Miscellaneous Research Report No. 9
(Forestry)

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FOREST TREE IMPROVEMENT
IN WISCONSIN

By
Robert G. Hitt

WISCONSIN CONSERVATION DEPARTMENT
Research and Planning Division

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Wisconsin Conservation Department
Madison 1, Wisconsin

1964

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FOREWORD

In 1948 the Wisconsin Conservation Department requested the Agricultural Experiment Station of the University of Wisconsin to institute a program of forest tree improvement with emphasis on red pine, the principal species in the Wisconsin reforestation program.

The author of this paper, Mr. Robert Hitt, was engaged by the Agricultural Experiment Station to develop the program. In 1963 Mr. Hitt accepted a position with the Eastern Tree Seed Laboratory, U. S. Forest Service, Macon, Georgia. Dr. Donald T. Lester, formerly of Yale University, has been engaged by the University of Wisconsin to carry on the program.

This paper represents a portion of the work carried on by Mr. Hitt which can be published at this time. That part of the work not ready for publication is being carried forward by Dr. Lester.

Donald J. Mackie

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INTRODUCTION

Man, for centuries, has sought to improve agricultural crops. Over a half-century of genetics research applied to agricultural crop plant breeding has produced results of inestimable value. To suggest that comparable results could be achieved with forest tree breeding research would seem to be somewhat presumptuous. This is especially true when one realizes that there are many unique problems associated with forest tree improvement research to which agricultural breeding methods cannot be directly applied. To suggest, on the other hand, that important results could not be achieved with forest tree breeding research would seem equally bold when one considers the tremendous acreages, the number of species involved, the range of variability found in many of the commercially important tree species, the increased demands being made and to be made for wood and wood products, and the improvements in wood technology.

Early recognition of many of these concepts led the Wisconsin Conservation Department to foster and financially support a program of forest tree improvement research in the Agricultural Experiment Station at the University of Wisconsin in Madison. The project was started in July of 1948, with initial emphasis on work with red pine (Pinus resinosa) and jack pine (P. banksiana). The primary objective of the research was to improve the genetic quality of the planting stock used in reforestation in Wisconsin. Research activities were centered around the following approaches:

1. The selection and progeny testing of superior forest tree species.

2. Hybridization studies with selected trees and species.

3. The conduct of special studies necessary for the development of the general tree improvement research program.

The project was started when there were few guidelines in tree improvement research, hence many of the early studies were exploratory. Considerable emphasis was also placed on the field aspects of the research and initially much "program selling" had to be done in the solicitation of assistance from practicing foresters. Their early attitudes of "reserve" soon turned to attitudes of "resolve" and much was accomplished at the field level.

Much of the work for the first decade of the project is well established as, for example, progeny and field trials, vegetatively propagated material and short-term tests. The results of some of the special studies have been reported in Project annual reports or have been incorporated into large-scale studies.

This report contains summaries of several studies which have been terminated. They are documented with the hope that they will be of assistance in furthering forest tree improvement activities both at the research and applied levels.

The author wishes to thank the staffs of both the Wisconsin Conservation Department and the College of Agriculture at the University of Wisconsin for their cooperation and assistance in the development of the tree improvement program. Likewise, field personnel of the Conservation Department rendered assistance of inestimable value.

SEED PRODUCTION SURVEY

The seed used by Wisconsin forest nurseries is generally harvested locally. Since the harvest or collection of seed must be done during a relatively short period in the spring or fall, when the conservation work load is greatest, the Conservation Department has come to rely heavily on private collectors. Seed source in forestry as in other phases of agriculture is very important - even more so in forestry than in other phases of agriculture when one considers the long-term nature of the crop involved. Planting stock derived from low-quality parental lines often produces the same general low-quality trees. These trees occupy a plot of ground for many years and return little for their tenancy. Therefore, the production of high quality planting stock is mandatory if reasonable returns are to be realized.

During the fall of 1957, a small-scale survey was conducted at three state-operated cone-buying stations. Primary interest in this survey was centered around where and how the seed was collected and by how many collectors. Information was obtained for about 10 per cent of all seed and cones purchased. Only the data for red pine, white pine, white spruce, and Norway spruce have been analyzed.

Information on state-wide conditions cannot be inferred from these data since the survey was conducted at only three collection centers. Nevertheless some useful observations can be pointed up.

Red pine

Cone collection sites were reported in five northwestern Wisconsin counties and five central Wisconsin counties, plus two out-of-state collections for red pine. Nearly 80 per cent of the red pine cones purchased and reported in the survey came from the northwestern counties. About three-fourths came from natural stands and were about equally divided between hand-picked and squirrel-cut cones. In the central area, about three-fourths of the cones came from plantations and were practically all hand-picked. In both the northern and central area, about 20 per cent of the cones came from open-grown scattered trees. Ten per cent of the collectors in the northwest produced 30 per cent of the crop while 6 per cent of the collectors in the central area accounted for 28 per cent of the cones.

The survey data for red pine shows that 17 and 18 per cent of the cones purchased were from plantation and open-grown sources, respectively, while 65 per cent were collected in natural stands. Fourteen collectors (10 per cent) produced about one-third of the cone crop purchased. The average northern collector produced 4.8 bushels of cones compared to 3.9 for the central Wisconsin collector. The over-all average of cones produced per collector was 4.76 bushels for red pine.

White pine

Cone collection sites were reported in four northwestern Wisconsin and two central Wisconsin counties for white pine. About 87 per cent of the white pine cones purchased came from the northwestern area. Over 71 per cent of the northern area cones and over 98 per cent of the central area cones were harvested from natural stands. Squirrels cut over 98 per cent of the purchased cones in both areas. Twenty per cent of the collectors in the northwest area produced nearly 48 per cent of the crop while in the central area, one-half of the collectors produced over 87 per cent of the crop.

The survey data for white pine cones purchased shows that 75 per cent of the crop came from natural stands and about 22 per cent came from open-grown scattered trees. Squirrels cut about 80 per cent of all cones harvested. Nineteen collectors or 22 per cent of the group produced over 53 per cent of the cone crop purchased. The average northern collector produced 6.5 bushels, the southern area collector 13.3; the over-all average was 7 bushels of white pine cones per collector surveyed.

White and Norway spruce

The survey noted cone collection sites for white spruce in three Wisconsin counties: two in the northwest and one in the central area. One Norway spruce collection was reported in Trempealeau County and one in Adams County. The majority (90 per cent) of the white spruce was hand-picked in plantation trees in a small area. Nearly two-thirds of the Norway spruce cones came from a few trees in a cemetery; the remaining one-third was equally divided between a hand-picking operation in a plantation and a collection of squirrel-cut cones.

Discussion

The trend toward volume cone collection by a few collectors probably holds true throughout the state, on the basis of total seed and cones purchased. If the individual trees or stands from which these collections were made were of average or better-than-average quality, future stand quality will be maintained. If this not be the case, future forest stand quality is in serious jeopardy. We can be reasonably certain that most of the cones came from the poorer forest types for the following reasons: (1) the higher-than-expected percentage of hand-picked cones purchased, (2) the descriptions given of the trees from which collections were made, (3) the information known about the collection areas, and (4) the generally known characteristics and traits of the cone collectors.

