchards and progeny tests
- -data collection, maintenance, and analysis
- -seed orchard management
- -controlled breeding

THE TREE IMPROVEMENT COMMUNITY

Applied forest tree improvement in Minnesota is an interest and activity of many organizations, as shown in the following table and diagram:

Organization	Tree Improvement Role
University of Minnesota	Research
U. S. Forest Service State and Private	Technology Transfer Research
University of Minnesota-Institute of Science and Technology Aspen/Larch Genetic Improvement Cooperative	Technology Transfer Research Applied Tree Improvement
Minnesota Tree Improvement Cooperative	Applied Tree Improvement Technology Transfer
North Central Fine Hardwoods Tree Improvement Cooperative	Applied Tree Improvement



The Tree Improvement Community

As shown in the preceding table, the DNR-Forestry is a member of three tree improvement cooperatives. The philosophy of cooperative tree improvement is that individual organizations join together to accomplish the same goals and objectives. In this way, the considerable workload is shared by the members, and all members reap the benefits. Thus, when the DNR-Forestry begins work on a particular species, other cooperative members also interested in that species will take on a portion of the workload. No member is left doing all the work on a given species.

THE HISTORY OF APPLIED FOREST TREE IMPROVEMENT IN MINNESOTA

Tree improvement has come a long way in Minnesota, and much progress has been made by the Division of Forestry. The following is a brief chronology.

1975: First selections of Ottawa Valley white spruce grafted at General Andrews Nursery.
First selections of Minnesota black spruce grafted at General Andrews.

1977: First white spruce seed orchard established near Cotton, Minnesota.

1978: First black spruce seed orchard established near Duxbury, Minnesota.

1979: Black spruce seed orchard established near Sturgeon Lake, Minnesota.

1981: Tree Improvement Plan for Minnesota is published.
Red pine progeny tests are established.

1982: Minnesota DNR-Forestry joins Minnesota Tree Improvement Cooperative as a charter member.

1983: Tree Improvement Plan for Minnesota is modified based on economic analysis.
Minnesota DNR-Forestry adopts Seed Source Control Policy

1984: Jack pine progeny tests are established.

1985: Division hires Tree Improvement Specialist to provide program supervision to growing tree improvement program.
Blister rust tolerant white pine and timber quality scots pine orchards established near Zimmerman, Minnesota.

1986: White spruce progeny tests established.
Intensive seed orchard management practices initiated.
Black spruce orchard near Duxbury rogued to best 600 trees.
Minnesota DNR-Forestry joins North Central Fine Hardwood Tree Improvement Cooperative.
Scots pine orchard named Showcase Orchard of the Year by MTIC.

1987: First black walnut plus tree selections grafted at General Andrews.
First crop of genetically improved seed harvested from Duxbury black spruce orchard.
Controlled breeding begun for black spruce advanced generation improvement.

1988: Two breeding sublines established for black walnut in Houston County.
DNR-Forestry joins University of Minnesota Institute of Paper Science and Technology Aspen/Larch Genetic Improvement Cooperative.
Installed trickle irrigation system at St. Francis Seed Orchard.
Harvested 152 bushels of cones from Cotton white spruce orchard.

Harvested 11 bushels of cones from Duxbury black spruce orchard.

1989: Minnesota DNR-Forestry named Cooperator of the Year by the Minnesota Tree Improvement Cooperative.
Established 5-acre black walnut seed orchard near Rochester.
Two additional walnut breeding sublines established in Fillmore County.
Established first hybrid aspen progeny test in Nickerson District.
Harvested 122 bushels of cones from Cotton white spruce orchard.
Harvested 15 bushels of cones from Eaglehead black spruce orchard.

1990: In response to the needs of a rapidly growing program, a revised Tree Improvement Plan for Minnesota was prepared to guide the Division of Forestry in future tree improvement activities.

CURRENT DIVISION OF FORESTRY APPLIED FOREST TREE IMPROVEMENT PROGRAM

Program Goal

To economically produce genetically improved plant materials, sufficient to meet the needs of the Division of Forestry nursery program.

Program Level

Seed Source Control

On June 27, 1983, a policy of Area control of seed sources was adopted. This policy, and the procedures to carry it out, are contained in Circular Letter # 3421-2 "Tree Nursery Seed Source Control". Simply stated, all collections of seed from natural stands and plantations are identified by the administrative Area of origin. Every attempt is then made to return seedlings back to the proper Area of origin. In 1984 the DNR-Forestry, in conjunction with the Minnesota Tree Improvement Cooperative, held a Source Control and Cone Handling Workshop for Division personnel. This workshop firmly established seed source control policy and the procedures for implementing the policy.

The source control policy helps ensure that only well adapted seed sources are used. The use of source controlled seed is a low cost means of improving plantation success and performance. As of 1988, all seeds purchased by the nursery are seed source identified. This amounts to nearly 1100 bushels of cones and 1200 bushels of hardwood nuts. Since this policy was adopted, all containerized stock have been source identified, amounting to nearly 10 million seedlings.

Seed Orchards

The following table summarizes the current level of seed orchard activity in the Division of Forestry applied forest tree improvement program.

SPECIES	ORCHARD NAME	DATE EST.	SIZE (ACRES)	TYPE	TRAITS SELECTED FOR IMPROVEMENT	PURPOSE	1988 PRODUCTION
white spruce	Cotton	1977	12	clonal	-growth rate -branch habit -frost avoidance -adaptability	seed production	150 BU.
	General Andrews	1989	3	clonal	-same as above	breeding	
black spruce	Eaglehead	1978	3	seedling	-growth rate	seed production	11 BU.
	Sturgeon Lake	1979	1	clonal	-growth rate	breeding	29 pollen lots 48 crosses
white pine	St.Francis	1985	3	clonal	-blister rust resistance	seed production	
scots pine	St.Francis	1985	3	clonal	-growth rate -straightness -branch habit -adaptability	seed production	
black walnut	Chester Woods	1989	5	clonal	-growth rate -apical dominance -straightness	seed production	
	Gordon	1990	4	clonal	-same as above	seed production	
	Wet Bark	1987	1	clonal	-same as above	breeding	
	Delanie	1988	1	clonal	-same as above	breeding	
	Goethite 1	1989	1	clonal	-same as above	breeding	
	Goethite 2	1989	1	clonal	-same as above	breeding	
	Rochester	1990	1	clonal	-same as above	breeding	
aspen	General Andrews	1990	1	clonal	-growth rate -straightness -wood quality -Hypoxylon resistance	seed production	

Progeny Tests

The following table summarizes the current level of progeny testing in the Division of Forestry applied forest tree improvement program.

SPECIES	DATE EST.	NO.OF SITES	TOTAL ACRES
red pine	1981	2	9
jack pine	1984	3	9
white spruce	1986	2	6
hybrid aspen	1989	1	2

Controlled Breeding

Controlled breeding is a very time consuming, yet necessary task in an applied forest tree improvement program. Efforts began in 1986 toward developing two fully pedigreed black spruce populations for advanced generation improvement. In 1986, pollen was collected and stored from 29 clones. In 1987 and 1988, additional pollen was collected and stored, and controlled crosses were made. To date, there is pollen from 83 clones in storage, and 78 full-sib crosses (out of a planned 450) have been made.

In 1987, grafting was initiated to develop a white spruce breeding orchard. A total of 280 white spruce clones are being progeny tested at present. These clones are being grafted now, so that when the progeny test data becomes reliable in the early 1990's, controlled breeding between the best clones can begin without delay. At present, 206 of the 280 clones have been grafted.

Unlike conifers, controlled breeding in large seeded hardwoods is extremely difficult, to the point of being impractical. In this case, a measure of pedigree control can be obtained by dividing the base population into smaller, distinct groups, called sublines. To this end, the Division has established two, 25-clone sublines for black walnut. Two additional walnut sublines will be planted in 1989.

Other Program Activities

As a member of the MTIC, the DNR-Forestry is a close cooperator with other members. The DNR has unilaterally undertaken activities that will benefit the entire membership (e.g. black spruce controlled breeding). The Division's Tree Improvement Specialist participates regularly as an instructor in annual Cooperative workshops.

As a member of the North Central Fine Hardwood Tree Improvement Cooperative, the DNR-Forestry works closely with the other state forestry organizations in the North Central Region. At present, the Tree Improvement Specialist serves as secretary to the NCFHTIC. In 1990, Minnesota will host the annual meeting of the Cooperative.

As a member of the University of Minnesota-IPST Aspen/Larch Genetic Improvement Cooperative, the DNR-Forestry has joined in the effort to further develop the important aspen resource in Minnesota. In 1989, the Division established a progeny test for the Cooperative.

The Tree Improvement Specialist serves as a technical advisor to the DNR-Forestry on matters pertaining to forest genetics and tree improvement. Division staff often have questions regarding some aspect of forest genetics that they have read about or heard at a meeting. There are also instances where a technology first tried in the tree improvement program becomes accepted by the silviculture program. One example of this is the use of Tree Shelters on walnut and oak.

The Tree Improvement Specialist attends one professional meeting per year, exchanging ideas with peers and keeping up to date on the latest developments. In 1987, two papers were published in the proceedings of the North Central Tree Improvement Conference.

BUDGET

The following is a cost summary for the Tree Improvement Program, FY 90.

Dedicated Nursery Account	
Salaries and Wages:	$ 41,340
Support and Supplies:	10,200
U of M Contract:	20,000
Total:	$ 71,540

At this point, the dedicated nursery account provides nearly all of the tree improvement budget. Special project funds may occasionally be available. A small portion of the Hybrid Aspen Initiative was allocated in FY 1989 for preparation of the aspen progeny test site.

MARKET FOR THE DIVISION OF FORESTRY APPLIED FOREST TREE IMPROVEMENT PROGRAM

The primary market for improved seed is the Division Nursery Program. Nursery customers including the Division of Forestry, forest industries, County Land Departments, SWCD's, and private landowners represent the secondary market in the purchase of genetically improved seedlings. At the harvest level the State of Minnesota, County Land Departments, forest industries, and private landowners derive benefit from the applied tree improvement program from genetically improved plantations.

The following tables will illustrate the tree improvement program effect on projected nursery seed demand by species, to the year 2000. With the passage of time, the percentage of seed demand supplied by genetically improved seed will steadily increase. At present, the Division is developing a priority list for the distribution of genetically improved seedlings. The long term goal is to provide 100 % of demand with genetically improved seed for those species in high level seed orchard programs. All other species will be supplied with 100 % source identified seed.

DNR NURSERY SEED NEEDS
COMMERCIALLY IMPORTANT CONIFER SPECIES

Fiscal Year

lbs of seed (percent improved)

Species	90	92	94	96	98	2000
RED PINE	612 (0)	612 (0)	612 (0)	612 (0)	612 (0)	612 (0)
JACK PINE	202 (0)	202 (0)	202 (0)	202 (0)	202 (0)	202 (0)
WHITE PINE	129 (0)	129 (0)	129 (0)	129 (10)	129 (20)	129 (40)
SCOTS PINE	24 (0)	24 (10)	24 (50)	24 (75)	24 (100)	24 (100)
WHITE SPRUCE	271 (115)	271 (10)	271 (100)	271 (20)	271 (100)	271 (50)
BLACK SPRUCE	396 (5)	396 (10)	396 (10)	396 (10)	396 (10)	396 (10)
NORWAY SPRUCE	43 (0)	43 (0)	43 (0)	43 (0)	43 (0)	43 (0)
BALSAM FIR	27 (0)	27 (0)	27 (0)	27 (0)	27 (0)	27 (0)
WHITE CEDAR	27 (0)	27 (0)	27 (0)	27 (0)	27 (0)	27 (0)
TAMARACK	38 (0)	38 (0)	38 (0)	38 (0)	38 (0)	38 (0)

assumptions:

1. All seed is source identified. Percent improvement refers to the amount of annual demand that is derived from seed orchards, and can thus be expected to result in varying amounts of improvement in one or more traits.
2. About 85 % of black spruce and about 60 % of jack pine demand is used for direct seeding.
3. White spruce crops are periodic, so there will be a "draw down" of seed in storage in-between bumper crops.
4. Demand is predicted by historic use patterns. Figures can be easily adjusted to reflect changes in demand.

DNR NURSERY SEED NEEDS
COMMERCIALLY IMPORTANT HARDWOOD SPECIES

		bushels of seed	Fiscal (percent	Year improved)		
Species	90	92	94	96	98	2000
RED OAK	160 (0)	160 (0)	160 (0)	160 (0)	160 (10)	160 (15)
WHITE OAK	16 (0)	16 (0)	16 (0)	16 (0)	16 (0)	16 (0)
WALNUT	1500 (0)	1500 (0)	1500 (0)	1500 (10)	1500 (20)	1500 (40)
ASH	16 (0)	16 (0)	16 (0)	16 (0)	16 (0)	16 (0)

assumptions:

1. All seed is source identified. Percent improvement refers to the amount of annual demand that is derived from seed orchards, and can thus be expected to result in varying amounts of improvement in one or more traits.
2. Demand is predicted by historic use patterns. Figures can be easily adjusted to reflect changes in demand.
3. Black walnut demand is expressed in "green" bushels.

FUTURE DIRECTION OF THE DIVISION OF FORESTRY TREE IMPROVEMENT PROGRAM

Species Priorities and Plans

Applied forest tree improvement includes all practices designed to produce genetically more desirable trees. This plan will concentrate on the following levels of tree improvement:

1. seed collection zones
2. seed collection areas
3. seed production areas
4. seed orchards
5. genetic testing
6. selective breeding
7. cooperative research

Seed Collection Zones

The first level of applied forest tree improvement is seed source control. Provenance testing for many different species indicates that, with rare exceptions, local seed sources are the best. Local seed sources have become adapted over time to the prevailing environmental conditions in a given area. These sources consistently outperform seed sources of non-local origin. At present, this is the minimum standard for seed supplied to the Nursery Program. Cones and nuts are identified by the administrative Area in which they were purchased.

One of the best known exceptions to the local seed source rule is the Ottawa River Valley white spruce. Located in southeastern Ontario, CANADA, this source has consistently outperformed local seed sources in provenance tests throughout northeastern North America. The DNR-Forestry applied tree improvement program has cloned over 100 select trees from the Ottawa Valley source, firmly setting the cornerstone for long term genetic improvement of white spruce in Minnesota.

Seed Collection Areas

Within a given seed collection zone, high quality stands may be chosen for seed procurement. Seed collection areas are usually chosen in high quality stands of mature timber. Usually, seed is harvested from trees during a logging job. A small amount of genetic improvement is possible, although the most important gain is made by the use of a known, local seed source.

Seed Production Areas

High quality stands or plantations less than rotation age can be developed into seed production areas. These stands are thinned from below, leaving only the best trees with regard to growth rate and form. Stand density is often reduced to encourage flowering, and the interior of the stand cleaned to facilitate seed harvest. Seed production areas are designed for repeated seed collection. Some genetic improvement can be expected in growth rate and straightness.

Seed Orchards

The establishment of seed orchards is a much higher level of applied tree improvement. A seed orchard is best described as

> "...a plantation of genetically superior trees, isolated to reduce pollination from genetically inferior outside sources, and intensively managed to produce frequent, abundant, easily harvested seed crops. It is established by setting out clones (as grafts or cuttings) or seedling progeny of trees selected for desired characteristics."[4]

Depending on species, seed orchards can produce large amounts of seed with considerable genetic improvement. In order for seed orchards to realize their potential, a long term commitment of manpower and resources is required.

