JOURNAL OF AGRICULTURAL RESEARCH

VOL. XXXI WASHINGTON, D. C., DECEMBER 15, 1925 No. 12

STUDIES IN WESTERN YELLOW PINE NURSERY PRACTICE [1]

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INTRODUCTION

In 1912 and 1913, when nursery experiments were started under direction of the then "Priest River" Forest Experiment Station, at Priest River, Idaho, and elsewhere, western yellow pine (*Pinus ponderosa*) was one of the principal species being planted on a large scale in the northern Rocky Mountain region and millions of plants were being raised each year in the Forest Service nurseries; but comparatively little careful study had been made to determine the best methods of handling this stock in the nursery to obtain good quality at a minimum cost. The experience of the years following 1909, when the nursery work was first undertaken on a large scale, demonstrated beyond question the need of experimentation in order to produce a better and more uniform quality of stock and to avoid the delays, uncertainties, and losses due to lack of exact information.

The investigative work undertaken at this time was limited to those phases of the western yellow pine nursery practice most suitable for study at a small experimental nursery with limited facilities and at a considerable distance from the large nurseries operating on a commercial scale. These phases were: (1) Depth of covering seed in the seed bed; (2) methods of sowing seed in the seed bed; (3) degree of shade to use on the seed bed; (4) amount of water to use on the seed bed, with or without cultivation.

Such phases as the proper amount of seed to sow, the best season to sow, the need for fertilizing the soil, development of a good root system, and methods and season of transplanting, could at that time be studied better at the larger nurseries, either because of the large scale on which it was necessary to conduct the investigations or because the problems were more or less local and could best be solved at the nursery where the results were to be applied.

While the four phases selected for study are to a certain extent interrelated with climatic and soil conditions, these conditions at the field station in northern Idaho sufficiently resemble those at the Savenac Nursery in northwestern Montana to permit putting into practice there the results obtained at the Idaho station. The mean monthly temperatures for the growing season at Savenac average only one or two degrees lower than those at Priest River. Percentage of sunshine and wind velocity are probably somewhat greater at Savenac, but the same general regional climate prevails at both places.

[1] Received for publication Apr. 14, 1925; issued December, 1925.

All studies were conducted at the Priest River field station, with the exception of duplicate experiments in the study of the depth of cover begun at the Savenac and Boulder nurseries in 1912 and at the Trapper Creek nursery in 1914, under the direction of the experiment station.

The 1912 depth of cover bed at Priest River was located at the Benton Flat nursery, a dry flat with a sandy loam soil and thin sandy subsoil. The 1913 studies of depth of cover, and all studies on the other three phases, were located in a group of sixteen 4 by 12 foot beds known as the Meadow nursery. These beds were on a gentle southerly slope just above a flat meadow near Benton Creek. They had about a 10 per cent gradient, and were terraced to make their surfaces level. The natural soil was a fine silt loam 12 to 18 inches deep with a reddish color and a marked tendency to become compact or caked on the surface. It was underlaid by a light gray, claylike silt subsoil so compact and hard that water penetrated very slowly. To overcome the heavy nature of the soil, sharp granitic sand was mixed with the top 6 inches of each bed, rendering the soil loose and loamy and largely overcoming the tendency to pack on the surface.

In all of the experiments included in this series, counts of germination and of loss were made approximately once a week throughout the germinating period of the first season in the seed bed. A survival count was made at the end of the season to check the totals which had been carried forward. Each seedling, as soon as its germination was noted, was marked by sticking a toothpick in the ground just north of it. Toothpicks were colored to indicate the month in which germination occurred. Dead seedlings and the corresponding toothpicks were removed at each weekly count and the cause of death noted. Damping-off was found to be the most prevalent cause of death of first-year seedlings.

In the fall or following spring, at the time of removing the seedlings from the seed beds, measurements and weights were obtained of representative plants to show relative development under different conditions. From one to five seedlings, depending on the number available, and representing as nearly as possible the average development of each lot of plants, were preserved for future record. Photographs were made of these specimen plants in the winter of 1916–17 to illustrate differences in development due to varying treatment in the seed beds.

DEPTH OF COVERING IN SEED BED

SUMMARY

Depth of covering layer has a direct effect on the temperature and moisture of the soil in contact with the seed, upon the amount of mechanical obstruction to the growth of the stem toward the surface, and on the favorable conditions for the development of injurious fungi as well as the vigor and resistance of the plants to fungus attack. It is because of these effects that variations in depth cause differences in germination and survival of seedlings.