Table 1 summarizes the activities of the cone collectors surveyed. Sixteen per cent of the cone collectors brought in almost one-half (46.5 per cent) of the purchase cone crop surveyed.

TABLE 1

Data on Cone Collections Based on
A Survey of Three Cone-Buying Stations

Species	No. of Persons Collecting: 1-5 Bu.	5-10 Bu.	10 and Over Bu.	Per Cent of Total Cone Volume Production Attributable to Large Producer Class (10 Bu. and Over)
Red pine				
All sources	86	36	14	
Per cent of total collectors	63.2	26.5	10.3	32.0
White pine				
All sources	41	25	19	
Per cent of total collectors	48.2	29.4	22.4	53.1
White spruce				
All sources	6	0	1	
Per cent of total collectors	85.7	0	14.3	81.3
Norway spruce				
All sources	-	-	3	
Per cent of total collectors	-	-	100.0	100.0

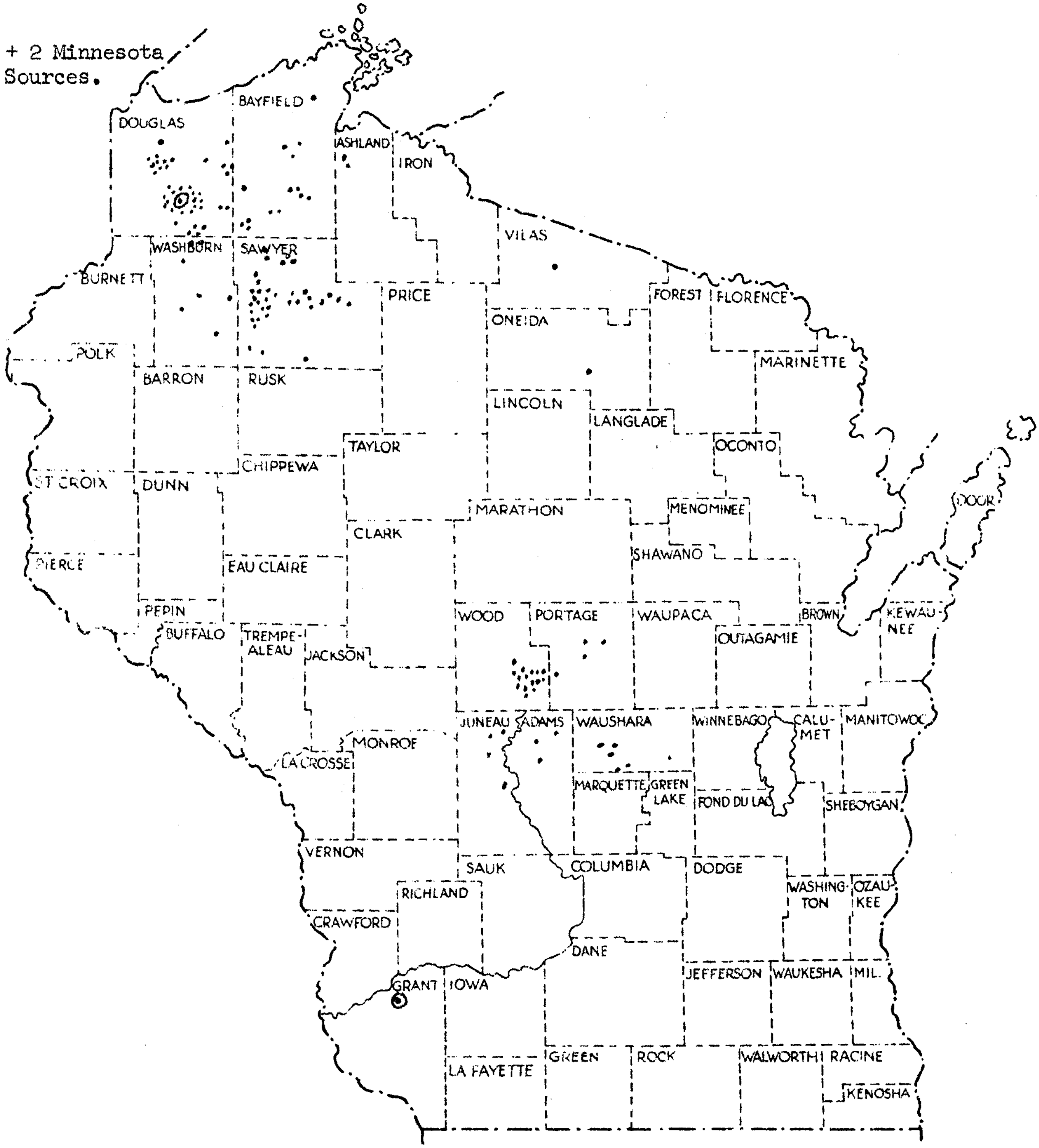

Figure 1. Approximate locations of collection sites of red pine cones reported in the survey.

FLOWERING STIMULATION TRIALS ON RED PINE

The establishment of a network of forest tree seed orchards in Wisconsin has been planned. These orchards would eventually produce seed of improved genetic quality for use in the production of planting stock in state forest nurseries. Management would require treatments designed to increase and sustain continuous seed production. With this in mind, the first of a series of experimental plots for flowering stimulation was established in Wisconsin on plantation-grown red pine during the summer of 1949.

The areas chosen for the trials were in central and north central Wisconsin. Each experimental area, containing 32 trees, was subdivided into 8 plots of 4 trees each. One tree received a wire strangulation, another a semi-circular girdle, another a spiral girdle, while the fourth tree served as a control or check tree. All of the strobili or cones (both ovulate and staminate) produced on the test trees were counted each year. The oldest trials ran for 10 years, with a number of additional trials running for less time. The age of the trees in the trials at the time of first treatment ranged from 7 to 30 years. All the trees within each experiment (32 trees) were of the same age.

In later experiments plot size was increased and the number of treatments was increased from 4 to 6 per plot.

The response of trees 30 years old at the time of first treatment was good. All trees responded to treatment by producing increased numbers of male and female "flowers"*. The semi-circular and the spiral girdled trees repeatedly gave the greatest flowering response. Usually, the spiral girdle treatment had a detrimental effect on the leader and other terminal shoots in the crowns of treated trees by causing death of the distal portion or all of the affected shoot. Response to strangulation on these older trees was not as immediate as was the response to girdling. The trees had to grow "into" the strangulation, hence response to this treatment was more gradual. It became most pronounced about the fifth year after application. By this time the effects of the girdling treatment which had been applied to other trees at the same time had been overcome and the flowering response to the girdling treatments had decreased.

Comparative responses in strobili production of 30-year-old trees in a Vilas County plantation are shown in Figure 2. These trials were established during the late summer of 1949, hence the floral primordia which were counted as strobili the following summer had already been initiated. Note the relative uniformity of the material as recorded in 1950. During the late spring and early summer of 1950, the primordia were initiated which were read as strobili during the 1951 season. Already the positive treatment response was beginning to show up for both the spiral and semi-circular girdle. At no time during any of the years did the control trees exceed the treated trees in flower production.

