THE VEGETATIVE PROPAGATION OF EASTERN WHITE PINE AND OTHER FIVE-NEEDLED PINES[1]

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With one plate

WITH the recognition of the root-inducing properties of heteroauxin and a number of chemicals with similar physiological activity, a new interest in vegetative propagation of forest trees was stimulated. This has resulted in studies of root regeneration in cuttings of species heretofore reproduced only by seed and whose ability to form roots from stem pieces was little known. With at least one conifer, *Pinus radiata* Don (11), large nursery operations are in progress with the reproduction of superior stock by means of stem cuttings. In the United States and Canada considerable study has been given the rooting characteristics of eastern white pine (2, 3, 5, 6, 14, 17 and 23). These investigations have clarified a number of features of the root regeneration characteristics of eastern white pine cuttings, but have not progressed to a point where extensive propagation programs could be started with confidence that consistent and abundant rooting would result.

The cuttings of this species have been found to be relatively difficult to root. They root most readily when secured from very young seedlings, but in a very irregular manner or not at all when obtained from older trees. Applications of root-inducing chemicals usually hastened and increased the rooting of cuttings from seedlings, but have not given consistently beneficial results with those from older trees. Considerable periods of time are required for roots to form on cuttings from older trees. With dormant cuttings the period may be three to five months or more. In the propagating bench many cuttings die from drying out and they are very subject to decay. The rooting of white pine stem cuttings is still considered to be in an experimental stage requiring many additional facts as well as confirmation of previous findings to make vegetative propagation a reliable procedure in silviculture, in tree breeding or in forest pathology programs.

The present study deals with the rooting responses of many collections of eastern white pine cuttings and a lesser number from seven additional species of five-needled pines: *Pinus monticola, P. parviflora, P. flexilis, P. koraiensis, P. peuce, P. Cembra* and *P. Lambertiana*. The influence of the age of the parent trees from which the cuttings were obtained was

[1]The experimental work was conducted at the Harvard Biological Laboratories and the Arnold Arboretum of Harvard University while the writer was in residence in 1940–41. Acknowledgement of thanks are extended to Professor A. B. Dawson and Professor K. V. Thimann for laboratory facilities and to Professor E. D. Merrill for the privilege of collecting material from the conifer collections in the Arnold Arboretum.

observed with shoots taken from trees 2 to 90 years old. Cuttings were collected from a number of plantations and the rooting responses of the cuttings of a number of individual trees were recorded. It has been previously observed (3) that considerable inherent variability in the ability of cuttings from certain individual trees to root may exist, so that any light upon associated characters of those trees which yield cuttings which root would be exceedingly useful. A very extensive series of auxin treatments was applied to the cuttings as well as trials of the effectiveness of treatments with sucrose and nitrogenous compounds. Observations on the influence of fungicides and dormancy-breaking chemicals were also made.

GENERAL METHODS OF PROCEDURE

The cuttings were collected in nurseries and plantations in Connecticut and Massachusetts, in the Arnold Arboretum of Harvard University, and one collection of white pine branches came from Wisconsin and one of sugar pine from California. In general, only lateral shoots of the current season's growth were taken from lower lateral branches. The cuttings were made to a length of 3 to 4 inches with snap-cut pruning shears. The propagating medium was fresh medium coarse sand in open central benches in warm greenhouses. One bench was equipped with electric coil heating units set to provide a temperature of 70° F. in the sand. Cheesecloth shades were provided to reduce the intensity of direct sunlight. The propagation conditions were excellent for cuttings that rooted readily and they permitted satisfactory survival of many collections of cuttings of adult pine trees for periods of five to eight months. The rooting responses of the cuttings were first inspected after they had been in the sand between two and three months.

ROOTING RESPONSES OF CUTTINGS FROM SEEDLINGS AND TRANSPLANTS

For some time it has been recognized that cuttings from seedlings of many trees root more readily than those from adult trees. Stoutemeyer (22) reviewed this subject in connection with a study of root formation in apple cuttings. The significance of the age factor to ease of rooting was shown to hold for various species, including eastern white pine, by Gardner (7). Thimann and Delisle (23) obtained rooting with cuttings of eastern white pine seedlings ½ to 3 and 4 years old. Deuber (3) found that cuttings from eastern white pine seedlings 2 to 4 years old rooted most abundantly, those from trees 5 and 7 years rooted much less and those from trees 15, 25, 35 and 60 years old rooted in a very irregular manner. With cuttings from trees 5, 10, 15, 20 and 40 years old Snow (17) reported rooting with those from the three younger ages. It was hoped that additional study of the conditions required for the rooting of cuttings from young pines would result in more consistently high rooting responses and would shed light upon the procedures most suitable for cuttings from older trees.

In the present investigation the most complete series of cuttings from trees 2 to 7 years old from the same source and handled uniformly were supplied by Mr. J. R. Brubaker of the Cheshire Nursery, Cheshire, Conn. One-half of the cuttings were treated with indolebutyric acid in talc (2 mg./gm.) just before being planted in mid-January. A second auxin treatment was given the non-rooted cuttings at the time of the first inspection. The data recorded in Table 1 give the progress in root formation at three periods during the six months the cuttings remained in the propagating bench. A series of typical rooted cuttings is illustrated in Plate 1.

TABLE 1.

Rooting Responses of Eastern White Pine Cuttings from Nursery Stock 2 to 7 Years Old. Planted Jan. 13, 1941.

