RED PINE--POTENTIAL FOR GENETIC IMPROVEMENT AND OBSERVATIONS ON CONE AND SEED PRODUCTION

by Ronald P. Overton and LeRoy C. Johnson
Geneticist and Area Geneticist, USDA Forest Service,
Northeastern Area State and Private Forestry
1992 Folwell Avenue, St. Paul, MN 55432

ABSTRACT Recent information has shown that two commonly held beliefs, namely, red pine lacks sufficient genetic variation to permit worthwhile genetic improvement, and red pine is an erratic seed producer, are not true. Studies in Michigan and Wisconsin have shown that first generation genetic gains of 5 to 10 percent in volume are possible for red pine. This species must be established and maintained in an open grown state to produce heavy and consistent cone crops, making it unsuitable for conventional progeny test/ seedling seed orchards. A modified mother tree selection system using deferred seed orchards is suggested as a method for first generation genetic improvement of red pine.

Red pine (*Pinus resinosa*) is one of the Northeast's most valuable and most productive conifers. The average annual per acre wood volume production potential of red pine in the Lake States (Minnesota, Michigan, and Wisconsin) is higher than potential production of loblolly and slash pine on average sites in the South (Lundgren 1982).

Red pine seedlings account for about one-third (25 to 27 million) of the annual conifer seedling production of State nurseries in the 20-state northeastern area. About 90 percent of these seedlings are produced in the three Lake States. Red pine planting programs have declined in New England, partly as a result of the potential risk for loss due to Scleroderris canker there (Skilling 1981).

Despite red pine's importance in reforestation programs, genetic improvement of red pine has proceeded slowly. By 1981, only 65 acres of red pine seed orchards had been established in the Northeast (USDA Forest Service 1981). Two reasons most frequently cited to explain the small amount of tree improvement effort given to red pine are:

1. Red pine has too little genetic variation to economically justify an improvement program and

2. Red pine does not frequently produce good seed crops; thus, seed orchards are not economically feasible.

Recent reports on potential genetic gain in red pine and our observations, as well as others, on the cone and seed production potential of red pine indicate both these reasons should be re-evaluated.

In this report, we review the information now available on the genetics of red pine. We also report our observations and review other studies on red pine cone production. Finally, we suggest strategies for first generation genetic improvement of red pine which include what we term deferred seed orchards.

GENETIC STUDIES

Genetic studies of red pine began with the establishment of several provenance and seed source studies in the 1930's (Rudolph 1947; Nienstaedt 1964; Buckman and Buchman 1962; Hough 1952). Results from these and similar tests established in the 1950's and 1960's (Wright et al. 1972, Lester and Barr 1965, Park and Fowler 1981) showed that red pine was less genetically variable than other pine species. For instance, although most tests found statistically significant differences between provenances, means for heights of the best provenances seldom exceeded the overall test mean by more than 10 percent up to age 20 (Fowler and Lester 1970). Most provenances contained both fast and slow growing families, and provenances which grew well in one location performed well in a number of other locations. Provenance performance was not strongly associated with clinal patterns of variation, although sources from the central part of the species' range in the Lake States and Ontario usually grew somewhat faster than trees from more northern latitudes (Park and Fowler 1981, Wright et al. 1963).

These studies produced few reliable estimates of genetic parameters for red pine. Field designs were not adequate to precisely estimate the smaller values occurring in the species, and nursery and seed size effects also confounded the results (Fowler and Lester 1970). However, the results did lead to controversy over whether or not red pine contains enough genetic diversity to economically justify a genetic improvement program. Opinions ranged from the possibility of negligible (Fowler 1964) to slight (Rudolph 1964) to worthwhile (Nienstaedt 1964, Lester 1964) levels of genetic improvement. A detailed review of the results of these earlier tests and other types of red pine genetic studies are presented in Fowler and Lester (1970).