In order to test the duration of the effects of the different treatments one-half of the trees on an experimental area were selected at random for re-treatment with each treatment type, while the remaining half of the trees were left alone.

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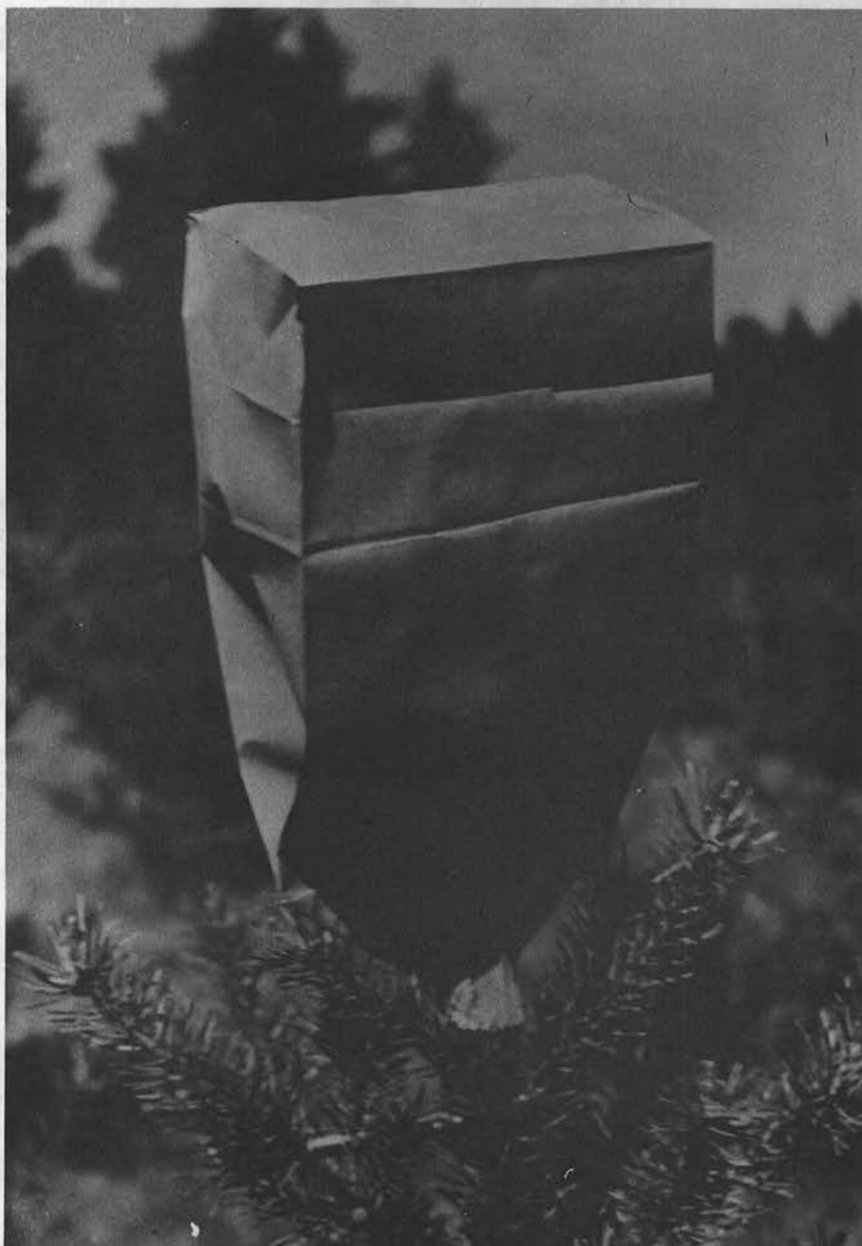
* "Flower" or "flowers" as used throughout the text refers to ovulate (female) and/or staminate (male) strobili.

Portion of a red pine plantation in central Wisconsin showing grafted red pine scions. Most of the trees have two or more grafts on them. The bags have been stapled together for mutual support.

Field grafts on a young red pine. Four scions have been grafted on this understock. The branches have been partially stripped of needles to provide an area for securing the protective polyethylene and kraft paper bags. The paper-covered completed grafts can be seen in the background.



A kraft paper bag used as a protective covering
for a graft made on a jack pine tree.

The flowering response was noted again on the re-treated plots. Although girdled trees responded, the number of flowers was not as great as that following initial treatment. The strangulation re-treatments showed the same gradual response pattern. The reduction in total numbers of flowers produced by all re-treatments was probably due to reduced numbers of live branches in the crowns of the trees. The crowns of the trees in the plantations were closing, and the total amount of live crown area per tree as well as the amount exposed to adequate light for good flowering was thus reduced. The trees which were not treated again (as well as the re-treated trees) continued to show a decrease in both male and female flower production over the years compared to the high production resulting in the first few years following initial treatment (Fig. 2).

One year after the trial was started, a telephone line was put through one of the areas causing some disturbance to one of the plots. The control tree in the plot was saved, however, and it stood completely exposed to sunlight in the clearing made for the telephone line. Under these released conditions an abundance of male and female flowers were produced. The usefulness of the tree for trial purposes was lost; however, it demonstrated well the importance of crown exposure and abundant light to reproductive growth.

Trials on younger trees also gave reproductive responses. The wire strangulation on young (12-15 years) actively growing trees must be released after the second growing season or the trees will be killed. On 7- to 11-year-old trees, annual release and re-application is necessary. On red pine trees 25 years old and older, the strangulation bands must be released 4 or 5 growing seasons after initial application.

Some flowering response to root pruning was shown by 8- to 12-year old trees. In one root pruning trial in central Wisconsin on 10- to 15-year-old plantation red pine, all treatments produced a limited number of female flowers at some time during the trial, while not a single control tree ever produced any female flowers. The male flower response was more pronounced on treated trees.

Phloem inversions and defoliation treatments were also tested. Flowering response to defoliation was negligible; however, phloem inversions where they were successfully established did stimulate female flower production.

Trees in an 8- to 12-year-old white pine plantation in Vilas County showed no flowering response to any of 5 treatments applied. No control trees were observed to flower either.

Trials to initiate and stimulate flowering on red pine through the application of fertilizers have been established. Several age class of plantation red pine were treated with various combination and levels of fertilizers. The results of these trials will be presented in another paper.