Type of shoot	Age of trees, Treatment	No. per group	Rooted after: 73 days	134 days	182 days
			%	%	%
	2 years				
Terminal	Control	36	2.7	38.8	41.7
Terminal	I.B. in talc	36	50.0	61.1	63.9
	3 years				
Terminal	Control	18	33.3	55.5	55.5
Terminal	I.B. in talc	18	50.0	61.1	72.2
Lateral	Control	40	15.0	62.5	67.5
Lateral	I.B. in talc	40	45.0	45.0	52.5
	4 years				
Branch terminal	Control	20	10.0	10.0	10.0
Lateral, upper whorl	Control	30	3.3	26.6	43.3
Lateral, lower whorl	Control	36	19.4	58.3	86.1
	5 years				
Branch terminal	Control	20	0	0	0
Lateral	Control	30	0	3.3	23.3
Lateral	I.B. in talc	30	3.3	23.3	43.3
	6 years				
Branch terminal	Control	20	0	10.0	10.0
Lateral	Control	30	0	6.6	40.0
Lateral	I.B. in talc	30	13.3	43.3	63.3
	7 years				
Branch terminal	Control	20	0	0	0
Lateral	Control	28	0	0	3.5
Lateral	I.B. in talc	28	0	7.1	28.5

The terminal shoots of 2- and 3-year old seedlings rooted satisfactorily, but the branch terminals of lateral branches from transplants 4 to 7 years old rooted very poorly or not at all. Another significant difference in the rooting responses between two types of cuttings was that between upper and lower whorl lateral shoots of 4-year old trees. Cuttings from the upper whorl of branches rooted 43.3 per cent and those from the lower whorl 86.1 per cent.

The cuttings from 3-year old seedlings were the most prompt in rooting. With cuttings of lateral shoots, sharply graduated decreases in rooting responses between cuttings from seedlings 2 to 6 years old did not occur. The rooting of cuttings from 7-year old transplants decreased markedly from those of the younger ages.

The auxin treatment of the cuttings both hastened root formation and increased the number that rooted in all but one instance, laterals of 3-year old stock. The most marked effect of the auxin treatments was with the 7-year old stock which rooted 3.5 per cent without treatment and 28.5 per cent when treated. Calculation of the χ^2 value for all the control groups compared with the auxin treated groups indicated that the influence of the auxin treatments was highly significant.

TESTS OF VARIOUS METHODS FOR TREATING THE CUTTINGS

At the end of March a large collection of cuttings was made from 6-year old seedlings growing in an old field. A variety of auxin treatments that had been tried with cuttings from adult trees was tested together with the influence of sucrose. These treatments and the rooting responses are recorded in Table 2. Most of the cuttings were pulled from the branches with a quick jerk so that a small heel of the bark of the previous season's growth remained attached to the stem bases. This method of preparing the cuttings was compared with cutting them off with a razor blade at the base of the current season's growth. The untreated control groups rooted 25 per cent when the cuttings were removed with a razor and 30 per cent when pulled off with a heel. A larger difference in favor of the cuttings with a heel was found when the cuttings were treated with indolebutyric acid in talc. Treatment of the cuttings with indolebutyric acid or α-naphthaleneacetic acid in talc dusts were of the same order of effectiveness in increasing the rooting of the cuttings above that of the controls. These treatments were particularly effective in hastening root formation.

Maximum rooting was secured when the cutting bases were placed in a solution of indolebutyric acid, 10 mg./1., for 3 hours. A similar treatment with α-naphthaleneacetic acid was just one-half as effective in inducing rooting. When the cuttings were placed in a 1.5 per cent solution of sucrose for 3 hours the rooting response was of the same order, 50 per cent, as the best treatment with indolebutyric acid in talc.

Solutions of auxins and sucrose were also employed with a modification of the vacuum method described by Butterfield and McClintock (1). Earlier trials in which pine cuttings were subjected to a vacuum in the presence of a solution of auxin did not prove satisfactory, nor did trials in which the cuttings were first subjected to a vacuum and then to pressure. In this experiment the cuttings were placed in a suction flask with auxin or sucrose solutions and a pressure of 1 atmosphere was applied from a cylinder of compressed nitrogen gas for 10 or 20 minutes. The pressure method for a 10-minute period was approximately as effective as the method in which cuttings stood in solutions of indolebutyric acid or sucrose for 3 hours. When the cuttings were treated with a solution containing both indolebutyric acid and sucrose the rooting response was of the same order as that of the controls. This result occurred in both the static and pressure methods of treatment.

TABLE 2.

THE INFLUENCE OF VARIOUS TREATMENTS UPON THE ROOTING RESPONSES OF CUTTINGS OF EASTERN WHITE PINE TREES 6 YEARS OLD. PLANTED MARCH 30, 1941.

