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EXPERIMENTS WITH CLASSES OF STOCK SUITABLE FOR FOREST PLANTING IN THE NORTHERN ROCKY MOUNTAINS [1] [2]

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INTRODUCTION

Except in unusually moist years the survival of planted stock in the northern Rocky Mountains, even on favorable slopes, has not been satisfactory. On good and poor sites alike, the principal cause of the unusual degree of mortality has been the combination of dry soil and dry winds during the hot days of July and August. The results have made it clear that the most important consideration in forest planting in this region is not the choice of a favorable site for planting, but the kinds of planting stock that are best suited to survive the unusually dry conditions, regardless of site.

Records of the United States Weather Bureau taken at Haugan, Mont., near the site of some of the experiments to be described here, indicate that the normal rainfall at that point during June is less than 2 inches, during July about 1 inch, and in August less than 1 inch (*2*).[4] At the same time low humidity, high temperatures, and wind during these months increase evaporation and thus increase the odds against which the planted trees must contend (*4*).

If it were possible to predict with certainty the occurrence of dry years, forest planting in this region could very profitably be confined to moist years, and in this way, with ordinary care, the immediate needs for planting could be met and a high degree of success would be insured. Large investments could be made in planting projects with reasonable assurance of satisfactory survival regardless of the quality of stock. Such reliable forecasts of weather conditions are, however, nowhere available as yet. The only factor directly under control is the class of stock to be grown for planting.

It is the purpose of this article to present the results of experiments in selection of planting stock that may be advantageously applied any year in any of the planting work in this region. The experiments, based on standard practices, were planned to measure the effects of length of roots, age, and size of trees on the survival of the stock in time of drought.

MATERIALS AND METHODS USED

The two tree species used in these experiments were the western white pine (*Pinus monticola*) and the western yellow pine (*P. ponderosa*). The planting sites were chosen only as typical of the class

[1] Received for publication May 9, 1928; issued August, 1928.

[2] Planting by the United States Forest Service in this region is confined at present to that part of the western white pine (*Pinus monticola*) belt in the St. Joe, Coeur d'Alene, Cabinet, Pend Oreille, and Lolo National Forests. Only land which was recently burned over twice is planted, because the areas burned only once usually are reseeded and the forest is satisfactorily reproduced by natural methods.

[3] The following men took part in the early experiments: D. R. Brewster, J. A. Larsen, E. C. Rogers, and P. C. Kitchen. The author made the later experiments.

[4] Reference is made by number (italic) to "Literature cited," p. 1000.

of land on which each species was being extensively planted. The white pine land ranged in elevation from 2,000 to 4,000 feet on northerly slopes and 4,000 to 5,000 feet on westerly and southerly slopes, but no southerly slopes were planted with western white pine unless the soil proved to be very favorable. Western yellow pine plantations were on elevations ranging from 2,000 to 4,000 feet on all slopes. Northerly slopes were, however, invariably planted with white pine rather than yellow pine.

The planting stock was lifted by means of spading forks, except when unusually long (10-inch) roots were desired and a spade was needed. The effort was made to handle uniformly all of the trees in any one experiment. Culling and heeling in followed the usual nursery practice. All of the grading, root pruning, sorting, etc., was done in the shade of a building and with the constant use of wet burlap to prevent drying of roots.

In all experiments, except as otherwise mentioned, planting was by the "slit" method, illustrated in Figure 1, used by the administrative planting crews of the Forest Service in the region. The more careful methods of planting, such as the cone method, may be ideal where cost is a minor consideration, but the slit method has here proved to be most efficient; it has yielded the largest number of living trees per dollar invested, and has shown no evidence of subjecting the trees to root rot or windfall in later life.

Season of planting was given scant consideration. A few experiments and several years of practice indicate that no great difference is to be expected between spring and fall plantings for an average year. Causes of loss of trees may differ somewhat for the two seasons and from one year to another, but the final effect on survival has usually been about equal for spring and fall work. The cold nights and warm days of an Indian summer following fall planting are apparently detrimental. If such weather does not occur, there may be an advantage in fall planting over that of the following spring, but this possibility seems to have no practical value in view of the present impossibility of forecasting such conditions.

As a rule, all trees planted in the field for experimental purposes were individually marked with stakes bearing symbols which designated the test. Sometimes individual serial numbers were used in order that a separate record might be kept for each plant. Lath stakes with tips painted white were used as markers when it was desired to observe the plants closely for three years or more. Otherwise the smaller and less durable, but more easily handled, manufactured pot labels or garden stakes were used to economize labor.

Spacing in plantations was not important in connection with studies that were not to be followed to the stage when crowns close. Hence, the usual method of spacing in plantations was modified to facilitate the taking of the frequent records needed. The different test lots to be compared were usually set in alternate rows, but sometimes, in order to mix them better, the two lots were set in the same row with plants alternating. The rows were of sufficient length to contain from 40 to 200 plants and ran approximately at right angles to contours. These arrangements, together with the use in each test of as uniform a slope as possible, tended to reduce experimental error due to local and unavoidable variations of site. An effort was made either to base each test lot on not less than 400 trees or to repeat the work during several seasons.

LABORATORY WORK

Because of the undesirability of field-planting trees from which detailed anatomical measurements had been taken and which had thereby been exposed to injury from drying, sample lots were devoted

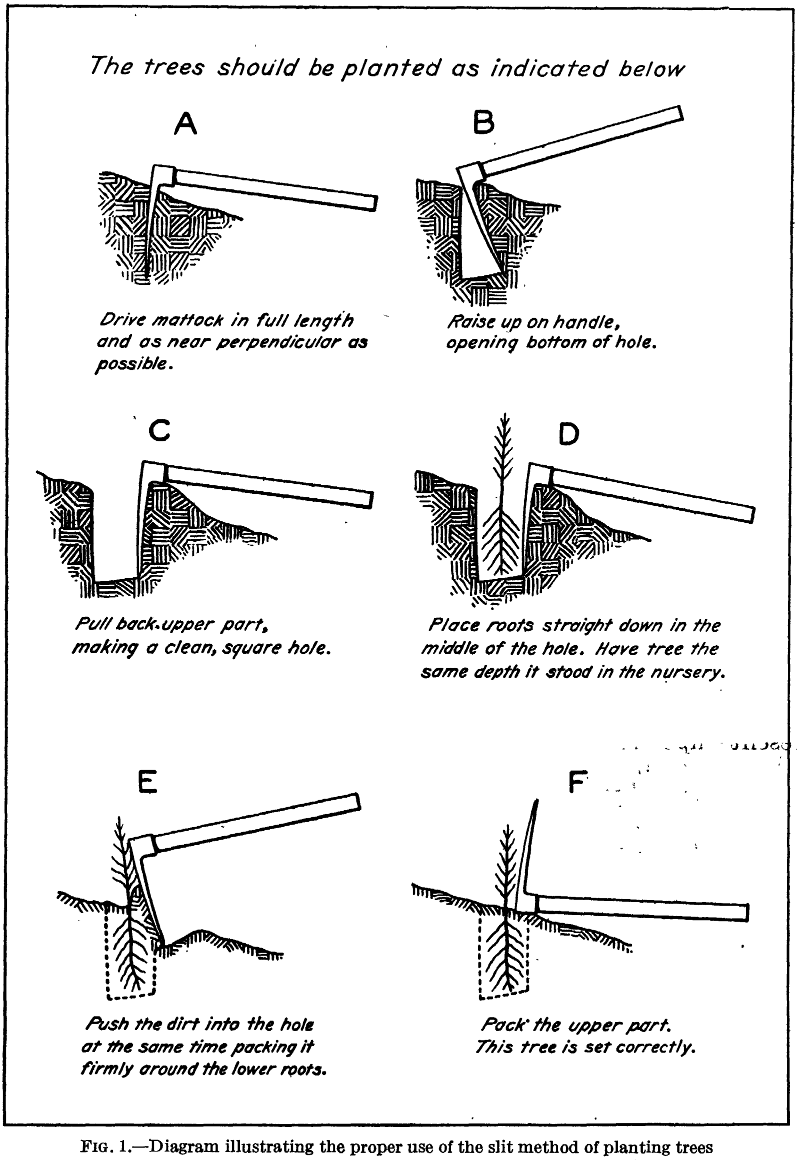

FIG. 1.—Diagram illustrating the proper use of the slit method of planting trees

exclusively to laboratory examination. These were selected mechanically in order to eliminate the factor of personal judgment. For example, if it was desired to plant 400 and to use 100 in the laboratory, then in counting out the 500, every fifth plant was reserved for study. In the laboratory every plant was tagged with a serial number and, ordinarily, the following measurements and counts were made:

(1) Diameter at the ground line in millimeters and tenths by means of a micrometer caliper.