Two recent studies involving intensive sampling of red pine within single states are significant in that they show red pine possesses enough genetic variation to permit improvement in growth traits with conventional recurrent selection techniques. These studies were initiated in Wisconsin (Lester 1976) and Michigan (Yao et al. 1971) in 1967 and 1961, respectively. Both contained large numbers (272 to 310) of open pollinated families, both had good experimental designs in the nursery and the field, and both were planted at several locations.

Analysis of age 10 (from outplanting) height data from the Wisconsin study (Ager et al. 1982) revealed:

1. Thinning to the best 10 percent of the 310 families in the test would yield genetic gains of 3 to 4 percent for height and 5 to 11 percent for volume in the progeny from the resulting seedling seed orchard.

2. Between family differences accounted for 88 percent of the total genetic variance in the study.

3. No significant genetic differences were found between regions within Wisconsin.

4. Family heritabilities for age 10 height ranged from 0.4 to 0.5.

5. Genotype X location interactions were significant but relatively small, and a number of families performed well at all locations.

Analysis of age 7 (from outplanting) heights in the Michigan study (Yao et al. 1971) revealed:

1. Thinning to approximately the best 10 percent of the 272 families would yield genetic gains of 2.5 to 3.5 percent in height and about 5 to 7 percent in volume.

2. Family heritabilities for age 7 height ranged from 0.1 to 0.2.

3. Lower Peninsula seed sources outgrew Upper Peninsula seed sources by 3 percent in Upper Peninsula plantations and by 10 percent in Lower Peninsula plantations.

Genetic gains of the levels predicted in these studies are economically worthwhile. A break-even benefit-cost analysis based on information from the Wisconsin study showed that at the 6 percent rate of return a genetic gain of only 1.3 percent was needed to break even for a seedling seed orchard producing 150,000 plantable seedlings per acre per year (St. Clair 1984).

CONE AND SEED PRODUCTION

Good red pine cone crops in natural stands occur in a given area every 3 to 7 years, with bumper crops every 10 to 12 years (Rudolph 1965). If crops occurred at this frequency in seed orchards, large acreages would be required to produce enough seed for reforestation programs. However, our observations and those of others show that open grown red pine produces heavy cone crops on a much more regular basis.

We observed open grown trees, trees in single rows, and trees in multiple rows in residential areas, along roads, and in parks. These trees were located around the Twin Cities (Minneapolis and St. Paul, Minnesota, 45° N Latitude), between the Twin Cities and Madison, Wisconsin, and in the Upper Peninsula of Michigan. Most of these trees were between 15 and 30 years old and 18 to 30 feet tall.