Genetic Testing

Seed orchards are usually supported by genetic tests. The genetic worth of selected trees can only be determined by evaluating the performance of their offspring. These "progeny tests" are most often comprised of either open-pollinated (half-sib) or control pollinated (full-sib) families, and are replicated within and across sites. Uniform sites, high survival, and freedom from competition are very important to reliable evaluation of progeny tests.

Selective Breeding

To pave the way for long term genetic improvement of forest trees, it is necessary to develop fully pedigreed breeding populations. This is done with controlled breeding. Controlled breeding has several objectives:

- provide data for evaluating parent trees
- estimate genetic parameters
- produce a base population for long term improvement
- estimate realized genetic gain

Controlled breeding is a labor intensive and time consuming activity. However, in high level, long term programs it is essential for success.

Cooperative Research

There are a number of unresolved research questions relating to applied forest tree improvement. Although this research is important, the DNR does not have a research mandate. Where applicable, the DNR does cooperate with ongoing forest genetics research. One example is cooperation with the US Forest Service Region 9 on white pine blister rust resistance.

Using these seven levels of applied forest tree improvement, important tree and shrub species in Minnesota may be classified by priority and future plans. To ease interpretation, species will be grouped as follows:

- commercially important conifer species
- commercially important hardwood species
- windbreak, wildlife, and shrub species

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[4] Bruce J. Zobel, *et al.* 1958. Seed orchards-their concept and management. Journal of Forestry. 56:815-825.

SPECIES PRIORITIES AND PLANS

COMMERCIALLY IMPORTANT CONIFER SPECIES

Species	Biological potential of species for improvement	Traits selected for improvement	Value of genetic improvement to Forestry program *	Expected genetic gain from improvement efforts	Current improvement efforts	Future improvement efforts
RED PINE	low	-growth rate	high	low	1, 2, 3, 5	1, 2, 3
WHITE SPRUCE	high	-growth rate -branching -adaptability	high	high	1 - 5	1 - 7
JACK PINE	high	-growth rate -straightness -branching	high	high	1, 2, 3, 5	1 - 5
BLACK SPRUCE	high	-growth rate	high	high	1 - 7	1 - 7
WHITE PINE	high	-disease resistance	high	moderate	1, 2, 3, 4, 7	1, 2, 3, 4, 7
SCOTS PINE	high	-adaptability -growth rate -straightness -branching	high **	high	1, 4	1, 4
TAMARACK	high	-growth rate -straightness -branching	low	high	1, 2	1, 2, 7
EXOTIC LARCH	high	-adaptability -growth rate -straightness	low	high	none	none
NORWAY SPRUCE	high	-growth rate -adaptability	low	high	none	1
NORTHERN WHITE CEDAR	high	-growth rate	low	low	1, 2	1, 2
BALSAM FIR	moderate	-growth rate	low	low	1	1

* Value is determined by stock demand, genetic potential, importance of fiber type, and range of planting.

**Scots pine has a very high potential value.

1-seed collection zones
2-seed collection areas
3-seed production areas
4-seed orchards
5-genetic testing
6-selective breeding
7-cooperative research

SPECIES PRIORITIES AND PLANS

COMMERCIALLY IMPORTANT HARDWOOD SPECIES

Species	Biological potential of species for improvement	Traits selected for improvement	Value of genetic improvement to Forestry program *	Expected genetic gain from improvement efforts	Current improvement efforts	Future improvement efforts
BLACK WALNUT	high	-straightness -apical dominance -growth rate	high	high	1, 2, 4, 7	1, 2, 4, 5, 7
RED OAK	high	-straightness -apical dominance -growth rate	high	high	1	1 - 7
WHITE OAK	moderate	-growth rate -straightness	low	low	1	1, 2
ASPEN	high	-growth rate -disease resistance	high	high	7	5, 7
BLACK ASH	high	-growth rate	moderate	moderate	none	1, 2
WHITE ASH	high	-growth rate	low	low	none	1, 2
WHITE BIRCH	unknown	-growth rate	low	low	none	none
BASSWOOD	unknown	-growth rate	low	low	none	1, 2
HYBRID POPLAR	high	-adaptability -disease resistance -growth rate	moderate	high	7	7

1-seed collection zones
2-seed collection areas
3-seed production areas
4-seed orchards
5-genetic testing
6-selective breeding
7-cooperative research

* Value is determined by stock demand, genetic potential, importance of fiber, and range of planting.

SPECIES PRIORITIES AND PLANS

WINDBREAK, WILDLIFE, AND SHRUB SPECIES

The Nursery Program also produces trees and shrubs that benefit wildlife and environmental programs. The most important trait for these species is adaptability. Use of local, or otherwise naturalized seed sources is the most cost effective means of achieving this objective. Species in this category are:

Silver maple	Colorado spruce
Bur oak	Black Hills spruce
Ginnala maple	Eastern red cedar
Russian olive	Caragana
Wild plum	Buffaloberry

Benefits and Costs

Applied forest tree improvement has been practiced in the United States since the early 1950's. On the strength of early estimates, tree improvement cooperatives sprang up in the southeastern US, Florida, the Texas Gulf Region, the Pacific Northwest, the Inland Empire, and the Lake States. These cooperatives have survived and grown, not on the hope of early estimates, but on realized gains. The leaders of forest industry (Weyerhaueser, International Paper, Blandin, Champion, Potlatch, Westvaco to name a few) continue to invest in tree improvement for one reason: **IT PAYS!** The 29 members of the NC State-Industry Tree improvement Cooperative spend a minimum of $ 250,000 each per year on tree improvement. Cooperative dues are but a small fraction of this amount (Talbert, *et.al.*, 1985). Clearly, the leaders of forest industry are convinced that investments in tree improvement yield very favorable rates of return.

The Cost of NOT Practicing Applied Tree Improvement

Any analysis of tree improvement benefits and costs should begin with a look at the cost of **NOT** practicing applied tree improvement. The underlying assumption is that the Division of Forestry will continue to produce tree seedlings for planting public and private lands in Minnesota. Without an applied tree improvement program, losses can be predicted at several levels.

1. Seed source control

Without this most basic level of applied tree improvement, plantation survival will be reduced by the use of mal-adapted seed sources. Of the trees that do survive, growth will certainly be reduced. When carried to rotation, these losses represent a significant decrease in wood production.

2. Seed orchards

At the seed orchard level, not having an applied tree improvement program results in an added increment of lost wood production. Depending on the species, reliable gain estimates range from 5 to 20 % volume improvement from rogued, first generation seed orchards. Assuming an average rate of 10 %

volume improvement, an annual harvest of two million cords is effectively reduced by 200,000 cords. At $ 8/cord, this is an annual loss of $ 1.6 million.

When VALUE improvement is considered, the losses are even greater. Because genetically improved trees are straighter and plantations are more uniform, stumpage value is increased. In an estimate on first generation loblolly pine, a 3-4 % height gain was increased to a gain of 32 % in value when improvements in wood quality were factored into the analysis (Talbert, *et al*, 1985). While direct application of these results cannot be made to the DNR program, the loss of value over and above volume losses must be counted as a bonafide cost of NOT having a tree improvement program.

In an aggressive tree improvement program several generations of improvement could be achieved over the course of a rotation. Each generation of improvement would have an increment of gain at least equal to the first. Thus, with time the potential volume losses associated with NOT having a tree improvement program would get worse and worse. The bottom line is, that without an intensive tree improvement program, wood production will definitely be reduced. The value of lost wood production is a legitimate factor to be considered in benefit-cost analysis of applied tree improvement.

3. Genetic diversity

In addition to gains in wood production, applied tree improvement is also important with regard to gene conservation. Through plus tree selection, individual trees (gene combinations) from separate origins are brought together in the base population. Mating trees from normally isolated locations results in the creation of new gene combinations, which never would have existed without an applied tree improvement program. Thus, applied tree improvement not only saves valuable genes, it can create new combinations to maintain genetic diversity.

The increasing demands of conflicting land use place a burden on forest tree populations, reducing the land base for timber production. Applied forest tree improvement can maintain and even create genetic diversity in a shrinking land base. Without forest tree improvement, valuable gene combinations and diversity could be lost. A reduction in genetic diversity is another important cost in NOT having a tree improvement program.

The Benefits and Costs of Applied Tree Improvement

1. Time factors

Inherent in economic analyses of forest management options is the factor of time. Trees are generally long lived, so that the return on investment in year one may not be realized until year 60. In tree improvement there are added time factors. For example, the time to abundant seed production in orchards, the time to reliable progeny test assessment, the time to complete controlled crosses all affect the profitability of the program. In an aggressive tree improvement program these time bottlenecks are minimized, resulting in increased profitability. The converse is also true.

In benefit/cost analyses of tree improvement, time plays another important role. The question is, at what time in the program life is the benefit/cost ratio calculated. In a real sense, a tree improvement program has no lifespan. There is enough genetic variation in trees to support continued genetic improvement for several lifetimes. In a tree improvement program, the costs are front-end weighted. In other words, early in the program nearly everything is cost. The use of source identified seed does yield immediate returns in the form of improved plantation survival and growth. However, large increases in volume growth are deferred until genetically improved seed is available from seed orchards.

It is of more than passing interest to note that forest industry leaders, some of whom have been involved in tree improvement for 30 years, still treat it as a pure cost center. These companies fully expect to be in the forestry business well into the future. When they begin to harvest genetically improved plantations, their investments in tree improvement will be rewarded quite handsomely.

2. Tree improvement costs

In the early stages of a tree improvement program, considerable time and effort is expended assembling a base population and getting it into a form that can be manipulated. Thus it may take several years of plus tree selection, grafting, site preparation, and planting just to get the base population established. Once seed orchards and progeny tests are established, they must be properly managed to minimize the time bottlenecks. Progeny tests furthermore, must be periodically measured and the data analyzed statistically. In some species it is appropriate to begin controlled breeding to create pedigreed populations for advanced generation improvement. These are all costs that can be incurred before there is any discernible return to the program.

As a tree improvement program matures, costs are directed toward maximizing seed production and developing the next generation of improved material. At some point in this stage, a new generation of improved material will come into production, gradually phasing out the first. The process is then repeated, following the program oulined above. Properly conceived and planned, there will be enough operational flexibility to be able to take advantage of new technological advances.

3. The benefits of tree improvement

The economics of tree improvement has been studied and researched, analyzed and evaluated, in many different ways since the late 1950's. A partial listing of papers on the economics of tree improvement is given in Appendix I. **WITHOUT EXCEPTION**, despite different assumptions, methodology, and species, these analyses conclude that applied forest tree improvement provides consistently high rates of return. Furthermore, analysis indicates that among a range of forest management options, tree improvement is usually the best choice. Finally, studies indicate that as investments in tree improvement increase, returns increase proportionally.

Specific tree improvement benefits include improved plantation survival and growth at the seed source level, to significant increases in volume production and stumpage value at the seed orchard level. By developing intensively managed seed orchards, seasonal variations in seed supply are much reduced. Genetically improved plantations can be harvested at a younger age, with greater product uniformity. Wood quality can be improved, producing wood with greater density and longer fibers. Pest resistance can also be improved.

Depending on species, reliable estimates of genetic gain range from 5-20 % in volume for seed from a rogued first generation seed orchard. Additional increments of gain of this magnitude are possible in successive generations.

Financial Analysis of Applied Tree Improvement

As previously noted, there is cost associated with the achievement of genetic gain. This cost can be applied to the cost of tree seedlings. For example, if seedlings with 0 % genetic gain cost $ 80/M, seedlings with 10 % gain in volume at rotation might cost $ 90/M. John Helmburger (Bureau of Real Estate Management) recently completed an analysis of applied tree improvement, using a model linking the increased cost of seedlings to varying levels of genetic gain. Figures 1 - 4 illustrate the effect on internal rate of return (IRR) by increasing genetic gain and increasing cost of white spruce, black spruce, black walnut, and red oak seedlings. These analyses used the following set of assumptions:

Real Discount Rate:	4.2 %
Real Price Escalation Rate:	1.2 %
Inflation Rate:	5.0 %
Sale Cost (1989 $/ac):	$115

For each species analyzed, the internal rate of return (IRR) **increased** with increasing genetic gain and increasing cost of seedlings. Fine hardwood tree improvement is an especially attractive investment, yielding 10.43 % and 12.88 % IRR for red oak and black walnut respectively, at 15 % volume increase and + $ 13.00/m seedlings. From this financial analysis model, it is clear that increasing investment in applied forest tree improvement is an excellent forest management option.

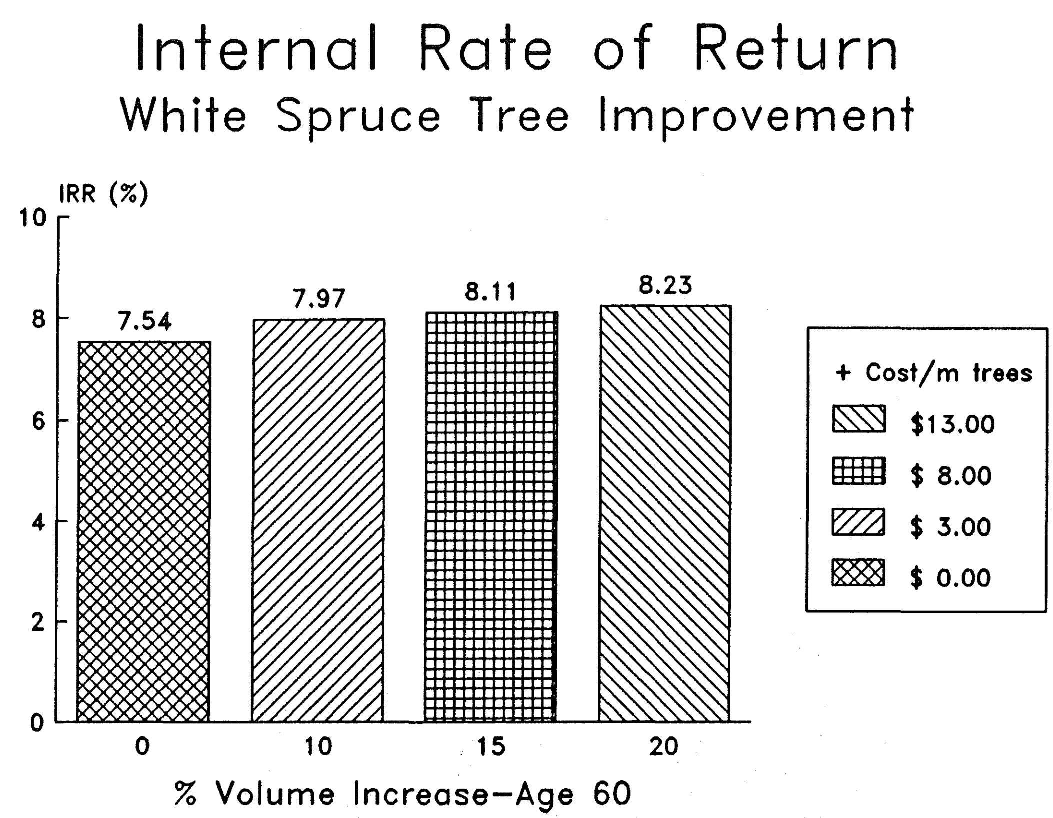


Figure 1.