(2) Length of stem from ground line to tip of terminal bud in inches and tenths.

(3) Number of primary lateral rootlets in two-length classes: (*a*) 0.5 to 2 inches, and (*b*) over 2 inches long.

(4) Number of secondary lateral rootlets divided into two classes on the same basis. By primary rootlet is meant a branch from the central or tap root, and all branches from the primary rootlets are called secondary.

(5) The length of one needle of average appearance taken from the center of the crown, in inches and tenths.

All measurements were then averaged, and from each lot a few plants having measurements falling close to those of the average tree were selected from the data sheets. The trees thus chosen as typical of stock planted were identified by their tag numbers and were photographed against a translucent screen, using only transmitted light, to obtain satisfactory silhouettes. These plants were severed at the ground line. In some tests the trees were cut just below the crown and also just above the root collar, the intervening section of bare stem being discarded because it functioned only in mechanical support and conduction. After separation, the masses of tops and roots were dried in a water-jacketed oven until no further loss of weight occurred. The averages resulting from the weights of this dried material were useful in judging relative plant development and the balance between top and roots.

EXAMINATION OF PLANTATIONS

In taking records of the plantations an effort was made to make the first examination three weeks or a month after planting in order to observe the early unthriftiness or death due to the shock that plants receive from being moved. Thereafter, during the first season, at least three examinations were made, not oftener than once a month. This was necessary in order to detect the trends of changes leading to the final condition of the trees in the fall. During the second season spring and fall examinations were usually sufficient.

Plants were classified merely as thrifty, unthrifty, and dead, with a notation of any fresh evidences of causes of unthriftiness or death. There was difficulty in fixing a dividing line between thriftiness and unthriftiness, and in the recent experiments a tree was not classed as unthrifty unless this condition was so well marked that it was believed the chances were even that the plant would not recover. Possibly the word "failing" would be more appropriate than "unthrifty." Many trees, suffering from the shock of planting and the first effects of drought, exhibited a partial browning of the needles formed the previous season which gave the plant an unthrifty appearance in the popular sense. Experience indicates that a large number of such plants usually recover, and, therefore, the present policy is to be conservative in calling trees unthrifty. This gives more meaning to a plant class which, at best, depends for its true significance on the accuracy and consistency of personal judgment. With very few exceptions, all test and control lots of trees were planted by the same man, and all records in any series were made by the same person.

TESTS OF AGE CLASSES

Besides showing how old trees are, the term "age class," as applied to forest nursery stock, refers to differences in time of transplanting in the nursery and hence indirectly indicates differences in plant development. Thus the age class 2–0 refers to seedlings which have been in the seed beds for two growing seasons and not transplanted; 1–2 refers to 3-year-old transplants that spent only their first year in the seed beds; and 1–1–1 refers to stock that is 3 years old and was transplanted each year in the nursery. For any given species of tree it is these differences in development that influence the quality of stock. In the experiments, age classes were tested in field plantations in order to guide the nursery work.

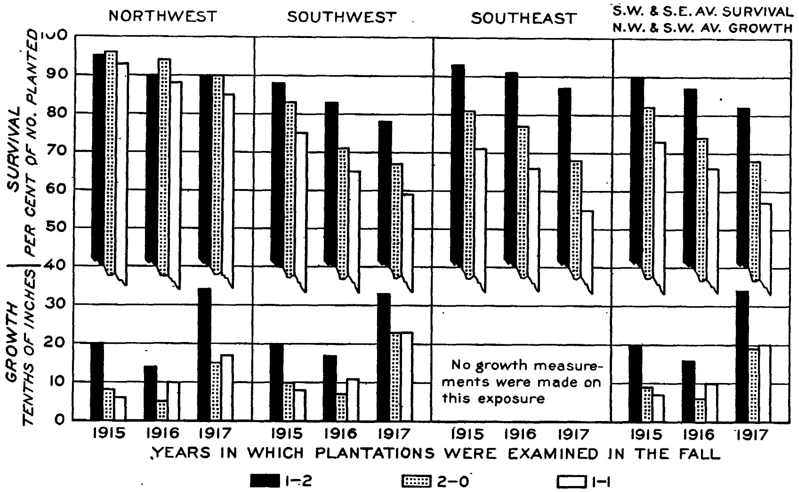

FIG. 2.—Survival and growth of western yellow pine: 7,200 trees of different age classes planted in the spring of 1915 near Wallace, Idaho

WESTERN YELLOW PINE

The earliest satisfactory experiments with western yellow pine age classes were started in the spring of 1915 on the Placer Creek drainage, near Wallace, Idaho, on an area severely denuded by the Idaho conflagration of 1910, and typical of the doubly burned-over land in need of reforestation in this region. About 7,200 trees divided equally among three age classes were planted on slopes of three different aspects. All members of the planting crew planted an equal number of trees in each test lot, thus excluding the effect of differences in quality of work on the comparison of later behavior of the trees. Growth measurements were made only on thrifty trees. Although the amount of rainfall during the summer of 1915 was about 2.5 inches above normal for the locality, most of the deaths of trees in the plantations could be attributed to no other cause than drought, and the data therefore indicate directly the relative drought-resisting powers of the several age classes, especially on the more severe sites.

The results of observations of growth and survival during three years are recorded graphically in Figure 2. It may be seen from the diagram that, on the northwest slope, where the percentage of survival was highest for all age classes, the differences in survival were not great enough to justify any comparison of the classes of stock, but on the two southerly slopes, more definite relationships were apparent. Clearly, the 1–2 stock was best able to survive planting, the 2–0 was intermediate, and the 1–1 stock was least well fitted to survive. Differences in growth between the 2–0 and 1–1 stock were negligible, but the 1–2 stock grew fastest from the start, on all slopes.

With vast areas of forest land lying idle, it is necessary first of all to make each dollar produce as many living trees as possible. Therefore, these age classes were also compared on the basis of cost of survival, or cost of planting per living tree. The cost per thousand survivors of each class was computed by dividing the total cost of planting a thousand trees by the percentage of survival attained and multiplying by 100.

The first cost of planting, including the production of stock, is usually greatest for large transplants. In this case, the 1–2 cost most, the 1–1 next, and the 2–0 least. When the cost of survival was computed, the age classes in the experiment compared as follows: On the favorable northwest slope, the 2–0 stock was most effective, the 1–1 next, and the 1–2 least desirable. On the less favorable southwest and southeast slopes, 1–2 was superior, 2–0 intermediate, and 1–1 inferior. The 1–1 stock made an especially poor showing on the southeast slope from this point of view. Considering the theoretical average cost of survival on all three slopes after three years, the 1–2 stock was most economical, with the 2–0 stock a close second. The survival of 2–0 stock was but 2 per cent more expensive than the 1–2, whereas the 1–1 stock was 23 per cent more expensive.

Very little 2–1 stock has been grown at Savenac. As a general rule, it has been observed in practice that the so-called shock of transplanting or setback in growth which follows the setting of a seedling in a new location persists throughout the following year. In other words, during the first year after transplanting the benefits usually appear to be entirely offset by loss of growth. This condition can be more easily understood from the fact that the 2–1 stock at Savenac Nursery develops quite irregularly, resulting in inferior development of about half of the plants. Culling out about half of the number makes the remainder expensive.

