

A STUDY OF THE HARVARD FOREST
PLANTATIONS 1909-1931

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INTRODUCTION

In 1908 when the Harvard Forest was first acquired, there were about 100 acres of old fields and pastures on the property. Planting on these was begun on a small scale in 1909 and the volume of yearly planting increased as time went on. Later, where cuttings failed to produce suitable reproduction, planting was resorted to in order to insure complete stands. The early plantings were made at a time when little was known in this country about planting methods and their results. Consequently many methods, stock sizes, species, etc. were tried in an effort to find which were best. Fairly complete records of all plantings on the Harvard Forest were kept, and at the present time when the oldest plantings have reached an age of twenty-five years, it was felt that much valuable information could be obtained through a study of the results of all these plantations.

The plantations have been made under a wide variety of conditions and for different purposes. In general, two classes are recognized. Experimental plantings include mixtures of several species to determine their behavior, a small exotic arboretum to test the adaptation of the species to the region, a planting method experiment with two species on the same site planted by several methods, and a spacing experiment to determine the rate of growth with different spacings of the same species on the same site. Plantations for the production of sawtimber have been established on cut-over lands and old fields.

There are two distinct types of cutover lands: those cut for sawtimber and those for cordwood. The second crop on cutover sawtimber lands is dependent upon the advance growth which started before logging and the few desirable species which seed in during the years immediately following the operation. Stump sprouts from large

stools form the natural reproduction on cordwood land; and due to their coarseness and to the rot which comes into them from the decaying stools, these are of no value for future timber production (). Experience has shown that successful group plantations can be developed on cutover sawtimber land by planting only the portions of the area where the hardwood is scanty or of poor quality, and on cordwood cuttings by using wide spacing and avoiding hardwood sprout clumps, planting in the best places only. The hardwood maintains the high density necessary for the production of desirable form and quality of the planted trees. Good form and quality is obtained in old field plantations only by closer spacing and at correspondingly higher planting costs.

Conditions on the old fields were fairly uniform, the greatest variations being in the amounts of low vegetation and brush present. These areas, of course, required complete planting.

The soils of the Harvard Forest are quite uniform with the exception of a small area of sandy esker in the Tom Swamp Block. They fall in the loam and sand loam classes of the Gloucester, Hinckley, Whitman, Charlton, and Merrimac groups (). Mechanical analyses made on the Forest in 1930 showed all of the soils except the sandy eskers to be sand loams ().

Early plantings were made pure on small old fields. It was not until 1914 that the first mixed planting was made with Norway spruce and white pine. This was on cutover land. It is interesting to note that until a comparatively recent date the usual size of the plantations ranged from a fraction of an acre to a maximum of four acres. Later plantings are larger, running up to twenty-nine acres, and include mainly cutover areas.

Of a total of 1975 acres of land on the Harvard Forest, 293 acres have been planted wholly or in groupwise mixtures with hardwood.

Method of Study

Data were obtained from office records and from observations and measurements taken in the field. The original records supplied necessary information as to year of planting, area planted, amount and size of stock, planting conditions, and costs. Later records described any operations or inspections carried on in each plantation. Field data include the measurement of 114 plots in 91 plantations. Some areas necessitated more than one plot to cover the range of conditions. The size of the plots ranged from one-fortieth to one-quarter acre depending on the density and uniformity of the stand. All plots were rectangular and were laid out with a staff compass and tape. Each corner was temporarily marked with a stake, and one corner is permanently located for future reference. The younger plantations required only three measurements: height, crown width, and leader length. In older plantings a certain number of sample trees, depending upon the height range, were recorded by height, diameter breast high, diameter at half the total height above breast height, crown class, crown width, average knot size, dead length, and leader length. The remaining trees were measured for d.b.h., and the crown class was recorded. A curve of height on d.b.h. was always drawn in the field to make sure that the full height range and sufficient data were represented in the sample trees. (Report of Comm. on Growth and Yield, 1926). Additional observations in each plot included density of the low vegetation, herbaceous and woody, and competition of hardwood.

In the office averages were computed from the younger plantations, and in the older ones average dimensions were obtained from a series of independent curves based on d.b.h. Site index curves were developed as a basis for classification of the plots.

DEVELOPMENT OF PLANTATIONS

Seed Source

Until 1925 the records included only an occasional mention of seed source. Since then a careful record has been kept; but owing to the age of the plantings, no appreciable difference has developed to date.

Two Scotch pine plantations, aged seven and ten years, were planted on cutover land with seed from Sweden and the Riga region respectively. Both had very straight stems. Two older plantings, eighteen and twenty-four years old, on old fields with seed presumably from central Europe were very crooked and forked from the start. Two other plantings of the same type were cut because of poor form.

Stock and Establishment

Stock Age and Survival

The relation between stock age and survival was indicated by the percentage of failures in the original plantings. An arbitrary standard of ninety per cent or over was set for a successful plantation. Plots were separated according to the age class of stock and the percentage of successful plantations in each group calculated. The results are shown in Table .

Table 1
Relation of Stock Age to Survival
Old Field Plantations

Species	Stock age	No. of plots	% of plots with survival over 90%
Red pine	2-1	3	100
	2-2	10	100
	2-3	4	100
White pine	2-0	2	100
	3-0	2	100
	2-1	7	43
	2-2	4	100
Scotch pine	2-0	1	0
	1-1	1	100
White spruce	3-0	4	25
	2-1	2	0
	2-2	3	100
	3-2	1	100
Norway spruce	2-1	2	100
	3-1	1	100
	2-2	3	66*
	2-3	1	100
European larch	1-1	1	100
	2-0	2	100
	2-1	5	100
	1-1-1	3	100
	2-2	1	100

* Poor stock.

Cutover land plantations

Species	Stock age	No. of plots	% of plots with survival over 90%
Red pine	2-2	14	93
	2-3	6	100
White pine	3-0	1	100
	2-1	3	100
	2-2	15	100
Scotch pine	2-0	1	100
	3-0	2	50
	2-1	1	100
	3-1	1	100
	2-2	1	100
White spruce	3-0	4	0
	2-2	7	86*
	2-3	1	100
Norway spruce	3-0	2	0
	2-1	1	100
	2-2	7	100
	2-1-1	1	100
	2-2-1	1	100
European larch	2-0	3	66* *
	2-1	3	100

* * One bad case of frost damage.

* One case of stock dried out in shipment.

White spruce planted with 3-0 and 2-1 stock on old fields proved to have the greatest numbers of failures. Three out of four plantations with this size of stock had to be filled in and all of the 2-1 plantations had to be partially replanted. These failures were apparently due to the inability of the small stock to compete with the heavy grass on the areas.

Planting Methods

The establishment of the earlier plantations on the Forest was accomplished by several variations of mattock planting, most of which have been successful. The terms used to distinguish these variations are mattock, mattock slit, and mattock side hole. Sod may be removed or left on in any of these methods.

1. Mattock Hole

With this method a hole is dug large enough to accommodate the roots when spread out naturally. The roots are placed in the hole at the proper depth and earth packed tightly around them.

2. Mattock Slit, Sod Off

A square foot of sod is cut away and the blade driven as deeply as possible into the ground with one stroke. The earth is lifted by a twist or pull of the mattock, leaving a hole into which the roots of the seedlings are slipped. The mattock is then removed allowing the earth to fall back into place. It is then firmed by stamping.

3. Mattock Slit, Sod On

This is exactly like the above method except that the sod is left intact.

4. Mattock Side Hole

A small hole is dug with one side as nearly vertical as possible. The tree is held against this side with one hand while the other is used to place earth over the roots and firm it.

5. Harvard Forest Planting Tool

This tool has been used in making all plantings on the Forest since 1924. It consists of a blade of boiler plate about $5\frac{1}{2}$ " x $5\frac{1}{2}$ " having a slotted iron pipe crossbar on its upper edge to regulate the depth of the hole. A socket of $1/8$ " steel is riveted over the crossbar onto the blade and a peavy handle fitted into it (Fig.).

Mr. W. E. Sanderson, formerly of the New York State College of Forestry, designed and first used this tool. Mr. A. C. Cline, Assistant Director of the Harvard Forest, introduced it into New England and has described its use in an unpublished manuscript. He says that while good holes can be made with a mattock, it is a great deal easier to make poor ones, and that the tendency of unskilled labor, especially when made to speed up, is to make a hole the easiest way possible.

In rough and uneven ground where hidden rocks and roots lie just under the surface, mattock planting is a slow and expensive process. What is needed is a tool, easy to use, and giving uniformly good results under a wide range of conditions with ordinary labor. The planting tool seems to be a close approach to this ideal. One of its outstanding advantages is the uniformity in size and shape of the holes. This feature is accomplished by the design of the tool itself rather than by the will of the workman. The crossbar prevents the tool from being driven deeper than the length of the blade, thus regulating the depth of the hole, while the width of the blade and the sidewise movements control the other dimensions. Contrary to expectations, the hole in cross section is not wedge shaped, wide at the top and narrow at the bottom, but rather it approximates the

shape of an hour glass, and the greater the arc through which the handle is moved, the wider are the openings made at the top and bottom. The plant is lowered vertically into the hole, shaken a few times to spread the roots, then held in place while the earth is firmed by stamping with the heel on either side of the hole. Care must be taken to avoid drawing the roots from the side into the hole. This forms a rope-like mass of roots resulting in poor anchorage and death to at least a portion of the root system.

The planting tool has a further advantage over the mattock in its greater ease of handling. It was purposely made heavy (about nine pounds) so that its own weight would assist the planter in driving the blade into the ground. The sharpened steel blade cuts through roots with little effort and the strong handle and socket make it possible to pry small rocks out of the way and to force holes through the toughest cover. The planter works in a comfortable, upright position and is able to "feel out" the ground for hidden rocks in order to find a suitable place to make a hole. Greater ease of handling makes for faster planting; and under favorable conditions, such as open land free from stones, one man can make holes as fast as two can set trees.