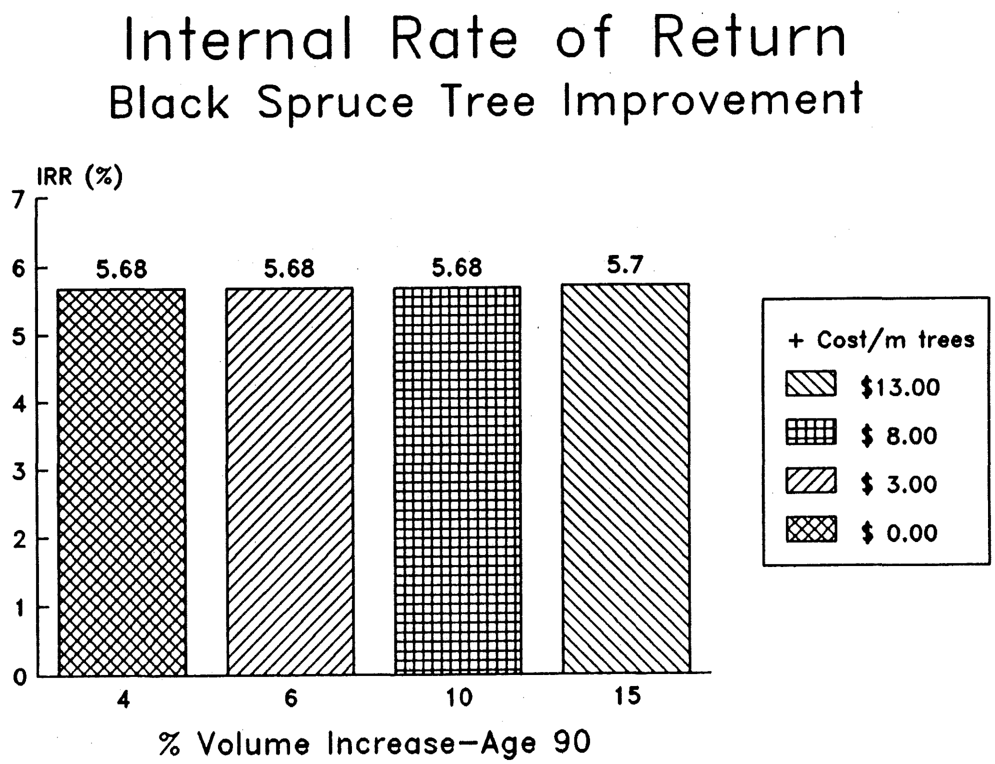


Figure 2.

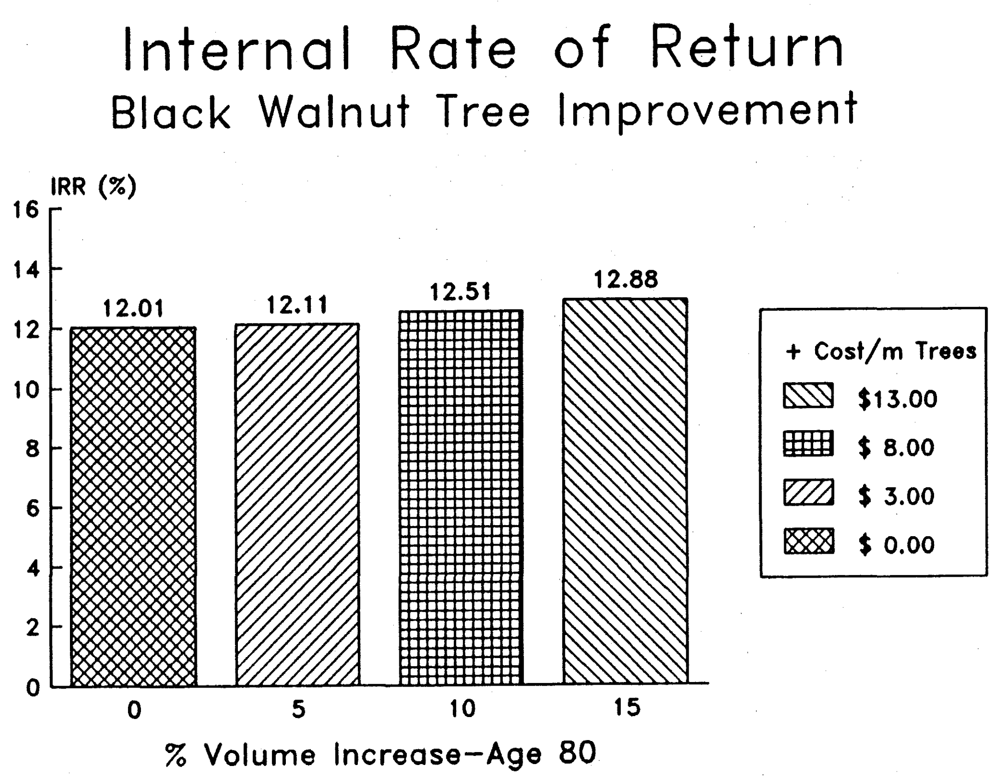


Figure 3.

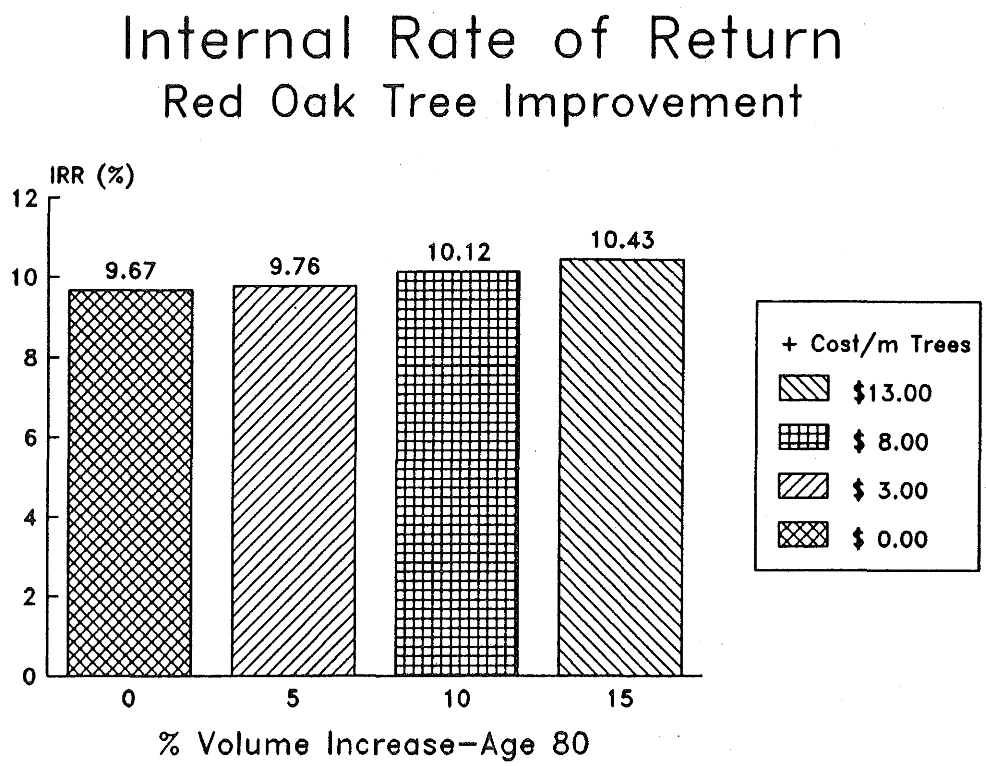


Figure 4.

PROGRAM FIT WITHIN THE DIVISION OF FORESTRY

For the forseeable future, the Division of Forestry Nursery Program will produce 20-25 million tree and shrub seedlings per year for planting public and private lands in Minnesota. Over 50 % of these seedlings are destined for private landowners. The Nursery Program clearly generates good publicity for the Division. Tree sales for reforestation, windbreaks, and wildlife plantings are viewed by the general public as a "good thing". It follows that producing **genetically improved** seedlings is an extension of good land stewardship. In this regard, applied tree improvement is a clear "plus" for the Division.

Applied tree improvement provides a good opportunity to promote sound forest management. When couched in terms of conservation of genetic resources and diversity, tree improvement shows that the Divsion is concerned about this issue and is doing something about it.

Internally, applied tree improvement should "fit" well in the overall forest management program. Applied tree improvement is nothing more than the application of sound genetic principles to forest management. In an organization devoted to good forest management, applied tree improvement is a natural fit.

On a regional scale, the Divsion of Forestry is recognized as a leader in many areas of forestry. With a strong tree improvement program, the Division would emerge as a leader in forest genetics. This outcome would clearly "fit" the long term goals of the Division.

PROGRAM FIT IN THE TREE IMPROVEMENT COMMUNITY

The fit with forest genetics research

Applied forest tree improvement "fits" very well in the forestry research community. Indeed, the two feed upon one another. Strong applied programs are needed to put research results into practice. Once the vital connection between research and development is established, both become stronger. Applied programs become more efficient by having the latest information and innovations. Research grows because a real value for research dollars has been established. A strong Division of Forestry applied tree improvement program would certainly help forestry research in the region.

The fit with other applied programs

The Division is a member of three tree improvement cooperatives:

- Minnesota Tree Improvement Cooperative (charter member-1981)
- North Central Fine Hardwoods Tree Improvement Cooperative (charter member-1986)
- Hybrid Aspen/Larch Cooperative (1988)

The strength of a tree improvement cooperative is defined by it's weakest member. When all members work steadily at a brisk pace, considerable progress can be made. It has also been shown in other tree improvement cooperatives that one or more members step to the front and become recognized leaders in the coop. This usually spawns a friendly spirit of competition, in which many members strive to match or even surpass the performance of the leaders. The overall result is a thriving, vibrant cooperative that accelerates it's progress.

The Division is recognized as a leader in the region, and even in the nation in certain aspects of forest management. A strong applied tree improvement program would "fit" quite well with the tree improvement programs of other cooperators. With the Division leading the way, all three cooperatives would grow stronger, leading to an overall acceleration of tree improvement progress in the region.

KEY SUCCESS FACTORS

The following are identified as key factors for success of the Division of Forestry applied tree improvement program:

- organizational support from the top
- long term commitment
- program stability (select species priorities and maintain)
- establishment and development of a seed orchard complex to consolidate management activities
- multi-specialty support (Silviculture, Insect & Disease, Soils)
- logistical support (availability of resources at biologically critical times
- sufficient budgetary support
- technical support (position)

Tree Improvement Program Management

The following organizational charts illustrate the management plan for the Division of Forestry applied tree improvement program.

Planning and Implementation

In applying a given tree improvement strategy, the Tree Improvement Specialist works with other Division staff to develop a detailed annual plan. For example, a bumper cone crop is predicted in the Cotton Seed Orchard. It is possible that both insects and disease may threaten the developing cone crop. So, the tree improvement specialist plans a spray project involving discussions with the Regional Silviculturalist, Region I & D, Area Supervisor, District Forester, Nursery Coordinator, Nursery Supervisor, and a Technician.

The Tree Improvement Specialist consults with the Nursery Coordinator to develop budgets, facilitate large purchases, prepare contracts, and coordinate nursery participation in tree improvement projects. Cone harvest, extraction, and utilization of orchard seed are also jointly administered by the Coordinator and the Tree Improvement Specialist.

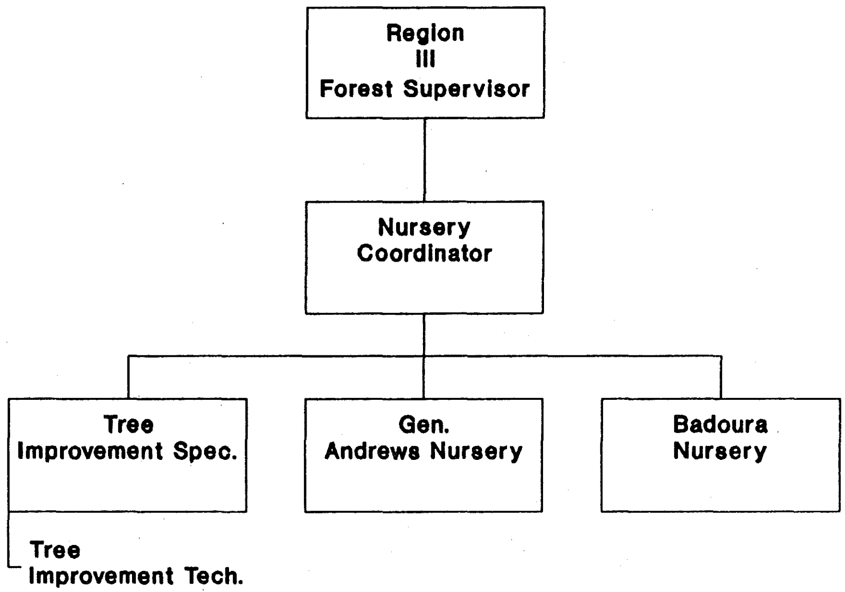
Technical and Field Support

Actual work on tree improvement projects is done by many different Division of Forestry employees. Labor assistance is usually supplied by the local Area or Field Station in which the project is located. In most cases, the Tree Improvement Specialist is the lead worker on field projects. For example, when a progeny test is planted, the Tree Improvement Specialist will organize the planting job, oversee the activities of a small planting crew, keep maps and records, and participate in planting as well. For the most part, all tree improvement projects are managed in this way including plus tree selection, scion collection, rootstock potting, grafting, controlled breeding, progeny test establishment, seed orchard establishment, management of orchards and progeny tests, and collection of data.

Technical support is often supplied by General Andrews personnel on projects located away from the nursery. For example, a nursery technician will apply pesticides or fertilizers according to a pre-determined plan.

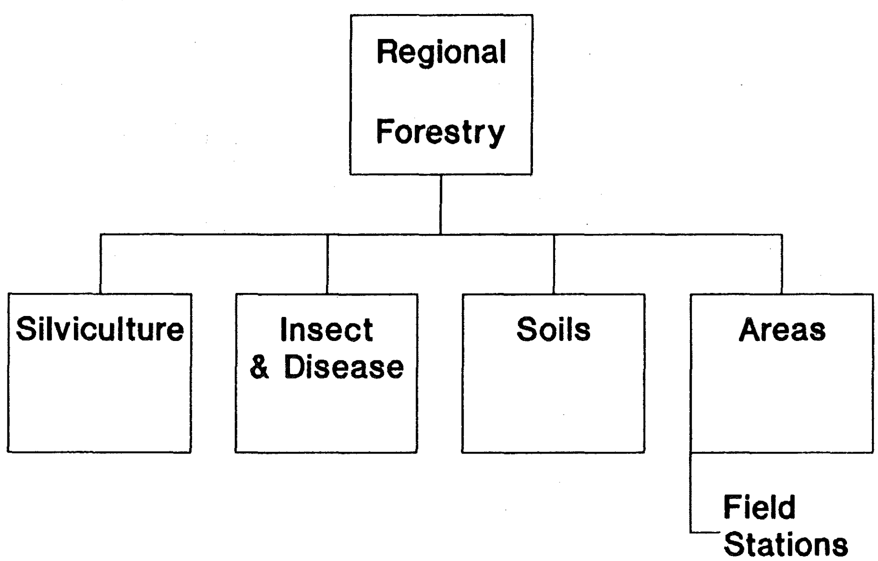
When a particular tree improvement project involves another specialty, such as Insect & Disease or Soils, Division specialists in the local Region are consulted. Often, these specialists are able to make specific recommendations for a given project. In some cases, other specialists are able to collect data relating to a particular problem in a seed orchard or progeny test. Multi-specialty support is very important to the long term success of the tree improvement program, since no one individual can be expected to be expert in all aspects of forest science. Multi-specialty support has been identified as a KEY SUCCESS FACTOR.