Correspondingly little has been done with 2–1 western yellow pine stock in the way of experimental field planting. The results of two early tests are conflicting. In the fall of 1912 a field test of 2–1 stock was installed at Priest River, Idaho, together with 1–2 and other stock. A year later 78 per cent of the 2–1 were alive and 79 per cent of the 1–2, but the costs per thousand living trees were \$23.28 for the 2–1 and \$18.94 for the 1–2. In the spring of 1918 another test was made at Haugan, Mont., and was watched during three years. This time the 2–1 led decisively. Its survival was 61 per cent, as compared to 43 per cent for 1–2 the first year, and 54 per cent as against 39 per cent for 1–2 the third year in the field. A comparison of the cost of survival showed the 2–1 stock to be \$4.73 cheaper per thousand third-year survivors.

In May, 1923, a test of 2–1, 1–2, and 2–0 western yellow pine was made on a southeast slope of the 1910 burn near Haugan, Mont. The site bore numerous ceanothus bushes and some grass, being typical of much of the nonforested land of the region. The trees were lifted from the beds at Savenac Nursery on May 1. . Not more than 3 per cent were rejected as unsuitable for field use and most of these were culled because of broken roots. In bunches of 50, all plants were root pruned at a point 6.5 inches from the ground line, removing about 3 inches from 2-0 roots, 3.5 inches from the 1-2, and 2 inches from the 2-1. About 50 trees from each lot were set aside for use in the laboratory, and 200 of each of the age classes were planted.

The trees were examined three times during 1923 and twice during 1924 in order to observe the causes of unthriftiness and death. There could be no doubt that drought was the principal cause. No marked differences in the condition of the three lots of trees occurred in the first year until the soil became dry in September. Survival was then 92 per cent of the number planted for 2-1 stock, 90.5 per cent for 1-2, and 84.5 per cent for 2-0. Dry weather started early in the spring of 1924, and thus more deaths than usual occurred during the second growing season, but the age classes still maintained the same order of drought resistance. (See Table 1.)

TABLE 1.—*Comparison of the percentages of survival and top-root ratios of western yellow pine of three different age classes at end of second growing season* [a]

Age class	Alive	Dead	Thrifty	Unthrifty	Weight of plant in top
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
2-1 stock	81.8	18.2	80.3	1.5	64.0
1-2 stock	77.1	22.9	76.1	1.0	71.5
2-0 stock	72.9	27.1	69.9	3.0	74.4

[a] Condition in October, 1924, of plantations made in the spring of 1923 on a southeast slope of the 1910 burn near Haugan, Mont.

As is shown in Table 1, field survival increased in the same order in which the percentage of total plant weight in the tops decreased. In other words, survival increased as the top-root ratio decreased. The 2-1, which survived best, had the best balance, whereas the seedling 2-0 stock, which survived least well, had the poorest balance. As will be seen later, this relation between balance and field survival does not always hold true, but the tendency is unmistakable and it should be a help in judging the ability of stock to withstand dry conditions. The appearance of the stock used in the experiments is shown by photographs of representative trees in Figure 3.

These tests indicate that 2-1 stock may excel 1-2 stock in survival if the percentage of weight in the top is less; but, because of the necessity of heavy culling and the consequent higher cost of production of 2-1 stock, it is doubtful if it will ever successfully compete with 1-2 stock. The results agree with the earlier experiments at Wallace in indicating the superiority of 1-2 over 2-0 planting stock.

This evidence of superiority was further corroborated a year later in an experiment testing size classes and length of root. In the spring of 1924, using a uniform grade of medium-sized stock with root systems pruned to a length of 8 inches, 491 plants of 1-2 and 494 plants of 2-0 stock were set out on a dry, rocky, severe south slope. The results are given in Table 2. About one-sixth of the trees in each lot were dead when first examined, and the two lots were in similar condition when the dry weather started. Mortality with the 2–0 then proceeded at a more rapid rate, especially in July, than with the 1–2 stock, and, although both plantations were virtually destroyed the destruction of the 1–2 was less complete.

TABLE 2.—*Mortality rate of two age classes of western yellow pine in a plantation destroyed by drought* [a]

Age class	Survival at different dates				
	May 26	June 26	July 26	Aug. 26	Nov. 7
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1–2 stock	83.9	73.1	23.8	10.6	7.4
2–0 stock	82.8	62.1	7.7	2.6	1.4

[a] Condition during 1924 on a south slope or the 1910 burn near Haugan, Mont.

The experiments with western yellow pine age classes agree in showing the superior survival of 1–2 over 2–0 stock. When it has a small top-root ratio, 2–1 stock may equal or excel 1–2 in the field; 1–1 is inferior to the other classes. In cost of survival the use of 2–0 stock is scarcely less economical than the use of 1–2 stock. As to other possible age classes it may be said that 1-year-old seedlings, are too small, and that the rather rapid growth of western yellow pine causes seedlings more than 2 years old or transplants more than 3 years old to be too large for economical handling in planting operations at the present time.

Korstian and Baker (*3*), working in the intermountain region obtained the best survival with 2–1 stock. With them the other age classes ranked as follows in descending order of survival: 2–0, 2–2 1–2, 3–0, and 1–1.

WESTERN WHITE PINE

In 1911, at the Priest River Experiment Station [5] in Idaho, a small clearing of about 1 acre was made in a 60-year-old stand of western white pine, Douglas fir (*Pseudotsuga taxifolia*), and western larch (*Larix occidentalis*) on a northeast slope. In the spring of 1915, 100 plants each of 2–0 and 1–2 western white pine were planted in the clearing. In 1921, 66 per cent of the 2–0 and 78 per cent of the 1–2 plants were alive. The 2–0 plants averaged 12 inches and the 1–2 plants 19 inches high.

Another experiment with western white pine age classes near Wallace, Idaho, in the spring of 1915, was combined with a study of aspects of planting sites. About 600 trees were planted in each test lot, or 12,000 trees in all. The details of this experiment have been reported in an earlier paper (*8*); it will be sufficient here to give the results of the work. Figure 4 shows the relative survival of five different age classes at the end of the third growing season after planting. This diagram of actual survival disregards the cost and the growth rates of the living trees. With cost and growth considered, it may be concluded that although in survival of planted trees and in height growth 2–2 western white pine transplants are

[5] Now a field station of the Northern Rocky Mountain Forest Experiment Station.

at the top, with 1–2, 2–1, 2–0, and 1–1 following in descending order, the cost of survival definitely favors 2–0 seedlings on moderate sites, and 2–2 or 1–2 only on the more severe sites.

No further work of this kind was attempted until the fall of 1922. That year dry weather continued so late into the fall that very little planting could be done on the sites selected. On October 27, 400 plants each of 1–2 and 3–0 age classes were planted on a northwest slope of the 1910 burn near Haugan. At the close of the following season the 1–2 stock showed 4 per cent higher survival and 12 per cent more thrifty plants than the 3–0. The growing season had been moist until September, when a deficiency of rainfall caused plants to suffer from drought. Had the summer as well as the fall been dry, the difference in survival would probably have been greater, because the transplants (1–2) had over 10 per cent more of their total weight in their root systems than had the seedlings (3–0). By the end of another growing season the transplants had increased their lead by an additional 4 per cent in survival.