Type of shoot and Treatment	No. per group	Rooted after: 60 days	140 days
		%	%
Lateral shoots			
Control, pulled off with a heel	20	0	30.0
Control, cut with a razor	20	0	25.0
I.B. in talc, 2 mg./gm., pulled off with a heel	20	45.0	50.0
I.B. in talc, 2 mg./gm., cut with a razor	20	20.0	35.0
(Cuttings of remaining groups pulled off with a heel)			
Nap. in talc, 2 mg./gm.	20	45.0	45.0
I.B. in soln., 10 mg./l., 3 hrs.	20	15.0	60.0
I.B. in soln., 10 mg./l., with pressure, 10 min.	20	0	55.0
I.B. in soln., 10 mg./l., with pressure, 20 min.	20	5.0	35.0
Nap. in soln., 10 mg./l., 3 hrs.	20	10.0	30.0
Sucrose, 1.5% soln., 3 hrs.	20	5.0	50.0
Sucrose, 1.5% soln., with pressure, 10 min.	20	0	45.0
I.B. soln., 10 mg./l. + sucrose, 1.5% soln., 3 hrs.	20	0	35.0
I.B. soln., 10 mg./l. + sucrose, 1.5% soln., pres. 10 min.	20	0	25.0
I.B. in lanolin paste, 4 mg./gm., to stem bases	20	0	0
I.B. in lanolin emulsion, 0.2 mg./ml., to stem bases	20	0	0
I.B. in lanolin emulsion, 0.2 mg./ml., to buds	20	0	10.0
I.B. in lanolin emulsion to stem bases and to buds	20	0	5.0
Branch terminal shoots			
Control	20	0	0
Toothpicks saturated with 95% alcohol	20	5	5.0
Toothpicks saturated with I.B. in alc., 10 mg./10 ml.	20	30.0	55.0
Toothpicks saturated with Nap. in alc., 10 mg./10 ml.	20	60.0	85.0

Application of indolebutyric acid in lanolin paste induced injury and early decay of the cutting bases. An emulsion of lanolin with indolebutyric acid prepared like colchicine emulsions, Warmke and Blakeslee (25), while not as injurious as lanolin paste, was not effective when applied to the stem bases, buds, or to both the stems and buds.

The large terminal shoots of lateral branches were induced to root and in relatively high percentages when sharpened ends of toothpicks previously soaked in concentrated alcoholic solutions of indolebutyric acid or α-naphthaleneacetic acid were inserted into the stems just above the base. This technique was described by Romberg and Smith (15) for the thick root cuttings of pecan. The work of Snow (17) and other investigators of eastern white pine propagation have shown that lateral shoots root so much more readily than branch terminals on all but the youngest seedlings that branch terminal shoots were only rarely used in this investigation. The magnitudes of the rooting responses were such that additional study of the method is warranted.

The data of this experiment with cuttings of 6-year old trees afforded the best opportunity in this investigation to compare the effectiveness of various methods of treatment with auxins and sucrose. A favorable circumstance was the fact that the control cuttings had an inherent ability to root. Both dust and solution treatments with indolebutyric acid increased rooting; the dust applications with indolebutyric acid or α-naphthaleneacetic acid hastened root formation more than solution treatments. No particular advantage can be ascribed to the pressure method, its brevity being counterbalanced by the additional equipment necessary, and with a period longer than 10 minutes the results were not satisfactory. Why sucrose and indolebutyric acid used separately were effective but when combined did not increase rooting is not known. Treatments with lanolin paste and lanolin emulsion did not prove satisfactory. The results with toothpicks saturated with auxin solutions for branch terminals were particularly effective.

RESULTS WITH CUTTINGS FROM TREES 8 TO 90 YEARS OLD

From November through April twenty-four collections of cuttings were secured from eastern white pine trees of intermediate and adult age classes. The trees from which the cuttings were made grew in well established plantations making vigorous growth or from suppressed trees, isolated mature trees, trees trained as hedges by annual trimming, or trees transplanted during the previous two or four years. The cuttings were treated with auxins in various ways, with sucrose and solutions of nitrogenous compounds. Since the rooting responses were generally highly irregular, with no rooting occurring in many groups of cuttings, the data have been condensed by omitting the majority of the negative results in Table 3. The total number of cuttings in each experiment and test group is indicated to give the scale of the test together with the rooting percentages of all the control groups and for the treated groups in which rooting occurred.

With the exception of collections of cuttings from trees 15 years old, irregular rooting and in relatively low percentages or complete failure to root characterized these data. While low rooting was more pronounced in cuttings from trees above 15 years old, those from trees 8 to 12 years old also rooted in an irregular manner. Some rooting did occur in cuttings from trees 8, 10, 12, 15, 16, 38 and 61 years old. These responses do indicate that all ability to regenerate roots is not lost in the shoots from older trees and requires additional search for the factors responsible. A

TABLE 3.

ROOTING RESPONSES OF CUTTINGS FROM EASTERN WHITE PINE TREES 8 TO 90 YEARS OLD. DATA FOR THE CONTROL GROUPS OF CUTTINGS AND ONLY THOSE OF THE TREATED GROUPS IN WHICH ROOTING OCCURRED.