In all of the experiments the shallower covers very uniformly show a more rapid germination, a larger total germination, a smaller loss from damping off and other causes, and a better development of the plants at the end of the season, when compared with the deeper cover. The contrasts are so marked that the use of the shallower cover can be unhesitatingly recommended for use with western yellow pine in all nurseries in this region, at least where artificial watering is possible. The best showing was, on the whole, made by the ¼-inch and ⅜-inch depths. A cover varying between these two, with an average of $\frac{5}{16}$ inch, should be adopted as standard and be adhered to as closely as equipment and facilities will permit, in order to secure greatest economy of seed and space in raising desirable plants.

While it may be difficult to secure and maintain an exactly uniform and minutely regulated depth of cover, owing to mechanical difficulties in applying the cover and because of the washing of surface particles in sprinkling the beds, it has been found possible, by the development (at the Savenac nursery) of a special machine for covering, and by care in watering, to keep variations usually within ⅛ inch and never more than ¼ inch. This makes it feasible to regulate the depth of cover to a range which can be maintained in large scale practice and one within which best results in germination and survival may be obtained.

PROCEDURE

In the spring of 1912, western yellow pine seed, collected on the Bitterroot National Forest in 1911, was sown in the Benton Flat nursery and at the Savenac and Boulder nurseries. Depths of ½ inch and ¾ inch were used, and seed was sown in plots 2 feet square, each containing 500 seeds. Counts were made once a week and seedlings were pulled as counted, thus restricting the record to germination alone.

In 1913 the work was carried out with greater completeness. One bed in the Meadow nursery was thoroughly spaded and worked over until in a good condition for sowing. The bed was then divided by wood strips into two series of six plots each for use with six different depths of cover. In one series the plots were 2 feet square for broadcast sowing, and in the other they were 1 by 4 feet for drill sowing. Thus by duplicating the different depths of cover with the two methods of sowing it was possible to make a combined study of depth and method of sowing in the same bed so as to bring out facts in regard to each phase as well as their relation to each other.

Fresh western yellow pine seed was used. It was collected and extracted at the experiment station the previous fall (1912). Sowing was done June 6, the comparatively late sowing being due partly to delay in getting the new nursery in shape for sowing and partly to the fact that the season of 1913 was from three to four weeks later than the average. About 375 seeds to the square foot were sown, or an amount of seed sufficient to produce an estimated stand of 200 seedlings in each drill, or 200 to the square foot, on the basis of the greenhouse figures. The seed used for each plot was accurately weighed to within a limit of error of 4 seeds or 1 per cent of the good seeds sown, the same weight being used for all plots. Seed was sown as uniformly as possible. The drills were 3 inches apart, 4 drills to a plot, lengthwise.

One plot in each of the two series was covered to one of the following depths: ¼ inch, ⅜ inch, ½ inch, ⅝ inch, ¾ inch, and 1 inch. Clean sharp sand, dug from the sterile subsoil at Benton Flat, was used for covering. After the seed was sown and lightly pressed into the surface several toothpicks were inserted in each plot so that their points projected above the surface to a height exactly equal to the depth of cover desired. The sand was then put on and smoothed off level with the tops of the toothpicks. The lath partitions between plots prevented sand from washing from the plots with deep cover to those with shallower cover.

For want of definite knowledge as to shading requirements, the bed was given one-half shade from the time of sowing to the end of the season.

Water was applied to the bed by means of a hose and fine spray nozzle toward the close of each day during the dry period, except immediately after rains, in a moderate quantity sufficient to keep the upper soil layers moist enough for good growth.

Counts of germination and loss were made once a week, and a final survival count was made October 4, using the colored toothpick method.

In the spring of 1914 the seedlings were removed for transplanting and 50 representative seedlings were mechanically selected for measurement by taking every third, fourth, or fifth plant, depending on the total number in the plot. Figures were obtained on the following points: Length of root in inches, length of stem in inches, weight of 50 tops (fresh and surface dried) in grams. Typical specimens were pressed, and those in the broadcast series were photographed, in February, 1917.

The rest of the seedlings were transplanted at the Benton Flat nursery in the spring of 1914, using a standard "Yale" board. Survival records of transplants were obtained in the fall of 1915, together with measurements of the height and diameter at the ground line of every tenth plant.