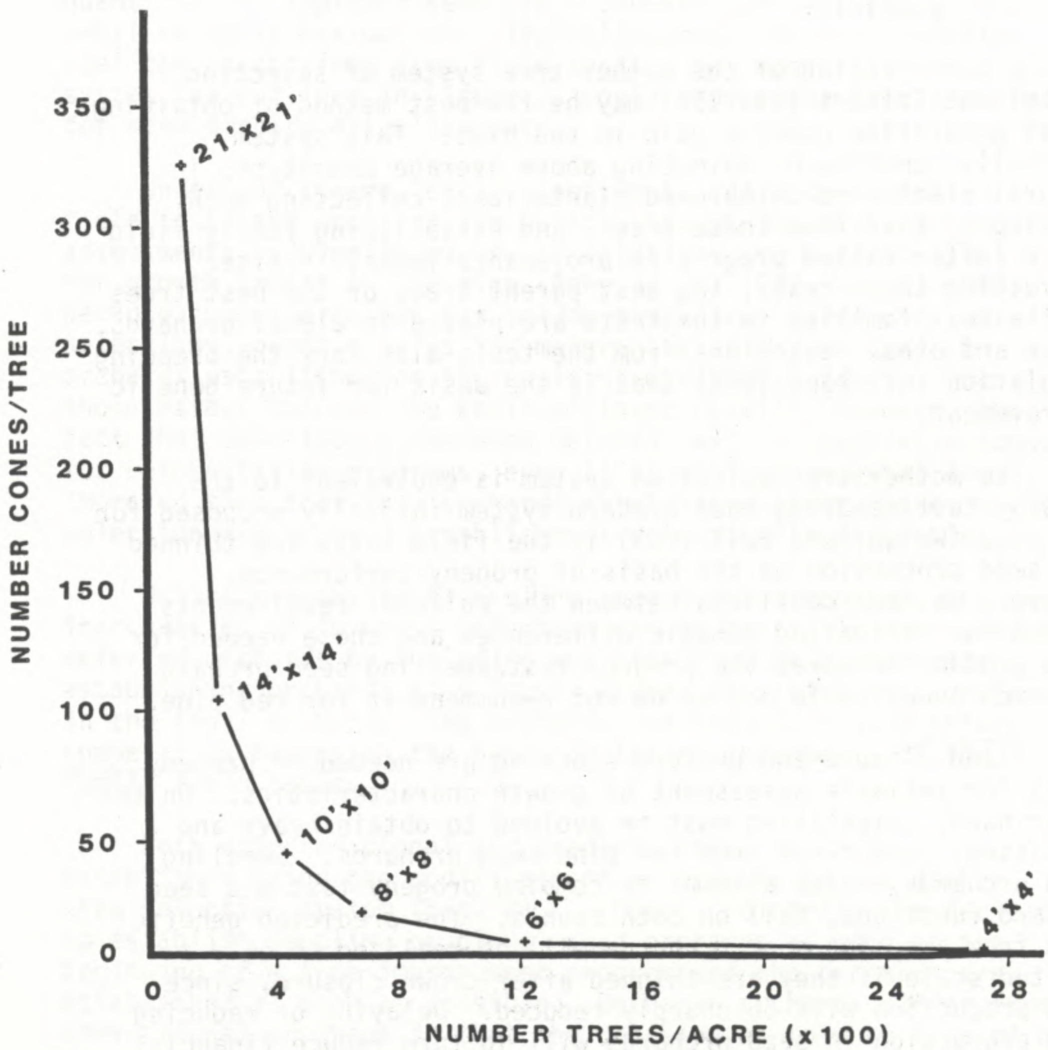
With few exceptions, the open grown (at least 25 feet between trees) red pines produced heavy consistent cone crops. For example, a stand of 15-year old trees near Eau Claire, Wisconsin averaged 540 second year cones per tree in May, 1984. Trees in this plantation were spaced 25 to 30 feet apart. We found evidence of annual cone crops for the previous 5 to 7 years on most trees in the stand and first year cones were as abundant as the second year cones. Trees 23-years old growing at 25 to 30 foot spacing in a golf course in St. Paul have produced cone crops for the past 10 years.

We found that trees growing 8 to 10 feet apart in single rows with competition on only two sides always produced fewer cones than nearby open grown trees. Red pine growing in multiple rows (8 to 10 feet square spacing) produced light crops at infrequent intervals if growing along the edge of the plantation. Interior trees produced almost no cones. Similar patterns of cone production have been reported in other closed stands of red pine (Wright 1964).

Our observation that open grown red pine produces heavy cone crops agrees with a more rigorous study by Stiell (1971). He measured cone production on 18-year old trees grown at 6 spacings near Petawawa, Ontario (fig. 1). Trees grown at the widest spacing, 21' x 21', produced an average of 325 cones per tree (32,300 cones per acre). Trees grown at 14' x 14' spacing produced only 104 cones per tree (23,100 cone per acre) even though crown closure had not occurred at either spacing. This was due to the fact that, even though stand closure had not occurred, crowns were smaller at the 14' x 14' spacing than at the 21' x 21' spacing. Trees grown at 8' x 8' spacing (closed stands) produced only 15 cones per tree (10,300 cones per acre).

We believe red pine must be established and maintained in an open grown state for maximum cone production. Losses in cone production due to competition (which begin even before crowns touch one another) may take many years to regain after the stand is thinned. Cone production can be increased in closed stands by heavy thinning and fertilization (Godman 1962; Cooley 1970), but yields following these treatments are still far below those from open grown trees.