Expt. No.	Age of trees and Treatment	Total No. cuttings	No. per group	Rooted
				%
	8 years			
32	Control	600	30	3.3
	Toothpicks saturated with I.B. soln.		30	10.0
	I.B. in lanolin paste		30	6.6
	I.B. soln., 10 mg./l. + sucrose 1.5%, 4 hrs.		30	3.3
	I.B. soln., 100 mg./l. + sucrose 1.5%, 4 hrs.		30	3.3
	10 years			
37	Control	260	20	0
	Nap. in talc, 2 mg./gm.		20	5.0
	I.B. soln., 10 mg./l., pressure 10 min.		20	25.0
	I.B. in lanolin paste		20	5.0
	12 years			
27	Control	180	20	5.0
	Toothpicks saturated with I.B. soln.		20	5.0
	15 years			
12	Control	178	24	33.3
	I.B. in talc, 2 mg./gm.		24	20.8
29	Control	270	30	36.6
	Control, pulled off with a heel		30	40.0
	I.B. in talc, 2 mg./gm., cut with shears		30	56.6
	I.B. in talc, 2 mg./gm., pulled off with heel		30	60.0
	I.B. in lanolin paste, cut with shears		30	23.3
	I.B. in lanolin paste, pulled off with a heel		30	6.6
	I.B. in lanolin emulsion, cut with shears		30	16.6
	I.B. in lanolin emulsion, pulled off with heel		30	13.3
	16 years			
13	Control	100	50	0
24	Control	380	20	0
	I.B. soln., 10 mg./l., pressure 20 min.		30	16.6
36	Control	80	20	0
	I.B. in talc, 2 mg./gm.		20	10.0
	Nap. in talc, 2 mg./gm.		20	5.0
	18 years			
13	Control	460	50	0
31	Control	440	20	0
40	Control	90	30	0

TABLE 3 (*continued*)

Expt. No.	Age of trees and Treatment	Total No. cuttings	No. per group	Rooted %
	20 years			
6	Control	80	20	0
	I.B. in talc, 2 mg./gm.		20	5.0
	I.B. soln., 200 mg./l., 2 hrs.		20	5.0
38	Control	180	20	0
12	Control	60	20	0
	26 years			
27	Control	360	20	0
41	Control	100	20	0
	15 to 35 years			
17	Control, a group from 1 tree	518	30	3.3
	I.B. in talc, 2 mg./gm., 4 groups of 4 trees		30	6.6
	I.B. in talc, 2 mg./gm., 4 groups of 4 trees		30	10.0
	38 years			
13	Control	500	50	10.0
	61 years			
10	Control	132	20	0
	I.B. in talc, 2 mg./gm.		20	5.0
13	Control	50	50	0
27	Control	160	20	0
38	Control	100	20	0
	67 years			
11	Control	100	20	0
25	Control	100	20	0
	90 years			
13	Control	50	25	0

feature which aided understanding of irregular rooting of Norway spruce and eastern white pine cuttings in a previous study, Deuber (3), was a high degree of variability in the inherent ability of cuttings from individual trees to root. This has been termed 'clonal variation' in ability to root. Some evidence also indicates that ability to root may be associated with the vigor of growth of the parent tree or shoots from which the cutting is made, suppressed and weakly growing trees at times yielding cuttings that root more readily than those from vigorous trees.

In the present experiments the cuttings from the younger trees 8 to 12 years old were random samples from stock growing vigorously. In but one group was the rooting response above 10 per cent. One solution treatment with indolebutyric acid did cause one group of cuttings from 10-year old trees to root 25 per cent.

With two collections from trees 15 years old and three from trees 16 years old, fairly consistent rooting occurred in one, Experiment 29. The cuttings of this experiment were from four suppressed trees 15 years old growing in an open stand of oaks. The rooting responses of the cuttings from each of the four trees were not recorded separately, but from the consistency of rooting in eight of the nine groups of cuttings it is probable that each of these trees yielded cuttings with ability to root. Of the 270 cuttings planted, 76 or 27.7 per cent rooted within 158 days. The control groups rooted 36.6 and 40 per cent respectively, and two groups treated with auxin rooted 56.6 and 60 per cent.

In the second test with cuttings of 15-year old trees, Experiment 12, the cuttings were from four moderately vigorous trees. The rooting recorded was with cuttings from but one of the four trees. Low rooting was again found with cuttings from two very vigorous trees 16 years old in Experiment 36.

The two additional collections of cuttings from 16-year old trees, Experiments 13 and 24, were random samples from a clipped hedge. Also, in Experiments 27 and 41, cuttings were obtained from another hedge composed of trees 26 years old. These hedges were long established, and close planting probably introduced serious root competition. It was desired to determine if annual pruning with consequent stimulation of new shoot formation brought about a physiological rejuvenation of these shoots with increased ability to regenerate roots. The results were definite in showing that root formation was not favorably influenced. Although a total of 940 cuttings from the two hedges were planted and given a variety of treatments with auxins, no rooting resulted. Survival of these cuttings was inferior to those from normal trees of the same age classes.

Only a limited demonstration of clonal variation in ability to root was found with cuttings secured from 38 individual trees 15 to 38 years old in Experiments 13 and 17. Ten vigorous trees 18 years old did not yield cuttings that rooted although in the previous year eight of these trees gave cuttings that rooted 5 to 20 per cent. Of ten moderately vigorous trees 38 years old, the cuttings from only one tree rooted. Professor A. J. Riker of the University of Wisconsin supplied the writer with branches of 18 trees selected for the resistance these trees were exhibiting to white pine blister rust. The trees varied in vigor and were 15 to 35 years old. Cuttings from this material received in January survived very well in the propagating bench but were very slow in starting to root. When first dug and inspected after 83 days they were treated with indolebutyric acid in talc. The first rooting of these cuttings was detected after they had been planted 188 days. One cutting had rooted from a tree 20 years old and another from a tree 34 years old. By September 26 or 260 days from planting, one to three cuttings had rooted in the groups from nine trees. The shoot growth of eight of these trees was classed as vigorous or moderately vigorous and of one as weakly vigorous.