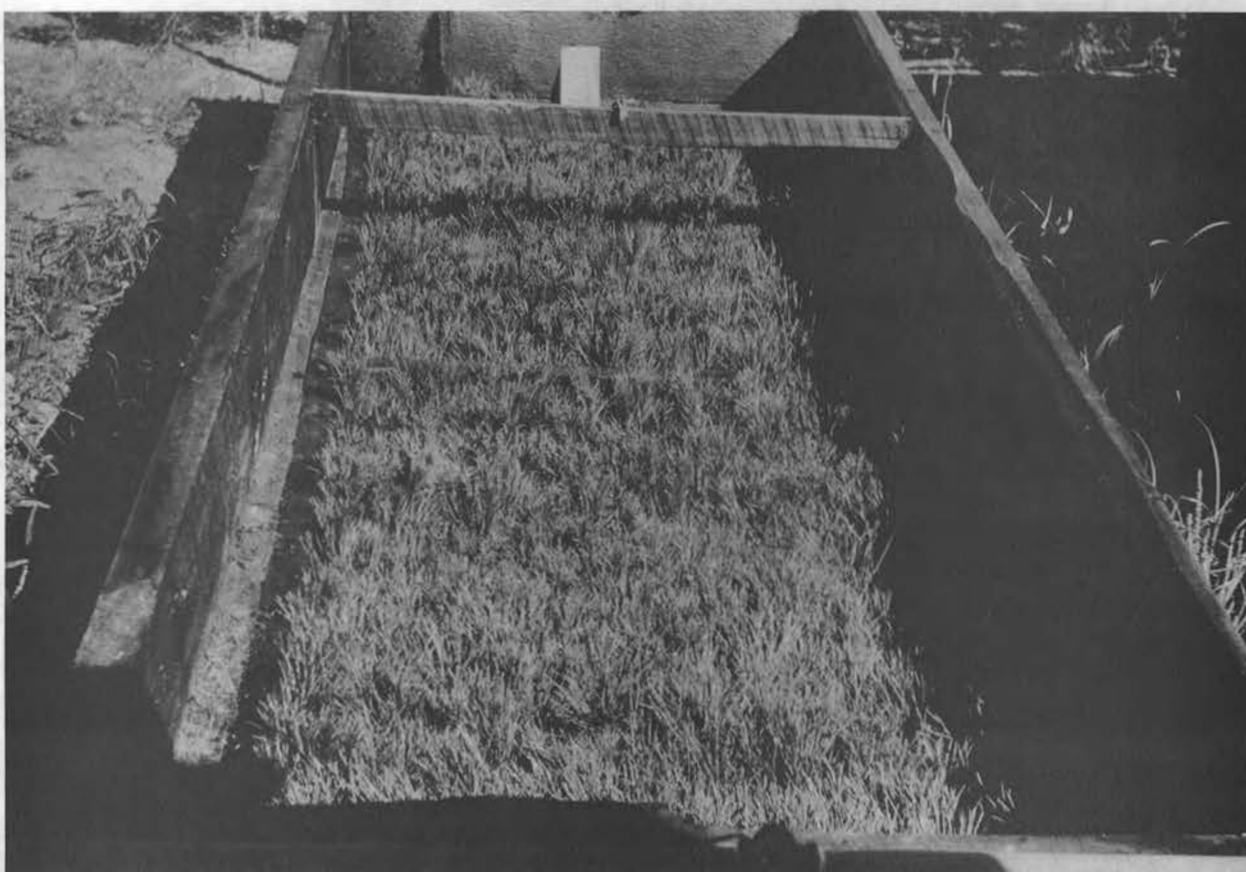
Summary

Flowering response to mechanical injury treatments was shown by 25- to 35-year-old red pines. The response on spirally girdled trees was immediate and continued high for one growing season longer than that shown by trees with a semi-circular girdle; however, the spiral girdle did more damage to the tree. Trees in this age group when re-treated generally showed an increased rate of both

male and female flowering, as compared to trees which were not treated again.

Response to strangulation was slow; nevertheless, increased flowering occurred as constriction increased. On 12- to 15-year-old trees, all treatments were effective. On 7- to 11-year-old trees, root pruning, girdling, and phloem inversions stimulated female flower production while little or no male flower response was observed. Eight to 12-year-old white pine showed no flowering response to treatments. Trials with several formulations and levels of fertilizers have been established.

A red pine field graft which had been latex tip-treated prior to grafting. The latex dip acts as an anti-desiccant following grafting. No additional protective covering was provided. Note the new shoot growth and thrifty appearance of this graft about three months after grafting.



One of the outdoor cutting beds at the Trout Lake Nursery. The photo was taken in the fall just prior to scoring the cuttings for rooting response.

VEGETATIVE PROPAGATION OF RED PINE

Vegetative propagation is of great importance in forest genetics and forest tree improvement research programs. Tree characteristics of interest to the research worker include rate of growth, tree form, angle of branching, degree of natural pruning, disease and insect resistance, wood quality, etc. Results to date indicate that striking individual tree differences for many of these characteristics occur. Once identified, the genotype of many of these outstanding trees must be preserved and produced in quantity for testing, for establishment of seed orchards and for commercial production. Several methods of vegetative propagation may be utilized for these purposes, including grafting, rooted cuttings, and air layering. This paper deals with the research on vegetative propagation of red pine that has been conducted at the University of Wisconsin in cooperation with the Wisconsin Conservation Department and summarizes the results of 12 seasons' work. The following subjects are discussed: (1) greenhouse grafting of red pine, (2) field grafting of red pine, (3) nursery and greenhouse cutting trials with red pine, and (4) air layering trials with red pine and other conifers.

Greenhouse Grafting

Vegetative propagation by grafting for forestry purposes utilizing greenhouse facilities provided an opportunity to use productively part of the winter season for the work and an opportunity for more rigid control of environmental growth factors.

The Scandinavian tree breeders were some of the leaders in this work, and the early efforts in Wisconsin were patterned after their techniques. Species differences, program emphasis, research results, etc., have resulted in modified techniques for this vegetative propagation.

Rootstock

Vegetative propagation of red pine is difficult. One must, therefore, provide the best possible conditions for each phase of the operation. At the time of grafting, vigorous, healthy, well-rooted understock or rootstock must be available. The stock must be top quality. It should be potted in 4-inch or 5-inch pots, the 5-inch being most desirable provided adequate greenhouse space is available.

With red pine, locally grown 2-1 or 2-2 stock proved to be best for potting. The trees were potted in a mixture of forest soil, compost, and peat moss, 3:1:1. Under Wisconsin weather conditions the results were best when the potting was done in late April or May. The potted trees were "healed in" nursery beds for the summer. Fertilization of the understock at this time proved beneficial. In the late fall the potted material was lifted and placed on hay or straw above ground to await transfer into the greenhouse.

Potting of stock for grafting was also attempted in the early fall and early winter, but stock potted in spring proved to be superior.

Only under emergency conditions should anything but spring-potted understock be used for late-winter greenhouse grafting. Understock not utilized during a grafting season may be held over, preferably out-of-doors during the summer season. Carrying understock beyond two grafting seasons following potting is generally not recommended, since by this time the trees are not as desirable for use because of their large size and suppressed growth.

A number of species have been used successfully as understock for red pine grafts (Table 2). The spread in range of graft success can be attributed to such factors as post-grafting understock failure, deterioration of grafting rubber, light conditions, and scion source variations. The percentage figures are shown here primarily to emphasize the range of variability. Though Scotch pine gave good results as an understock, its widespread use is not recommended at the present time, since the root collar weevil (Hylobius radicis Buchanan) is particularly damaging to Scotch pine in Wisconsin. Further testing of geographic sources for insect resistance may be desirable. The use of Japanese red pine (Pinus densiflora) should be investigated, particularly for sources which may have a dwarfing effect on scion growth accompanied by the initiation of precocious flowering of the graft.