TREE IMPROVEMENT
PROGRAM MANAGEMENT



Planning and Implementation

TREE IMPROVEMENT
PROGRAM MANAGEMENT



Field and Technical Support

- Tree Improvement Technician

In addition to technical assistance on individual projects, a Tree Improvement Technician is needed to assist on various ongoing projects including, but not limited to:

- plus tree selection
- scion collection
- grafting
- potting rootstock
- greenhouse care
- controlled breeding
- pollen testing
- progeny test layout
- progeny test planting
- maintenance of records
- seed orchard planting
- progeny test management
- seed orchard management
- nut and cone harvest
- harvest and extraction of control pollinated seed
- maintenance of tree improvement plantings at GAN
- data collection
- maintenance of irrigation systems

The Tree Improvement Technician must understand basic genetic concepts and the fundamentals of tree improvement, be self-motivated, and be able to work without supervision. This position has been identified as a KEY SUCCESS FACTOR.

TREE IMPROVEMENT PROGRAM OPERATING PLAN

Project Schedule

Project schedules for the major forest tree species in the applied tree improvement program are presented below. In each case, the schedule is carried out to the year 2000.

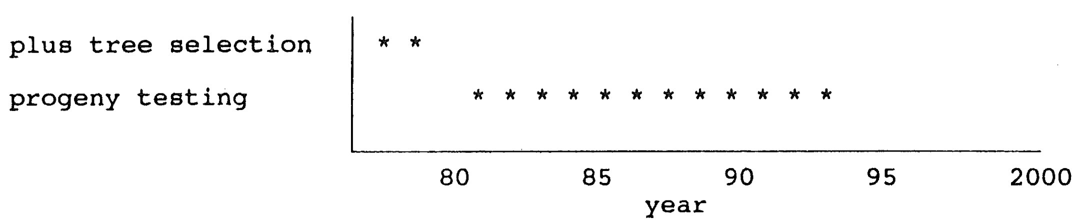


Figure 5. Red pine project schedule

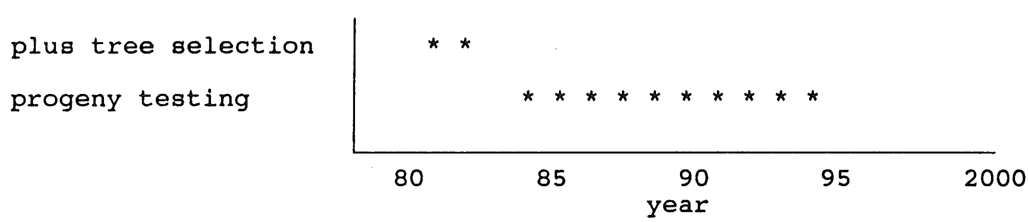


Figure 6. Jack pine project schedule

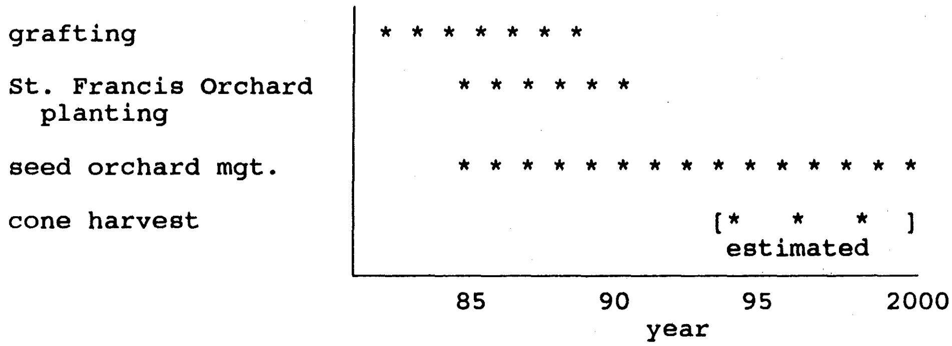


Figure 7. White pine project schedule

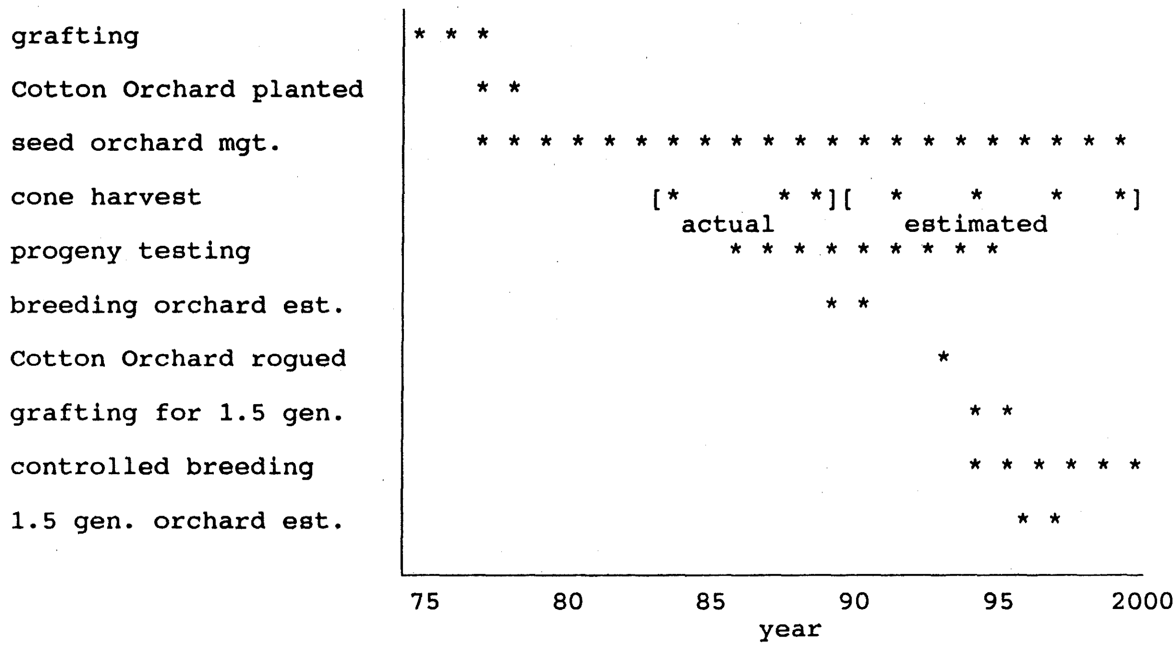


Figure 8. White spruce project schedule

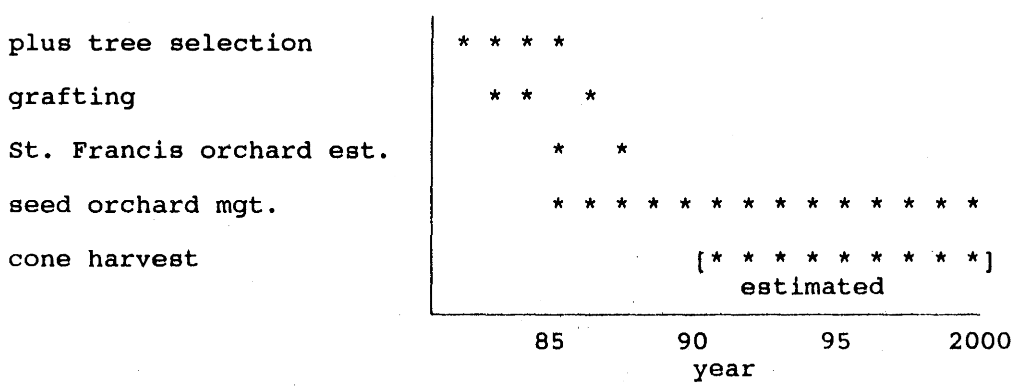


Figure 9. Scots pine project schedule

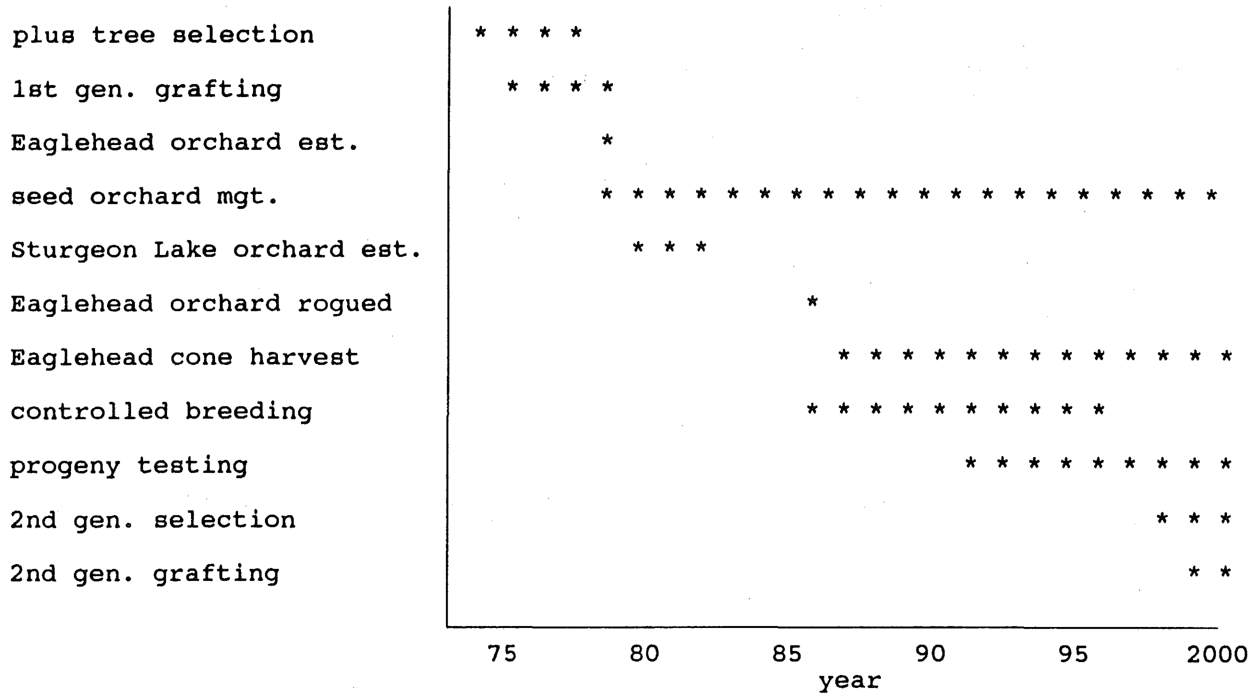


Figure 10. Black spruce project schedule

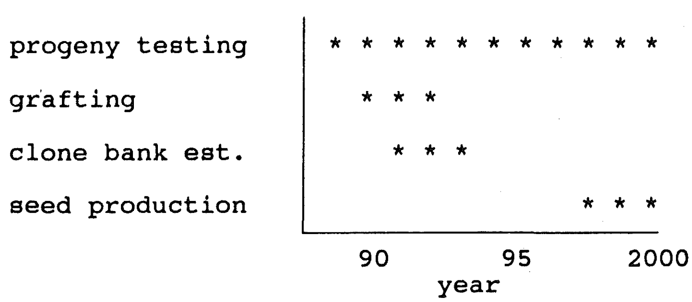


Figure 11. Hybrid aspen project schedule

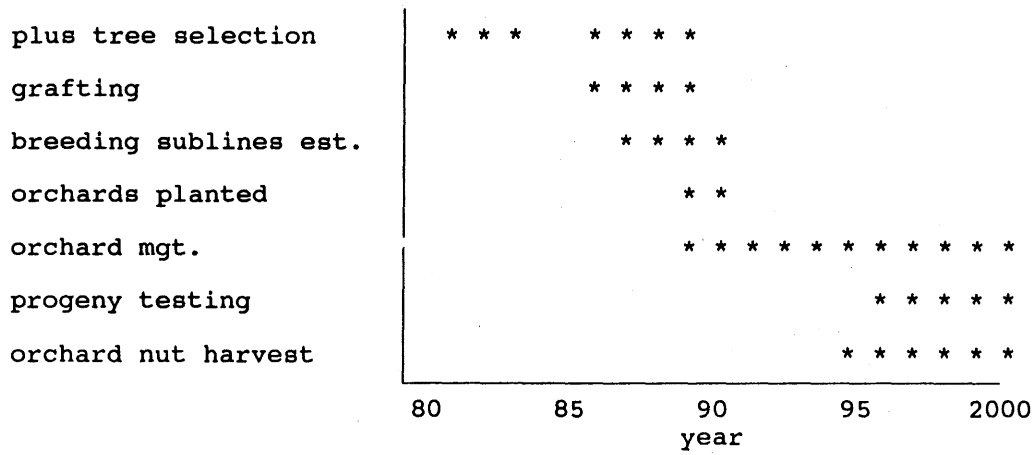


Figure 12. Black walnut project schedule

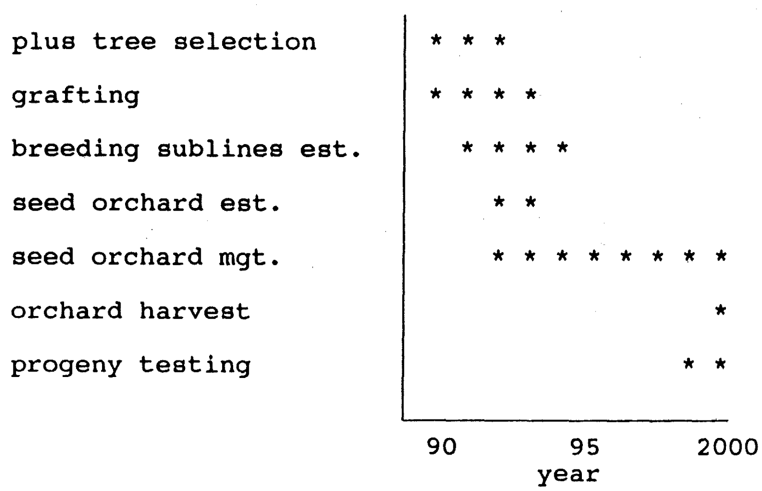


Figure 13. Red oak project schedule

Equipment and Supplies

In applied tree improvement, the "tools of the trade" are somewhat unique and unusual. A listing of equipment and supplies is best split into two categories: Expendable Goods and Capital Expenditures. For this plan expendable goods are defined as equipment and supplies that are quickly used and often are purchased on at least an annual basis. Capital Expenditures are large ticket items with a long usable life.

- *Expendable Goods*

pots
fertilizers
tree tags
insect traps
potting mix
pesticides
stake flags
grafting supplies
pollination bags
ammunition

-*Capital Expenditures*

greenhouse refit
irrigation supplies
subsoiler
sprayer
aerial lift
orchard ladders
fertilizer spreader
brush hog
tractor
data recorders

All of the above items are currently available from a variety of different vendors. Tractors and other farm equipment may be leased to reduce program cost.