A 60-year old tree sampled at various times in 1940 yielded cuttings that rooted 10 to 30 per cent. In four collections from this tree in the present study but one cutting rooted, Experiment 10. Two trees 67 and 90 years old gave no cuttings that rooted.

INFLUENCE OF VARIOUS TREATMENTS UPON THE CUTTINGS OF OLDER STOCK

Numerous tests were made of the effectiveness of treatments with auxins and sucrose of the cuttings of the intermediate and adult trees together with several tests with nitrogenous compounds. The number and variety of these tests is not adequately shown in Table 3 because they were usually not effective when rooting failed to occur in the control cuttings. In other than the results of Experiment 29, with cuttings from trees 15 years old, the rooting responses were too irregular to make comparisons between the effectiveness of the auxin treatments except indications of survival, callus formation or injury.

In Experiment 29, treatment of the cuttings with indolebutyric acid in talc induced an increase in rooting above that secured in the control groups. This method was definitely superior to applying auxin in a lanolin paste or emulsion. Many instances of injury or early decay of the cutting bases were found with the paste applications and the emulsion applications were only rarely effective.

While a number of trials with auxins in aqueous solutions containing 10, 100 or 200 mg./1. of the auxin for periods of 2 to 18 hours were made as well as tests of the pressure method previously described, no consistent improvement in the rooting responses were recorded. Doran *et al.* (5) reported one unusually good result with cuttings of 30-year old white pine trees treated with a high concentration of indolebutyric acid in solution for five hours. Similar treatment of cuttings in this investigation did not prove effective. It is quite possible that considerable variation exists in the manner in which cuttings from different trees respond to auxin treatments.

Toothpicks saturated with alcoholic solutions of auxins, while effective with branch terminal shoots of young stock, rarely induced the rooting of cuttings from older trees. In a number of cases severe chemical injury to the stem tissues at the point of insertion resulted.

When the cuttings were placed in a 1.5 per cent solution of sucrose alone or in combination with indolebutyric acid, rooting was not increased. In a few instances callus formation appeared to be favored by treatment with sucrose.

Several investigators have found that treatment of cuttings with solutions of nitrogenous compounds or a nutrient solution increased rooting. Doak (4) found solutions of certain amino acids and inorganic nitrogen compounds to aid the rooting of rhododendron cuttings, and Grace (8) secured increases in the rooting of Norway spruce cuttings by supplying a complete nutrient solution to the sand during propagation. In two experiments with eastern white pine cuttings, the cuttings were placed in 0.1 per cent solutions of ammonium sulfate, sodium nitrate or urea for 16 hours before planting. While no rooting occurred, the best survival and callus formation was found in the cuttings supplied sodium nitrate. Ammonium sulfate was slightly injurious and retarded callus formation. In Doak's experiments with rhododendron cuttings, ammonium sulfate was superior to the nitrate salt. Recently, Thimann and Poutasse (24) found root formation in leaf cuttings of *Phaseolus vulgaris* promoted especially by adenine and potassium nitrate, while ammonium sulfate had an inhibitory effect.

From the numerous tests with cuttings of eastern white pine trees of intermediate and adult ages, a method or combination of methods was not found that would consistently promote the formation of roots. Unknown internal conditions governing root formation were but rarely favorably influenced by applications of auxins, sucrose or nitrogenous compounds.

TREATMENTS WITH FUNGICIDES

Decay of dormant pine cuttings in the propagating bench is a serious problem. The writer has found no reason to subscribe to the suggestion of Snow (18) that fungi in the propagating medium may be beneficial. Cuttings from some collections are more subject to decay than others and those from older trees are the most susceptible. The latter also require three to five months or more to form roots, thereby increasing the chances for infestation. With greenwood cuttings taken during the summer and propagated in outdoor benches, the time required for root formation is longer than with dormant cuttings. Previously, Deuber (3), the use of peat or peat and sand mixtures was found to be less desirable for propagating media than sand, chiefly because of a greater prevalence of decay with peat or a peat and sand mixture than with clean sand. While the use of fresh clean sand is helpful in preventing decay of the cuttings, rotting of stem bases usually appears within the second or third month. Grace (9) encountered difficulty with decay when using sucrose and reported that treatment of the sand with ethyl mercuric bromide eliminated fungus infestation from Norway spruce cuttings. In the early part of this investigation tests were made of the effectiveness of acidifying the sand, treating the sand with ethyl mercury iodide, and disinfecting the cuttings with mercuric chloride solution or an organic sulfur dust.

When the sand was acidified with acetic acid to give a reaction of pH 4.0, there was no appreciable difference between the number of cuttings that decayed as compared with the controls in sand at pH 6.9. A preparation of ethyl mercury iodide supplied by the Research Department of the Bayer-Semesan Co. was applied to the sand a week before planting pine cuttings. Considerable chemical injury was associated with this treatment. The bark and cambium of the lower portion of the stems became discolored and many of the cuttings died within two months.

One method of disinfecting the cuttings was to stand the bases of the cuttings or to immerse the entire cuttings for five minutes in an acidified solution of mercuric chloride according to the procedure recommended by Leach *et al.* (13) for potato seed pieces. These treatments gave a preliminary protection from fungi but were not entirely free of injurious action. The most successful method tried was one in which the cutting bases were dipped in an organic sulfur dust preparation supplied by the Research Department of the Bayer-Semesan Co. Applications of the sulfur dust preparation did not interfere with previous treatments with solution or dust applications of auxins. The sulfur fungicide gave considerable protection to the cuttings over periods of three to five months and was considered especially useful when new cuttings were planted in sand in which pine cuttings had been previously grown.