Figure 1. The relationship between cones per tree and stand density in 18-year-old red pines growing at 6 different spacings (source: Stiell 1971).



FIRST GENERATION IMPROVEMENT STRATEGIES

First generation tree improvement strategies for red pine should have two objectives:

1. To begin a selection program that provides significant amounts of genetic gain as quickly and inexpensively as possible but which also results in a breeding population with enough genetic variation to ensure future gains.

2. To establish seed orchards which produce genetically improved seed for reforestation programs as quickly as possible.

A modification of the mother tree system of selection (Zobel and Talbert 1984:156) may be the best method of obtaining first generation genetic gain in red pine. This system typically consists of selecting above average phenotypes in natural stands and unimproved plantations, collecting open pollinated seed from these trees, and establishing family field tests (often called progeny or provenance tests). After evaluating these tests, the best parent trees or the best trees of the best families in the tests are placed in clonal orchards. These and other selections from the tests also form the breeding population (cf. Kang 1982) that is the basis for future genetic improvement.

The mother tree selection system is equivalent to the progeny test/seedling seed orchard system initially proposed for red pine (Wright and Bull 1963) if the field tests are thinned for seed production on the basis of progeny performance. However, we feel conflicts between the cultural requirements needed for evaluating genetic differences and those needed for seed production makes the progeny test/seedling seed orchard approach undesirable and we do not recommend it for red pine.

Stand closure and uniform stocking are needed in progeny tests for reliable assessment of growth characteristics. On the other hand, competition must be avoided to obtain heavy and consistent cone crops from red pine seed orchards. Seedling seed orchards, which attempt to combine progeny test and seed orchard functions, fail on both counts. The predicted genetic gain from seedling seed orchards will be realized on only a limited scale if they are thinned after crown closure, since seed production will be sharply reduced. Delaying or reducing seed production in seed orchards will in turn reduce financial returns on the entire tree improvement program. Converting progeny tests to seed orchards before stand closure (i.e., at young ages) will increase seed production but reduce genetic gain, since selection must be made solely on the basis of early performance. Furthermore, conversion to seed orchards eliminates the possibility of obtaining later, and possibly more reliable, genetic information from the tests.

Individual (mass) selection in natural stands also offers some opportunities for genetic gain in red pine (Ager, et al. 1982). However, mass selection in red pine will be less effective than similar efforts in more genetically variable species (e.g., southern pines). The practice followed in first generation improvement programs of southern pines (i.e., establishing grafted orchards solely on the basis of phenotypic selection in wild stands and roguing the orchards on the basis of subsequent progeny tests) would result in low genetic gains if used for red pine.