Human Resources

The Division of Forestry applied tree improvement program covers nearly all of the 17 species grown in the DNR nurseries, and is state-wide in scope. Species emphasis is necessarily different from north to south, but clearly the entire Division has a vested interest in a successful tree improvement program. The program is directed from, and has much of the technical assistance and labor supplied from the Nursery Program. The constraints of state geography however, mandates that assistance be available from the Region, Area, and Field Station in which a given project is located. Quite clearly, tree improvement activities must become a regular part of the overall Division Forest Management Program.

In many Areas and Field Stations, the tree improvement program will have little, if any impact on personnel. Aside from supervising seed collections from specific areas or stands, these Areas and Field Stations will not be required to devote manpower and resources to tree improvement. Yet, these same Areas and Field Stations will surely benefit from the program in the form of genetically improved plantations.

In those Areas and Field Stations with specific tree improvement projects (progeny tests and seed orchards), close cooperation and the commitment of manpower and resources will be needed. The following table illustrates the current distribution of tree improvement projects on a statewide basis.

DISTRIBUTION OF TREE IMPROVEMENT PROJECTS, SUMMARIZED BY REGION, AREA, AND FIELD STATION

Region	Area	Field Station	Species
I	Bemidji	Bemidji	jack pine
II	Cloquet	Cotton	red pine white spruce
III	Moose Lake	Nickerson	jack pine white spruce hybrid aspen
		Eaglehead	red pine black spruce
		Moose Lake	black spruce
	Cambridge	Zimmerman	white pine scots pine
	Backus	Washburn Lake	white spruce
	Brainerd	Long Prairie	jack pine
V	Lewiston	Caledonia	black walnut
		Preston	black walnut
	Mankato	Rochester	black walnut

As can be seen from the table above, existing tree improvement projects are scattered across the state on a variety of sites. In some cases, this dispersion is necessary. Progeny tests must be planted on a variety of sites to adequately sample the range of environmental conditions. Hardwood sublines must also be separate from one another to maintain genetic integrity. These aspects of the applied tree improvement program will not change. Assistance in establishing progeny tests and sublines will still be required from the Regions, Areas, and Field Stations. However, future development of seed orchards need not be done on widely separated sites.

Seed Orchard Complex

Consolidation of future seed orchards to a single site will greatly facilitate their management. Equipment can be housed on site, ready to be used at the most appropriate time. An irrigation system can be set up to service all species. When fully developed, this "seed orchard complex" would be a satelite station, with an office, garage, pumphouse, and chemical storage. Clearly, the seed orchard complex will require a workforce to be effectively managed. One scenario might be to have a small crew hired locally, supervised by a DNR Technician. The crew would be needed on an interim basis for the period March 15-October 31 for such projects as pruning, weed control, mowing, irrigation, fertilization, pest control, roguing, cone and seed harvest, and maintenance of records. Other alternatives include contracting individual jobs, contracting with consultants, and stewardship contracts.

DNR-FORESTRY APPLIED TREE IMPROVEMENT PROGRAM

BUDGET PLAN FOR THE PERIOD 1990-2000

STATEWIDE	Units	1990	1992	1994	1996	1998	2000
Staffing Needs[a]	fte	2	4 *	6**	6	6	6
Budget Needs[b]							
1. salaries	$(M's)	42	75	100	100	100	100
2. supplies	$(M's)	2	8	10	10	10	10
3. operations	$(M's)	8	20	25	25	25	25
4. T. I. Contract	$(M's)	20	22	22	22	22	22
TOTAL BUDGET NEEDS		72	125	157	157	157	157

* Increase in fte's and salary $'s in 1992 reflects the addition of a tree improvement technician position
** Increase in fte's and salary $'s in 1994 reflects increased staff participation in the tree improvement program and funds to manage the seed orchard complex

a fte = 1730 hours per year

b 1989 dollars

CAPITAL BUDGET

	purchase	lease
1. Equipment		
a. tractor		$1200/mo
b. brushhog	6,000	
c. sprayer	1,500	
d. subsoiler	1,500	
e. fertilizer spreader	800	
f. aerial lift		1200/mo
g. orchard ladders	1,200	
2. Greenhouse refit	10,000	
3. Data recorders	2,500	sub-total: $ 13,500
4. Seed orchard complex		
a. land	title transfer	
b. irrigation	20,000	
c. electricity	2,000	
d. buildings	7,500	grand total: $ 43,000

Acquisition of capital purchases is recommended over a three year period.

Applied Tree Improvement Program Budget - Potential Sources

In the preceding section, future tree improvement program direction requires a budget increase. There are at least two potential sources of income that should be explored.

Surcharge on the Sale of All Nursery Stock

There is established precedent for this funding approach. Based on an economic analysis of the Nursery and Tree Improvement Program done in 1983, a surcharge of $ 3.00/M trees was established. Given an annual Nursery production of 20 million trees per year, the surcharge nets $ 60,000/year, or about 83 % of the current funding level. To sustain the budget proposed in this plan, the surcharge would increase to $ 6.25/M in 1992, and $ 7.85/M in 1994.

Premium Price for Sales of Genetically Improved Stock

Beginning with fall sowing in 1989, there will be enough improved seed to sow white spruce with 100 % improved seed. As time passes and the seed orchards become more productive, increasing quantities of improved seed will be available. This presents an excellent opportunity to provide a budget source for the tree improvement program. For example, assume that 2 million genetically improved white spruce are produced. Sold at a $ 10/M premium, the result is $ 20,000; a $ 20/M premimum nets $ 40,000. Although the situation is probably not as simple as presented here, clearly there is a good opportunity to generate operating revenue. This option should not be ignored.

In the final analysis, the tree improvement budget will likely derive from a combination of the two sources outlined above. There may be other sources not evident at this time.

APPLIED TREE IMPROVEMENT PROGRAM UNCERTAINTIES, PROBLEMS, AND RISKS

Forest genetics and tree improvement are both cursed and blessed by their central focus, the tree. Being long-lived and relatively slow to flower, it simply takes time to make measureable progress. For example, the Cotton White Spruce Orchard was grafted in 1975-77, planted in 1977-78, but did not produce it's first bumper crop of seed until 1988. During this time frame, the trees are subject to many different threats, both biotic and abiotic. Progress can be abruptly interrupted, or even halted by an untimely storm or insect attack. Intensive management helps to shorten this time period, and can reduce disruptions when they occur. But the fact remains that trees are exposed to potentially serious environmental threats prior to achieving genetic improvement.

Fortunately, the forest geneticist is blessed with the fact that as a group, trees have a tremendous amount of natural variation. This means that trees can be improved for many generations without losing momentum. In other words, there is plenty of "fuel" to drive the tree improvement "engine". Beginning with a sufficient genetic base, most tree species can be continuously improved. Each generation of improvement will have an increment of gain at least equal to the one preceding it. Thus, barring factors that cannot be controlled (the weather), there are no genetic barriers to long term tree improvement.

PART II: DETAILED PLANS

INTRODUCTION

In plotting the future course of the DNR-Forestry applied forest tree improvement program, each species produced by the Nursery Program will be assigned to one of three priority classes. These classes are low, intermediate, and high. In general, these priority classes reflect the importance of the given species to forestry in Minnesota and the potential for genetic improvement. In the species plans, priority will be addressed in terms of the following levels of applied tree improvement:

1. seed collection zones
2. seed collection areas
3. seed production areas
4. seed orchards
5. genetic testing
6. selective breeding
7. cooperative research

Species priority will be reflected in program intensity. An extensive approach will be used on low priority species, concentrating mainly on seed source control. As priority increases, more program effort will be devoted to seed orchards and genetic testing. At the highest level, plans will include provisions for long term genetic improvement. When the Tree Improvement Plan for the Minnesota DNR is updated, any changes in species priority can be incorporated.

LOW PRIORITY

Species in the low priority class are generally those produced in small quantities by the Nursery program. These species are used for erosion control, windbreaks and shelterbelts, and wildlife plantings. Species of low priority include

tamarack	exotic larch	norway spruce
N. white cedar	balsam fir	white oak
black ash	white ash	green ash
white birch	basswood	hybrid poplar
silver maple	ginnala maple	bur oak
Russian olive	wild plum	Colorado spruce
buffaloberry	caragana	Black Hills spruce

The primary market for these species is the private landowner. This customer purchases more than 50 % of all seedlings sold by the Nursery Program. The private landowner wants seedlings that will survive well and grow reasonably well, often under harsh conditions and climates. Thus, the most important trait for the species listed above is adaptability. This goal can be accomplished most efficiently in the following ways:

- use of local seed sources

- use of naturalized seed sources

- proper provenance selection

Local Seed Sources

Local seed sources are simply seed harvested from native trees growing "near" the intended planting area. What constitutes "near" for many of the species listed above is unknown. In the absence of good provenance information, it is prudent to try to match the climate, soils, and other ecological knowledge of the seed source to the intended planting area. Gross differences in these factors should be avoided. For example, it would not be advisable to collect green ash seed in Houston County to be used for planting in Morrison County. Until such time as reliable seed source data is available, it is best to adhere to established Division policy of collecting seed on the basis of Administrative Area. Thus, green ash seed harvested in Houston County would only be used in the Lewiston Area.

Naturalized Seed Sources

Some species such as Colorado spruce and ginnala maple are not native to Minnesota. These species exist in the state **only** because someone planted them. Non-native species often are not adapted to local conditions, especially if the wrong seed source was used. It is not uncommon for plantations of non-native species to suffer heavy mortality. However, some trees will survive and grow well, strong evidence that these trees possess the genetic ability to adapt to the new environment. This is known as a land race.

With non-native species it is important to evaluate a land race for at least half a rotation, ensuring that the trees will tolerate the natural range of conditions. Once a land race has proven that it can "weather the storm", seed can be harvested with strong assurance that it too, will be adapted. These naturalized seed sources are good choices for non-native species.

Proper Provenance Selection

In some cases there may not be enough established plantations of an exotic species to develop a land race. In this situation, it is very important to use those provenances which have a high liklihood of being adapted. An example of this is european larch. This species in Minnesota is often hampered by late spring frosts and winter injury. However, provenance research indicates that some Polish and Czechoslovakian sources are more cold hardy and may be used in some parts of Minnesota. Therefore, it is critical to make sure an appropriate seed source is used for non-naturalized exotic species.

- *Cooperative Research*

At the present time several species on the low priority list are being investigated by different research organizations. These species are tamarack, exotic larch, and hybrid poplar. As applicable, the DNR-Forestry will cooperate with this research. In the future, these species may become increasingly important to the forestry community in Minnesota.

INTERMEDIATE PRIORITY

Species classified as intermediate priority include red pine, jack pine, white pine, and scots pine. It should be noted that in the 1981 Tree Improvement Plan for Minnesota, red pine and jack pine were considered highest priority species, while white and scots pine were rated as intermediate (Mohn and

Berndt, 1981). At present all four of these species are an integral part of the Division's applied tree improvement program. The following sections will detail future plans.

Red pine

The Minnesota State Tree, red pine continues to be the single most important forest tree species produced by the Nursery Program. In 1989, 10.9 million seedlings and transplants were sold. Red pine performs well in even-aged plantation silviculture and is valuable for both pulp and solid wood products. It is also planted for Christmas trees, soil protection, and wildlife habitat.

There can be no doubt that red pine is a major reforestation species in Minnesota. However, debate continues to swirl regarding the potential for red pine genetic improvement. Different genetic field tests have yielded conflicting results. Early studies indicated that red pine is fairly genetically uniform, *i.e.*, there is very little genetic variation to be exploited in an applied program (Lester and Barr, 1965). Based on this data, program recommendations usually were to use a low level approach for red pine (Fowler, 1964; Rudolf, 1964). Later, other research suggested that volume improvements from a rogued, first generation seedling seed orchard could be in the range of 5-11 % (Ager, *et.al.*, 1982; Yao, *et.al.*, 1971). This data would suggest that a high level applied tree improvement program is justified.

The discussion of potential for genetic improvement, when coupled with reduced demand for pine stumpage at present, has led to a Division recommendation to reduce tree improvement program emphasis on red pine. The following sections will outline the future course of red pine tree improvement for the Minnesota DNR.

Seed Source Control

The first level of applied tree improvement is control of seed source. Established Division policy is to identify cone collections by Administrative Area. Seedlings are then returned to their origin for reforestation. This system will continue to generate all of the red pine seed used by the Nursery Program.

Progeny Testing

In 1981 the Division established five progeny test sites as part of a cooperative progeny test. Three of these test sites have been abandoned because of poor survival. The remaining two sites (Cotton and Eaglehead) continue to be managed. In the fall of 1986, the progeny tests were measured for height and survival. The tests will be measured again in 1989.

As a member of the Minnesota Tree Improvement Cooperative, the DNR-Forestry has an obligation to maintain and assist in data collection in the red pine progeny tests. Furthermore, the progeny test sites will be available to the Cooperative for selection and collection of improved material.

Jack pine

Jack pine is a fast growing, small to medium sized tree, common on sandy sites throughout northern Minnesota. It performs well in plantations, and is often the only choice for dry, sandy sites. An extremely variable species, important traits are moderately to strongly inherited (Yeatman, 1974). In a high level program, considerable genetic improvement can be achieved.

Since the early 1980's, the relative importance of jack pine as a reforestation species has declined steadily. In 1985, the Nursery Program produced about 3.5 million seedlings. By 1989, this figure had fallen to less than 1.5 million. This decline, when combined with lower demand for pine pulpwood, has led to the decision to reduce tree improvement program emphasis on jack pine.

Seed Source Control

In keeping with Division policy, all jack pine cones harvested are identified by the Administrative Area of origin. The resulting seedlings are then returned to their Area for planting. In jack pine, it is also worthwhile to establish seed production areas. Stands considered for seed production should be well-stocked natural stands or plantations, 15-30 years old, with a site index of at least 60. A significant improvement in straightness can be achieved by thinning the crooked trees from the stand. This thinning will also result in increased cone production due to increased light.

Each Administrative Area that plants jack pine should develop at least one seed production area. Thought should be given to method of cone collection. Although there are a variety of aerial lifts available, felling a portion of the stand each year is more economical. As one seed production area is phased out, another should be developed so that a continuous supply of source identified seed is always available.

Progeny Testing

In 1984 the DNR-Forestry established four sites of a Cooperative progeny test. Since 1984, other Cooperators have also planted test sites. One of the four DNR test sites has been abandoned due to excessive deer browsing. The remaining three continue to be managed to fulfill the DNR obligation to the Minnesota Tree Improvement Cooperative.

The DNR jack pine progeny tests were measured for height and rated for gall rust incidence in the fall fo 1986. In the fall of 1989 the tests will be remeasured, and the data analyzed by the MTIC. The DNR will continue to manage the jack pine progeny tests as directed by the Cooperative, including thinning. Furthermore, the DNR will allow the collection of genetic materials from the test sites as necessary.

White pine

Once dominating the virgin forests of Minnesota, today white pine is but a minor component of natural stands. On the proper sites however, white pine has no peer in the northern forest. It is a large, fast growing tree producing wood valuable for solid wood products.

As a reforestation species the importance of white pine has declined in recent years. In 1985, the Nursery Program shipped 1.2 million seedlings. By 1989 this figure had dropped to 850,000. Clearly, a major cause for the decline in white pine planting is white pine blister rust. Many forest managers have indicated they would plant more white pine if a blister rust tolerant source were available.