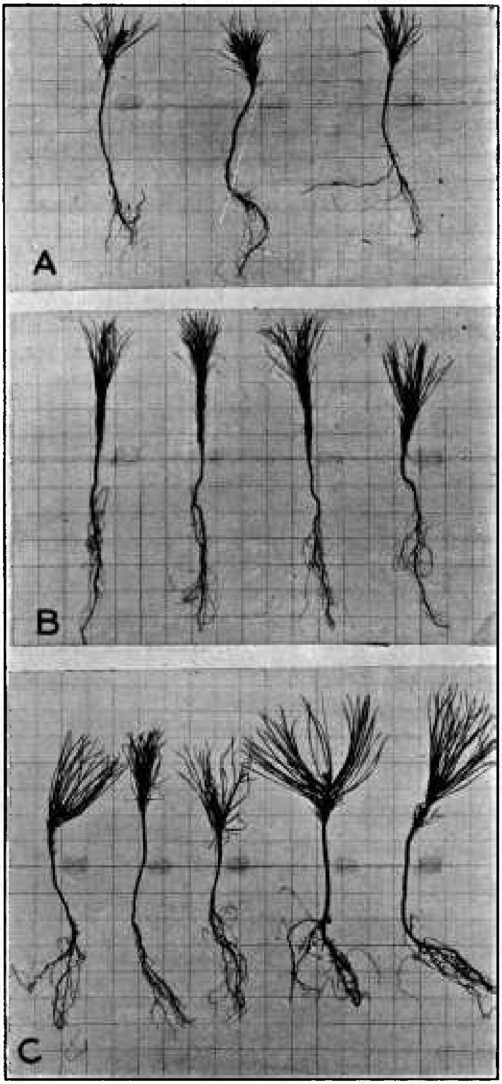

FIG. 3.—Western yellow pine age classes, 1923: A, 2–1 stock; B, 2–0 stock; C, 1–2 stock

The next test, of 1–2, 3–0, and 2–0 western white pine, was started in the fall of 1924, the trees being lifted from the nursery during the last week of September. From the 2–0 stock 3 per cent and from the 3–0 and 1–2 stock 1 per cent of the trees were culled out because of extremely poor development or injury in lifting. Uniformity in the lot of trees was increased by culling out both the largest and smallest individuals until only about half of the original number remained. All roots extending more than 8 inches from the ground line were pruned off at the 8-inch point. Average measurements of these trees are given in Table 3, and the appearance of representative trees is shown in Figure 5. Four hundred trees of each of these age classes were planted in October, 1924.

TABLE 3.—*Anatomical characteristics of western white pine stock planted in the fall of 1924, as determined by average measurements* [a]

Age class	Stem length	Length of needles	Diameter at ground line	Lateral rootlets		Oven-dry weight	Weight in top	Weight in root
				0.5–2 inches	Over 2 inches			
	Inches	*Inches*	*Millimeters*	*Number*	*Number*	*Grams*	*Per cent*	*Per cent*
1–2 stock	2.4	1.4	2.1	22.2	12.3	1.0	52	48
3–0 stock	4.1	1.5	2.5	20.1	12.8	1.6	67	33
2–0 stock	2.6	1.5	2.0	17.3	7.1	.7	61	39

[a] Basis: Weight measurements, 55 trees; other measurements, 60 trees.

In the following winter, during a period of exceptionally severe weather when the trees were but partly covered with snow, the tops appeared to be seriously injured. However, detailed observation failed to indicate any relation between the relative drought hardiness

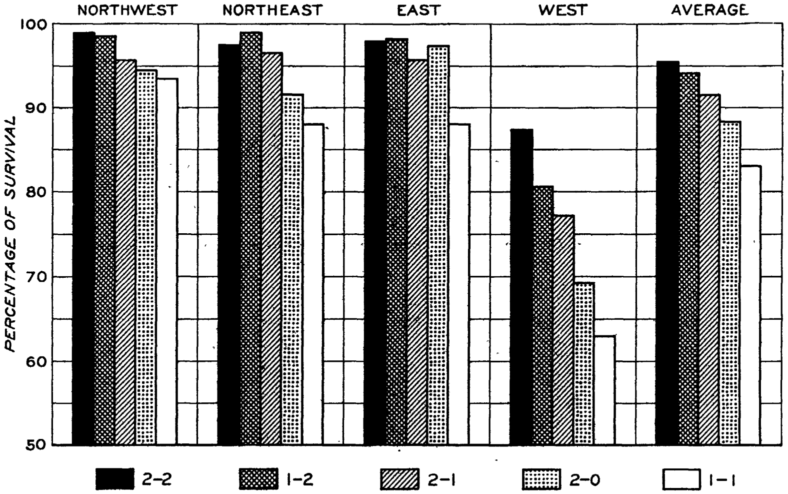

FIG. 4.—Survival of western white pine age classes: 12,000 trees three years after planting in the spring of 1915 near Wallace, Idaho

of the different age classes and either the numbers of buds remaining dormant or the extent of injury to foliage. During the following growing season the winter injury was seen to be less serious than was thought at first; adventitious buds formed readily, and, although the growth of several plants was checked, survival did not appear to be affected. At the end of the season the condition of the plantations was as shown in Table 4.

TABLE 4.—*Condition in September, 1925, of western white pine age classes planted in the fall of 1924, on a northeast aspect near Haugan, Mont.*

Age class	Alive	Dead	Thrifty	Unthrifty
	Per cent	*Per cent*	*Per cent*	*Per cent*
1–2 stock	85.7	14.3	83.7	2.0
3–0 stock	82.7	17.3	78.2	4.5
2–0 stock	72.0	28.0	70.7	1.3

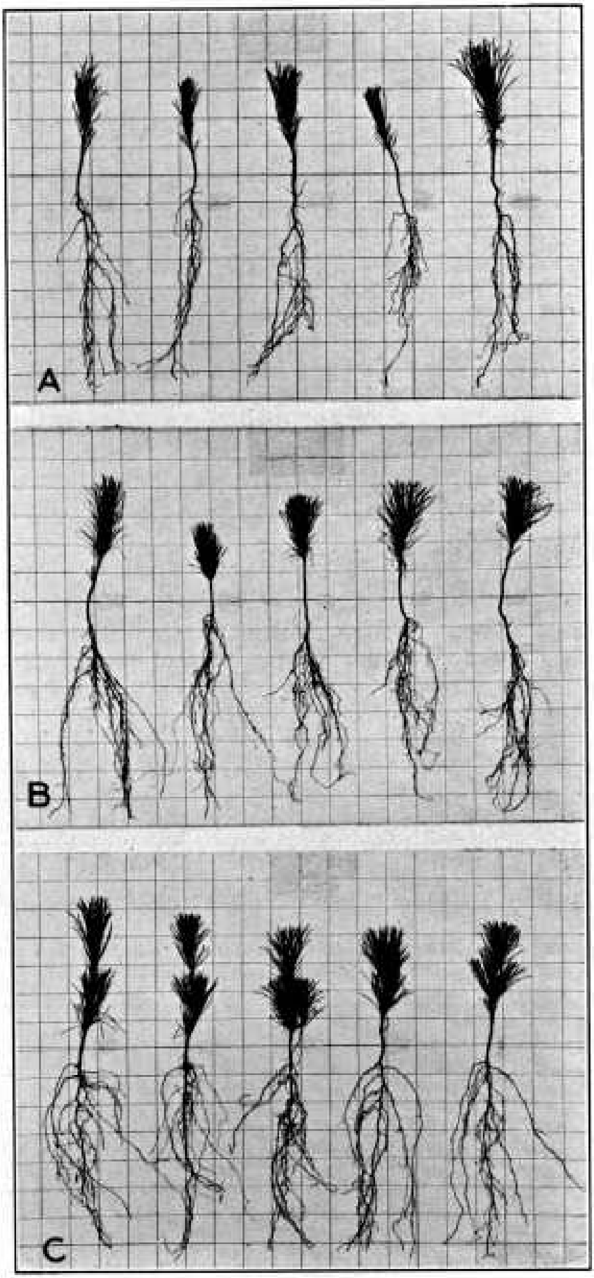

FIG. 5.—Western white pine age classes, 1924: A, 2–0 stock; B, 1–2 stock; C, 3–0 stock

That the 2–0 stock survived least well was not surprising, for its inferior development was apparent. (See Table 3 and fig. 5.) At first glance, the 3–0 stock seemed to be better developed than the 1–2 in most respects. However, the 3–0 stock had poorer balance because of its larger tops and slightly fewer roots than the 1–2. The fact that it had 15 per cent more of total plant weight in the tops than the 1–2 seems an adequate explanation of its inferior survival.

The indicated superiority of 1–2 over 2–0 stock is in full agreement with the results attained 10 years earlier in the tests at Priest River and Wallace, Idaho. In the experiment at Haugan the survival of the 3–0 stock was intermediate between those of 1–2 and 2–0, corresponding to the 2–1 stock in the experiment at Wallace. This suggests that much the same results may be expected from 2–1 and 3–0 stock, although no comparative tests have as yet been made. From the tests actually made, the western white pine age classes rank in this order in ability to survive field planting: 2–2, 1–2, 2–1, or 3–0, 2–0, and 1–1. But when cost of survival is considered, 2–0 stock leads on the less severe planting sites. Of the other possible age classes, 1-year-old trees are too small, and 4-year-old seedlings or 5-year-old transplants are too large for field planting by present methods.