Notwithstanding the advantages just enumerated, there remains the all important question of results. This tool has been used exclusively on the Forest since 1924, and during this time sixty-one plantations, totaling over 200 acres, have been made, only fourteen of which required filling in. These failures can be traced directly to poor stock.

Planting Method Experiments

Experiments were conducted on two areas to determine the effect of planting methods on the survival and growth of several species. The first, discussed by Carter () was established in 1913 on a nearly level pasture covered with closely cropped grass and patches of sweet fern. Several rows of white pine, Scotch pine, Norway spruce, Douglas fir, and western yellow pine were planted with each method. The planting methods were mattock hole, slit sod off and slit sod on. Three-year transplants in good condition were used.

In 1913 and 1914 the rows were inspected and a record of the condition and survival of each tree was made. In 1931 all trees in two rows in each planting method of white pine and Norway spruce were measured for d.b.h., height, and growth. Survival was again recorded. The average growth measurements (Table) show comparatively little difference in either species, indicating that planting methods have no effect on size. However, results in terms of survival are striking. The percentage of survival is higher in white pine, and in both species the greatest survival was found in the mattock hole rows followed by slit sod off and slit sod on respectively. This agrees with German experiments () covering twenty years using oblique planting with a mattock. This method is very similar to the mattock slit as used here. It gave good results with seedling stock on cut-over lands but was not found adaptable to transplant stock or planting on sod land ().

As was to be expected, nearly all failures in the two species occurred during the first two years after planting and the present survival is practically the same as recorded seventeen years ago.

The second area was similar to the first. Red and white pine in alternate rows were planted by four mattock methods: careful mattock hole, side hole and slits, sod on and sod off. The results again show no size difference within the species for the different planting methods. Survival was higher with red pine, but there was so little variation between the results of planting methods that comparisons are inconclusive. The lowest survival with red pine was ninety-one per cent and with white pine, seventy-nine per cent.

Table

Survival of Stock Planted by Different Methods

Per cent Survival

Age from seed	Mattock Hole	Slit sod off	Slit sod on
<u>White Pine</u>			
4	99	79	60
5	94	77	58
22	86	69	53
<u>Norway Spruce</u>			
4	81	68	42
5	78	61	41
22	77	61	40

Development of Root Systems

The survival and early growth of planted trees depends largely upon the development of their root systems. In natural stands roots are developed where they will most benefit the tree and extend vertically and horizontally according to the character of the soil profile and the location of nutrients and water. There is a general tendency to either plant too deep or to wad the roots up. The holes are not

always the proper shape or size, and the great variation in stock and the length of their roots makes it increasingly difficult to plant so the tree can most advantageously make use of its initial root system. Following deep planting a secondary root system must be developed at the proper depth, with the result that early growth is considerably slowed down and death often results during this period.

To determine the response of root systems to planting and to compare them with those in natural stands, several trees each of white pine, red pine, and white spruce in both types of stand were dug up, the roots examined and photographed. All trees of a species grew on comparable sites. Those in plantations were planted with the planting tool.

1. White Spruce

Old field white spruce, nine years old, was obtained in northern New Hampshire from a site similar to the old fields in Petersham (Fig.). The root system is very shallow, starting within one inch of the ground line and continuing horizontally at a depth of two inches or above. Where the original roots of planted white spruce of the same age on old fields were somewhat deeper with the topmost roots at a depth of three inches, the secondary root system developed one inch below the ground line and approximated the trend of the natural spruce. Where the topmost original roots were at a depth of one inch, no secondary system was formed (Fig.). The secondary system eventually takes the place of the original one. Spruce suffers most of any species studied from deep planting and should be planted in a wide, shallow hole with the roots well spread.

2. Red Pine

Red pine, about nine years old, planted and natural, was taken from a light soil because of the lack of natural stock on the heavier soils in the region. Roots on the natural pines start one to two inches below the ground line and gradually grow deeper (Fig.). It takes deeper planting to cause red pine to develop a secondary root system than spruce. Trees planted with the topmost roots three inches or less below the surface continue to develop the original system. However, observation has shown that planting at depths of five inches or more causes either the development of secondary roots or the death of the tree. In all the planted trees a strong vertical system is developing, although not so advanced as in natural stock of the same age.

3. White pine

Roots of natural white pine start at or even above the ground level but go down deeper than those of white spruce. Planting with the topmost original roots at a depth of four to five inches causes the development of a secondary system at normal depth (Fig.).

From these investigations it may be seen that the proper planting of each species on each site is a problem in itself, and too much care cannot be taken in properly placing the root systems. If they are planted at the normal depth with the roots well spread, the best growth results, and losses from root-rotting fungi are kept at a minimum.

Yellowing of White Spruce Following Planting

A contrast in the color of white spruce planted in the spring of 1931 was very striking. Some were deep green, some a pale yellow, and the rest between the two in color. This condition was first thought to be due to poor planting; but after digging up several specimens of each color, it was found that this was not the case.

Two hundred trees selected at random were recorded as to color, proximity to stumps, amount of shading, the presence or absence of slash, and, in the latter case, if it had been burned. When separated according to these classifications, 91 trees remained without overlapping of the factors considered. When separated according to burned or unburned areas, it was found that the same proportion of one burned to two unburned held whether the trees were yellow, intermediate or green in color. So data from the two areas were combined and reclassified according to the color of the spruce as shown in the following table.

Table , Classification of planted white spruce according to color, shading, etc.

	Open	Green (Number)		Total
		Half shade	Full shade	
Slash*	1	3	4	8
Stumps**	3	8	3	14
Rubus***	2	14	22	38
Vaccinium#	0	0	3	3
Totals	6	25	32	63
		Intermediate		
Slash	0	1	0	1
Stumps	0	3	0	3
Rubus	4	8	0	12
Vaccinium	0	0	1	1
Totals	4	12	1	17
		Yellow		
Slash	0	0	0	0
Stumps	3	0	0	3
Rubus	6	2	0	8
Vaccinium	0	0	0	0
Totals	9	2	0	11

* Trees planted in slash.

** Trees planted within 2' of a stump.

*** Trees in beds of Rubus prostratum.

Trees in beds of Vaccinium pennsylvanicum.

This classification shows that all trees growing in the open tend to be yellow, while those in the full shade of young hardwood sprouts are practically all green. Half shade produces results between the two in color. Under Vaccinium there were not enough trees to draw any deductions. In trees growing in slash there was a marked tendency for those in all degrees of overhead shade to be green. While the trend is not so clear, there is a tendency for trees within two feet of stumps to be green. It was thought that the presence of Rubus prostratum indicated abundant nitrification, which should show in the color of the trees. However, in the open, there was a very marked tendency for the trees to be yellow, while in the half and full shade the tendency was reversed, being much stronger in the full shade. This seems to indicate in another way the importance of shade. A recent study by Marshall () shows in this connection that of twelve species of young coniferous seedlings, white spruce wilted at the highest water content of the soil.

Precipitation and Survival

It was thought that precipitation of the winter previous to planting and of the growing season following might influence the survival of planted stock. Precipitation was calculated for three periods: the December-March total, total for the two weeks before planting, and that for the two weeks after, and for the last half of May, June, and July following planting. From records kept at the Forest headquarters an average was determined for this eight-month period, assuming May first as the average planting date. The deviation in inches and tenths of inches for each year was computed from this average and compared with survival in plantations with 2-2 stock of red pine and white spruce. In twenty-four red pine plantings, twenty-three had a survival of more than

ninety per cent, and one had been filled in. Fifteen of these were planted during periods with subnormal rainfall ranging to minus 5.3 inches. Nine plots had supernormal rainfall up to a maximum of 9.1 inches, and the one plantation requiring filling in and having a survival of eighty-two per cent was made during a period with an excess of 1.3 inches of rain. Of ten 2-2 plantations of white spruce, nine had a survival of over ninety per cent. Three of these were planted during periods with a deficiency of precipitation, the greatest being 8.6 inches. The only plantation filled in was planted with badly dried out stock during a period of practically average rainfall. This record of plantings shows that there is enough precipitation during even the driest years to insure successful plantations if other conditions are favorable.

Low Vegetation as Affecting Survival and Growth

Low vegetation affects planted trees in several ways. Heavy vegetation is a hindrance to good planting. Its root competition is a check on the growth of the planted stock; and if the vegetation is tall and dense enough, its shade causes decreased growth. Low vegetation includes grasses, ferns, sweet fern, Ericaceous shrubs, mosses, Spiraea, and miscellaneous herbs, but excludes the species which will eventually become trees or large shrubs.

Of the total number of plantations on the Forest, eighty-three per cent were not filled in. A wide variety in composition and density of ground vegetation is represented, indicating no pronounced effect on survival. An exception to this is a planting of European larch in which a part was in dense raspberry briars. There were very few survivals after three growing seasons, although the rest of the plantation was very successful.

The effect of shade on growth is indicated by a planting of red pine and white spruce in an area partly covered with dense Solidago sp. In this golden rod the white spruce averaged 1.7 feet in height as compared with 2.3 feet outside, and the red pine averaged 2.5 feet in height as contrasted with 4.4 feet in the open areas.