Seed Source Control

Consistent with established DNR policy, white pine cone collections are identified by their Administrative Area of origin. This system ensures that the Areas will receive local source seedlings for planting. To begin to address the blister rust issue, Areas planting white pine should establish seed collection areas. White pine seed collection areas should be located in high quality stands with a good stocking to white pine. Any blister rust infected trees should be removed and destroyed. Over time, if new infections occur these trees should also be removed. Under no circumstances should cones be collected from infected trees.

This type of sanitation program will not guarantee blister rust resistance. However, it clearly will not add to the problem. It is possible that disease free trees do have some resistance, tolerance, or mechanisms of avoidance. These traits would be passed along to their offspring.

Once seed collection areas of set up, the Areas should make every effort to collect their seed requirements only from the SCA's. One option might be to let a contract for cone harvesting, specifying from which area the cones are to be picked.

Seed Orchard

Beginning in the early 1980's, the DNR-Forestry has undertaken an intensive white pine tree improvement program devoted solely to blister rust resistance. Initially, scion material was received from the US Forest Service (Region 9). Later, scions were also obtained from the Quetico Wilderness Research Center. These clones had exhibited increased resistance to blister rust, although testing methodology had not been refined. In 1985, a grafted seed orchard of 17 clones (412 ramets) was planted in the Sand Dunes State Forest. This seed orchard, along with an adjacent scots pine seed orchard, is named the St. Francis Seed Orchard.

Unfortunately, the white pine seed orchard has suffered continuous abiotic threats every year since 1985. A late spring frost in 1986 and the record drought of 1987-88 have had the most impact. The dry weather has continued into 1989, although a trickle irrigation system has helped moderate drought effects.

The abiotic impacts have had two major results on the orchard trees. One, survival has been low, with only about 100 live trees at the end of 1988. Two, the surviving trees have grown very slowly. Thus, considerable regrafting has been necessary and seed production will be delayed.

About 150 new grafts were planted in the orchard in 1989 with good survival. An additional 100 grafts were produced in 1989, for planting in 1990. These plantings should increase the trees in the orchard to a manageable number. There will be a total of 15 clones in the orchard. With the irrigation system in place, drought losses should be minimal.

SEED ORCHARD MANAGEMENT

The white pine orchard at St. Francis is managed according to a regular schedule. In May, the orchard is fertilized to stimulate tree growth. Pocket gophers are also controlled during this time. By mid-June, the orchard is in need of mowing. This service is contracted out. Depending on available soil moisture, the orchard will be irrigated as needed. During excessively dry periods, the orchard is irrigated three days per week. The objective of management at this time is to get the trees growing as fast and vigorously as possible. This will help to shorten the time to seed production.

When the trees begin to produce cones it will be necessary to institute an integrated pest management program. White pine seed orchards are sometimes heavily attacked by two insect pests, the white pine cone beetle (*Conophthorus coniperda*) and the white pine cone borer (*Eucosma tocullionana*). Large cone crops in North Carolina white pine orchards have been **completely** destroyed by these insects[5]. Integrated pest management tactics will probably include a combination of chemical and cultural controls, such as clean harvesting and prescribed burning.

SEED PRODUCTION

Because of the abiotic impacts to the seed orchard, seed production will be delayed. In white pine orchards, male flowering is typically delayed, so that early cone crops do not contain viable seed. Experience in older white pine orchards indicates that significant seed production begins at about age 9-10. Thus, about the earliest a cone crop could be produced would be 1995-96.

Once white pine orchards do begin to produce, cone harvests can be quite heavy. At age 20, a white pine orchard in Ohio produced 50 bushels/acre. Thus, it is reasonable to predict that the St. Francis white pine orchard will ultimately produce 150 bushels in a good cone year. Seed yields for white pine are generally 8-10 ounces/bushel. A crop of 75 lbs would produce about 780,000 seedlings.

Cooperative Research

Although the problem of white pine blister rust has been studied for many years, development of truly resistant material has remained an elusive goal. Perhaps the most critical research question is how can testing procedures be developed that will correlate well with field performance. The US Forest Service and the University of Minnesota continue to work on this problem. However, research organizations require the assistance of an operational program to assess research results. The DNR-Forestry has an important stake in the development of truly blister rust resistant white pine. Thus, continued involvement in cooperative research efforts will remain an important aspect of the white pine tree improvement program.

Scots pine

Viewed as an alternative to red pine, the DNR began a scots pine tree improvement program in the early 1980's. At present, the Nursery Program produces about 500,000 seedlings per year. These seedlings are used solely for Christmas trees. The goal of the scots pine tree improvement program is to develop a timber type variety.

As a timber species there is considerable potential for scots pine in Minnesota. When proper seed sources are used it grows much faster than red pine. Healthy, vigorously growing trees are more able to withstand insect and disease attack. The wood quality of scots pine is very comparable to red pine.

Scots pine is an exotic in Minnesota, *i.e.*, it is not a native species. Scots pine has a large trans-continental range, from Norway to Siberia and as far south as Spain and Turkey. As with all exotics, seed source is critical. Use of the wrong seed source is probably the single most important cause of "bad" scots pine in North America.

In the late 1950's, a scots pine provenance trial was initiated in Minnesota. With time, several seed sources emerged as doing very well under Minnesota conditions. These sources include northeastern Germany, Poland, western

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[5] K. O. Summerville, State of North Carolina, Dept. of Natural Resources and Community Development. Personal communication

Germany-eastern France-Belgium, southern and central Germany-central Austria, and western Russia.

In the early 1980's, plus tree selections were made in Minnesota provenance test plantations, **ONLY** from those sources that had done well. No plus tree selections were made from non-adapted sources. A total of 40 clones were grafted, with first orchard planting in 1985. All told, a three acre grafted orchard was established at the St. Francis Seed Orchard.

Seed Orchard

The St. Francis Scots Pine Seed Orchard is comprised of two distinct blocks. The first block, planted in 1985, consists of about 100 grafts. This block is growing vigorously and has begun to produce cones. The second block was planted in 1987 and unfortunately has suffered severe drought effects. Survival and growth of the 1987 block is reduced, although the scots pine grafts do show more drought tolerance than do the white pine in the adjacent orchard. The entire orchard is now irrigated, so further drought losses should be minimal.

At present the scots pine orchard contains 276 ramets representing 40 clones. In light of the discussion regarding the use of scots pine in Minnesota, there are no plans to do any additional grafting to fill in the orchard. The orchard will continue to be managed for the production of seed. Management activities include gopher control, fertilization, irrigation, and mowing.

Seed Production

Scots pine is a very fruitful species, flowering at an early age, and maintaining regular abundant cone crops. As noted earlier, the 1985 orchard block has already begun to produce cones. Collectible crops should be available in the St. Francis orchard by the early 1990's. Although estimates of scots pine seed production are scarce in North America, data from Sweden may provide an indication of potential seed yields. In Sweden, one report on a mature scots pine seed orchard gave production figures of 10 kg/hectare/year. This is equivalent to 9 lbs/acre/year. It would seem reasonable that the St. Francis scots pine orchard should be capable of producing about 15-20 lbs of seed in a good seed year. Assuming 20 lbs/year, this amount of seed would be sufficient to produce about 375,000 seedlings.

Use of Genetically Improved Scots Pine

Currently, there is strong Division bias against the planting of scots pine for anything other than Christmas trees. This bias is due in large measure to the use of improper seed sources in Minnesota. Bad provenance selection leads to insect and disease attack. Unthrifty scots pine plantations then serve as centers of spread of insects and disease, moving to adjacent healthy plantations of other tree species. However, it is clear that the use of proper scots pine seed sources has not been given a fair chance in Minnesota. Toward this end, individual members of the Minnesota Tree Improvement Cooperative have agreed to set up test plantations of scots pine from the St. Francis Orchard. These demonstration plantations should provide the information necessary to make a final decision on scots pine tree improvement. The Division would do well to participate in these applied field trials, and defer judgment until the plantations can be objectively evaluated.

HIGH PRIORITY

Species classified as high priority are white spruce, black spruce, black walnut, red oak, and aspen. When compared to the 1981 Tree Improvement Plan for Minnesota, the high priority list has several significant changes. Both white and black spruce were Priority 1 species in 1981, black walnut was Priority 2, red oak was Priority 3, and aspen *did not appear on any list*. The emergence of fine hardwoods and aspen reflect the increase in economic importance of these species. It is estimated that the fine hardwood resource alone is worth at least $ 500 million to the Minnesota economy as measured by stumpage and value added products[6]. With aspen, current and planned major expansions at four mills are testimony to the rise of the aspen resource.

White spruce

After red pine, white spruce is the second most important species produced by the Nursery Program. There is a fairly steady demand for about 6 million bareroot seedlings and 300-400 thousand containers per year. Considerable potential exists for substantial genetic improvement of white spruce, owing to it's competitive stumpage value and large genetic variation.

White spruce is one of those exceptions that proves the rule. In nearly all cases, a local seed source will be superior to an exotic source. This is because the local source, through thousands of years of evolution, has become adapted to the prevailing local environment. However, provenance tests of white spruce have revealed that the Ottawa Valley (Ontario, Canada) source is consistently superior throughout northeastern North America.

Plus tree selections from Ottawa Valley sources form the cornerstone of the DNR-Forestry white spruce tree improvement program. Over 100 plus trees were selected from provenance tests, and grafted in the mid-1970's. Through the Minnesota Tree Improvement Cooperative, the Division has access to a total of 144 Ottawa Valley clones. In addition to the Ottawa Valley clones, another 140 white spruce clones of Minnesota and Wisconsin sources have been propagated. Thus the first generation breeding population is comprised of over 280 clones.

Currently, the Division operates a 12-acre clonal seed orchard near the Cotton Field Station. This orchard consists of about 1400 trees representing 102 Ottawa Valley clones. In 1988 152 bushels of cones were harvested from this orchard, yielding 220 pounds of high quality seed (germination: 92 %). Another large crop was harvested in 1989, with 122 bushels yielding 180 pounds of seed. Seed from these two crops would be sufficient to meet white spruce seed demand in the Nursery for two years.

In support of the seed orchard, the Division established two progeny test sites in a six site Cooperative test in 1986. Both of these tests are doing well with high survival and vigorous growth.

At General Andrews Nursery, a white spruce breeding orchard is nearing completion. This orchard will ultimately contain at least one ramet from each of the 280 clones in the Cooperative program. At such time when the progeny tests yield reliable data, the breeding orchard will be readily available for advanced generation controlled mating.

Seed Source Control

For white spruce in Minnesota, the Ottawa Valley source is clearly the first choice. With the onset of abundant seed production in the Cotton Orchard, a ready supply is assured. As added insurance, the Areas should maintain white

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[6]John Krantz, Utilization and Marketing Program Supervisor, Minnesota Department of Natural Resources, Division of Forestry. Personal Communication.

spruce seed production areas to provide sources of local seed. Seed production areas are needed because it is possible for several years to pass before the next crop can be harvested from the Cotton Orchard. University of Minnesota research indicates the north shore of Lake Superior should be avoided; otherwise local sources are sufficient.

Seed Orchards

The white spruce applied tree improvement program has reached the stage where it is appropriate to discuss the plans for three separate seed orchards. Each orchard will represent an increasing level of genetic improvement.

COTTON SEED ORCHARD

This is a first generation, unrogued, clonal seed orchard. It contains about 1400 trees representing 102 clones. By the early-to-mid 1990's, the 1986 progeny test should yield data reliable enough to make roguing decisions. In consultation with the University of Minnesota and the MTIC, the Cotton Orchard will be rogued. Factors considered will include desired genetic gain and seed production after roguing. In all probability, the Cotton Orchard will be rogued down to the best 30-40 clones. This will result in considerable genetic gain.

1.5 GENERATION ORCHARD

The 1986 progeny test will also identify the very best clones in the entire 280 clone base population. The top 15 clones will be grafted and established in an orchard. This interim step is known as a 1.5 generation orchard. Another increment of genetic gain will be achieved, over and above the first generation orchard. This orchard could be established by 1995-96, and would be producing harvestable cone crops by the turn of the century.

SECOND GENERATION ORCHARD

Establishment of a true, second generation orchard will necessarily be delayed by controlled breeding. Progeny test data will permit the ranking of the 280 clones in the first generation base population. The bottom half of the clones will be eliminated. The remaining clones (about 140) will be mated according to a design that will meet the needs of the Cooperative. The resulting control pollinated seed will be used to establish progeny tests. When the progeny tests yield reliable data, superior trees will be selected from the best families and grafted to establish a second generation orchard. This orchard will produce seed of even higher genetic quality than the 1.5 generation orchard. The second generation orchard could be established by about 2008, and would be producing collectible seed crops by 2014.

The following time line shows graphically the development of the three seed orchards, illustrating how they will overlap in time.

C O T T O N   S E E D   O R C H A R D   2 ND G E N. O R C H A R D

1977----------------1990------------2000------------2010------------2020

                                        1 . 5   G E N.   O R C H A R D

The Cotton Orchard will most likely be phased out of production by early in the 21st century. As time passes, it will become increasingly difficult to reach the tops of the trees for cone harvesting. Topping will be necessary. However, the Cotton Orchard will provide a substantial amount of genetically improved seed for at least the next 10-12 years.

Under intensive management, the 1.5 and second generation seed orchards should begin seed production at about age 7-8. Fertilization, irrigation, weed control, mowing, and pest control properly applied should result in fairly regular seed crops. Topping may be necessary to manage tree height for efficient cone harvesting. By about age 20, these orchards should be nearing the end of their useful lives. At such time, the ever present breeding program should be ready with the next generation of improved white spruce.

Progeny Testing

Progeny testing is, and will continue to be an integral part of the white spruce applied tree improvement program. The current white spruce progeny test was established in 1986. The Division manages two sites; one in the Nickerson District and the other in Washburn Lake. The data from these tests will be used to rogue the Cotton Orchard and to select the very best clones for the 1.5 generation orchard. Even after these decisions have been made, it will still be important to maintain the progeny tests sites. For example, the tests may be periodically measured to track the changes in genetic variance over time. Or, the tests may be thinned to determine the genetic variation in wood quality. Ultimately, the progeny tests will result in high quality white spruce plantations.

About the turn of the century, another series of progeny tests will be established. This test will consist of control pollinated material generated from the top 50 % of the clones in the base population. It would seem likely that members of the MTIC will share the task of establishing and managing these tests.

Cooperative Research

The DNR-Forestry will continue to support and participate in white spruce cooperative research projects.

Black spruce

In Minnesota, black spruce is an important forest tree species. It is recognized worldwide for the production of premium quality newsprint. There is also a large land base in Minnesota for which black spruce is the most reasonable choice for planting after harvesting.

At present there is a fairly steady demand for about one million black spruce seedlings per year, divided evenly between containers and bareroot stock. This level of production requires about 25 pounds of seed. Over 300 pounds of seed are also used for direct seeding. The following plan will address the needs of both nursery production and direct seeding.

Seed Source Control

In keeping with established Division policy, black spruce seed should continue to be collected on an Area basis. However, now that the Eaglehead Seed Orchard is producing good crops, seed collected from natural stands and plantations should only be used for direct seeding. When planning future timber harvests in black spruce stands, foresters should be aware of direct seeding requirements. Probably the most efficient method of black spruce cone collection is top picking during a winter logging job. Black spruce cones are semi-serotinous, so new cones will retain most of their seed throughout the winter. Top collection should be reserved to the better quality stands. Plantations of known origin are also a good source of seed. On well-drained soils, young black spruce is a regular and prolific cone producer. These cones are much larger and contain more filler seeds than those of mature trees.