TESTS OF SIZE CLASSES

Strictly speaking, the best size of trees for planting can not be considered independently of the method of planting. Large trees can not be removed from the nursery without the loss of many roots, nor can they be properly planted except by more expensive methods than those ordinarily employed. Also there is a point beyond which the reduction in size of planting stock is not economical. In most places the trees in forest plantations have to fight drought, fungus diseases, rodents, insects, or any of a variety of enemies. Except in very favorable localities, destructive influences limit the reduction in size of planting material and preclude the possibility of success from the sowing of seeds directly in the field (*7*). The study of the best sizes of trees for planting has thus been restricted within definite limits.

TABLE 5.—*Average tree measurements at the time of planting 1–2 western yellow pines, at Priest River, Idaho*

Size class	Length of root	Length of top	Diameter of stem
	Inches	*Inches*	*Milli-meters*
Large	8.2	3.8	3.3
Medium	9.0	3.3	2.4
Small	7.8	2.7	2.0

WESTERN YELLOW PINE

Plantations on flat ground at the Priest River station in the fall of 1913 and spring of 1914 were made with 1–2 western yellow pines from the Savenac Nursery.[6] The trees were sorted into three size

[6] All of the experiments at Priest River station were planned and executed by J. A. Larsen. The work was entirely independent and separate from that at Wallace, Idaho, and Haugan, Mont., but is discussed here as it is within the region and essentially a part of the subject with which this article deals.

classes, the large and well-developed plants being placed in one group, the noticeably small and underdeveloped in another group, and the remaining medium-sized trees in a third group. This grading resulted in 524 large, 978 medium, and 824 small trees. An idea of the relative size of these trees may be obtained from Table 5, which gives the average measurements of 50 mechanically selected representatives of each size class. Planting was done by the so-called prepared-side-hole method. This differs from the slit method principally in that the soil is loosened by a few strokes of the mattock before the hole is made and the tree inserted. The results of this work are shown in Table 6.

TABLE 6.—*Survival and height growth of 1–2 western yellow pines according to size classes* [a]

Size of trees and season of planting	Survival in different years						Height in different years					
	1914	1915	1916	1917	1919	1921	1914	1915	1916	1917	1919	1921
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Planted in fall:												
Small	52	44	42	41	41	41	4	5	9	12	20	31
Medium	50	44	42	42	42	42	2	6	9	13	18	32
Large	65	60	57	57	57	54	5	7	11	15	24	37
Planted in spring:												
Small	70	51	49	44	44	44	3	4	8	10	18	34
Medium	74	60	58	56	52	52	4	5	9	12	22	33
Large	89	79	79	76	73	73	5	6	12	16	26	38

[a] Plantations made in the fall of 1913 and spring of 1914 on flat land at Priest River, Idaho.

The large trees survived best in both plantations, and following spring planting the medium-sized trees survived better than the small trees. Spring planting resulted in higher survival than fall planting. In both plantings the small and medium-sized trees grew at about equal rates and were surpassed by the large grade. The thrifty appearance of this plantation of large trees after nine years' growth is shown in Figure 6, A. Although this experiment clearly indicates that size of trees greatly influences results, it gives no definite basis for judging the portion of stock that should be rejected before planting in the field.

Greater refinements in grading into size classes were attempted in the spring of 1915, with the view of making it possible to give specific recommendations regarding the proper degree of culling necessary to exclude weak plants. A lot of 4,300 trees were classified into the eight grades illustrated in Figure 7, A, and were planted in the spring of 1915 on a flat and on a southwest aspect.

The relative survival of the trees is indicated in Figure 8. The results on the flat show some tendency toward a reversal of those on the slope, but the order is confused. The uniformly higher survival on the flat is taken as an indication of better soil moisture conditions there than on the slope. The more severe conditions on the slope bring out clearly the inferiority of the lowest grade or smallest 5 per cent of the stock. The smallest 20 per cent of the whole (or lots numbered 1, 2, 3, and 4) remained constantly lower in survival than the 80 per cent of larger plants. Average growth measurements showed that the growth rate increased steadily with the size of trees planted until, in 1921, the trees from the largest grade were 1 foot taller than those of the smallest grade. The results indicate that although no trees of the grades tested need be rejected

FIG. 6.—Highly satisfactory plantations of 1-2 stock: A, 9-year-old plantation of large-grade western yellow pine stock, trees about 3.5 feet tall, 1922; B, 8-year-old plantation of large-grade western white pine, trees about 2 feet tall, 1922

for planting on favorable sites, about one-fifth of the trees should be culled out before planting the drier slopes.

In May, 1923, about 750 1–2 western yellow pines were lifted at the Savenac Nursery for a test of size classes. After rejecting 5 per cent of these because of poor development or injury, the lot was graded into three classes, large, medium, and small, each consisting of one-third of the total number. Roots of the large plants were pruned to a length of 7 inches, the medium size to 6.5 inches, and

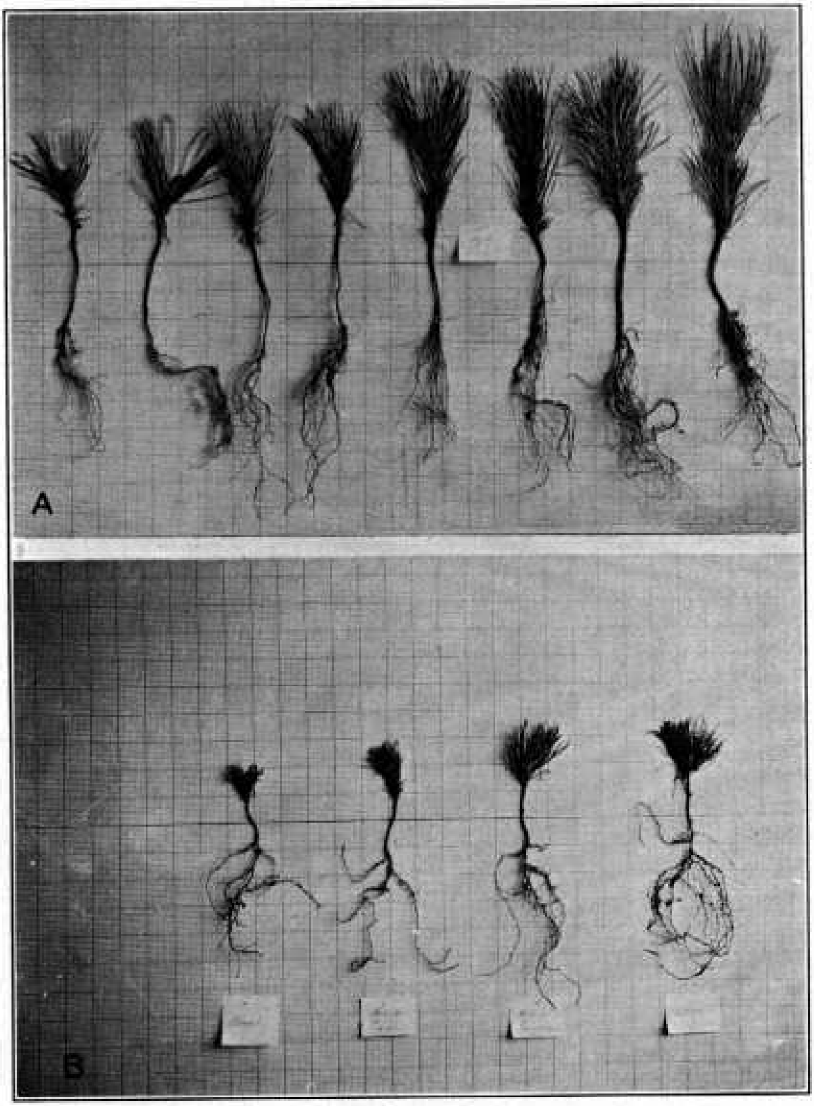

FIG. 7.—Graded sizes of 1–2 planting stock: A, Eight grades of western yellow pine planted in the spring of 1915; B, four grades of western white pine planted in the fall of 1914 and the spring of 1914

the small to 6 inches, in order to maintain as nearly as possible the same balance in the different lots. The figures in Table 7, giving percentage of total plant weight contained in the tops, show this effort to have been successful. The table also shows in detail the difference in size of the plants. Early in 1923 the small grade showed the largest number of unthrifty plants, the large grade the fewest, and the medium grade an intermediate number, but survival was uniformly high until drought occurred in September. On the seventh day of the month the grades ranked as follows in survival: Large, 90 per cent; medium, 80 per cent; and small, 62 per cent. Each size had the benefit of roots one-half inch longer than those of the next smaller size. Undoubtedly this influenced the results obtained, but as the deeper layers of soil within the root zone did not become dry until September, it does not seem likely that root length alone was responsible for any more of the differences in survival than were the other characteristics shown in Table 7. Mortality during the