TABLE 2

Survival of Understock Used for Red Pine Grafts

Per Cent Survival							
Pinus resinosa	Pinus strobus	Pinus sylvestris	Pinus densiflora	Pinus thunbergii	Pinus mugo	Pinus nigra	Pinus banksiana
53.0*							
42.0	37.8	38.3	20.0	15.0	22.7	4.0	22.6
15.0		57.9	50.0		43.6		
37.0			31.3		48.6		
35.3							
23.4							
40.5							
51.4							
21.9							

* Each figure represents a season or separate trial result.

Scions

The collection, storage and pre-grafting preparation of the scions is another important part of the grafting program. The use of healthy, straight, current season, upper crown, terminal or second order terminal shoots as scion material is as important to grafting success as is high quality understock. Primary terminal shoots are somewhat larger in diameter than second order terminals, hence a mixed collection is desirable. This permits more careful matching of scion and stock during the actual grafting operation.

The best scions are often found high in the tree and in the peripheral regions of the crown. Collection of scion material from this upper one-third of the crown is recommended also because most ovulate strobili or female cone production occurs in the upper one-half to one-third of the crown. Scions collected in this region may retain their capacity for female cone production for several years and therefore are very important in seed orchard programs.

In general, older trees have poorer quality scions available than younger trees; however, a few good quality scions are always available even from the older trees and these should be carefully sought out. Although topophysis has been reported for grafts of some forest tree species, this condition has not been observed on any of the grafted red pine material in Wisconsin.

Scions should be collected as near the time for grafting as possible. Late fall (October, November), early winter (December, January), late winter (February, March), and early spring (April) scion collections were made in Wisconsin.

The late fall and early winter series did not graft as successfully as did the late winter and early spring collected scions. When it was necessary to collect scions several days to several weeks before grafting, the scions were put into burlap bags into which generous amounts of snow had been placed at the collection sites. The bags were tied shut and then buried in snow out-of-doors, or put into deep freeze units where they remained until ready for use. A few days prior to grafting, the bags containing the scions were placed in a cool room (38° - 42 F.) to thaw. The melting snow kept the scions moist until ready for cleaning.

Most scions intended for use by collaborators were collected during late January or early February. They were placed in cold moist sphagnum moss in wooden containers for shipment. On some occasions, polyethylene film was used to help keep the sphagnum moss from drying out excessively in transit.

One trial was conducted with a longer period of deep freeze storage. Scions which had been collected in mid-March were cleaned, put into polyethylene bags containing some snow, and placed in a deep freezer. They were kept frozen until mid-December. At this time, they were removed from storage, thawed gradually, and grafted. In spite of the prolonged storage (9 months) and not too favorable grafting date, 11 per cent of the grafts survived.

Greenhouse and equipment

It is very important that all knives and clippers be very sharp and be kept so for the entire grafting period. Sanitation practices were maintained continuously to keep insect and disease problems minimal. Under Lake States conditions understock can be moved into the greenhouse during the period from mid-December through mid-January. Four to six weeks is necessary to bring most stock which has been stored out-of-doors under winter conditions into a stage of growth satisfactory for grafting.

The following general observations were made with regard to species growth: Japanese red pine (*Pinus densiflora*) and jack pine (*P. banksiana*) were the first of the tested species to show root and shoot development. Red pine and white pine (*P. strobus*) followed, with Scotch (*P. sylvestris*) and Mugo (*P. mugo*) pines being the last to show signs of root and new shoot development. It must be recognized that these conditions could vary considerably depending on the seed source of the stock, the greenhouse temperatures, and the time the stocks are brought into the house.

Freezing temperatures were occurring at the time the stock was brought into the greenhouse; therefore, the temperature in the house was maintained for several days at temperatures only a few degrees above freezing to allow gradual thawing of the stock and soil (35° - 38°F.). After a few days and regularly every 4 to 5 days thereafter, this temperature was raised at 5 degree intervals until the 67° to 72°F. range was attained. The temperature at the pot level was around 65°F. when room temperature was running 67° to 72°F. Weather conditions had to be considered in this temperature control program to insure that prolonged periods of sunny or cloudy conditions did not adversely affect growth response.

Watering of the stock started after thawing had occurred and after excess dirt had been removed from the top of the pot. Grafting was carried out soon after root and shoot growth was detected. The stock was pruned of some of its new growth as well as some of the older growth prior to grafting. This was done to reduce somewhat the growth of the understock. Cleaning of the understock was generally done during the second week the plants were in the greenhouse. This involved removal of the lower branches and needles to provide a cleaned section of stem onto which the graft could be made.

Grafting

The scions which had been thawed were cleaned by removal of one-half to two-thirds of the needles from the basal end. For several years, sweat boxes were used as growth chambers following grafting. This practice has also been used extensively in vegetative propagation work in Europe and Canada. The potted grafts were immediately placed in enclosed beds with a moist mixture of peat moss and sand (2:1 or 3:1) packed around each pot. The beds were kept closed for one to several weeks. The warm humid conditions were reported to be favorable to graft development. A fine mist system was installed over the aisles in the greenhouse. This helped maintain higher humidities than were normally found in the house. It also served as a cooling system during the early spring weeks when temperatures in the greenhouse could become excessive on sunny days.

The use of sweat boxes was discontinued in Wisconsin after several seasons due to excessive graft losses caused by high bed temperatures and insect and disease problems in the closed beds. In recent years the scions have been dipped in an anti-desiccant solution prior to grafting to cut down transpiration during the post-grafting period. Good-Rite VL-600, a liquid latex base material, was used in a 25 per cent aqueous solution to which a small amount of spreader had been added. The cleaned scions were dipped into the solution and allowed to dry. Standing them erect by carefully pushing the needles of the inverted scion through 1/4-inch hardware cloth aided the drying process. This allowed the needles to protrude below the surface of the hardware cloth and thus excessive latex solution could drip off of the needle tips.

The side graft and the veneer graft were the two graft types used. Several trials in which grafts were exposed to extended day lengths (12 hours and 20 hours) did not respond to treatment. These results agree with more recent findings which show that red pine does not respond significantly to photoperiodic changes.

Greenhouse temperatures can become excessively warm during bright sunny spring weather and thus can be detrimental to grafts. Shading material was applied to the greenhouse to reduce solar radiation. Often a "splatter" application was used early in the season to offer partial shade; this was followed by complete glass coverage as the season progressed.

Post-grafting care

It is important that as much attention be given to the grafts after grafting as was given the constituent parts beforehand.

Carefully considered pruning of individual stock was performed several times. Uniform post-grafting treatment of the grafts was not possible because graft development was not uniform. A constant vigil for insect and disease outbreaks was maintained. Some time prior to the outplanting date, which under Wisconsin conditions was in late May or early June, the plants had to be "hardened-off". Successive "cut-backs" of the understock top had reduced most graft units to the understock roots, graft and perhaps a branch or two of the understock top. On plants having small grafts or where scion-understock union was limited, removal of the entire understock top was delayed. Had too much understock top been removed prior to the formation of good graft union, the roots would have suffered due to an inadequate supply of photosynthates from the graft crown. Loss of the entire plant might have resulted.