Crown Width:

The term crown width which at any age determines the relative crown and diameter development is largely a result of the growing space available to the tree and is defined as the average, maximum crown diameter measured horizontally (11). These measurements for the species studied are presented in the following table:

Table , Average Crown Width in Feet (from curves)

Age	Red Pine		White Pine		Scotch Pine		White Spruce		Norway Spruce		Eur. Larch	
	O.F.	C.O.	O.F.	C.O.	O.F.	C.O.	O.F.	C.O.	O.F.	C.O.	O.F.	C.O.
3												.3
4												.6
5		.3										1.0
6		.5		.8				.6				1.3
7		.7		1.2		1.7		.8			1.6	1.6
8	1.5	1.0		1.6		1.9		1.0			2.2	2.0
9	2.4	1.3		2.0	3.3	2.1	1.2	1.1		1.4	2.7	2.3
10	3.2	1.7	3.7	2.4	3.6	2.2	1.6	1.2	2.0	1.8	3.2	2.6
11	3.9	2.1	4.1	2.8	4.0	2.3	2.0	1.3	2.6	2.2	3.7	
12	4.6	2.5	4.6	3.3	4.5				3.2	2.7	4.2	
13	5.2	3.0	5.0	3.7	5.0				3.7	3.1	4.7	
14	5.7	3.5	5.4	4.1	5.4				4.2	3.5	5.1	
15	6.2	4.0	5.8	4.5	5.8				4.8	3.9	5.6	
16	6.6	4.6	6.1	4.8	6.2				5.3	4.3	6.0	
17	7.0	5.2	6.4	5.2	6.6				5.8	4.7	6.4	
18	7.4	5.8	6.7	5.5	6.9				6.2	5.0	6.7	
19	7.7		7.0	5.9	7.2				6.6	5.4	7.1	
20	7.9		7.2	6.2	7.6				7.0	5.7	7.4	
21			7.4	6.5	7.9				7.4	6.0	7.7	
22			7.6	6.9	8.1				7.7	6.3	8.0	
23			7.7									
24			7.8									
25			7.9									
No. Plots	16	22	12	18	4	6	12	11	7	11	7	5

By comparing crown widths of various species on old fields at the common age of ten years, it is apparent that the three pines as a group have the greatest dimensions, white pine being the largest followed closely in order by Scotch and red. European larch is the same as red pine and then come Norway and white spruce, both being over a foot less in average crown diameters. Crown widths on cutover land are highest with European larch followed by white pine, Scotch pine, Norway spruce, red pine, and white spruce, diameters in each species being considerably smaller than on old fields.

Red pine shows the greatest reduction of crown width on cutover lands as compared to old fields, the variation at twelve years being two feet. In white pine at the same age the difference is only 1.2 feet. The effect of the hardwood sprouts on Norway spruce is much less, the difference in the crown diameters at twelve years being only .5 feet. However, this increases somewhat in later years. Data on white spruce, Scotch pine, and European larch were too few to bring out a comparison.

Measurements in the four white pine spacing experiment plots show that crown width increases with the square of the spacing as given in the following table:

Table

Variation of Average Crown Width
with Growing Space

Growing Space square feet	Average Crown Width feet
9	4.4
16	4.9
25	6.1
36	8.6

Average Diameter Breast High as Controlled by Growing Space

The growing space available for a tree exerts a tremendous influence on the diameter at breast height (). Spacing of the stems and age of the stand together with the development of the crowns determine the diameter growth rate of the stem. Table shows the relation of age and number of trees per acre to average d.b.h. on varying sites.

Table

Relation of Diameter Breast High to Number of Trees
per acre, Age, and Site Index

Pure Stands, Old Fields

Species	Age	Site Index	Trees per Acre	Av. D.B.H.
Red pine	15	25	1680	2.4
	15	23	920	2.5
	17	19	900	2.5
	17	23	1180	3.1
	20	21	1412	4.3
	20	21	1334	4.2
White pine	17	18	1760	2.9
	20	20	3942*	2.5
	20	21	3214*	2.7
	20	20	2533*	2.9
	20	21	2157*	3.2
	20	20	1551*	3.5
	20	21	1238	3.6
	20	21	1080*	3.6
	20	18	840	3.8
	23-24	17	1540	3.8
	25	16	1180	4.3
25	15	1140	4.7	

* Plots from spacing experiment

Table (Cont.)

<u>Species</u>	<u>Age</u>	<u>Site Index</u>	<u>Trees per Acre</u>	<u>Av. D.B.H.</u>
Scotch pine	21	18	1680	6.1
	22	24	940	7.7
Norway spruce	18	21	1000	2.5
	20	21	1248	3.7
	22	14	1700	3.3
European larch	20	35	860	4.5
	20	40	826	5.0
	20	33	800	4.5
	20	34	680	4.1
	20	29	600	5.8
	22	34	540	6.0

Pure Stands, Cutover Lands

Red Pine	15	24	1340	2.4
	15	20	660	1.3
	15	23	640	1.8
	16	22	680	2.1
	18	20	860	3.3
	18	20	620	2.5
	White pine	19	18	980

An experimental field planting, now twenty years old, on a uniform site where white pine was planted exactly 3 x 3, 4 x 4, 5 x 5, and 6 x 6 showed clearly the effect of growing space on diameter breast high. The starred plots of Table show the relation of growing space and diameter breast high.

Current and Total Height Growth

Leader length, the current height growth for a given year, is dependent upon several factors which, in combination, increase or retard growth. Height growth occurs during only a few weeks in the summer, and the length of the period is affected by precipitation, temperature, and amount of sunlight. The end of this period marks the culmination of all height growth for that year, unless later favorable growth conditions cause a secondary growth on certain individuals.

In an attempt to correlate height growth of larch seedlings to weather conditions, D. R. Brewster () measured the yearly growth on several sample plots in northern Idaho over a period of five years, keeping careful weather records. At the end of the experiment he concluded that, of the necessary factors - precipitation, temperature, and sunlight - no one alone directly affects growth, but rather the right combination of all factors is required.

Further study during four years by H. I. Baldwin () with several conifers over a wide range of territory in New England shows that soil and air temperatures exert the greatest influence in determining the beginning and rapidity of height growth. Shading and late frost have a marked effect in retarding the start of growth. Much depends on the crown class of the tree. If sunlight is partially cut off, growth is very slow at the start, and a slow rate may continue through the growing season; while a tree a few feet away receiving full light will get off to an early start, and its total growth will be much greater.

Under the conditions in the present study the factor of shading can be considered as effective on cutover lands as contrasted to old field plantings. This is shown in the majority of cases by the fact that the old field height growth is greater for a given species and stock age than on cutover lands. The data on leader length for the various species, stock ages, and total ages are given for old field and cutover stands in Table . There seems to be a tendency for larger stock ages to produce greater leader lengths at a given age, but the data are too variable and scattered to give definite conclusions.

Site index curves showing the range of total height developed at any age, were constructed for each species according to the method described by Bull (). All curves were made on the basis of a twenty-

Table . Total Heights at Five-year Intervals
of the Important Species Studied

Age in Years	<u>Red pine</u>		S i t e I n d e x			Based on 36 plots
	12	15	18	21	24	
	Total height in feet					
5	.4	.6	.7	.8	1.0	
10	1.4	2.3	3.3	4.2	5.2	
15	4.6	6.8	8.7	10.9	13.0	
20	12	15	18	21	24	

White pine, cutover

5		.6	1.5			Based on 17 plots
10		3.8	5.2			
15		8.9	11.0			
20		15	18			

White pine, old field

10		4.6	5.4	6.3		Based on 20 plots
15		9.0	10.7	12.6		
20		15	18	21		
25		22.1	26.8	31.4		

Scotch pine

10		3.4	4.1	4.9	5.6	Based on 10 plots
15		7.6	9.5	11.6	13.5	
20		15	18	21	24	

Norway Spruce

5	.3	.6	1.0	1.3		Based on 18 plots
10	1.9	3.2	4.2	5.1		
15	5.4	7.6	9.9	12.2		
20	12	15	18	21		

White spruce

	S i t e		I n d e x			
	1	2	3	4	5	
	Total height in feet					
5	.1	.3	.5	.7	1.0	Based on 23 plots
10	1	2	3	4	5	

European Larch

	S i t e		I n d e x			
	20	25	30	35	40	
	Total height in feet					
5	1.0	1.4	1.7	2.0	2.3	Based on 14 plots
10	4.2	5.6	7.1	8.4	9.7	
15	10.5	13.7	16.8	20.0	23.0	
20	20	25	30	35	40	

Table

Leader Length and Age for Varying Stock Sizes

	R e d P i n e				W h i t e P i n e						S c o t c h P i n e							
	2-3		2-2*		2-1		2-2		2-1		3-0		2-2		2-1		3-0	
	OF	CO	OF	CO	OF	CO	OF	CO	OF	CO	OF	CO	OF	CO	OF	CO	OF	CO
5			.4	.6														
6			.6	.7				.6 ¹										
7			.7	.8				1.0 ¹					.8 ¹					
8			.9	.8				.9 ⁴										
9			1.1	.9				.9 ²										
10			1.3	1.0				1.0 ³				.8 ¹			.9 ¹			.7 ¹
11			1.6	1.1	1.8 ¹			1.6 ²										
12				1.1						1.3 ¹								
13				1.3														
14				1.4														
15	2.2 ²	1.6 ²		1.6				1.3 ¹										
16		1.1 ²																
17	2.2 ²							1.3 ¹										
18		1.6 ²																
19								1.0 ¹										
20								1.0 ¹										1.3 ¹
21																		1.2 ¹
22																		
23																		
24																		
25								1.0 ¹										

* Based on curves for sixteen trees each

OF= old field

CO = cutover

year index except white spruce, which, due to the young age of all plots, was based on ten years. Except in the white pine, data for old field and cutover land were combined, since little variation could be found between the two types.

Table , based on five-year intervals, shows the corresponding growth rates between species. At the common age of ten years the species arranged by heights in descending order are European larch, white pine (old field), Scotch pine, white pine (cutover), Norway spruce, and white spruce. At twenty years the greatest height growth is still held by European larch followed by red pine, Scotch pine, white pine (old field), Norway spruce, and white pine (cutover).

Differentiation

Differentiation is a relative term concerned with the variation in development of individuals in the stand. A stand with trees of all crown classes well distributed is said to have dominance well expressed, while one in which the trees are all equal in crown development has little expression of dominance. Good differentiation is necessary to make a sufficient number of trees free to grow in the upper crown classes, thus doing away with the necessity for early thinnings to prevent growth stagnation. Deen () explains that a large number of trees per acre alone does not necessarily result in lack of differentiation and resulting stagnation. He found that the standard deviation of diameter breast high, when supplemented by average age is a good criterion of differentiation, the larger deviations being associated with stands having good differentiation. The standard deviation of height can also be used, there being little difference in correlation between the two standard deviations. He states that the only stage

of stand development in which variation in height is discernible is during the first ten to twelve years, when the observer can look over the tops and note the appearance of the canopy.