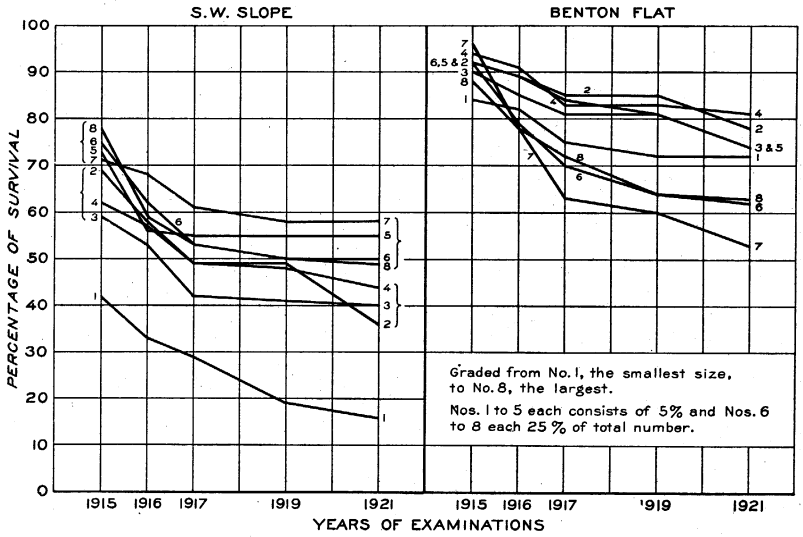

FIG. 8.—Size classes, series F, graded 1–2 western yellow pine stock, basis 4,300 plants; plantation of spring of 1915, Priest River Experiment Station, Idaho

second season was also less for the larger sizes. In October, 1924, survival was as follows: Large, 82 per cent; medium, 68 per cent; and small, 45 per cent.

TABLE 7.—*Anatomical characteristics of the root-pruned 1–2 western yellow pine size classes, as determined by average measurement* [a]

Size class	Stem length	Length of needles	Diameter at ground line	Lateral rootlets		Oven-dry weight	Weight in top	Weight in root
				0.5–2 inches	Over 2 inches			
	Inches	*Inches*	*Millimeters*	*Number*	*Number*	*Grams*	*Per cent*	*Per cent*
Large	4.1	3.5	3.6	27.6	15.1	2.6	72	28
Medium	3.4	3.3	3.0	14.8	9.1	1.6	72	28
Small	2.6	2.6	2.2	8.0	4.9	0.8	73	27

[a] Planted in May, 1923, near Haugan, Mont. Averages based on measurements of 60 trees of each size class.

These results were corroborated in 1924 by the results of a plantation containing over 1,175 western yellow pines in each of the size classes—large, medium, and small. In April, the trees were planted on a steep, gravelly south slope where conditions of plant growth were obviously severe. Five examinations during the season showed that survival was constantly highest for the large, intermediate for the medium, and lowest for the small stock, but the differences were not large and by the end of the season less than 15 per cent of the plants were alive in each grade. The combined effect of a severe site and a dry year was the cause of the failure to obtain satisfactory survival. The foregoing results agree with those obtained by Show (*5*) in California, who found that graded sizes of 1–2 western yellow

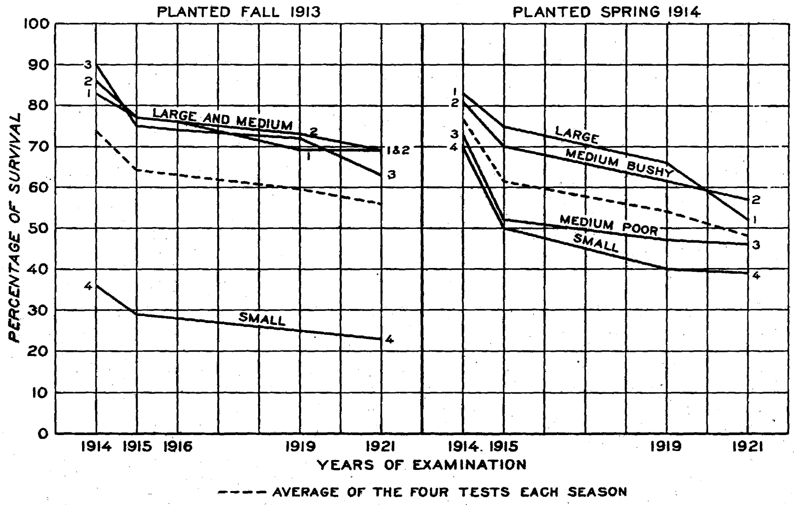

FIG. 9.—Size classes, series A, graded 1–2 western white pine stock, about 400 plants in each test; plantation on Benton Flat, Priest River Experiment Station, Idaho

pine survived as follows in 1916: Large, 50 per cent; medium, 38 per cent; and small, 23 per cent.

WESTERN WHITE PINE

Experiments similar to those with western yellow pine were made with the western white pine at the Priest River station in the fall of 1913 and spring of 1914, using 1–2 stock grown at Savenac Nursery. This time the trees were sorted into four grades: (1) Large stock with large, well-developed roots; (2) medium-sized trees with well-developed roots; (3) medium-sized trees with poor and stringy roots; and (4) small plants. About 40 plants were mechanically selected from each grade for the measurements given in Table 8; representative trees are shown in Figure 7, B. The trends of survival in these plantations are shown in Figure 9.

A quantity of moisture greater than normal was available in the summers of 1914, 1915, and 1916, so that differences in drought hardiness of the various classes do not stand out clearly in all cases. Of the lots planted in the fall the smallest size did very poorly, while the other grades were all much alike. In the fall plantation survival was on the average higher than in the spring plantation. In the spring plantation the relative order of survival of the grades was constant for six years, showing the tendency toward higher survival of the larger plants. Measurements of total height in 1921 showed that the small class averaged about 4.5 inches shorter than the others, which were all about 22 inches high. (Fig. 6, B.)

TABLE 8.—*Average tree measurements of 1–2 western white pines at the time of planting (fall, 1913, and spring, 1914) at Priest River, Idaho*

Size class	Length of root	Length of top	Diameter of stem
	Inches	*Inches*	*Millimeters*
Large class	8.4	2.7	2.5
Medium with bushy roots	6.5	2.4	2.1
Medium with stringy roots	6.9	2.2	1.9
Small class	6.3	2.0	1.5

PRUNING TOPS TO MAINTAIN BALANCE

The term "balance" as used in speaking of forest-planting material means the relation between the capacity of the root system to absorb moisture and the capacity of the crown or top to transpire moisture, which in turn is a measure of the water use of plants. It is true that other things besides balance influence the economical use of water by plants. Bates (*1*) has shown how the water requirements of trees vary with different species. Numerous external factors influence the water-supplying power of the soil and the evaporating power of the air, thus controlling the flow of water through a plant. But balance, as an attribute of the plant itself, is to a certain extent capable of modification in the nursery.