THE INFLUENCE OF DORMANCY-BREAKING CHEMICALS

Although the seasonal characteristics for the optimum time to collect eastern white pine cuttings for propagation has not been determined, the general trend in work with dormant cuttings in 1939-1940, Deuber (3), indicated that rooting was more likely to occur when the cuttings were taken in January through March in the vicinity of New Haven, Conn. Norway spruce shoots, on the other hand, reached an optimal state for collection in December. To see if activity of the buds of eastern white pine and Norway spruce shoots could be stimulated and root formation influenced, a few tests were conducted in November and December with the dormancy-breaking chemicals ethylene chlorhydrin and thiourea.

Vapor treatments with ethylene chlorhydrin consisted in placing the cuttings in sealed flasks containing one drop of the chemical per liter for 2, 4 and 25 hours. Norway spruce cuttings were severely injured in all three of the time periods. The pine cuttings did not show early visible signs of injury but within 38 days most of them died without bud development or rooting being influenced. Pine cuttings subjected to a similar concentration of the vapors of ethylene chlorhydrin for periods of 10, 20, 40 and 60 minutes survived for over two months, but neither bud opening nor rooting occurred. Standing the bases of pine and spruce cuttings or immersing the entire cuttings in 2 per cent solutions of thiourea for 1 to 3 hours reduced the survival of the cuttings of both species and did not positively influence bud development or root formation. The preliminary results with these treatments did not warrant additional tests.

THE ROOTING RESPONSES OF OTHER SPECIES OF FIVE-NEEDLED PINES

The relative resistance of various species of five-needled pines to white pine blister rust caused by *Cronartium ribicola* has been under observation for many years. Among the American forest pathologists who have studied this problem are Spaulding (19, 20, 21), Lachmund and Hansbrough (12), and Hirt (10). Since the root regeneration characteristics of all but *Pinus Strobus* appear to be practically unknown, the writer took the opportunity to test the rooting of the shoots of seven species of *Pinus* growing in the Arnold Arboretum. The species tested were: *Pinus monticola, P. parviflora, P. koraiensis, P. peuce, P. Cembra* and *P. Lambertiana*. In addition, a collection of branches from ten trees of *P. Lambertiana* was kindly supplied by Mr. James L. Mielke, U. S. Department of Agriculture, Division of Forest Pathology, from San Francisco, Calif.

Since the number of trees of a given species in the Arnold Arboretum was limited, cuttings were taken from individual trees, and in all but *P. Cembra* they were mature, ranging in age from 32 to 69 years old. Trees of *P. Cembra* 12 and 23 years old were available. The trees from which the California collection of *P. Lambertiana* were secured ranged between 12 and 25 years in age. The data of these tests are recorded in Table 4.

TABLE 4.

ROOTING RESPONSES OF THE CUTTINGS OF SEVEN SPECIES OF FIVE NEEDLED PINES.

Species	Age in years	Total No. cuttings	No. per group	Rooted
				%
P. monticola	56	196	18	5.5
P. monticola	45	120	20	0
P. parviflora	69	80	20	0
P. flexilis	56	80	20	0
P. koraiensis	36	60	15	0
P. peuce	32	220	20	0
P. Cembra	23	200	25	0
*P. Cembra**	12	60	30	30.0
*P. Cembra***	12	60	30	10.0
P. Lambertiana	57	40	20	0
P. Lambertiana	12 to 25	660	30	0

*Cuttings made from shade shoots. **Cuttings made from sun shoots.

Exceedingly limited rooting of the cuttings of these trees was found. This may be attributed to the age of the parent trees or to other unknown circumstances which may also apply to the difficulty in rooting found with the older age classes of eastern white pine. Some of the exotic pine trees were in a vigorous condition, while others were not. The *P. monticola* tree from which one cutting rooted was vigorous and its cuttings survived in large numbers during the first 90 days in the propagating bench. The cuttings from trees of *P. koraiensis, P. flexilis* and *P. parviflora* decayed and died in large numbers. The rooting responses of 30 per cent with shade shoots and 10 per cent with sun shoots of a 12-year old tree of *P. Cembra* is of interest because of the recognized resistance of this species to white pine blister rust, Spaulding (21) and Hirt (10).

The large collection of cuttings of *P. Lambertiana* trees from their natural range in California survived very well for over six months. Callus development was stimulated by several treatments with auxins but no rooting occurred. After six months, chlorosis of the needles became general and many cuttings died. The cuttings of one collection of this species from a tree in the Arnold Arboretum behaved in a similar manner to those collected in California. This preliminary survey of the rooting characteristics of seven species of five-needled pines growing in the Arnold Arboretum and one from its native range indicates that similar problems in root regeneration apply to these species as found with those of eastern white pine trees. The cuttings root with great difficulty.

DISCUSSION

The general results of this investigation indicate that the vegetative propagation of five-needled pines has some very definite limitations. Somewhat over 10,000 dormant cuttings were placed under conditions favorable for root regeneration, but consistent rooting, with a few exceptions, occurred only with cuttings from young trees, 2 to 6 years old. Occasional rooting in relatively low percentages characterized the cuttings secured from trees 7 years old and older. Even cuttings from juvenile stock of these pines do not root as promptly nor as abundantly as cuttings from species that root easily. Unknown features of the shoots or parent trees from which they are obtained make the regeneration of roots an exceedingly uncertain process.