During the course of the present study ocular observations on differentiation of height in the plots were made and recorded as "even", "little", or "marked". A comparison of the results with the standard deviation of diameter breast high shows that ocular measurements are not satisfactory and that except at the extremes differentiation is not easily discernible.

Deen states that differentiation is caused in a measure by site quality, and the best expression of dominance is found on the better sites. With the uniformity of site on the Forest this factor may be disregarded, and with three exceptions on a gravelly esker all plantations can be considered as growing on similar sites.

Standard deviation of height was used for determining differentiation in the younger plantations in which diameter measurements could not be taken. The standard deviation of d.b.h. was used for the older plots.

The data summarized in Table show the increase in differentiation with age and with the number of trees per acre. All plots represented are for pure stands only.

There were too few plots comparable in old field and cutover plantings to show the variation in differentiation, but the available information indicates a slightly greater expression of dominance on cutover land.

For the purpose of comparing species, standard deviation of d.b.h. is used throughout. In the twenty-year age class, with 1001 to 1500 trees per acre, white pine has an average standard deviation of .95; red pine, .87; Norway spruce, .79. Japanese larch twenty years old with 501 to 1000 trees per acre has a standard deviation of 1.35; while with

Standard Deviations of Diameter Breast High and Height
for Different Species, Ages, and Number of Trees per Acre

Age	Trees/A	Old Field		Cut Over		S.I.
		by Ht.	by D.b.h.	by Ht.	by D.b.h.	
<u>Red Pine</u>						
8	360	.80				22
	1040			.43		23
9	600			.73		20
	820		.74			23
10	600	.73				23
	820			.93		19
15	820			1.09		23
	1080			.68		20
16	500			.68		21
	920			.62		19
17	920		.57			23
	1340				.49	24
18	640				.43	23
	660			2.6		20
19	920			1.37		12
	680				.53	22
20	1180		.81			23
	900		.69			19
21	620				1.04	20
	860				.83	20
22	1344		.84			21
	1290		.90			21
<u>White Pine</u>						
8	560			.87		16
	480			.62		16
9	700			.72		16
	500			.86		17
10	1200			1.48	Fair stock	16
11	1260	1.58				21
12	1440	1.87				20
13	760			1.87		14
14	1760		.73			18
15	980				1.04	18
16	3942	1.74	.72			20
	3214	2.96	.79			21
17	2533	1.97	.85			20
	2157	1.97	.87			21
18	1551	1.58	.96			20
	1080	2.1	.94			21
19	340		.97			18
	1238	.96				21
20	1540	1.00				17
21	1180	1.24				16
	1140	1.40				15

Table (Cont.)

Age	Trees/A	Old Field		Cut Over		S.I.
		Av. Dev. by Ht.	by D.b.h.	Av. Dev. by Ht.	by D.b.h.	
<u>Scotch Pine</u>						
10	750			1.26		14
13	820			1.67		13
21	1680		1.18			18
22	940		1.30			24
<u>European Larch</u>						
7	680	.61				25
	920			1.08		28
20	860		1.22			35
	826		1.05	3.6		40
	800		1.45			33
	680		1.04			34
	600		1.45			29
22	540		1.62	4.17		34
<u>Japanese Larch</u>						
20	530		1.26			
	600		1.45			
<u>Norway Spruce</u>						
9	680			.50		13
10	1100			.68		15
	800			.73		14
18	1000		.58			21
20	1248		.79			21
22	1700		.72			14
<u>White Spruce</u>						
8	440			.78		4
9	960	.37				3
11	1720	.79				2
	1240			1.40		4
	510			.44		1
	860			.55		1

European larch of the same class the deviation is 1.24. The standard deviation of Scotch pine twenty-one years old with 1680 trees per acre is slightly less than that of the larches but greater than with white pine, red pine, or Norway spruce. The smallest deviations are found in white spruce.

The standard deviation of d.b.h. decreases with an increase of stocking in planted stands (). The starred plots in Table show that in an even-aged stand, where graded stock was planted on a uniform site with different spacings, there is a marked decrease in the standard deviation of d.b.h. with a corresponding increase in number of trees per acre. The standard deviation of height on the same plots gives a smaller increase.

Dead Length and Knot Size

Dead length, a term applied to that portion of the stem on which branches are dead, develops only after the crowns have closed and the lower branches die from shading. This development has a pronounced effect on the grade and quality of wood produced, inasmuch as the age at which the limbs die determines knot size. Dead length is expressed as a percentage of the average height in a stand and varies with growing space and age. The youngest plantation on the Forest showing any dead length is red pine fifteen years old.

Owing to the fact that early plantings were made on old fields, there are only five plantations having a dead length on cut-over lands. This lack of sufficient data obscures as yet any possible contrast between the two types.

Table . Dead Length as Influenced by Age
and Number of Trees per Acre.

Age in Years	Trees per Acre	Dead Lengths (%)	
		Old Fields	Cutover
<u>Red Pine</u>			
15	660		.14
16	680		21
17	1180	11	
18	860		11
18	620		14
20	1412	45	
20	1334	42	
<u>White Pine</u>			
17	1760	19	
19	980		30
20	3942*	44	
20	3214*	47	
20	2533*	33	
20	2157*	30	
20	1551*	35	
20	1238	28	
20	1080*	31	
20	840	21	
23 & 24	1540	38	
25	1180	35	
25	1140	33	
<u>Scotch Pine</u>			
21	1680	41	
22	940	44	
<u>Norway Spruce</u>			
20	1248	17	
22	1700	21	
22	1460	21	
<u>European Larch</u>			
20	860	24	
20	826	34	
20	800	19	
20	680	29	
20	600	16	
22	540	25	
<u>Japanese Larch</u>			
20	600	35	
20	530	35	

In the starred white pine plots taken in the spacing experiment plantation, where stock age and site are uniform, there is a very definite relationship between trees per acre and dead length.

While stock age has undoubtedly influenced dead length on the plots, there seems to be a fairly good relationship between species with comparable ages and numbers of trees per acre. With comparable stockings and at ages from twenty to twenty-two years, Scotch pine and red pine have the highest percentage of dead length, followed by Japanese larch, European larch, white pine and Norway spruce in the order named.

Knot size, which largely governs the grade of lumber produced in a stand, was obtained by measuring the diameters of average dead limbs at a point close to the main stem. Live limbs were not measured because they are still increasing in size.

Data from the plots are presented in the following table:

Table 11.

Dead-Knot Size for Varying Ages and Number of Trees per Acre
Pure Stands.

Species	Total Age	Trees per Acre	Knot size in inches	
			Old Fields	Cutover
Red pine	15	660		.3
	16	680		.2
	17	1180	.6	
	18	860		.3
	18	620		.4
	20	1412	.9	
	20	1334	.9	
White pine	16	700		.6
	17	1760	.6	
	19	980		.6
	20	1238	.7	
	20	840	.6	
	21	700	.5	
	23 & 24	1540		
	25	1180	.7	
Scotch pine	25	1140	.9	
	21	1680	.8	
Norway spruce	22	940	.9	
	20	1248	.5	
European larch	22	1700	.6	
	20	860	.5	
	20	826	.5	
	20	800	.5	
	20	680	.6	
	20	600	.6	
	22	540	.7	
Japanese larch	20	600	.7	
	20	530	.6	

In a mixture planted on an old field to show the interrelations between species, the following knot sizes have developed with a stocking of 1460 trees per acre:

Species	Age	Knot Size
Scotch pine	21	1.0
White pine	22 & 23	.9
Western yellow pine	22	.9
Douglas fir	22	.5
Norway spruce	22	.5

In the white pine spacing experiment a curve based on six plots and 75 trees twenty years old gave the following knot sizes for the corresponding numbers of trees per acre:

Trees per Acre	Average Knot Size
1000	.7
1500	.6
2000	.55
2500	.5
3000	.5
3500	.5
4000	.5

Hardwood competition on cutover lands tends to produce smaller branches in the planted species by early shading out of the branches.

Straightness

The straightness of the trees in a stand varies with the species and number of trees per acre. It is an inherent tendency of some species to grow crooked stems regardless of site and mixtures, which is illustrated by Scotch pine from central European seed. In contrast, many species, such as red pine, are naturally straight regardless of growing conditions and competition.

Straightness was determined by ocular observations and recorded as "straight", "fair", or "crooked". Of 39 red pine plots on both old fields and cutover lands, ranging from eight to twenty years of age, all were straight. In 26 white spruce plots, six to eleven years old, all on both types of plantings were also straight. Two Japanese larch plantations on old fields and one on cutover land, between the ages of six and twenty years, were straight. Of 24 white pine plots, seventeen to twenty-five years old, on old fields, seven were straight, seven fair and ten crooked. On cutover land in 18 plantings ranging in age from six to twenty-one years, one-third of the plots fell in each straightness class. However, of the six plots listed as straight,

five were eight years of age or younger, which means that weeviling could not yet have become important. Of three Scotch pine plots on old fields, two, presumably of central European origin, were very crooked, and one from Riga seed was straight. On cutover land, of a total of five plots, two of Baltic origin and two others supposedly the same are straight, and one from Riga seed was fair. Of a total of six Norway spruce plots on old fields, five were straight and one, due to budding by squirrels, was fair; while thirteen on cutover lands were all straight. Seven European larch plots of a total of eight on old fields were straight; one, due to porcupine girdling, was fair. On cutover lands five of six plots were straight, the other having been damaged by frost.

The effect ~~through~~ recovery from weeviling of the number of trees per acre on straightness is shown very plainly in the pure white pine plantings on old fields as presented in the following table.

Table . Relation of Straightness to Number of Trees per Acre.