It is the aim of forest nursery practice to produce plants with tops as small as possible in comparison with the usable portion of the root system. As a rule transplants have much better balance than seedlings that have never had their roots pruned during their period of development, and the usual higher survival of transplants is largely ascribed to their smaller top-root ratio. If differences in survival can correctly be attributed to corresponding differences in balance, as was done with the test of western yellow pine age classes planted in the spring of 1923, it is essential that balance be measured by as precise a method as is practicable. In transpiration tests made in 1917, Bates (*1*) computed the area of leaf surface from needle dimensions and volume displacements, but he recognized the error due to the inclusion of stem volume. Similarly, the weight of wood in stems and roots is a source of error in judging balance from measurements of weight alone. Yet simple comparisons of oven-dry weights are easily made, and the unavoidable error should not destroy the value of the method unless there be great variation in size of the trees compared. Because the method of weight comparison can be applied to representative lots of 100 or more nursery trees at one time, and is easy to use, it is preferred to the "leaf exposure" method.

The balance of trees taken from forest nurseries is almost invariably inferior to that of naturally grown trees of the same age. This is because the root systems penetrate the nursery soil so deeply that they are seldom removed intact, and also because the especially long roots that did not happen to break off in the soil are pruned off previous to planting in order to prevent them from being doubled up in the planting holes. With hardwoods top pruning is commonly practiced in order to restore the balance that is lost in root pruning. In horticultural practice, because symmetrical tops are desired, the tops of conifers are not pruned, but symmetry is nonessential to forest trees less than 4 years old. Light and severe pruning of needles with both white and yellow pine has been tested in field plantations near Haugan, Mont. Although the results were negative, a few words about the tests may interest those who may have contemplated similar trials.

In preparing 1–2 western yellow pine for planting in April, 1923, certain lots of trees were top pruned. By cutting horizontally with shears, the uppermost portions of needles were removed, leaving only the part of the crown that could not be removed in one cut without injury to the terminal bud. This resulted in plants with about 10 per cent less of their total dry weight in the tops, an improvement in balance that appeared sufficient to increase field survival. No excessive bleeding of sap from the cut ends was observed; the needles promptly sealed their wounds, and the dying of needle tissue progressed only about one-sixteenth inch from the cut ends. Nevertheless, the vitality of the plants must have been reduced in some way by the pruning, because survival was lowered in spite of the improved balance of the trees. Too severe reduction of the organs of photosynthesis is a plausible explanation of the injury. This idea was strengthened by the field observation that the plants that died were principally the smallest ones, which lost the largest proportion of their crowns, and the observation that numerous very thrifty plants were all among the large trees with very slight or no top pruning.

Probably the reduction of the plants' equipment for assimilating food was especially injurious because it was made early in spring, the season of naturally rapid growth. Later pruning might help the plant through the critical period of summer drought without this early interference with vital functions, but of course it could not be considered as a separate operation in practice. The question arose as to whether pruning of tops might be beneficial in connection with late planting. Heavy and light top pruning was tried in both early and late plantations. The lightly pruned trees in the late plantation did best of all, but were not sufficiently superior to the unpruned trees to form evidence in favor of the theory under test. In general, pruning lowered survival.

PROPER LENGTH OF ROOT SYSTEM

The benefits from deep setting of roots on exposed sites have been mentioned by Toumey (*6*). From 1921 to 1924 the following theory along the same line was tested by various experiments: The heavy drought losses in the forest plantations the first season following plantings are largely due to the downward desiccation of the soil during the dry season, the soil often becoming devoid of available moisture beneath the lowermost level reached by the roots. Seedlings arising from natural reproduction immediately extend their roots downward in an attempt to keep ahead of the advancing dry soil, but planted trees fail to do this with sufficient promptness. Owing to the shock of planting, the downward penetration of roots during the first season is negligible.

A preliminary test was made with 2–0 western white pine in the spring of 1921. Six hundred seedlings were root-pruned at points 8 inches from the ground line and planted on a northwest slope together with 400 seedlings with unpruned roots. Holes were made sufficiently deep to accommodate the roots of each plant without any doubling back. This gave the unpruned lot the advantage of about 1½ inches greater depth of roots. By the end of September, 43 per cent of the unpruned trees and 59 per cent of the pruned trees were dead. Nearly all of the deaths occurred during July and August and were attributed to drought.

With trees planted in the spring of 1923 more thorough tests were made of the influence of root length on survival. Of 1–2 western yellow pines lifted from the nursery in the usual manner, 5 per cent were rejected because of root injury and 2 per cent because of poor development. Many but not all of the trees retained roots 10 inches long, and variation in balance was apparent. Accordingly, as trees were pruned individually at points 4, 6, 8, and 10 inches below the ground line, they were also graded sufficiently so that the larger trees were pruned to the longer and smaller trees to the shorter lengths. This prevented the larger trees from becoming extremely top-heavy. In general, the procedure tended to equalize the balance of the four lots.

The trees were planted in April, 1923, near Haugan, Mont., on a southwest slope having soil of medium quality. During that season this plantation was examined six times at monthly intervals, thus affording opportunity to observe evidences of external causes of injury while they were still fresh. All such causes, other than drought, which appeared to contribute to upthriftiness or death of individual trees were noted and the record of such trees was excluded from further considerations. The number of trees so excluded was not more than 4 per cent of any lot and did not seriously reduce the basis for conclusions.

A study of soil moisture revealed some points of interest. At monthly intervals 10 soil samples were taken to represent the soil at each of two depths, 4 and 10 inches, in different parts of the plantation. As determined in another experiment, the wilting coefficient for western yellow pine is about 3.9 per cent of the weight of dry soil. Applying this figure to the results obtained from field samples permits their expression in terms of moisture available to western yellow pine. (See Table 9.) On July 3 the soil within reach of the trees appeared quite uniformly moist, whereas a month later the top layers had dried out until the soil at the 4-inch level contained only about one-third the amount of moisture available at the 10-inch level. The rains of August then added nearly enough moisture to the upper layers to offset further losses, but did not penetrate as deeply as 10 inches. However, the continued dampness of the soil about 10 inches from the surface for a month after the upper soil was dry had a perceptible effect on the trees.

TABLE 9.—*Soil-moisture determinations at 4 and 10 inch depths*

Date	Moisture at 4-inch depth		Moisture at 10-inch depth	
	Total	Available	Total	Available
	Per cent	*Per cent*	*Per cent*	*Per cent*
July 3	18.9	15.0	18.6	14.7
August 3	7.4	3.5	15.5	11.6
September 3	6.6	2.7	6.2	2.3
October 3	6.3	2.4	5.9	2.0

Soil-moisture losses were greater than gains during the summer, but the precipitation for the season was above normal in amount each month until September, and until then the survival of all lots of trees remained high. A 20-day rainless period accompanied by high

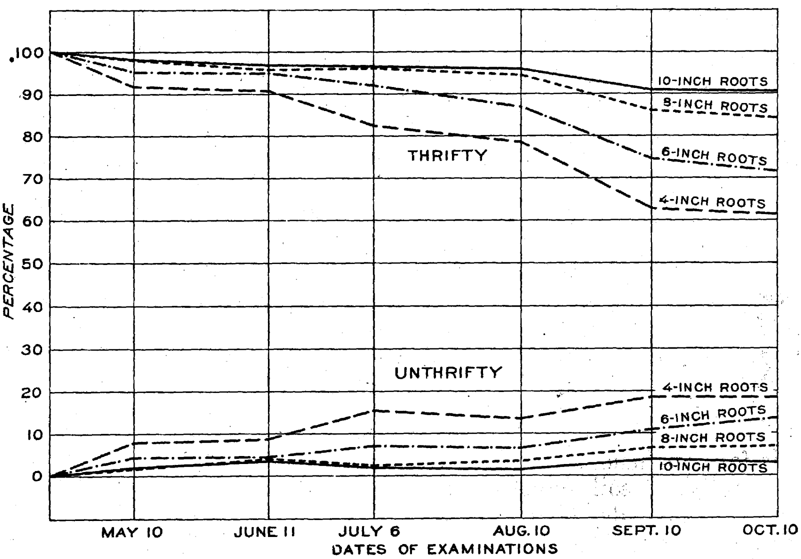

FIG. 10.—Root-length test: Relative thrift during 1923 in the 1–2 western yellow pine plantation of the spring of 1923; stock graded to preserve balance; roots measured and pruned individually; plants affected by causes other than dryness are not considered; southwest aspect

temperatures started on August 27, causing an acceleration of the death rate in plantations. Drought hardiness increased with the length of roots. At the end of the season figures of the percentage of survival for the different root-length classes were as follows: 4 inch, 80 per cent; 6-inch, 85 per cent; 8-inch, 91 per cent; and 10-inch, 94 per cent. Although these percentages, owing to the moist season, are all unusually high, they serve the purpose of the experiment in showing clearly and consistently the influence of length of roots. From observations made at intervals figures were compiled showing the relative number of thrifty and unthrifty trees in percentage of the total number planted. These figures, plotted in Figure 10, show clearly that throughout the season the trees with short roots were less thrifty than those with longer roots.