Considerable evidence indicates that standard methods of applying root-inducing chemicals in the form of dusts or solutions are especially effective with cuttings from young trees. These treatments were most effective when the control cuttings were able to root to some extent. The treatments hasten the formation of roots and increase the number of cuttings that root. Hastening root formation is highly significant, for the survival of unrooted cuttings is constantly threatened by drying out and by decay. Delisle (*2*) described some of the histological and anatomical changes induced by auxin treatment of eastern white pine cuttings but concluded that differences in rooting ability between cuttings of young and old trees appeared to be largely of a physiological nature.

Occasionally applications of auxins increased the rooting of cuttings from older trees, but the action was not consistent. The best responses were obtained when the control cuttings possessed some ability to root. A retreatment of cuttings with indolebutyric acid in talc after they had been in the bench two or three months was a favorable practice in several experiments. Supplying sucrose to the cuttings was favorable at times but not consistently so. Placing the cuttings in solutions of nitrogenous compounds did not increase the rooting.

There were some indications, but not conclusive ones, that moderately suppressed trees yield cuttings that root more readily than those from highly vigorous trees. Shade shoots of one *Pinus Cembra* tree rooted much better than sun shoots. These observations appear to be in order with the well established facts that lateral shoots root more readily than terminal and that shoots from lower branches root better than those from near the top of the crown.

Some evidence supports the view that ability to root varies markedly from tree to tree. But the data are not so conclusive as those obtained by Snow (16) with red maple cuttings or for Norway spruce by Deuber (3). In the few instances in which collections of cuttings were made from the same pine trees for two seasons, the rooting responses of the second year's collections were much less than the first. It is therefore not possible to state that adult eastern white pine trees which yield cuttings that root one season will continue to yield cuttings that will root in succeeding years.

From studies of the rooting characteristics of many five-needled pine cuttings over a period of three years, the suggestion is put forth that some factor in the nature of an inhibitor will be found to account for the difficulties experienced in root regeneration. It was found by Jacobs (11) that cuttings from trees of *Pinus radiata* up to 6 years old were the most dependable for propagation purposes. Cuttings with terminal buds containing male cone primordia always failed to root and most of the vigorous shoots of trees 7 to 8 years of age possessed male cones. It was reported by Deuber (3) that shoots of *P. densiflora* from branches bearing young ovulate cones rooted much more abundantly than those from branches without ovulate cones. In the present study, a marked transition appeared to occur in ability to root between eastern white pine cuttings from trees up to 6 years old and those 7 years old or older. The cuttings from 7-year old trees responded to auxin treatment much like cuttings from younger trees. With the exception of a few trees 15 years old, the cuttings from older trees did not respond to any appreciable extent to auxin applications. It is quite possible that such facts as the greater ability of lateral shoots to root than terminal or branch terminals, those from the basal branches of the crown than those from the apical branches, and the more frequent rooting of cuttings from somewhat suppressed trees than very vigorous trees will be explained on the basis of a physiological inhibitor.

In view of the uncertainties with root regeneration with cuttings of older five-needled pine trees, vegetative propagation may for the time be confined to young stock. Nursery or field stock 4 to 6 years old yields sufficient numbers of cuttings to multiply superior types of trees. Stock in these age classes can be tested for resistance to diseases common to juvenile and adult trees as is being done by Hirt (10). Valuable progeny of tree breeding experiments may be increased by vegetative propagation of young stock.

SUMMARY

The rooting of numerous collections of dormant stem cuttings of *Pinus Strobus* were tested as well as those of lesser numbers of cuttings of *P. monticola, P. parviflora, P. flexilis, P. koraiensis, P. peuce, P. Cembra* and *P. Lambertiana.*

Cuttings from eastern white pine trees 2 to 6 years old possessed considerable natural ability to root.

With the exception of a few trees 15 years old, cuttings from trees 8 to 90 years old rooted only occasionally and in relatively low percentages or not at all.

Treatment of the cuttings of young stock with indolebutyric acid or α-naphthaleneacetic acid in talc dusts or in aqueous solutions was effective in hastening and increasing the rooting responses.

Similar treatments with cuttings from older trees were somewhat effective in a few collections but not consistently so.

Indolebutyric acid supplied in lanolin paste or in lanolin emulsion was generally unsatisfactory. In many cases injury to the stem bases occurred with the paste applications.

Ends of toothpicks saturated with alcholic solutions of indolebutyric acid or α-naphthaleneacetic acid inserted in the bases of cuttings made from branch terminal shoots of 6-year old trees were effective in inducing root formation. Similar treatment of cuttings from lateral shoots of older trees generally produced chemical injury.

Supplying sucrose to the cuttings with or without auxin did not appreciably influence root formation.

Placing the cuttings in solutions of ammonium sulfate, sodium nitrate or urea, preliminary to planting, did not increase the formation of roots. Sodium nitrate was favorable to callus development while ammonium sulfate was slightly injurious.

Cuttings secured from eastern white pine hedges pruned annually did not root as satisfactorily as those from normal trees of the same age.

Some evidence of clonal variation in rooting ability was found among various collections of cuttings from individual trees.

Dipping the bases of cuttings in an organic sulfur fungicide gave the most satisfactory protection against decay.