Seed Orchards

For the time being, the Eaglehead Seed Orchard will be the principal source of genetically improved black spruce seed for the Nursery Program. This orchard was established in 1978, rogued in 1986, and produced it's first crop in 1987. Small cone crops were produced in 1987-88, yielding about 7 pounds of seed. In 1989 a bumper cone crop of 13.3 bushels was harvested, yielding 7 pounds. This seed, or at least a portion thereof, should be moved into nursery production as soon as possible.

There are several options for further seed orchard development in black spruce. These include no development, a 1.5 generation orchard, and/or a second generation grafted orchard.

NO DEVELOPMENT

Currently, the trees in the Eaglehead Orchard are 10-25 feet tall. Before too much longer, it will be increasingly difficult to harvest cones without an aerial lift. Topping experiments indicate this practice does not work well in black spruce. With the passage of time more and more cones will be produced at Eaglehead, but they will be increasingly expensive to harvest.

Under the 'no development' option, the orchard would eventually be cut down to harvest the last cone crop. At that point, the Division would be without a source of genetically improved black spruce seed. Although it is difficult to predict, it is reasonable to estimate that the Eaglehead Orchard will be phased out of production by the turn of the century.

1.5 GENERATION ORCHARD

The 1978 black spruce Cooperative progeny test was planted on four separate sites by the DNR, Blandin Paper, Potlatch Corporation, and the University of Minnesota. A total of 200 open-pollinated families were included in the test. In 1986, data from these tests were used to construct a selection index, resulting in a numerical score for each and every tree in the test. The selection index was comprised of a value for family performance, plus a value for the performance of each tree in it's respective plantation. Thus, all trees in the test (nearly 11,000 trees) were ranked. Considerable genetic gain could be achieved by grafting the top 15-20 trees into a 1.5 generation orchard.

At 10 x 15 feet spacing, a three acre orchard would contain 870 trees. This orchard would then be capable of producing at least 40 bushels of cones in a good crop year. This level of production should keep pace with the demand for black spruce seed in the Nursery Program. Assuming the selection of a suitable orchard site, phase-in of the 1.5 generation seed orchard would occur over a five year period. Beginning in 1990 with the potting of rootstock, grafting would take place during 1991-92, with orchard planting in 1993-94. This orchard would begin seed production by the late 1990's, or at about the time the Eaglehead Orchard has reached it's useful life. With a 1.5 generation orchard, the Division would have a reliable source of genetically improved black spruce seed well into the 21st century.

SECOND GENERATION ORCHARD

A *bonafide* second generation orchard could be established with selections from a full sib progeny test. Development of this orchard is still some years away. Controlled breeding of black spruce is an ongoing project, but it will be several years before the full sib progeny test is planted (see following section). Assuming the progeny test is established in the mid-1990's, at best the second generation orchard could be started 8-10 years later. Seed production would begin sometime in the 2010's.

From the preceding discussion it is clear that the 1.5 generation orchard, if started soon, will provide a ready source of genetically improved seed when the Eaglehead Orchard is finished. It will also provide a good interim source before the true second generation orchard is ready. Final decisions on the course of black spruce orchard development depend on the perceived need for a source of genetically improved seed in the future. Whether or not the second generation orchard is developed, the 1.5 generation orchard remains a good choice to ensure genetically improved seed for the next 25 years.

Progeny Testing

In order to secure genetic improvement of black spruce for the next generation, full sib progeny testing will be needed. This involves the creation of a fully pedigreed population by controlled breeding, followed by the establishment of a Cooperative test. At present, the Division is in the midst of the controlled breeding stage. By the mid 1990's, enough seed should be available to begin the establishment of a second generation Cooperative progeny test.

Cooperative Research

The Division will continue to support and participate in black spruce cooperative research efforts.

Black walnut

One of the most highly prized North American fine hardwoods, black walnut has an important role in Minnesota forestry. In natural stands it occurs primarily as scattered individual trees, rarely in small groups. However, it performs well in plantation silviculture and is planted regularly in southeastern Minnesota. The Nursery Program has a steady demand for 300-400,000 walnut seedlings per year.

In 1986 the Minnesota DNR became a charter member of the North Central Fine Hardwoods Tree Improvement Cooperative (NCFHTIC). This Cooperative is comprised of the state forestry organizations of Minnesota, Wisconsin, Iowa, Illinois, Missouri, Indiana, Ohio, and Michigan. The NCFHTIC has had a tremendous impact on hardwood tree improvement in the North Central Region. In walnut alone, members have selected 970 plus trees, most of which have been propagated by grafting. Considerable progress has also been made in establishing seed orchards and breeding populations. In just three short years Minnesota has selected an additional 80 plus trees, bringing the total to 140. About 130 of these trees have been cloned by grafting, and either have or will be planted in seed orchards and breeding sublines.

Seed Source Control

At the base level of applied tree improvement, seed source control has not been a major problem in black walnut. The species is only native to the southeastern part of the state, and principally within the Lewiston Area. The Nursery Program purchases about 1400 green bushels of walnuts each year, roughly divided between Lake City, Caledonia, and Preston. This system will be maintained until such time as seed orchards begin producing regular crops.

Breeding Sublines

Perhaps the most important effect of the NCFHTIC is to promote a cooperative approach to hardwood tree improvement. In this way, the workload of developing a base breeding population is shared. The Cooperative geographic area has been divided into three breeding zones which overlap state boundaries. Minnesota is included in a breeding zone with Wisconsin, northern Iowa, and northern Illinois. Each state in the breeding zone has the responsibility to establish and maintain separate "mini" breeding populations. These small breeding populations are known as sublines.

The Cooperative has set a goal of at least 300 plus trees and 10 sublines for each breeding zone. To date, Minnesota has established four sublines of 25 clones each, for a total of 100 clones. These sublines were planted in 1988-89. Another set of grafts were produced in 1989 and will be used to establish a fifth subline in 1990.

The breeding sublines are arguably the most important facet of the walnut applied tree improvement program. The sublines are the foundation upon which future genetic improvement rests. The Minnesota sublines are comprised of 25 clones with about 5 ramets per clone. Managed like a seed orchard, the goal of the sublines is to produce nut crops as quickly as possible. These nuts will be harvested by clone, and used to establish progeny tests. New selections will be made from the progeny tests to form new breeding sublines for advanced generations of improvement.

By the mid-1990's, the sublines should be producing nut crops sufficient to begin progeny testing. Attempts will be made to include at least two sublines in a single progeny test.

Seed Orchards

FIRST GENERATION

In 1989, the Division established a 5-acre grafted walnut seed orchard in Olmsted County, near Rochester. The orchard contains about 440 trees representing 76 clones. A second orchard will be planted in 1990, containing about 45 clones and 300 trees. Both orchards will be managed intensively including pest control, weed control, mowing, and fertilization.

Solid data on potential orchard production is scarce. Young orchards typically produce erratically. In Indiana, walnut orchards about 10 years old produced an average of 500 nuts per tree[7]. Using these figures as a guide, the Minnesota orchards should produce about 850 bushels in a good seed year, sufficient to grow about 150,000 seedlings.

Seed orchard roguing must necessarily be delayed until progeny test data becomes available. Assuming progeny tests can be established in the mid-to-late 1990's, the seed orchards could be rogued by midway through the first decade of the new century. Because of the necessity of progeny testing, the first generation orchards will stay in production about 25 years.

SECOND GENERATION

Selections for a second generation seed orchard will be available from the cooperators in each breeding zone. Thus, a Minnesota second generation orchard would likely contain clones originating in Minnesota, Wisconsin, Iowa,

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[7]Mark Coggeshall, Tree Improvement Specialist, Indiana Department of Natural Resources. Personal Communication.

and Illinois. This type of approach has several distinct benefits. First, no one state has to produce all of the clones for a given orchard. Second, the seed resulting from such an orchard would be broadly adapted. Third, the production gene pool would include new genetic combinations that never could have existed in nature, thus building up genetic diversity.

Establishment of the second generation seed orchard would occur sometime during the first decade of the 21st century. Seed production would begin about 2012.

Progeny Testing

As soon as the sublines begin producing good seed crops, progeny testing will start. This should occur in the mid-to-late 1990's. Since walnut seed does not store well, it will be necessary to collect enough nuts from each clone in a subline all in the same year. A tentative objective is to try to install at least two sublines together in the same progeny test. This would be a total of 50 families planted on a minimum of two sites.

The experimental design to be employed will be some form of the California Design (Libby and Cockerham, 1980). This design uses random non-contiguous plots in interlocked replications. It is an efficient design requiring fewer numbers of trees per family. This could be a very important feature, allowing the establishment of progeny tests at the earliest possible time.

Cooperative Research

The DNR-Forestry will continue to support and participate in cooperative research in black walnut.

Red oak

In recent years, the red oak resource has become increasingly important in Minnesota. Once under-utilized, today the harvest of red oak exceeds annual growth in some areas. Accordingly, red oak has become a more important species in the Nursery Program. The 1985 Nursery Seeding Plan called for the production of 230,000 seedlings. By 1988, sowing levels had risen to a production level of 1.5 million seedlings. It is worth noting that the availability of acorns is very periodic. In 1987 for example, acorns were sown at a rate to produce only 280,000 seedlings. About all that can be said is that demand for seedlings will remain strong, but the supply will be intermittent.

Of the Minnesota fine hardwoods, red oak is clearly the most important species in terms of stumpage and value added products. For example, in 1982 the FOB mill price for 100" sawbolts was $ 52 per cord. By 1988 the price had risen to $ 86 per cord[8]. The combination of high value and abundant genetic variation make red oak an attractive choice for intensive tree improvement.

Within the North Central Fine Hardwoods Tree Improvement Cooperative, the State of Wisconsin is actively working on red oak applied tree improvement. To date, Wisconsin has selected and grafted over 60 red oak plus trees. The framework of the Cooperative would allow the sharing of this material in the Minnesota program. The following plan will reflect the potential use of this material in Minnesota.

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[8]Minnesota Forest Products Price Report 1988. Minnesota Department of Natural Resources, Division of Forestry.

Seed Source Control

As always, applied tree improvement begins with seed source control. For red oak, the establishment of seed production areas is very appropriate. A major problem with the oaks is periodic seed shortage. The development of a series of seed production areas could alleviate this problem.

The demand for red oak seedlings comes from two areas; Region III and Region V. These Regions should immediately begin the development of several seed production areas for red oak. Candidate stands should be of high quality with good red oak stocking. Stands selected for seed production should then be thinned of all poor quality oak and all non-oak species. The goal is to create an open, park-like stand. This will have two direct benefits. First, opening up the stand will encourage heavier, and perhaps more frequent acorn crops. Second, a clean understory will aid the efficient harvest of acorns. The establishment of three seed production areas per Region would greatly improve the availability of local, adapted seed sources.

Plus Tree Selection

Given the current rate of red oak timber harvesting, it is of paramount importance that field foresters begin marking and saving red oak plus trees. In brief, the most important traits are those that affect wood quality, such as straightness and apical dominance. Red oak plus trees generally will have one or less crooks, and at least 45 % of total tree height in merchantable bole (up to the first fork). Plus trees should also be vigorous and fast growing.

The preliminary target for plus tree selection is 50 trees each in Region III and Region V. These trees should be selected by January, 1992.

Grafting

The first red oak plus trees will be grafted in 1991 following procedures established by the Indiana DNR. Quality rootstock will be selected from nursery beds in the fall of 1990 and placed in cold storage. In March of 1991 the rootstock will be potted and placed in the greenhouse. Scions will be collected and grafted as soon as the rootstock is ready. Surviving grafts will be overwintered and planted out the following spring. This sequence will be repeated in 1992.

Sublines

The goal of the initial phase of the program is to establish two, 25 clone sublines in each Region. To meet this goal, sites must be selected and prepared the summer and fall prior to planting. Site selection criteria include good access, loam soil, level topography, and isolation from wild sources of red oak. Because of the necessity of frequent intensive management practices (weed control, mowing, fertilization, irrigation), it is also desirable to locate subline sites near a work center.

The planned implementation schedule for subline establishment is to plant one site in each Region in 1992, and again in 1993. Thus, at least one site in each Region must be selected and prepared by the fall of 1991.
The sublines will be managed intensively in order to encourage early and abundant acorn production. These acorns will then be used to establish progeny tests.

Seed Orchards

Red oak is a species that grafts fairly easily. Success rates of 80-90 % have been achieved by members of the NCFHTIC. Thus, there should be enough extra grafts to establish a seed orchard in each Region. At this time it is impossible to predict how large the orchards might be. However, a reasonable target is five acres. A five acre orchard planted at 20 x 20 feet would require about 540 grafts.

Prediction of future orchard seed production can be a hazardous practice, especially in a species relatively new to the tree improvement scene. However, it seems reasonable to estimate production of about 20 bushels from a five acre orchard. This seed would produce about 54,000 seedlings. At this time it seems reasonable to limit orchard area to five acres each. The clones in the first generation orchards will be untested. More genetic gain will be achieved by using tested clones in second generation orchards.

Progeny Testing

As soon as the sublines produce sufficient seed, progeny tests will be established. This should occur by about the turn of the century. The experimental design will employ random non-contiguous plots with interlocking replications. Each subline will be tested on at least two separate sites.

Cooperative Research

The DNR-Forestry will continue to support and participate in red oak cooperative research.

Aspen

The rapid rise of aspen on the Minnesota forestry scene over the past 20 years has been well documented. In 1978 a total of 900,000 cords of aspen were harvested. Ten years later the statewide harvest had grown to 1.87 million cords. By 1995, total aspen harvest is expected to be about 2.8 million cords[9]. Four major plant expansions or developments are committed, based solely on the aspen resource.

Aspen is an ideal species for extensive forest management. It is fast growing and is readily reproduced following timber harvest. Typical yields of about 30 cords per acre at age 50 are possible on good sites. However, a potential problem looms on the horizon. The aspen age class distribution contains a discontinuity in the 20-40 year age classes. This will amount to a shortage of aspen in about 10-15 years given the current level of utilization.
The importance of the aspen resource has led the Division to begin investigating the potential for artificial regeneration. In 1988, the DNR-Forestry became a member of the IPC Hybrid Aspen Cooperative. In 1989, the Division played a key role in relocating this Cooperative to Minnesota. The Aspen Cooperative brings over 30 years of research and development to Minnesota, setting the stage for a major thrust in applied aspen tree improvement.
There is considerable potential for aspen tree improvement. The Aspen Cooperative has developed specific crosses that grow extremely fast with

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[9] John Krantz, Department of Natural Resources, Division of Forestry, Utilization and Marketing Program Supervisor. Personal Communication.

superior wood quality. Yield estimates of 30-40 cords per acre at age 20 have been made. Also, some crosses produce wood with significantly higher specific gravity and longer fibers. The cornerstone of the Aspen Cooperative is the triploid aspen. These crosses usually involve a tetraploid male *Populus tremula* mated to various diploid *P. tremuloides* females. Crosses between a tetraploid (four sets of chromosomes) and a diploid (two sets of chromosomes) yield a triploid (three sets of chromosomes). There are also several superior crosses involving normal diploid *P. tremuloides* parents.