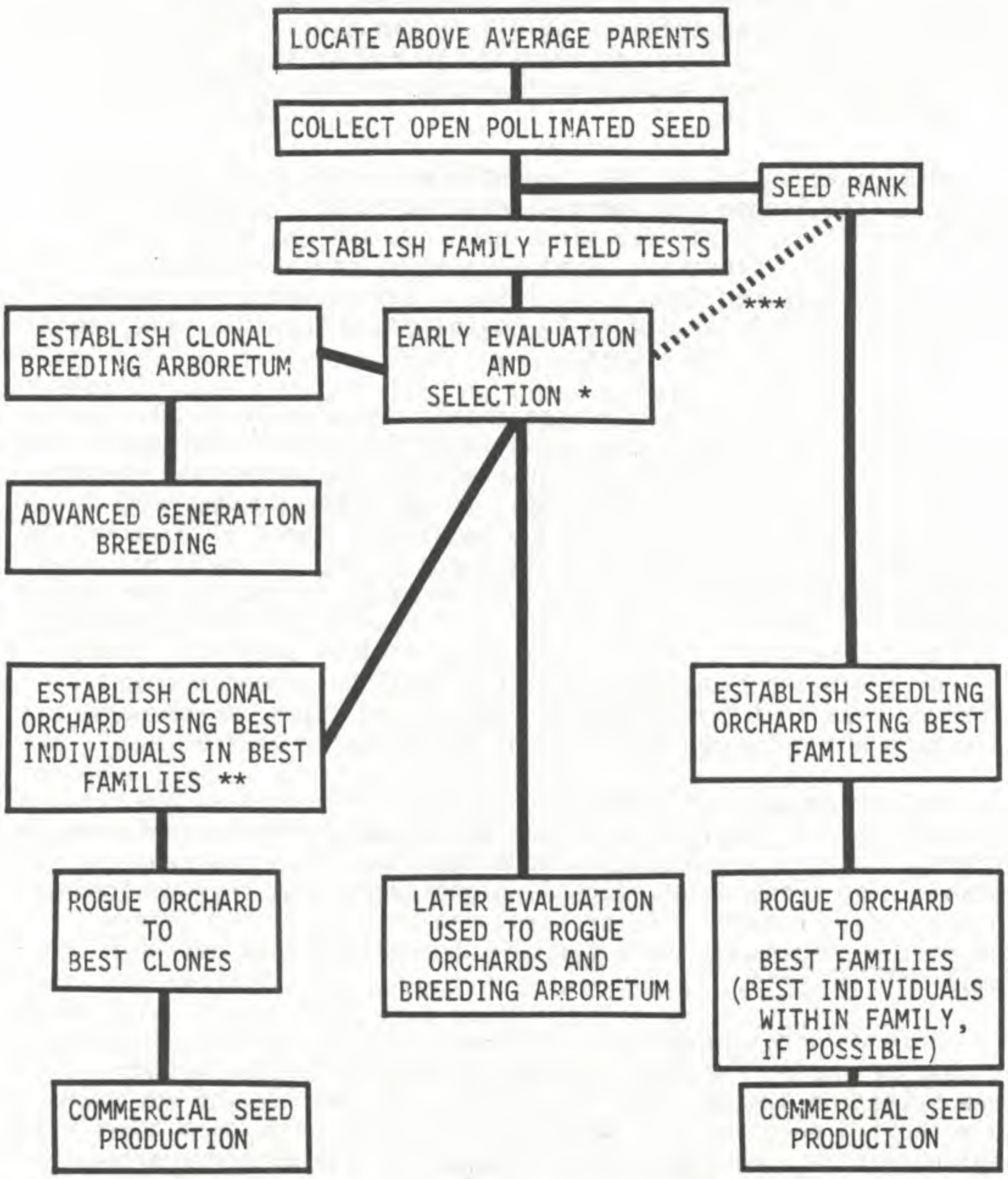
One disadvantage of the conventional mother tree selection system is the longer time period required to obtain commercial quantities of improved seed since orchards are not established until reliable evaluations (typically about one-half rotation age) can be obtained from field tests. Our modification of this system, as outlined in Figure 2, could reduce the time required for seed orchard establishment.

Under our scheme, early assessments are made in family field tests and orchards are established on the basis of these assessments. Juvenile-mature correlations are moderately strong for growth traits in red pine (Ager et al. 1982; Wright 1980). Because juvenile selections seldom completely agree with later selections, genetic gains for mature traits may be lower in orchards established on the basis of early test results than in those established on the basis of later results. However, the fact that genetically improved material will be available sooner for reforestation programs, even if it will be somewhat less improved than that from orchards established later, makes early selection and orchard establishment economically desirable.

Unlike progeny test/seedling seed orchard schemes, the inaccuracies of juvenile selection can be partially corrected in deferred orchards by including more families or clones and establishing orchards at slightly higher densities than desired in the final orchard. The orchards can then be rogued <u>before competition begins</u> on the basis of later assessments of the family field tests.

Both deferred clonal and seedling orchards can be established using the modifications we propose to the mother tree selection system (fig. 2). (Note: Ordinarily the decision to establish seedling or clonal seed orchards is made at the beginning of a tree improvement program and the orchards are established as soon as possible. Deferred orchards differ from conventional programs in that the decision as to what type of an orchard to establish can be delayed until the family field tests give some reliable data on family performance. A key advantage of the deferred seed orchard and mother tree system is that everything that goes into the orchard is tested to some degree by the family field tests.)