Successful grafts removed from the greenhouse were handled in one of two ways: either they were planted directly into the field or they were held over in the nursery for an additional season or two before field planting.

When planted out directly into the field, the planting site had been previously cleared and disked. The grafts were hauled to the site in their pots and spread over the area. The spacing varied from 12 x 12 feet to 20 x 20 feet depending on the type of use to be made of the grafted material. They were then hand-planted by removing them from the pots and placing them into a hole comparable in size to that of the pot from which they had been removed. An effort was made to partially break down the pot-shaped clod of roots and dirt, however, care was necessary to avoid excessive damage to the roots. The planted grafts often were watered down soon after planting. Site and weather conditions were the determining factors.

At the time of field planting, removal of all of the original understock top was carried out on those grafts where this had not been carried out, provided graft growth was satisfactory. Care was also taken to permanently label and map each successful graft. Continued surveillance for insect and disease infestations was necessary.

Weed control around the grafts was important. Squares and circular pieces of heavy weather-proof paper were first used to control weed growth. A slit was cut from one edge into the center of the paper, the paper was then slipped around the graft and held down by soil thrown onto the corners or along the edges of the paper. In recent years herbicides have been used.

Weak or special grafts were often kept for a season or two following grafting in the forest nursery under partial shade. Here particular attention was given to the material to insure proper watering, spraying, pruning, etc. Grafts were removed from the pots, planted in a 1 x $1\frac{1}{2}$-foot spacing in standard nursery bed widths, labeled and their bed positions mapped. Survival data from one series of grafts made during the last half of February, 1955, and carried through a post-grafting nursery culture plan are shown in Table 3.

TABLE 3

Survival of Grafts Under Nursery Culture

Per Cent Survival				
April 16, 1955	May 16, 1955	August 25, 1955	November 22, 1955	April 22, 1958
64.5	62.0	39.4	37.9	27.8

The heavy mortality between May 16 and August 25 represented losses of grafts that appeared to be alive under the greenhouse culture but which succumbed following removal to the nursery. The small mortality from August 25 to November 22 shows the effectiveness of the nursery culture. After 2 years in the nursery there was an additional 10 per cent loss, caused primarily by an unfortunate prolonged spring flooding of a portion of the graft beds in the nursery. This resulted in heavy losses of vigorous grafts for several scion sources, and emphasized the desirability of spreading scion lots along the length of the bed or scattering them in the field to partially overcome possible heavy losses from sudden insect or disease epidemics or climatic conditions.

Field Grafting

Efforts to mass propagate red pine in Wisconsin by means of field grafts were undertaken by the University of Wisconsin for the first time during the spring of 1954. Research work both in this country and abroad had demonstrated that field grafting of forest tree species could be carried out successfully. Because red pine is a difficult species to propagate vegetatively, a number of techniques reported to be successful for field grafting with other species were attempted on red pine.

Bottle grafting trials

The bottle grafting technique for vegetative propagation had been used successfully for greenhouse and out-of-door grafting by several European and American workers. It involves the use of an approach-type graft which has the basal portion of the scion submerged in a vial of water. However, freezing temperatures caused the water in the vials to freeze and break the vials. In addition, the distances between field grafting operation areas often made daily maintenance of the water levels in the vials difficult. These factors soon dictated the impracticability of this technique for use in vegetative propagation in Wisconsin.

Kraft bag covering trials

A second series of experimental grafts involved the use of protective coverings for the grafts. After a standard side or veneer graft had been made on the stock, the graft was enclosed in a polyethylene film bag which was fastened securely around the understock stem below the graft. Next, the graft and bag were enclosed within a larger brown kraft bag which was carefully folded and stapled into place. Often a portion of the understock stem was included in the bag to give support to the kraft bag. When several grafts were made on the same understock, corners of the expanded flat bottoms of the bags could be overlapped and stapled together for mutual support.

This technique also proved unsatisfactory for Wisconsin conditions for several reasons. Warm, clear days with strong gusty winds are not uncommon in Wisconsin spring weather patterns. These conditions severely damaged the kraft bag "protective" coverings on several occasions allowing the temperatures in the polyethylene bags to become excessive due to solar radiation. Graft mortality was high. In addition, on the successful grafts it was necessary to "harden off" the grafts to lowered humidity conditions by several gradual bag opening steps over a period of days before final removal of the entire polyethylene bag. This post-grafting care was time consuming at a season when many other tree improvement activities had to be performed. Thus this technique was also abandoned.

Anti-desiccant dip trials

A third series of trials was undertaken to test the effectiveness of an anti-desiccant dip to protect the scion following grafting. Some work had been done commercially with anti-desiccant sprays on material to be transplanted and the results were encouraging. A commercial liquid latex (Good-Rite VL-600) was obtained from the B. F. Goodrich Company to use in the trials. The results of these trials and subsequent trials indicated this method or technique could be used successfully on a large scale for field grafting operations. Details of the technique follow.

Sturdy understock was essential for good field grafting results. Initially, field grafting was done on 8- to 12-year old trees ranging in height from 3 to 6 feet. They were plantation trees planted on an approximate 6 x 6-foot spacing. From one to five scions were grafted on each selected understock, depending upon stock size, graftable area, available scion source, and purpose of the grafting. In general, grafts were made on the understock at an average of $3\frac{1}{2}$ feet above ground. With successful callus formation and continued growth, grafts were then often 5 to 6 feet above ground before any significant "crown" development occurred. From the standpoint of seed orchard management, the lower the "flowering" and producing crown could be kept, the easier it would be to work later. In more recent field grafting operations, an effort was made to graft onto plantation trees 15 to 20 inches high and 5 or 6 years old.

The grafting was done in late March and early April. As with greenhouse grafting, the scions were collected as close to the time of grafting as possible but sometimes late winter collections were made and the scions held in cold storage until field grafting began.

Scions for field grafting were 4 to 6 inches long although shorter scions can and have been used successfully. From one-half to two-thirds of the total scion length was stripped of needles. The scions were dipped in a 25 per cent solution of liquid latex to which a small amount of spreader sticker had been added. After the solution had dried on the scions, grafting was carried out. Generally, a side or veneer type graft was made. The scion was held securely in place with grafting rubbers and the graft area was coated with a commercial grafting compound called "Tree Seal"*. The graft was tagged and no further attention was necessary for several weeks.

After the graft had taken, successive cut-back of the understock was started. Care had to be exercised not to hasten this operation. By mid-summer the Tree Seal coating had started to flake or "weather" away and the grafting rubber showed signs of disintegration. At this time more individualized attention was given to the successful grafts to insure proper cut-back of the understock based on graft growth, removal of the grafting rubber, attachment of a permanent label to the grafted plant, mapping of the successful grafts, etc. The growth response of each graft was generally different, hence each had to be treated separately. Some material needed a "nurse" branch or two left on the understock near the grafted portion for the first full growing season or two following grafting. It was not desirable to immediately cut away all of the branches on the understock below the graft especially when the grafting had been performed on the older understock. This had to be a gradual process and was done over several seasons. The development of the grafted top dictated "how much" and "how often" pruning had to be done.