At present the Aspen Cooperative is the only source of improved aspen seed. Production has been fairly stable at about 1-1.5 million seeds per year. This level is not sufficient to meet expected demand. Thus it behooves the Division to begin the development of it's own aspen seed sources.

Seed Supply

Until such time as the Division can develop it's own source of genetically improved aspen, the Aspen Cooperative will remain the principal source of seed. During this development phase improved seed will likely remain in limited supply.

Clone Bank Development

Through over 30 years of research, the Aspen Cooperative has identified a number of genetically superior crosses. The parents of these crosses are currently available in various arboreta in Minnesota and Wisconsin. Without delay, these parent clones should be grafted and established in a clone bank at General Andrews Nursery. Once the parents are established, the program can move toward the commercial production of improved seed.

At present there are about 70 hybrid aspen seedlings potted up at General Andrews Nursery, available for use as rootstock. It may also be possible to obtain rootstock from other cooperators such as Blandin or Potlatch. The rootstock will be moved into the greenhouse in late February, 1990, following the completion of spruce grafting. Scions will be collected from the best parents and grafted when the stock is ready. Surviving grafts will be repotted and placed in the shadehouse for the summer. The grafts will be planted into a clone bank at General Andrews in 1991. Grafting will continue in succeeding years as needed to accumulate stable numbers of ramets from the identified superior clones.

It will be very important to intensively manage the aspen clone bank in order to encourage rapid growth and development. This will reduce the amount of time to flowering. Under this type of program, it may be possible to begin production of improved seed by the late 1990's.

Production of Improved Seed

The classical orchard approach to the production of genetically improved aspen seed is difficult if not impossible to implement. Native unimproved aspen is so prevalent in Minnesota that it would be very hard to locate an orchard convenient to an operations center that would not be contaminated by outside pollen. Consistent, reliable production of truly hybrid seed would be impossible under such conditions. Given this situation, a different approach has been applied to hybrid aspen.

Under an intensive management regime of irrigation, pest control, fertilization, and weed control, aspen clones can be encouraged to flower fairly early. At this point, flower-bearing branches can be pruned and brought into the greenhouse for controlled pollination. This is a tried and true technique used for many years by the Aspen Cooperative. Following pollination, aspen seed develops very rapidly and is often beginning to shed within two weeks. The seed is easily separated from the cottony fluff, and will germinate immediately without stratification. Aspen seed can also be stored for several years in a refrigerator over a dessicant.

The approach outlined above will allow the Division to begin developing it's own supplies of genetically improved aspen seed. The clone bank also serves as an extra source of parent material for the Aspen Cooperative, providing an insurance policy against possible catastrophic loss at another facility.

Progeny Testing

In 1989, the Division established a two acre hybrid aspen progeny test in the Nickerson District. As a member of the Aspen Cooperative, the Division has an obligation to assist in the development of new genetic resources. This test will be managed according to the direction of the Cooperative. It is fully anticipated that the Division will continue to be involved with additional aspen progeny tests in the future.

Cooperative Research

The Division will continue to support and participate in cooperative research projects involving aspen. Particular interest includes genetic improvement of bigtooth aspen, vegetative propagation, seed encapsulation, container and nursery production practices, and silvicultural methods.

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APPENDIX I

THE ECONOMICS OF TREE IMPROVEMENT-SELECTED REFERENCES

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GLOSSARY

Unless otherwise indicated by an asterisk (*), the following terms have been supplied by the "Glossary for Forest Tree Improvement Workers" by E. B. Snyder (1972).

ADAPTATION. The process of evolutionary (genetic) adjustments fitting individuals or groups to their environment. Also the changed structure or function itself.

BREEDING ARBORETUM. A collection of selected trees or species established for breeding. If the collection is preserved vegetatively it is sometimes known as a clone bank. Spacing, culture, and protection are designed to stimulate early and prolific flowering for controlled pollination and seed harvest.

CHARACTER (TRAIT). A distinctive but not necessarily invariable feature exhibited by all individuals of a group and capable of being described or measured; *eg*, color, size, performance. A character of a given individual will have a certain phenotype (state) as determined by the individual's genotype and environment.

CHROMOSOME. A microscopic, usually rod-like body carrying the genes. Number, size, and form of chromosomes are usually constant for each species.

CLONE. A group of genetically identical plants derived asexually from a single individual.

COMBINING ABILITY. A statistical value indicating the capacity of a parent in crosses with other parents to transmit genes for a certain degree of character expression. Good *general combining ability* (GCA) of a parent signifies the high average performance of its progenies in various crosses, as compared to progenies of other parents in the same test. The "breeding value" of a parent is twice its GCA. Good *specific combining ability* (SCA) refers to two parents which, when crossed together, produce progeny better than expected on the basis of the parental GCA values.

CONELET. An immature cone (strobilus) in the conifers. The term is applied to the young cone from the time of female "flower" scale closure after pollination until the initiation of rapid development of the cone a few months before maturity.

CONTROLLED POLLINATION. Transfer or permitted transfer of pollen from a known source to receptive flower parts of known seed parents, all other pollen being excluded (as by covering flowers with isolation bags prior to pollination).

CROSS. Same as *hybrid*. Also an abbreviation of *cross-pollinate*.

DIPLOID. A cell is diploid when it contains two sets of chromosomes ($2n$), one set from each parent. Most higher organisms are diploid except for their sex cells and associated tissue.

ELITE. A tree or stand verified by appropriate testing as highly superior or desirable for a specified environment and propagation system. The superiority of crossbred parents is determined by progeny tests, and that of clones by clonal tests.

EVOLUTION. The stepwise development (or extinction) of biological groups, as a result of the natural selection and increase of hereditary variants in the population. Assortments of initially ill-adapted variants survive or are replenished in small numbers each generation. Then through successive generations change in the environment or a new environment to which the organisms have migrated favors the survival and reproduction of the aberrant individuals with a consequent increase of their genes in the population. The causative processes include mutation, recombination, drift, migration, isolation, and natural selection.

EXOTIC. A plant introduced from another country. Since political boundaries are often without biological significance, this term has limited value.

FAMILY. A group of individuals directly related by descent from a common ancestor.

FAMILY SELECTION. The selection of progeny families on their mean performance. In addition, the best individuals are usually selected in the best families.

FERTILIZATION. Union of the nucleus and other cellular constituents of the male gamete (sperm) with those of a female gamete (egg) to form a zygote. In some species, fertilization may occur months after pollination.

FOREST TREE BREEDING. Applying knowledge of genetics to develop improved trees. In a narrow sense, the term refers to propagation by artificial pollination. Usually, however, it connotes breeding systems varying from harvesting seed from only the best sources (mass selection) to sophisticated multi-phase, multi-generation programs of controlled pollination.

FOREST TREE IMPROVEMENT. Usually synonymous with forest tree breeding, but may refer to tree breeding in combination with cultural practices.

GENE. The smallest transmissible unit of genetic material consistently associated with a single primary genetic effect. The genes are ultra-microscopic and act as if linearly arranged at fixed places (loci) on a chromosome. Each gene, by interacting with other genes and the environment, governs a certain physiological effect in the cell and is expressed as one or more characters.

GENETIC GAIN. Average impreovement in a progeny over the mean of the parents. Gain is achieved by selection in the parental generation; the amount depends on selection intensity, parental variation, and heritability.

GENETICS. Genetics is the basic science dealing with causes of resemblances and differences among organisms related by descent. It takes into account the effects of genes and the environment. When the basic knowledge of genetics is applied to breeding trees, the effort is preferably referred to as forest tree breeding or forest tree improvement.

GENOTYPE. (1) An individual's hereditary constitution, with or without phenotypic expression of the one or more characters it underlies. Also the gene classification of this constitution expressed in a formula. The genotype is determined chiefly from performance of progeny and other relatives. It interacts with the environment to produce the phenotype. (2) Individual(s) characterized by certain genic constitution.

GENOTYPE-ENVIRONMENT INTERACTION. The failure of entries to maintain the same relative ranks and level of differences when tested in different environments. The tests are planted at more than one location or under more than one cultural condition.

GEOGRAPHIC VARIATION. The phenotypic differences among native trees growing in different portions of a species' range. If the differences are largely genetic rather than environmental, the variation is usually specified as racial, ecotypic, or clinal.

GRAFTING. Uniting parts of separate individuals by matching their tissue so that union and growth can occur. Commonly, an aerial portion (scion) is joined with a rootstock. Both the site of the union and the composite individual are termed grafts. Because the scion retains its original genetic constitution, grafting is valuable for preserving, testing, and propagating.

HAPLOID. having one complete set of chromosomes per cell. These are the n chromosomes normal in sex cells as compared to the $2n$ in vegetative cells.

HERITABILITY. Degree to which a character is influenced by heredity as compared to environment. *Narrow-sense heritability* is the fraction of total variation that is contributed by additive effects of genes; *ie,* it is the ratio of additive genotypic variance to phenotypic variance. *Broad-sense heritability*, applicable to vegetatively propagated species, includes also non-additive effects. High heritability indicates that individual phenotypes are indicative of their genotypes. If calculated from parent-progeny data it estimates the degree of resemblance between parent and progeny.

HETEROSIS. Hybrid vigor exhibited when the mean F_1 hybrid phenotype falls outside the range of the parents. Statistically: An increase over the mean of the parents. Usually applied to traits such as size or general thriftiness.

HYBRID. (1) The offspring of genetically different parents. The term is applied as well to the progeny from matings within species (intraspecific) as to those between species (interspecific). Hybrids combine the characteristics of the parents or exhibit new ones. (2) An individual possessing unlike alleles.

INBREEDING. Production of relatively homozygous offspring by mating related organisms, usually by selfing. This procedure, especially if carried out for a number of generations, exposes undesirable recessive characters and is used with selection to fix desirable ones, *ie,* to render them true-breeding. Inbreeding of normally crossbred organisms frequently results in an "inbreeding depression" of vigor or fertility, but the vigor can usually be restored and may even be increased by crossbreeding again, *eg,* the heterosis of hybrid corn.

INDIVIDUAL SELECTION. From a family or population single plants are selected on their own merit as parents or ortets. Sometimes called phenotypic selection.

LOCAL SEED SOURCE. Source native to the locality in which the seedlings are to be grown, *ie,* belonging to the indigenous geographic race. Its seed-collection zone is usually defined experimentally as being within a certain distance or elevation of the planting site.

MASS SELECTION. Use of seed from individuals chosen for a certain common phenotype from a larger population, and then composited. The larger population provides the male parentage, and selections are not intermated prior to seed use. Thus, seed may be collected from selected trees of a wild stand and used in a commercial planting of for establishing a seedling seed orchard. The process may be repeated through successive generations. Note, however, that collecting seed from a rogued orchard is recurrent selection.

MATING DESIGN (SYSTEM). The pattern of pollinations set up between individuals. It is described, *eg,* as random, systematic, diallel, or according to parental similarities.

OPEN POLLINATION. Natural pollination effected by wind or insects, and not directly influenced by man. As a progeny-test method, it may provide information on general combining ability of the seed parents.

ORTET. The original plant from which a clone has been derived.

PEDIGREE. Record of ancestry.

PHENOLOGY. The study of relations between plant development and seasonal climatic changes, such as in temperature or day length, especially as such changes affect periodic phenomena like leafing, flowering, and dormancy.

PHENOTYPE. The plant or character as we see it; state, description, or degree of expression of a character; the product of the interaction of the genes of an organism (genotype) with the environment. When the total character expressions of an individual are considered, the phenotype describes the individual. Similar phenotypes do not necessarily breed alike.

PLUS. Appearing distinctly superior to the average. The term is used for describing phenotypes of both stands and single trees. The superior character(s) shaould be specified, *ie,* plus for volume, quality, pest-resistance, or combination of characters.

POLLINATION. Deposition of pollen on the receptive part of the female flower. In angiosperms this is the stigmatic surface, in gymnosperms the ovule tip.

POLYPLOID. Having more than twice the basic number *x* of chromosomes of the ancestral species in its vegetative cells. A cell, tissue, or organism having three sets (3x) is called a triploid, and four sets (4x) tetraploid.

POPULATION. Genetically, a group of similar individuals related by descent and so delimited in range by environmental or endogenous factors as to be considered a unit. In cross-bred organisms the population is often defined as the interbreeding group.

PROGENY TEST. Evaluation of parents by comparing the performance of their offspring. Accuracy is usually gained because several to many offspring per parent are evaluated under more controlled conditions than exist for the parent.

PROVENANCE. The original geographic source of seed, pollen, or propagules.

QUANTITATIVE INHERITANCE. Inheritance of characters, such as size, which vary continuously (quantitavely) and which cannot be reasonably categorized. From three to hundreds of genes may control such characters. These genes (multiple factors or polygenes) act cumulatively and cannot be detected by their individual effect. Quantitative characters are usually subject to considerable modification by the environment and hence require refined statistical techniques in their study.

RAMET. An individual member of a clone.

RECURRENT SELECTION. Selecting individuals or families and intermating them or allowing them to interpollinate to produce the next generation, *eg,* a seed production area or a clonal seed orchard. The new generations are generally used as foundation populations in which to start repeated cycles of selection and breeding.

ROGUING. Systematic removal of individuals not desired for the perpetuation of a population; culling.

ROOTSTOCK. The root-bearing plant or plant part, usually stem or root, onto which another plant is grafted.

SCION. An aerial plant part, often a branchlet, that is grafted onto the root-bearing part (rootstock) of another plant.

SEED COLLECTION ZONE. Zone of trees with relatively uniform genetic (racial) composition as determined by progeny-testing various seed sources. The encompassed area usually has definite geographic bounds, climate, and growing conditions. A single geographic race may be divided into several zones.

SEED ORCHARD. A plantation consisting of clones or seedlings from selected trees, isolated to reduce pollination from outside sources, rogued of undesirables, and cultured for early and abundant production of seed.

SEED PRODUCTION AREA. A plus stand that is generally udgraded and opened by removal of undesirable trees and then cultured for early and abundant seed production.

SEED SOURCE. The locality where a seed lot was collected; also the seed itself. If the stand from which collections were made was in turn from nonnative ancestors, the original seed source should also be recorded and designated as the *provenance*.

SELECTION. Often synonymous with artificial selection, which is the choice by the breeder of individuals for propagation from a larger population. Artificial selection may be for one or more desired characteristics. It may be based on the tree itself (phenotypic), or on the tree's progeny or other relatives (genotypic). Refers also to the tree selected.

SELECTION INDEX. A value quantifying the overall desirability of selected parents by simultaneously considering their characters. The weight toward total score assigned to a character of a selected individual depends on the character's phenotypic magnitude, heritability, correlations with other characters, and economic value.

SELF-POLLINATION. "Selfing" is the pollination of a flower with pollen from the same tree or clone, the offspring being termed "selfs".

SIBS (SIBLINGS). Offspring which have one or both parents in common. Full sibs have both parents in common; half-sibs, only one.

SUBLINE*. A small breeding group, usually comprised of 30 or less clones, separated out from the main population. These breeding groups are usually maintained as distinct plantations, isolated from other sublines and from wild sources of pollen.

VEGETATIVE PROPAGATION. Propagation of a plant by asexual means, as in budding, dividing, grafting, rooting, and air layering. Hereditary characteristics of the resulting clone (ramets) are identical with those of the original plant (ortet).