Figure 2. Diagram of a modified mother tree selection system for red pine using either a deferred clonal or a deferred seedling first generation orchard with provisions for advanced generation breeding.



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* Some families could be eliminated based on nursery performance.

** Rootstock of the same families could be grown from the reserved seed in the bank. This may help reduce graft incompatability.

*** Data from the family field tests are used to select outstanding families to include in the seedling seed orchard.

Clonal orchards of ramets from the best mother trees or the best individuals in the best families in the field tests would yield greater genetic gains than seedling orchards, since higher selection intensities can be achieved. However, a 12-year old red pine grafted seed orchard at the USDA Forest Service Oconto River seed orchard complex in northeastern Wisconsin has thus far produced only small cone crops. This is partly due to the frequent late frosts at this site. These trees also have short first order branches and few second and third order branches; hence, the ramets have fewer sites for cone production than do trees of seedling origin. The ortets of these clones were 40 years old, and this branching pattern may be partly due to ortet age effects. Ramets in a deferred clonal orchard could originate from ortets as young as 7 to 15 years of age and may have better branching characteristics.

We have not observed red pine grafts at other locations so we cannot determine if the performance of the clones at Oconto River is typical for the species. Flowering on these trees may be adequate for the needs of a breeding arboretum, but heavier cone crops are needed in production orchards. This problem needs further investigation before recommendations can be made regarding the use of clonal orchards for red pine.

To establish deferred seedling orchards, a portion of the seed from each mother tree is retained in a seed bank. Following an early assessment of the field test, seed from the best families are taken from the seed bank and used to establish seedling seed orchards. As in the case of clonal orchards, gain can be increased by relaxing selection intensity when establishing the orchard and planting at somewhat higher density. Thinning to final density and selection intensities could then be done on the basis of later evaluations of the family field tests. Genetic gain from deferred seedling orchards is based mainly on family selection. If the orchards were located on sites similar to those where the improved seedlings were to be used, additional gain could be obtained from within family selection when thinning the orchard.

SUMMARY AND CONCLUSIONS

Recent studies have shown that two commonly held beliefs, namely, red pine lacks sufficient genetic variation to permit worthwhile genetic improvement, and red pine is a poor seed producer, are not true. Furthermore, at current planting levels the potential first generation gains from tree improvement in the Lake States, in terms of actual increases in wood volume, are probably greater for red pine than for any other species. Larger per acre volume increases are possible in other species. but these are offset by the greater number of acres planted to red pine.

Red pine must be open grown to produce consistent and abundant cone crops. Conventional progeny test/seedling seed orchards are not suitable for red pine since thinning to promote seed production must take place before reliable assessment of progeny performance is possible. Deferred grafted or seedling orchards of material identified as superior in family field tests are recommended as an effective ways to produce commercial quantities of improved red pine seed. However, preliminary observations indicate red pine grafts (at least from 40 year old ortets) may produce fewer cones than seedlings of the same age.

The mother tree selection system appears to be the best method of identifying superior genetic material in the first generation. Phenotypic (mass) selection in natural stands or plantations may be of some value in red pine, but will not be as useful as it has been in other pine species.

Interest in genetically improving red pine has recently increased in the Lake States. The Michigan Tree Improvement Cooperative (MICHCOTIP) is establishing a clonal orchard and breeding arboretum using selections from earlier progeny tests, and has also begun testing new material (MICHCOTIP 1984). The Wisconsin Department of Natural Resources is converting the three plantations analyzed by Ager et al. (1982) into seedling seed orchards. These trees are now beginning to produce seed but the research value of the plantations is lost. Open pollinated progeny/provenance tests of red pine have also been established by the Minnesota Tree Improvement Cooperative using material from Minnesota, Wisconsin, and Michigan.

All these programs require additional selected material to ensure adequate genetic variation for continued genetic gain. The lack of strong clinal differences within red pine may allow exchange of genetic material among programs in the Lake States. Coordination of these programs will be necessary to maintain genetically diverse breeding populations and parental identity.

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