The dormancy-breaking chemicals ethylene chlorhydrin and thiourea were not effective in forcing the development of buds or roots.

Cuttings from adult trees of *Pinus parviflora, P. flexilis, P. koraiensis, P. peuce, P. Cembra* and *P. Lambertiana* did not root.

Low rooting occurred in one collection of cuttings from one tree of *P. monticola.*

The shade shoots of a *P. Cembra* tree 12 years old rooted considerably better than sun shoots.

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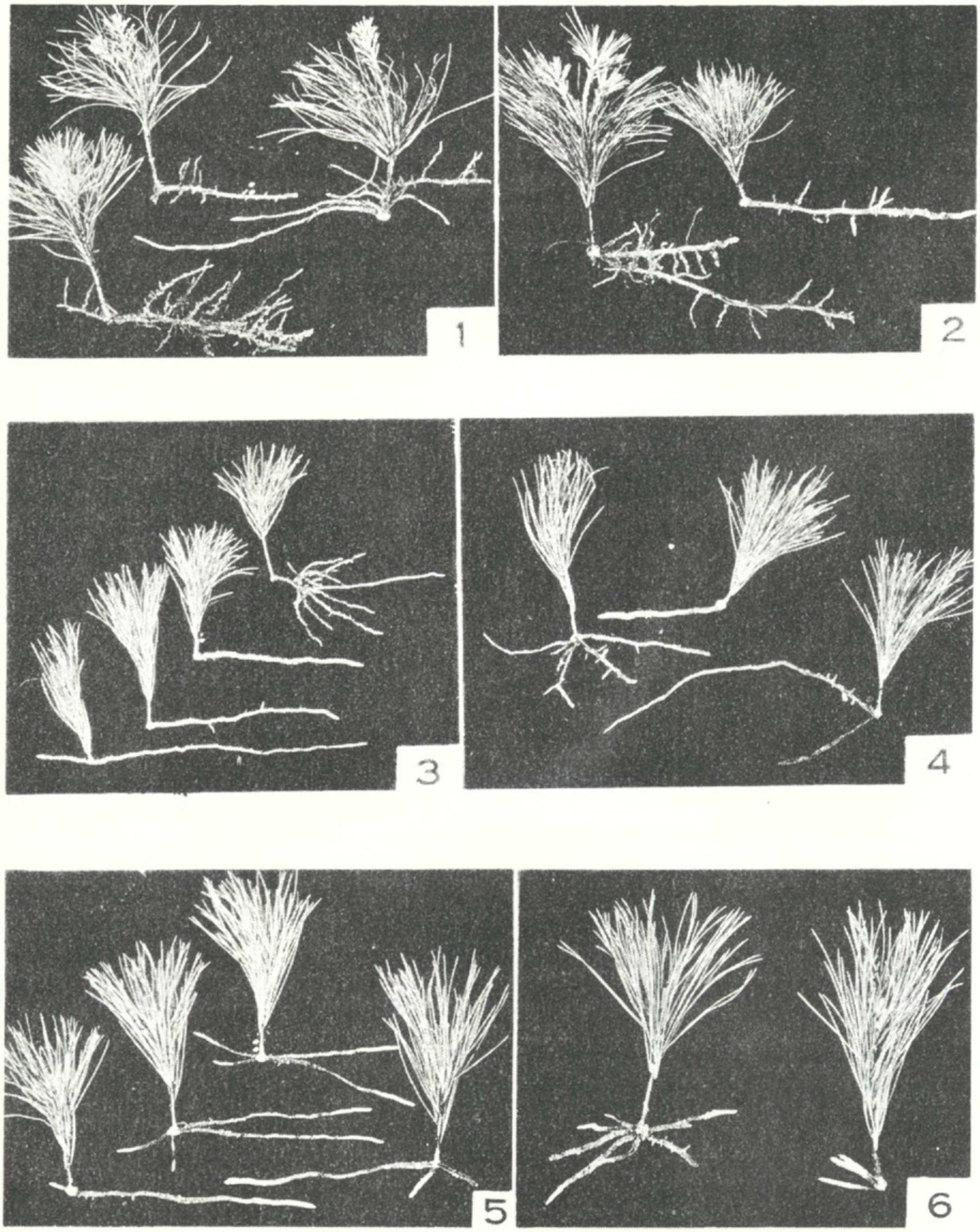

Deuber, Vegetative Propagation of Eastern White Pine

FULL-TONE — MERIDEN

EXPLANATION OF PLATE

Pinus Strobus cuttings from trees 2 to 7 years old. Planted in January and photographed after 134 days in the propagation bench.

Fig. 1. Cuttings made from terminal shoots of trees 2 years old. No chemical treatment.

Fig. 2. Cuttings from trees 3 years old, the one on the left from a terminal shoot, the one on the right from a lateral shoot. No chemical treatment. In these and the cuttings in Fig. 1 lateral root development was much more advanced than in cuttings from older trees.

Fig. 3. Cuttings from trees 4 years old made from lateral shoots. No chemical treatment.

Fig. 4. Cuttings from trees 5 years old made from lateral shoots. Treated with indolebutyric acid in talc.

Fig. 5. Cuttings from trees 6 years old made from lateral shoots. Treated with indolebutyric acid in talc.

Fig. 6. Cuttings from trees 7 years old made from lateral shoots. Treated with indolebutyric acid in talc.

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