<u>White Pine</u>				
Total Age	Trees/A.	Straight	Fair	Crooked
20	3942	*		
20	3214	*		
20	2533	*		
12	2380	*		
20	2157	*		
17	1760			*
20	1551			*
23-24	1540			*
12	1440	*		
11	1260		*	
20	1238		*	
25	1180			*
25	1140			*
20	1080			*
20	840			*

Volume

Volume in cubic feet for the older plantations was determined by the use of form class volume tables. All figures presented are inside bark.

The volume of red pine was obtained by converting the Canadian Government form class table 65 () into the necessary lower form classes by comparison with the white pine tables in Harvard Forest Bulletin 13 (). Form class 70 was taken directly from the Canadian publication. The tables made on the Harvard Forest () were used for white pine. The volumes for Norway spruce were taken from Tor Jonson () and converted from the metric into the English system. For European larch the form factors developed by the British Forestry Commission () were used.

In a comparison between old-field and cutover land plantings the former have larger volumes, because the cutover lands are planted in groupwise mixtures with hardwood, thereby reducing the total number of coniferous stems per acre.

Table , arranged by species and age, with the number of trees per acre in descending order within like ages, gives the respective volumes in the plantations old enough for this measurement. White pine has the highest volume, having been planted in denser stands. It may be seen that within the twenty-year age class volume decreases with the reduction in number of trees per acre. European larch, with the smallest number of trees per acre, has a higher volume than any other species in the same density class. Red pine has a slightly higher volume than white pine within the same age and density class.

All plantings listed are pure stands, coniferous mixtures being too young for volume measurement.

Table 13.

Volume per Acre Arranged by Species, Age,
and Number of Trees per Acre.

<u>Total Age</u>	<u>Site Index</u>	<u>Trees per Acre</u>	<u>Volume per Acre</u>
Red Pine			
<u>Old Field Plantations</u>			
15	25	1680	536.0
15	23	920	216.0
17	23	1180	544.0
17	19	900	302.0
20	21	1412	1723.2
20	21	1334	1523.6
20	21	1290	1643.0
<u>Cutover Land Plantations</u>			
15	24	1340	358.0
15	23	640	48.0
16	22	680	158.0
18	20	860	408.0
18	20	620	220.0
White Pine			
<u>Old Field Plantations</u>			
17	18	1760	847.2
20	20	3942	1729.0
20	21	3214	1865.0
20	20	2533	1476.0
20	21	2157	1729.0
20	20	1551	1197.0
20	20	1238	994.2
20	21	1080	984.9
20	18	840	644.8
23 & 24	17	1540	1534.6
25	16	1180	1602.6
25	15	1140	1595.8
<u>Cutover Land Plantations</u>			
19	18	980	681.0
<u>Norway Spruce: Old field plantations</u>			
18	21	1000	431.0
20	21	1248	813.3
22	14	1700	981.8
<u>European Larch: Old field plantations</u>			
20	35	860	968.0
20	40	826	1558.8
20	33	800	924.4
20	34	680	672.9
20	29	600	1034.4
22	34	540	1532.9

Damage

The Harvard Forest plantations during twenty-three years have been subject to attack by practically every insect and fungus common to the region, and in some cases the results have caused a marked decrease in the growth rate and even heavy losses. Among the important enemies are the white pine and pales weevils, squirrels, porcupines, rabbits, other rodents, and a few fungi.

With few exceptions every species is subject to attack from one or several pests, the seriousness and extent of damage being dependent upon a number of factors. The most significant are: Proximity to other areas already affected, species planted, history of the site (old field or cutover land), care used in planting, climatic conditions, and control measures adopted.

Observations on damage were made during the course of the field study and recorded for each sample plot. Any damage noted was confined to those trees within the limits of the plot, and trees dead or missing from unknown causes were not considered. The total number and percentage of trees affected by each agency were calculated for each species.

1. White pine

(1) White pine weevil

The white pine weevil (Pissodes strobi Peck) is the most serious local insect and pest affecting the white pine. Publications by Blackman (), Peirson (), Graham (), and MacAloney () describe its biology and silvicultural methods of control.

A record was made in the field of the number of weeviled trees and the number of weevilings per tree on all plots infested. These figures are given in the following table.

Table

Amount of Weeviling as Affected by Age
and Number of Trees per Acre

Total Age	Trees per Acre	Percent of Trees Weeviled	Average No. of Weevilings per Tree Weeviled
<u>Old Field Pure Stands</u>			
11	1260	63#	1.1
17	1760	91	2.3
20	3214	12*	1.1
	2157	34*	1.2
	1551	46*	1.4
	1238	50	1.2
	1080	78*	1.3
	840	98	3.6
23-24	1540	95	2.2
25	1180	92	3.1
	1140	96	3.8
<u>Old Field Mixtures</u>			
10	1720	58	1.6
	1660	80	1.2
	1640	62	1.4
11	1460	49	1.1
22-23	1460	73	3.3
<u>Cutover Pure Stands</u>			
7	600	10	1.0
8	700	11	1.0
	560	4	1.0
	500	8	1.0
	480	8	1.0
10	1200	25	1.1
15	760	55	1.4
19	980	96**	2.8
21	1020	69	3.0
<u>Cutover Land Mixtures</u>			
9	1340	39	1.1
	640	27	1.0
10	1340	48	1.1
	1200	65	1.2
	680	50	1.1
	540	36	1.2
11	880	5	1.0

* Spacing experiment plots.

** In spite of the high percentage of trees weeviled, the stand was little affected until the hardwood was eliminated at about 16 years of age. Trees are very straight.

Weevils picked twice during egg-laying periods of the last three years.

A special case where a plantation was made on an old field known as the Peach Orchard shows very clearly the protection afforded white pine by hardwood. The northern part of this field was used to grow wheat during the war. Immediately following abandonment gray birch seeded in at the rate of at least 40,000 stems per acre. The southern part of the area remained in sod and no birch seeded in. Both areas were planted with white pine in 1923. Due to failures in the southern part, red pine was filled in two years later. Dr. H. J. MacAloney of the Northeastern Forest Experiment Station has kept a careful record of the trees on a permanent sample plot in each area since 1926. Until the winter of 1929-30 the birch on the northern part was allowed to keep up with the pine. A fairly heavy weeding was made during the winter, while the southern part was untouched. In 1929 five per cent of the trees in the birch were weeviled as compared to twenty-three per cent in the open. Following the weeding the figures for 1930 were nineteen and twenty-five per cent respectively. In 1931 when the birch had again grown up to or slightly above the pine, only five per cent were attacked as compared with forty-five per cent where there was no birch.

It may be seen from the tables that more weeviling occurs in old field stands than in cutover land stands, and that there is no significant difference between mixtures of white pine and other conifers and pure white pine on either old fields or cutover lands. Entomologists differ in opinion on this subject. MacAloney recommends planting white pine in mixture with older conifers to reduce weeviling. There were no stands of this kind in any of the mixtures studied. Peirson states that coniferous mixtures have no effect upon weeviling, but every author shows the beneficial effect of hardwood on white pine

in mixture with it. Figure shows the relation in percentage of weeviled trees between old field and cutover land plantings.

In both types the period of heaviest attack occurs between the ages of eight and twenty years. Weeviling does not start until the trees are from two to four feet in height and from five to eight years old (). During the 8-12 year period (Figure) there is no great difference between the cutover and old field stands; but with increasing age there is a greater increase in weeviling in old field stands until at twenty-four years, the oldest age represented by both types, ninety-five per cent of the trees on old fields and seventy-eight per cent of those on cutover lands have been weeviled. Blackman, Peirson, and others state that the infestation is at its peak when the trees attain a height of twenty to twenty-five feet and gradually decreases until at sixty feet it has practically ceased. The greatest average height of the white pine plantations on the Forest is twenty-five feet, and infestation seems to have reached its maximum with practically all trees weeviled (Figure).

The heavy weeviling of white pine in all types of plantings on the Forest may be attributed largely to their location. With one exception these are all near or adjoining natural old field pine stands (). In one plantation where several seed sources are being tried out, the weevils have been picked from each tree twice during each egg-laying period for three years. About 300 weevils were collected each year from .4 acres. This plantation adjoined a fifty-year-old old field pine stand.

The density of the hardwood sprouts on cutover lands results in a wide variation in the amount of pine weeviled. The stands with dense hardwood suffer much less than those where it is scattering.

In one case where the stand was surrounded on three sides by old white pine but where the hardwood sprouts in the plantation were very dense, only five per cent of the pines had been weeviled at eleven years of age. In another case where heavy weedings were made to free smaller spruce planted in mixture with the pine, sixty-five per cent of the pines were weeviled at ten years of age.

The relation between number of trees per acre and weeviling on old fields is shown by the figures from the spacing experiment given in Table .

The number of times a tree is weeviled depends upon its age and the density of stocking in the stand. The number of attacks recorded on a tree on the Forest varied from one in the younger age classes to eleven at twenty-five years. The average number of weevilings per tree is figured only from weeviled trees.

The data show no significant difference between the average number of weevilings per tree in pure and mixed coniferous stands (). Figure shows that in the stands studied weevilings per tree are slightly higher in old fields than in cutover lands between the ages of ten and sixteen years. Beyond this point when the hardwood is mostly eliminated on the cutover land and a wide spacing is approximated, the number per tree decreases with an increase in the number of trees per acre, as shown by data from the spacing experiment. This number increases from 1.1 weevilings per tree in the 3 x 3 spacing to 1.3 in the 6 x 6. This is doubly significant because of the greater percentage of trees weeviled in the wider spacings.

(2) Pales Weevil (Hylobius pales Herbst)

Since 1916 when Carter discovered the feeding of the adults on coniferous seedlings (), all plantings on cutover coniferous

land have been deferred until the third season after cutting, when the infestation of logs and stumps has ceased and there is no further danger that planted stock will be girdled by the adult beetles. Deferred planting has resulted in damage to only one of the thirty-four white pine plantations. In this case seven per cent of the trees were injured, the area being near a later pine cutting.