A year later the relative survival was the same as at the end of the first season, the differences amounting to 6 or 7 per cent for each 2-inch increase of root length. Measurements of current stem growth

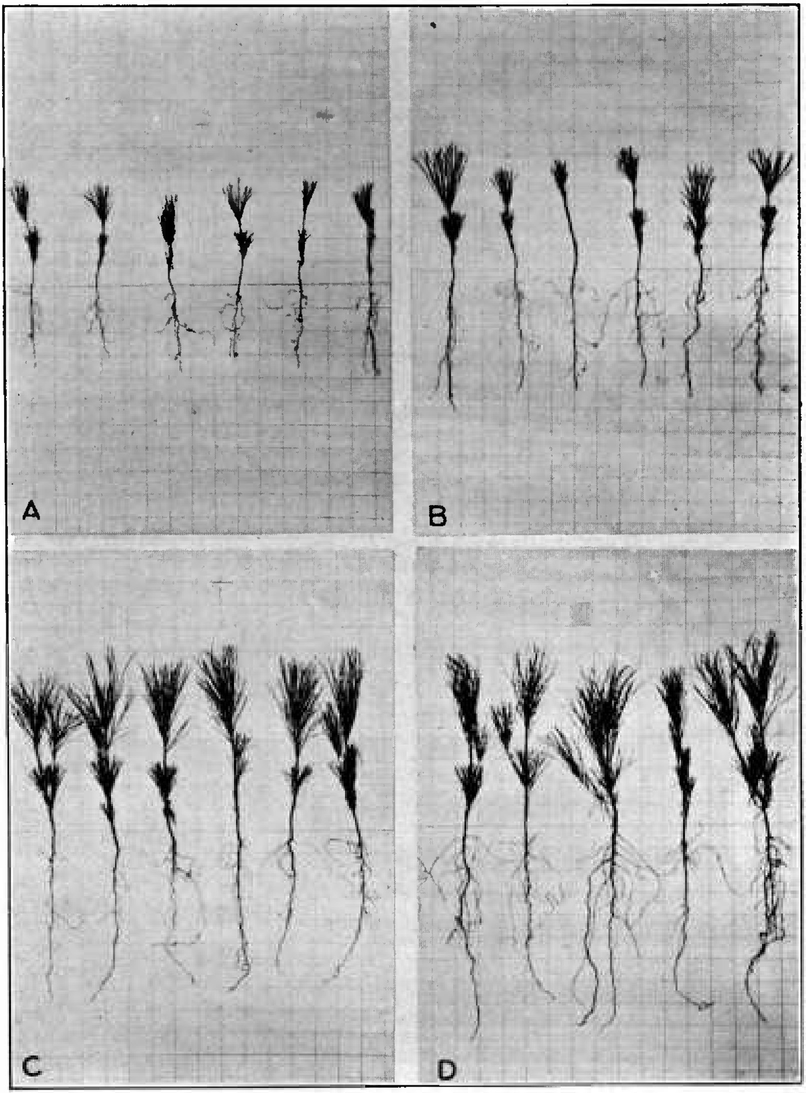

FIG. 11.—Western white pine root lengths: A, 4-inch class; B, 6-inch; C, 8-inch; and D, 10-inch

showed small but consistent increases in growth for the longer root lengths.

In 1923 a very similar experiment was made with 3–0 western white pines planted on a northwest slope. The trees are illustrated in Figure 11. The results were much like those attained with western yellow pine.

In weighing the results, the probable effect of the preliminary grading that tended to equalize the balance should be considered. Had the grading been omitted the long-rooted trees would have been less top-heavy and the short-rooted trees more so. Differences in survival of the various root-length classes might well have been still greater had it not been for the preliminary grading.

In sowings made in April, 1924, it was considered that in actual practice in pruning roots to certain lengths thorough grading will rarely precede the pruning of roots, and therefore no attention was paid to size and development of trees. More than 1,250 1–2 western yellow pines from each of three root-length classes, 6, 8, and 10 inches, were planted on a gravelly south slope presenting severe conditions for plant life. By the end of June the soil had become quite dry and but 63 per cent of those with 6-inch roots, 76 per cent of those with 8-inch roots, and 83 per cent of those with 10-inch roots were alive. By the end of July, the driest month, survival was as follows: Those with 6-inch roots, 14 per cent; 8-inch roots, 27 per cent; and 10-inch roots, 36 per cent.

A post-mortem examination of numerous trees indicated that the difficulty of planting properly in a loose gravelly soil and on a brushy site had resulted in a loss of the desired depth of root penetration at the time the trees were set out. Owing to slight root curvature, doubling back, inclination, or depth of setting, the average penetration was about 0.5 inch less than was intended, the different lots being affected differently. The 6-inch roots had lost about one-quarter inch, and for each additional 2 inches of root length, the loss of depth increased about a quarter inch. In other words, the trees with 6-inch roots actually penetrated 5.75 inches, the trees with 8-inch roots, 7.5 inches, and those with 10-inch roots, 9.25 inches, making the interval 1.75, rather than 2 inches. This condition did not affect the applicability of the results, because a better quality of planting could not be expected on such sites. However, it served to show that low survival on severe sites may be due not only to direct action of the site factors but also to the indirect action of the site in decreasing the quality of planting. A similar observation was made in California by Show (*5*), who found that quality of planting decreased with the increase in density of brush cover.

The four experiments described above indicate consistently that, within the limits tested, increases in the length of roots planted result in corresponding increases in survival.

SUMMARY

The results of the experiments with western yellow and western white pine showed that, other factors being equal, large stock survived better than small stock, that transplants are usually preferable to seedlings, that stock with roots 8 inches long or longer succeed better than stock with shorter roots, and that a low top-root ratio indicates better planting stock than a high ratio.

A higher proportional survival was found in the older age classes of both species. In one planting upon northwest, west, and southwest slopes, 1–2 stock of western yellow pine grew most rapidly from the start and also appeared the most economical from the standpoint of the cost per unit of surviving trees. In another test, comparing survival of two age classes, 2–1 stock did better than 1–2, but 1–2 still remained the more economical. In one western white-pine planting 1–2 stock ranked superior to 2–0. In another planting of white pine in which 2–2 stock was used, this stock had the highest survival, with 1–2, 2–1, 2–0, and 1–1, in descending order. Upon the basis of cost per unit of survival 2–0 white-pine stock appeared most economical on moderate sites, but on the more severe sites 1–2 stock, or possibly 2–2, proved the least expensive.

In several experiments with size classes large stock of western yellow pine survived better than small stock on severe sites. Medium-sized stock appeared best on favorable sites. When western white-pine stock graded into four size classes was planted, only the smallest class resulted in poor survival.

When 1–2 western yellow-pine stock was root pruned to furnish root lengths of 10, 8, 6, and 4 inches, highest survival attended the stock with 10-inch roots. The survival declined quite uniformly with the decrease in root lengths regardless of whether the stock has been sorted into size classes so that the root pruning was in proportion to the total size of the stock or not. Roots 8 inches or longer seemed best.

In general the season of planting appears to have slight effect upon survival.

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