After the grafted portion had become well established, tip clipping and other pruning was started to shape the crown for future scion production. Some results of field grafting operations are shown in Table 4.

TABLE 4

Results of Field Grafting Experiments

Location	Species	Source of Scions	Number Grafted	Number Live Grafts	Per Cent Survival
Wisconsin Rapids (Central Wisconsin)	Red pine	Stored	291	115	39.5
Wisconsin Rapids (Central Wisconsin)	Jack pine	Stored	116	58	50.0
Trout Lake (North Wisconsin)	Red pine	Stored	406	252	62.1
Potato Farm Area (North Wisconsin)	Red pine	Fresh	348	248	71.3
Total			1,161	673	58.0

* Tree Seal - Purchased from Morrison's Orchard Supply Company, Yuba City, California

Girdle "A" (semi-circular girdle type) on 30-year-old red pine 1 month after application

Girdle "B" (spiral girdle type) on 30-year-old red pine 1 month after application

A flexible metal conduit through which a heavy wire was passed served as the strangulation treatment. Response beginning to appear as constriction increased due to tree growth. Photo on left taken in fall, 1950, photo on right, fall 1952.

1949

1950

1951

Growth of individual red pine tree "into" strangulation treatment. Heavy gauge wire was used in this trial.

1952

There was a wide range in grafting success with the same scion lots in central and northern Wisconsin. Part of this may be due to climatic differences; however, the grafting success proved also to be related to the skill of the workers. Eighteen different scion lots were grafted in northern Wisconsin, while nine different scion lots were grafted near Wisconsin Rapids. The range of successful grafts for all lots ran from 18 to 91 per cent. Freshly collected scions gave a higher percetage of successful grafts than did stored scions. This difference is probably not as significant as it seems since the stored scions generally came from older trees.

The technique for field grafting just described provided results under Wisconsin conditions with red pine which indicated that the technique can be used immediately for the establishment of clonal forest tree seed orchards. The technique should have potential application throughout the Lake States. Field grafts are more economical to produce than greenhouse grafts and many more field grafts can be made in a day than by other previously tested methods. Costly greenhouse operations for vegetative propagation can be minimized or eliminated. Post-grafting care is minimal, and costly outplanting of successful grafts is also eliminated.

One disadvantage of the technique is that graft failures in seed orchards mean regrafting operations must be carried out at a later date. However, this disadvantage has its counterpart in the greenhouse graft which fails after outplanting. In general, the advantages of field grafting currently far outweigh any of its disadvantages and its practice is recommended for large-or small-scale grafting programs.

Nursery and Greenhouse Cutting Trials

The results of the trials to vegetatively propagate red pine by means of rooted cuttings were very poor. At no time during the 7 seasons the trials were run did the rooting percentage exceed 25 per cent. Often it was 5 per cent or less. Yearly fluctuations as reported by other workers for other species were not discernible.

Outdoor cutting beds at the Trout Lake Nursery were constructed during the summer of 1951. The rooting media for most of the trials run in these outdoor beds was a 1:1 or 2:1 mixture of builder sand and vermiculate or straight vermiculate. Over the years, cutting for these trials came from red pine trees ranging in age from 3 to over 60 years. Small trials were also made with cuttings of jack pine, white, black, and Norway spruce; and balsam fir.

Results of an outdoor cutting trial started in the beds at Trout Lake during the second week of May, 1955, are noteworthy. Cuttings from lateral branches of 2-2 red pine were collected 1 to 2 weeks prior to the start of the trial from trees in the nursery at Trout Lake. The cuttings were treated, planted, and allowed to "grow" over the summer. One bed was read on September 12, 1955. The second bed was held over and readings were made on it in August of 1956. Results are presented in Table 5.

TABLE 5

Results of Cutting Trials made at Trout Lake in May, 1955

Treatment	Trial Read September 1955			Trial Read August 1956		
	Total Rooted	Per Cent Rooted*	Rank	Total Rooted	Per Cent Rooted	Rank
Rootone 101	17	9.7	5	11	6.3	4-5
Rootone 102	11	6.3	6	8	4.6	6
Rootone 103	21	11.9	2	19	10.8	3
Rootone 104	44	25.0	1	33	18.8	1
Rootone 10	19	10.8	4	20	11.4	2
Coconut milk soak	8	4.6	7	5	2.8	7
Control	19	10.8	3	11	6.3	4-5
Total	139	11.3		107	8.7	

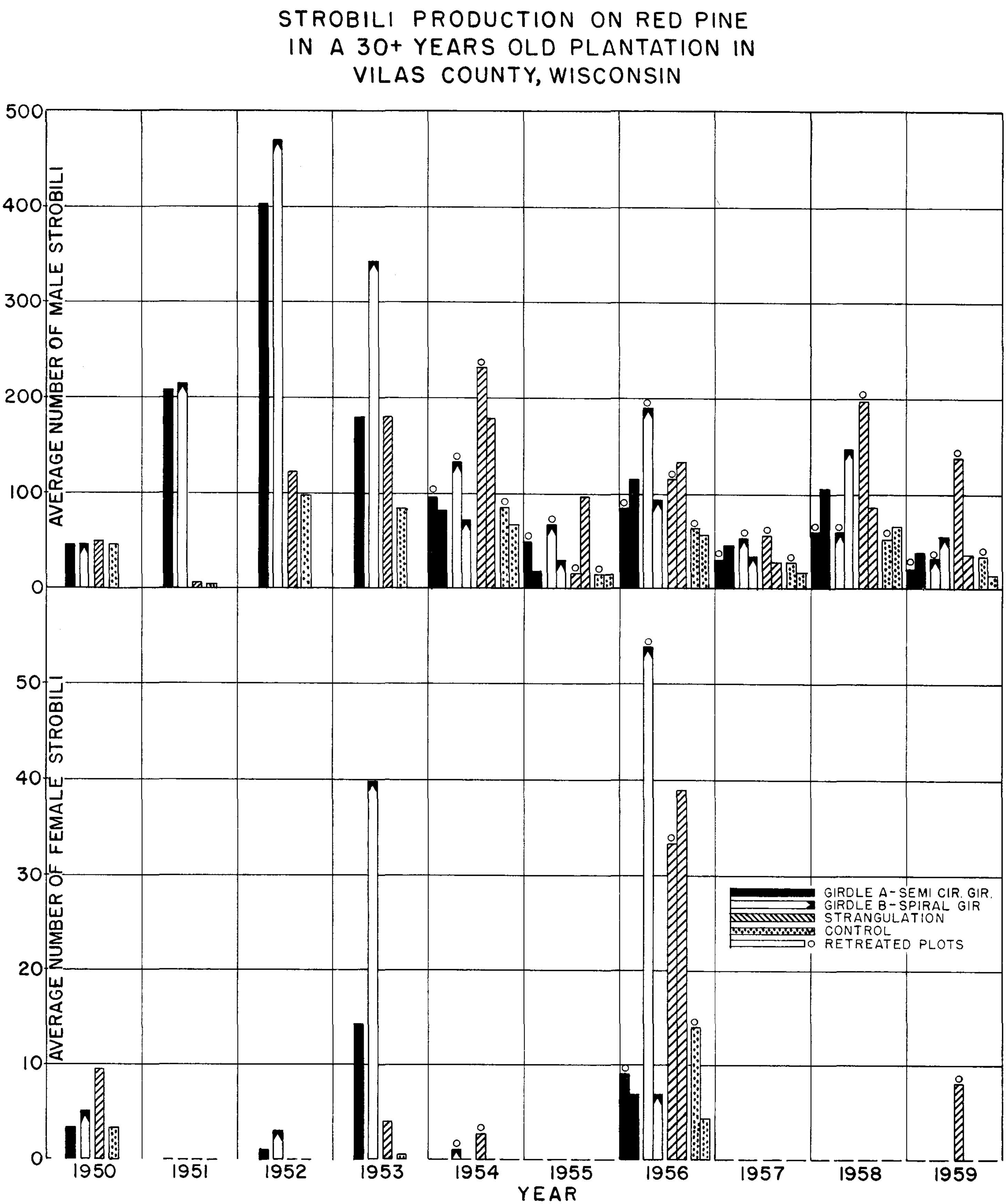
* Based on 44 cuttings/treatment replicated 4 time/bed. Total cuttings/treatment/bed = 176.