(3) Armillaria Mellea

Among the fungi present in plantations on the Forest, Armillaria mellea is the most serious. This disease, which was found only on cutover land or on the border of older stands, becomes serious as a result of poor planting. Infected trees were pulled up and the roots examined, disclosing that in practically every case they were planted too deeply or the roots were wadded up. The development of a secondary root system had been retarded, thus weakening the tree and giving the fungus a chance to enter. The mycelium often enters through a wound (Plant Disease Reporter, 1927) which might be made by rough handling during planting.

Armillaria was found in one white pine plot with seven per cent of the trees affected. This fungus was noted in several others, but no infected trees were present in the sample plots.

(4) Blister Rust (Cronartium Ribicola)

Blister rust infection on the Forest has been practically eliminated by two eradications of Ribes in 1919 and 1926. Of a total of thirty-four white pine plots, two were found to have the disease with two per cent of the trees affected in one plot and three per cent in the other.

(5) Deer Damage

The only animal damage found on the white pine plots was caused by deer (Adocoileus virginianus borealis, Miller). They rubbed

their antlers against young trees removing the bark, impairing growth, and sometimes killing the tree. With four per cent of the trees damaged in one plot, it may be said that deer damage in these plantations was practically negligible.

(6) Damage by Snow and Ice

Snow and ice caused damage to eighteen per cent of the trees on one plot. Branches and leaders of white pine are relatively limber and will not break with the ordinary weight of snow and ice. However, in winters of heavy ice storms considerable damage is done.

(2) Red Pine

Damage to forty-one red pine plots studied was confined to attacks by fungi, animals, moundbuilding ants, and breakage by snow and ice.

(1) Armillaria Mellea

As described previously, Armillaria is very prevalent on cutover areas, and as a result of poor planting any species is subject to infection. Two of the seventeen pure red pine plantations established on cutover lands were infected, with three per cent of the trees killed in one and eight per cent in the other. Close examination of the infected trees showed that the roots had been wadded up or broken in planting (Figure).

Red pine planted in mixture with other conifers showed a higher loss than in pure stands. This was apparently due to the character of the site and not to the mixtures. The soil in every case was very rocky with a dense cover of ericaceous growth, making it difficult to dig proper holes and the root systems were correspondingly distorted. This resulted in the death of the old root systems and the entrance of

Armillaria. Three out of five of these plots in mixtures were found to have seventeen, four and six per cent of the trees infected. Several trees were recorded as dead or missing from unknown causes and were not included under this head.

(2) Solidago Rust

A fungus disease of minor importance and found to be active in only one red pine plantation is Solidago rust, Coleosporium solidaginis. This fungus attacks the needles of the previous year's growth and appears in the form of small orange colored pustules bursting through the epidermis. Its presence has been noted for several years on a number of plantations, but with no serious results. The only apparent effect is to slow up growth during the period of infection.

(3) Red Squirrel

The red squirrel, Sciurus hudsonicus loquax Bangs, as described by Hosley () does severe damage during periods of deep snow when the usual food supply is cut off. At such times buds of certain coniferous species are eaten with serious results to the stand. Investigations showed that of all conifers studied, red pine is least subject to attack, and that out of hundred^s of this species examined in 1928 only one tree was found budded.

Observations in the present study show that two plots close together, of a total of forty-one, were affected with the damage occurring during the heavy snows of 1930-31. On one plot eighty-one per cent of the trees were damaged; and on the other, which was further from natural squirrel cover, twenty-nine per cent were affected.

(4) Deer Damage

Deer damaged six per cent of the trees in one plot. As explained under white pine, this is not serious enough to influence

the development of a plantation and can be disregarded.

(5) Mound-building Ants

Mound-building ants, Formica exsectoides, have caused considerable damage to some of the younger plantations on the Forest. One of the characteristics by which this damage may be easily identified is the absence of any trees in a circle around the mound.

In an early study Hawley () and Record () state that ants and not fungi were responsible for the death of the trees near the mounds. Haasis () concluded that the construction found at the base of all dead trees was due to a fungus and not to ants. Peirson (), in a study made on the Harvard Forest, found that ant colonies were always located in young stands which afforded plenty of sunlight. All trees casting shade on the mounds were killed by the ants in order that the sun might hatch the eggs. Subsequent experiments in the field and laboratory proved that the trees were killed by the injection of formic acid, causing a constriction or lesion at the base of the stem.

Ant colonies were found in only one red pine plantation. Thirty-seven per cent of the forty-eight trees in the sample plot had been killed, but observations of the entire plantation disclosed a number of colonies with similar results. This area was originally an old field, and the occurrence of the ants is a matter of chance rather than a characteristic damage to red pine.

(6) Damage by Snow and Ice

Three of the eleven pure red pine plots in field plantations were damaged by snow or ice. The relatively large, limber branches are able to withstand a heavy load before the breaking point is reached, but the great amount of ice and snow collected by the long, heavy needles sometimes is great enough to pull the branches out of

the tree. The leaders which are not so limber suffer more breakage than the branches.

3. Scotch Pine

Scotch pine on the Forest has been sporadically attacked by the white pine weevil, red squirrels, and mice, and has been damaged by snow and ice.

(1) White Pine Weevil

In a list of host trees arranged according to susceptibility to attack, MacAloney () places Scotch pine in the third group under the heading of "occasionally attacked". Further study () showed that while many eggs were laid in the leaders of this species, the injury is slight, especially in the "Riga" strain. The probable reasons for its resistance to attack are the vigor of the tree and the heavy flow of sap, which apparently drowns the larvae. Of a large number of trees examined by the authors, one-third had been attacked, but of this number only 1.15 per cent of the leaders had died.

In the present study very little weeviling was found in the ten plots examined. One plot of pure Scotch pine growing on cutover land had two per cent of eighty-two trees injured.

(2) Red Squirrel

Hosley () found that of all the species studied, Scotch pine suffered most from the red squirrel. Large bud clusters on the terminals and branches have a great attraction and are usually cut off, leaving none to carry on the following year's growth. Adventitious growth causes a peculiar "broom" of small branchlets to form, one of which may become a new leader. One injury may not greatly retard height growth, but repeated attacks will result in stunted, poorly formed trees.

Data taken in the fall of 1931 show three of the ten Scotch

pine plots to be damaged by red squirrels. Two were on cutover lands, one being pure and one mixed, and the other, a pure stand, was on an old field. The percentages of trees damaged in these plots were seventy-six, six, and three respectively.

(3) Mice

No recent injury by mice was found, but the office record for one Scotch pine planting made on an abandoned field in 1912 showed fifty-six of a total of 822 trees killed by mice in 1918, and three-fourths of the remainder attacked. Damage was found to have occurred during the winter under deep snow, the trees being girdled at the base.

4. Norway Spruce

Damage to Norway spruce has been caused by the white pine weevil, red squirrels, Armillaria mellea, and mound-building ants.

(1) White Pine Weevil

Blackman (), Peirson (), Graham (), and other entomologists report severe weevil injury to Norway spruce. MacAloney () places it next in order to white pine as a host tree, and states that it is sometimes injured to as great an extent.

Nineteen Norway spruce plots were examined during the present study. Weeviling was found in fifty per cent of the plots in pure stands on cutover land, and eighty-nine per cent of the plots in mixed stands on the same type of land. One hundred per cent of all the plots on old fields were weeviled. Old field plantings have been more severely injured than those on cutover lands, but, owing to the lack of data, corresponding ages could not be compared; and in view of the fact that Norway spruce was not planted on cutover lands until recently, no definite conclusions can be made. However, the figures indicate at least

twice as much weeviling in white pine as in Norway spruce. All weeviled plantations were located either adjoining or near old field white pine stands. A comparison of the amount of weeviling in white pine and Norway spruce is shown in Table 15. These are all from coniferous mixtures on cutover land.

Table 15. Percent of Trees Weeviled in Norway Spruce and White Pine Stands of Varying Ages and Densities.

Total Age	No. Trees per acre	Percent of Trees Weeviled	
		White Pine	Norway Spruce
9	640	27	
	1340	39	
10	500	36	18
	600	50	
	700		31
	800		
	900		14
	1000		9
	1100		
11	1200	65	
	1300	48	12
	880	5**	
20	1400		70
21	1020	69*	12*

*Contiguous plantings

**Very dense hardwood sprouts

(2) Red Squirrels

In a study of the mammals of the Harvard Forest, Hatt () found the red squirrel to be the only animal damaging Norway spruce. Hosley () states that on side branches a section bearing a number of buds is usually cut off, but the terminal bud is cut out from the base, leaving it apparently intact. Recovery from one injury is more rapid than in Scotch pine, and the effects are less noticeable and serious as growth continues.

The present investigation showed that three of the nineteen

Norway spruce plots had been budded by squirrels. Injury occurred in nine, sixty-eight, and ninety per cent of the trees respectively.

There seems to be little relation between the type of planted stand and these injuries but rather upon the nearness to suitable squirrel cover.

(3) Armillaria Mellea

Armillaria was found in several Norway spruce plantations on cutover land. Infected trees were present in only two of the sample plots. Four per cent of the trees in one and eighteen per cent in the other were infected and dead.

(4) Mound-building Ants

Mound-building ants have located on one Norway spruce plantation killing seventeen per cent of the trees in the sample plot.

5. White Spruce

The white spruce plantations on the Forest have been practically free from damage. This species has not been planted until recently, and the oldest age of any plantation is eleven years, which may partially explain its apparent immunity to injury. Damage was confined to slight injury by the white pine weevil and an occasional budding by rabbits.

(1) White Pine Weevil

White spruce is rarely attacked by the white pine weevil (), although cases are occasionally found. Weeviling was found in two plots out of a total of twenty-five. Both were old-field mixed stands. The extent of the injury was almost insignificant, with three per cent of the trees in one plot attacked and one per cent in the other.

(2) Rabbits

In the winter of 1930-31 rabbits (Sylvilagus transitionalis, Bangs) removed a few terminal buds in one white spruce plantation, slightly damaging three per cent of the trees.