Rooting success ranged from 4.6 to 25 per cent with an over-all average of 11.3 per cent for the 17-week trial. For the 64-week trial, success ranged from 2.8 to 18.8 per cent, with an over-all average of 8.7 per cent. Spraying system difficulties during the second summer made hand watering of the cuttings necessary. Thus the lower percentages on this longer trial may be due to the death and disintegration of young roots which may have formed on the cuttings earlier but were no longer intact at the time of the readings.

Rootone powder Number 104 (IBA at 20 mg/gr. of talc) gave the best rooting results. The coconut milk soak gave the poorest rooting results, the lowest number of healthy callused cuttings, and the highest number of non-callused cuttings.

The results of this spring "planted" cutting trial and from another spring trial later suggests the desirability of continued efforts along these lines.

Cutting trials were also conducted in the greenhouse in Madison. In addition to testing most of the hormones, etc., previously mentioned for outdoor trials, several additional treatments and media were tested. Although very few cuttings rooted, the formation of callus on many cuttings suggested that with a longer period in the rooting media, the percentage of cuttings to strike root might be increased. Under greenhouse conditions, therefore, it seems advisable to test for rooting response with cuttings collected in the late fall or early winter (November or December) and run them into June. This would permit collection of the cutting materials after a short period of exposure to freezing temperatures


STROBILI PRODUCTION ON RED PINE
IN A 30+ YEARS OLD PLANTATION IN
VILAS COUNTY, WISCONSIN
AVERAGE NUMBER OF MALE STROBILI
AVERAGE NUMBER OF FEMALE STROBILI
500
400
300
200
100
0
50
40
30
20
10
0
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
YEAR
GIRDLE A-SEMI CIR. GIR.
GIRDLE B-SPIRAL GIR
STRANGULATION
CONTROL
RETREATED PLOTS

and still permit them to remain in the cutting beds in the greenhouse for 5 to 6 months before summer greenhouse temperatures become excessive.

One of the trials established in the greenhouse in Madison involved the use of Kinetin, Indolebutyric acid (I.B.A.), and Vigoro in various concentrations and combinations. At the time the trials were read, no cuttings had formed roots. Very few cuttings had formed any callus tissue, probably due to the very moist conditions in the rooting media. Cuttings treated with Vigoro, either straight or in combination with Kinetin and I.B.A., showed needle yellowing and death. No new shoot growth was observed. I.B.A., either alone or in combination, gave poor results although the lower concentration (100 ppm) appeared to inhibit new shoot elongation less than did a higher (200 ppm) concentration of the hormone. Kinetin alone appeared to stimulate bud growth, best results occurring with low concentrations (5 ppm). All control trees had good color and shoot elongation was greatest for control cuttings and the low concentration Kinetin cuttings. Additional studies could be undertaken to test lower concentrations of the Kinetin.

Bud break and shoot elongation was greater on those cuttings collected in early March as compared to cuttings collected in early February. This same general pattern has been reported by others and appears to be true also for scions which are collected for late-winter greenhouse grafting. Scions collected late in the winter "flushed" more quickly after grafting and gave a higher percentage of successful takes than did scions collected in mid-winter. This should be considered in planning a trial involving late-fall-collected material.

The results of this research on the rooting of cuttings of red pine suggest that the investigations should be continued with primary research emphasis on the physiological factors of rooting.

Air Layering Trials

Air layering is another type of vegetative propagation which has been used for centuries by horticulturists. Only recently has its utility in forestry research been emphasized. With this technique, an attempt is made to induce root formation on branches while they are still attached to the donor plant. The air layer is best applied to 1- or 2-year-old wood in the actively growing portion of the crown.

Several thousand air layers were applied to a number of Wisconsin forest tree species: red, white, jack and Scotch pine; white spruce; balsam fir; and large-toothed aspen. The age of the trees ranged from 8-year-old plantation stock to mature trees growing in natural stands for all species escept the spruce, aspen, and balsam fir.

The needles along the section of branch to be treated were stripped away, and a 1/2-inch to 3/4-inch ring of bark and cambium removed by girdling the branch with a sharp knife at the desired spot. Care was taken that no cambial tissue remained, which could form a callus bridge between the upper and lower cut bark and cambial surfaces, by scraping the girdled area with the knife blade. The exposed cut surface on the distal portion of the branch was dusted with a growth hormone. The girdled area was then wrapped or surrounded with moist sphagnum moss and enclosed within a polyethylene film. The upper and lower ends of the film were securely fastened around the branch to insure minimal loss of moisture by evaporation from the enclosed moss. With proper application and no damage to the polyethylene film, the sphagnum moss remained moist for several months under Wisconsin conditions.

Application dates ranged from early April through late July. Readings were made on the trials from 3 months to 13 months following treatments. Although some rooting occurred, the general results were very poor.

White pine branch tips broke off at the point of application or else simply died. Although no roots formed on jack pine, many branch tips remained alive. Some rooting did occur on young Scotch pine with Rootone Experimental Powder 104 (I.B.A. at 20 mg/gr. of talc). Bulbing of the callus was also pronounced on the Scotch pine. There appeared to be great variation in the amount of callus formed on girdled areas. It ranged from nil to very heavy on the same tree with the same and/or different treatments as well as with the controls. In one trial with 12-year-old red pine, although no rooting occurred, over 75 per cent of the branches were still alive 13 months after treatment. Callus formation was unusually light.

The results of these trials indicate that additional trials could be undertaken utilizing lower concentrations of rooting hormone. The prolonged trials apparently are of no value.

Summary

Vegetative propagation of red pine is difficult. Although the species can be grafted and cuttings can be induced to root, the results leave much to be desired. Basic studies on the physiology of rooting with this species should be undertaken. Refinements in the field grafting technique can be made. Additional studies of the effects of different species when used as understock on scion or graft development seem warranted. Continually improving techniques and methodology in tree improvement research indicates that investigation on vegetative propagation need no longer be considered a major item with regard to time and budget allocations.