6. European Larch

European larch on the Forest has met with serious injury. Wherever it has been planted in sections inhabited by porcupines, its existence is impossible without control of the animals.

(1) Porcupines (Erethizon dorsatum dorsatum)

Porcupines have caused more damage to this tree than all of the other destructive agencies combined. The bark of European larch is one of the most sought-after foods, and the animals often travel considerable distances to plantations of this species, making well beaten trails between the dens and the food supply (). The first attack usually results in the girdling of the top, Fig. , and repeated attacks often kill the tree.

Six of the older plantings established as pure stands on old fields have been severely damaged. Dens were found near all six stands, and the lack of damage in the seventh may be explained by its location near a house and more than a mile from any known den. The extent of damage varies from fourteen to ninety per cent of the trees injured in each plot. One planting on cutover land was slightly damaged, and within a short distance from the area a large inhabited den was found. The age of the plantation, seven years, explains why not more than four per cent of the trees were attacked.

No damage was found in the other five larch plantings, which varied in age from three to eleven years.

(2) Red Squirrels

Red squirrels attack larch by clipping off slender twigs from which they later eat the buds. Leaders are seldom cut, the damage being confined to the smaller pendulous twigs and growth is retarded only in very severe cases ().

In four of the seven old field plots, two to eighty per cent of the trees were budded. Further observations show some of the same trees to have been attacked for several years with little apparent effect.

(3) Damage by Snow and Ice

The brittle branches of European larch offer little resistance to the added weight of snow and ice. Rogers () reports that trees with many fine brittle branches are more subject to breakage than those having flexible or stout branches. Hunt () states that brittleness is intensified during the winter when the wood is frozen, and damage is most severe in windswept locations and in plantations of high density.

Trees in three of the thirteen plots were found to have been snow broken. Damage ranged from nine to twelve per cent of the trees in the plots affected. A result of the breakage is the formation of a crook, which has not been outgrown in any of the trees observed.

7. Japanese Larch

Japanese larch on the Forest is limited to two older plantations on small fields, each containing a few trees for experimental purposes, and to one young stand planted on cutover land. No definite conclusions can be made of the susceptibility of this species to injury. Field observations disclosed that porcupines have from time to time attacked it but have caused no serious injury. This is probably a result of location away from porcupine dens. The action of snow and ice

on this species is similar to that on European larch.

8. Jack Pine

One plantation of this species has been made on the Forest for experimental purposes. After twenty years no damage was found.

9. Hemlock

The use of hemlock has been restricted to mixed planting with other species on cutover land. With an average of ten to eleven years, the four plots have suffered no damage.

10. Douglas Fir

One plantation with Douglas fir planted in mixture with four other species proved to be uninjured, except that the needles were being shed by sixteen per cent of the trees. The cause of this defoliation was determined by Dr. Spaulding as Rhabdocline pseudotsugae, the Douglas fir leaf shedding fungus.

11. Western Yellow Pine

Western yellow pine has given very poor results on the Forest. The five pure plantations on old fields are infected with rust fungus, Cronartium comptoniana, which causes cankers on the trunk and apparently results in slow growth of the trees. Data from one sample plot showed forty per cent of the trees to be infected. Another pest is the pine shoot moth which bores into the branches causing a large mass of pitchy material to exude, but with no serious effect to the tree.

Planting Costs

Planting time in man-hours per acre varies with the character of the land planted, whether old fields or cutover lands, size of stock, number of trees planted per acre, and the planting method employed.

From the office records the cost of planting in man-hours per acre was determined for all plantations and is presented in Table . By comparing the time required by the different methods, it may be seen that for 2-2 stock nearly twice as much time is required for mattock hole planting in pure stands on cutover lands as for the planting tool on the same type. Still within the same type, the time for the mattock slit sod on is practically the same as for the planting tool.

In old field pure stands with 2-2 stock, time for the planting tool averages about two hours less per acre than for the mattock hole method. Removing the sod doubles the planting time with the planting tool.

A comparison of the time required for planting pure stands on cutover land and old fields with the planting tool shows that when 600 to 1100 trees per acre are planted, faster planting can be done on cutover land. Beyond that density old field planting is more rapid. The relatively greater time required for cutover lands with closer spacings may be explained by the increasing care necessary in finding suitable places for the additional trees.

In old fields more time is required to plant mixtures than pure stands. The greater time required with the mixtures in arranging the species in reference to each other is the obvious cause.

There were too few plots to compare with those having 2-2 stock to form conclusions as to the relative planting time with varying stock sizes.

Weeding Costs

In order to bring through any usable number of planted coni-

fers on cutover land, weeding is always necessary regardless of the species planted; but of a total of fifty old field plantings, only seventeen have required weeding. The number of weedings required before a plantation is above hardwood varies with the species planted, size of stock, density and vigor of the hardwood. Due to the fact that all weeding records were kept on an acre basis regardless of whether hardwood groups made up a part of the stand or not, the figures for weeding cutover cordwood and sawtimber stands are not exactly comparable. On sawtimber areas the planted stand makes up only a varying percentage of the total area, and due to the smaller size of the hardwood stools, weeding costs within these groups are less than on cordwood land. However, more time is required to decide on the group borders, and due to the care necessary in selecting the crop trees, hardwood weeding is always more expensive than that to free conifers, so the total time per acre is practically the same as on cordwood lands. Also labor which is more skilled is required in weeding the sawtimber areas; and although the total man-hours per acre are about the same as on cordwood cuttings, the actual cost is greater.

Weeding costs were compiled in tabulated form for each plantation shown in Table . There was so little variation in weeding costs between white, red, and Scotch pine that they were placed in one group. Similarly, Norway and white spruce were placed in the second group. Combinations of pine and spruce were also grouped. A weighted average for all plots of the same stock age in each density class of the hardwood for cordwood and sawtimber lands was determined by multiplying the weeding time of each plantation by its age and dividing the sum of these products by the sum of the ages represented.

Table
Weeding Time in Man-hours as Affected by Composition,
Age, and Hardwood Competition

		<u>Cutover Lands</u>					
Total Age	Stock Age	H a r d w o o d C o m p e t i t i o n					
		Light		Medium		Heavy	
		Type of Previous Stand					
		C'dw'd	Sawtimber	Cd.	St.	Cd.	St.
		<u>Pure Pine Stands</u>					
6	2-2				3.4		
7	2-2		3.5			5.2	
8	2-2		3.5	2.5		6.7	8.0
10	2-2					16.4	16.4
11	2-2						16.8
12	2-3	4.5					
15	2-2						12.7
15	2-3					29.5	30.0
17	2-3	5.5					
Weighted Averages		5.1	3.5	2.5	3.4	17.4	17.7
		<u>Pure Spruce</u>					
9	2-2-1			2.5			
10	2-2				12.3		18.8
11	2-2					18.8	
		<u>Pine & Spruce Mixtures</u>					
9	2-2			14.0			
10	3-0					20.9	
10	2-1					18.4	
10	2-2					21.3	
11	3-0					28.9	
11	2-2					17.6	
22	2-1-1		5.4				
Weighted Averages							
2-2 & 2-1						19.0	
3-0						25.0	
2-1-1			5.4				

Old Fields

Total Age	Stock Age	Hardwood Competition		
		Light	Medium	Heavy
<u>Pure Pine Stands</u>				
9	2-2	4.9		
12	2-1		16.6	17.5
14	2-0	.3		
	2-3			15.0
15	1-2 & 2-1	1.0		
23	2-2	5.8		
<u>Pure Spruce Stands</u>				
11	3-0	4.8		
12	2-1	2.2		
	2-3	1.0		
14	3-1 & 2-2	1.0		
<u>Fine & Spruce Mixtures</u>				
9	2-2	2.5		
10	2-2		14.6	
11	3-0	4.8	15.3	20.9
12	2-2	4.8		

Spruce is more expensive to weed than pine when both are growing in pure stands on cutover land (Table). Early spruce growth is slower than that of pine, and more weedings are necessary to bring it through the hardwood.

There were insufficient comparable larch plots to determine its weeding time, but owing to its fast early growth relatively little time is required.

Table indicates that the time required to weed pine and spruce mixtures is practically the same as that for pure spruce stands. It is also shown that seedling plantations require more weeding than those made with transplants.

Plantations in which weeding has been finished have an average age of fifteen years at the time of the last weeding. The total time required in weeding pure stands averages twenty-five man-hours per acre. No coniferous or coniferous-hardwood mixtures have been completely weeded as yet.

Weeding costs in old field plantations were compiled in a manner similar to that for cutover lands. Hardwood in old fields is the result of seeding in, and its occurrence is largely a matter of chance and location in relation to seed trees. Two-thirds of the plantations were never weeded, and the weeded areas show such a wide variation in time required that no comparisons could be made between species or stock sizes. Weeding time ranged from .3 to fifteen man-hours per acre for plantations in which the weeding has been finished.



Fig. — Red pine and white spruce in
alternate rows, plantation 25 $\frac{1}{2}$ K.; The spruce
which has kept pace with the pine was
large 2-2 stock 12-15" tall.



Fig. —. Red pine and white spruce 10 years
 old in alternate rows, plantation 26-11.
 The spruce which is only about $\frac{1}{3}$ the
 height of the pine was small 2-2 stock

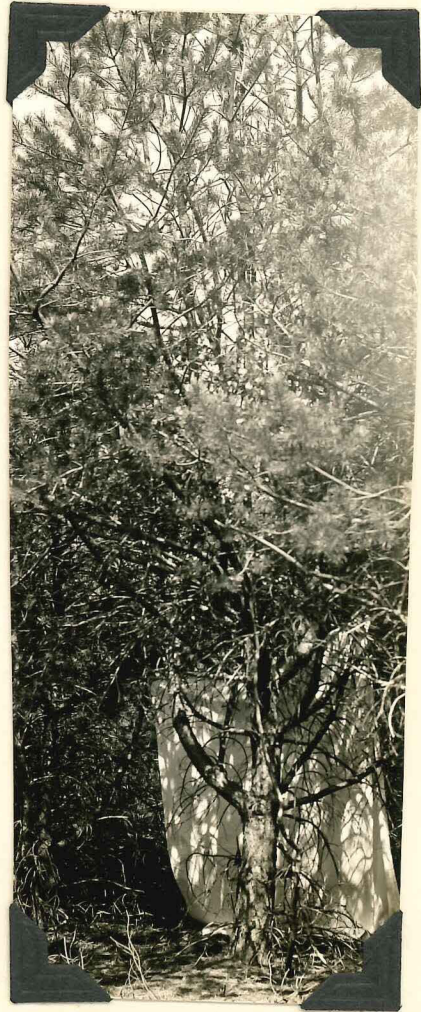
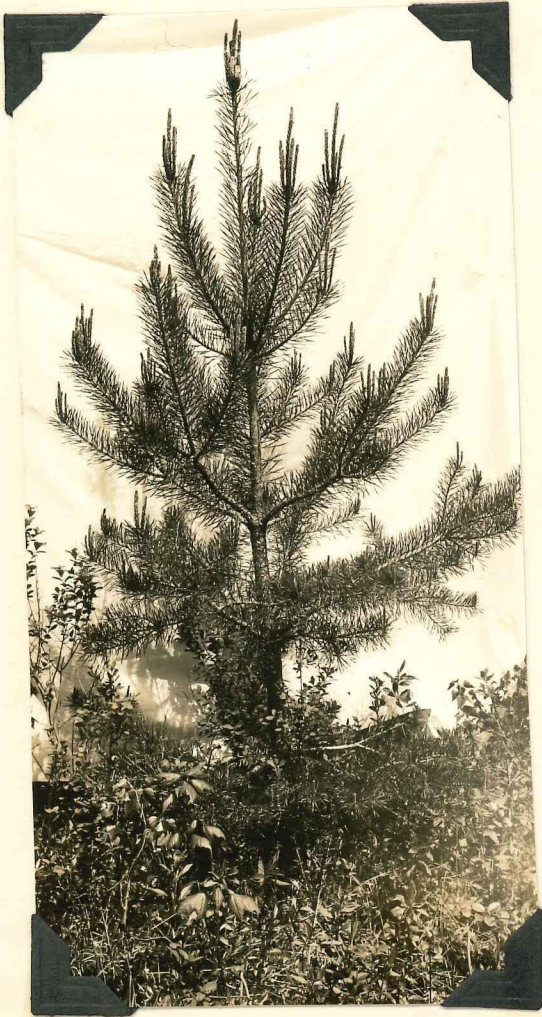


Fig. — Scotch pine of two races. The ^{small-branched} straight tree on the left is from seed of ^{original} origin while the ^{coarser, bushy} one on the right came from seed presumably of ^{actual} European origin.

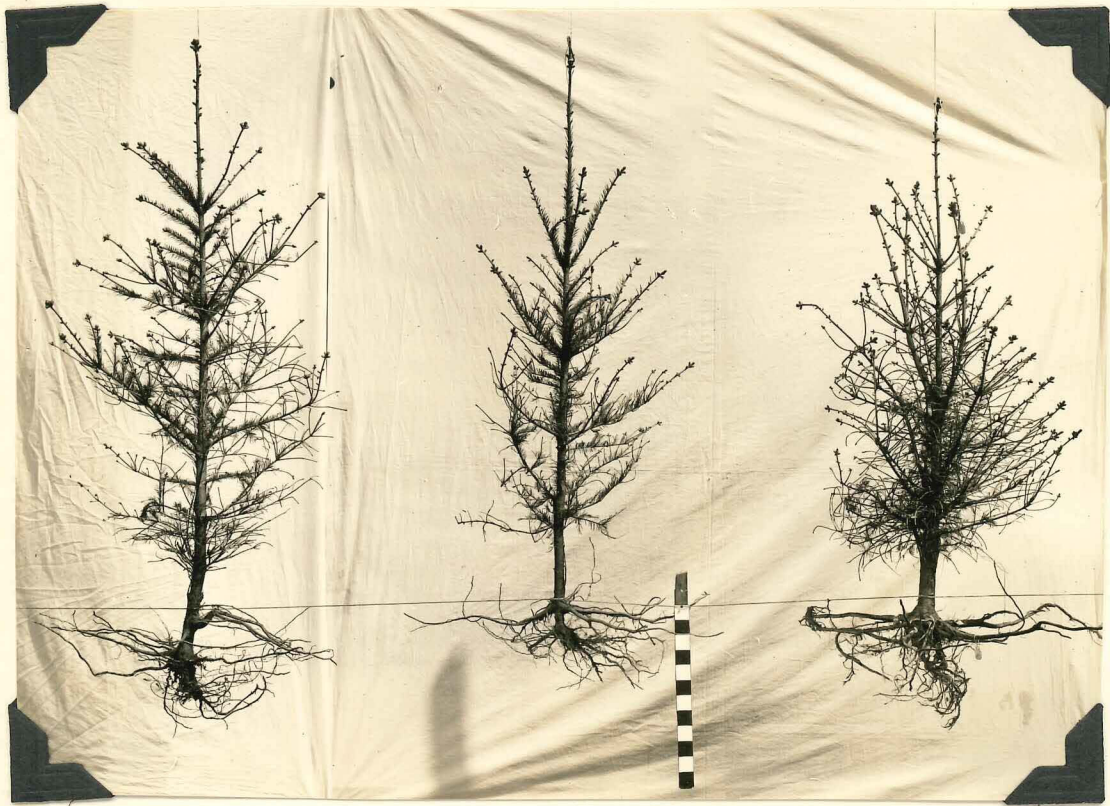


Fig — White spruce 9 years old
planted on old field. The two trees on the
left were planted so deeply a secondary
system developed at normal depth.



Fig. —. White spruce ^{dying or dead} showing
results of deep planting. Top of
board represents the ground
line as the trees were planted



Fig. — Natural white spruce
9 years old showing the shallow
root system. (String indicates
ground line. Scale is in inches)



Fig. 15. White spruce planted (above)
and natural (below) showing horizontal
root development.



Fig. — ^{with forward look} Natural (Red pine 9 years old) (left) and planted (right). The deeper root system is developing strongly on the planted trees.



Fig. — Red pine planted (above) and
natural (below) showing the horizontal
development

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.



Fig. — White pine 9 years old, natural (left), and 12 years old, ^{with the taproot} planted (right). The middle planted tree developed a strong secondary root system following deep planting.

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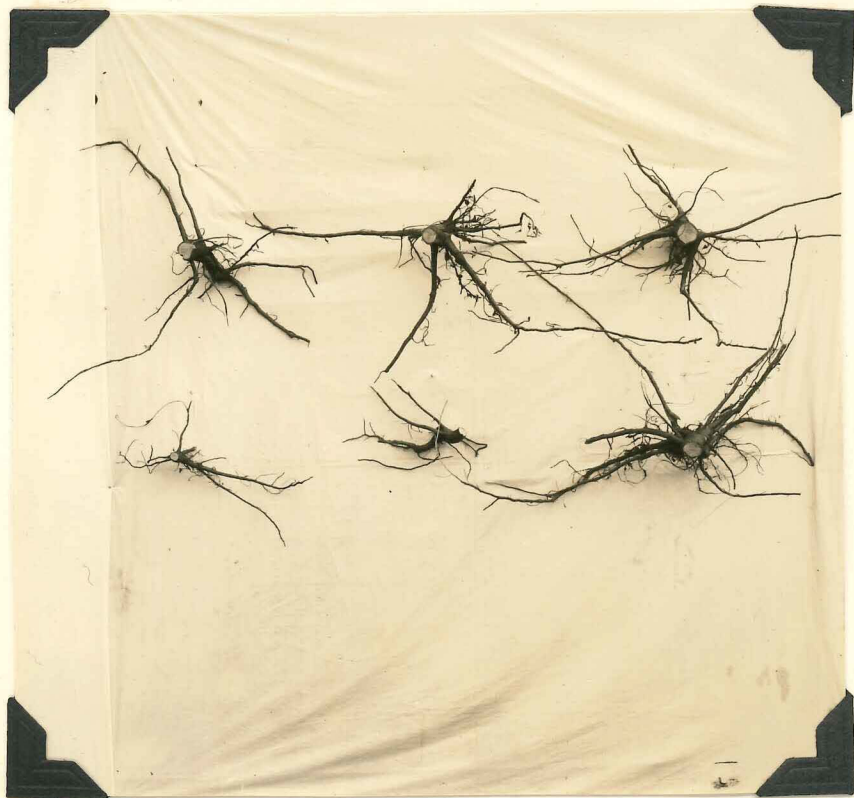


Fig. — White pine planted (above) and natural
(below) showing horizontal root development.



Fig. — Old field plantation of red pine
 — year old plantation 15-F. Difference
 is very noticeable in the absence of height difference

January 21, 1921

Best Friends

To see how ready to announce the complete list of
 names for the Syracuse Mount Red Pine Course which we are organizing



Fig. — Red pine planted on
cut-over land showing
Armillaria fruiting at the
ground line (top of board) note
deep planting and wadding
up of roots.



Fig. — Norway spruce plantation 19-c
— years from seed. Note the
weeviled leader in the foreground.



The volumes we have selected for the first year's reading
 together with the price of each volume, as indicated

Fig. — Europe 19 years
 old planted on old field Plantation

A-d.

1.	100	100
2.	100	100
3.	100	100
4.	100	100
5.	100	100
6.	100	100
7.	100	100
8.	100	100
9.	100	100
10.	100	100
11.	100	100
12.	100	100
13.	100	100
14.	100	100
15.	100	100
16.	100	100
17.	100	100
18.	100	100
19.	100	100
20.	100	100



Fig. — European larch showing
the resulting porcupine gnawing. The
point of gnawing is just above the
uppermost green limbs on the tree at the
right center.



Fig. Characteristic form of white pine grown in mixture with hardwood (left) and in pure stands (right). Stands are contiguous and spacing is 6X6' in both cases.