One bed sown at the Trapper Creek nursery on the Bitterroot National Forest May 27, 1914, contained 4 plots, each 1 by 4 feet, each plot containing about 600 seeds. One plot was covered to each of the following depths: ¼ inch, ⅜ inch, ½ inch, and ⅝ inch. Seed was sown in drills 3 inches apart, 4 drills per plot, lengthwise. Counts of germination and survival were made June 15, July 1, 15, and 22, and again October 1. Owing to the conditions at Trapper Creek, it was not possible to control this experiment as carefully or have as complete records as for the 1913 experiment at Priest River. The value of this experiment lies chiefly in confirming, in a general way, the Priest River results, and in throwing an interesting sidelight upon the effect of different climatic conditions and methods of irrigation on the optimum depth of cover for yellow pine.

DATA

The germination figures obtained in the 1913 series at the three nurseries—Priest River, Savenac, and Boulder—are summarized in Table I.

TABLE I.—*Germination percentage under different depths of cover, 1912*

Depth of cover	Comparison of nurseries			
	Savanac	Priest River	Boulder	Average
	Per cent	*Per cent*	*Per cent*	*Per cent*
½ inch	50.6	41.4	31.8	41.0
¾ inch	48.6	40.8	27.2	38.9

The differences in these figures for the different nurseries may be partly explained by the fact that sowing was done May 1 at Savenac, May 15 at Priest River, and June 5 at Boulder, because of differences in the beginning of the growing season and the time when it was possible to do the sowing. Climatic differences at the three places are indicated in Table II.

TABLE II.—*Comparison of temperatures and precipitation at nurseries, 1912*

Nursery	Monthly mean temperature		Mean maximum temperature		Precipitation	
	May	June	May	June	May	June
	° *F.*	° *F.*	° *F.*	° *F.*	*Inches*	*Inches*
Priest River	51.7	60.5	80	97	2.68	2.14
Savenac	50.6	59.0	83	97	2.33	1.12
Boulder	46.2	57.4	75	90	4.03	1.32

The temperature figures furnish one evident reason why germination at Boulder was lowest. The higher mean maximum air temperature at Savenac was probably one of the contributing factors in producing greatest germination at that place, when combined with the advantage of early sowing.

While the differences between germination at the two depths are quite small, the fact that they are consistently in favor of the shallower depth of ½ inch at all three places and under different conditions is excellent evidence, when taken in connection with similar evidence from later experiments, to show that ½ inch is a better depth than ¾ inch for covering yellow pine seed.

The germination figures obtained in the 1913 study at Priest River are shown graphically in Figures 1 and 2, where the effects of the different depths of cover and of the two methods of sowing are compared.

The following points in regard to germination are brought out by these curves:

(1) Greatest germination was attained with a ¼-inch depth of cover, which was the shallowest; and the second greatest was with ⅜-inch depth. The ½-inch and ⅝-inch covers showed about the same amount, due to the fact that on the ⅝-inch broadcast plot the depth of cover was reduced by washing, with a consequent marked increase in germination for that plot. The deeper sowings showed still less, the ¾-inch plot taking fifth place, and the 1-inch plot sixth place.

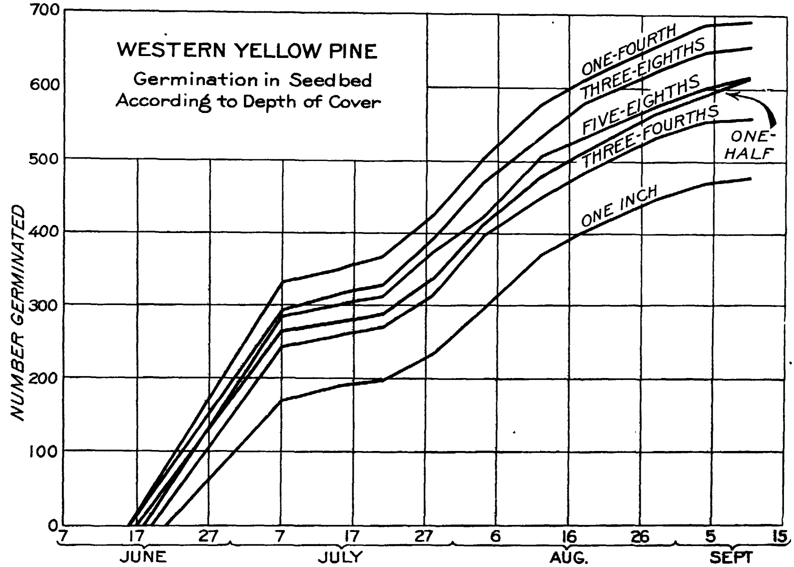

FIG. 1.—Weekly march of germination, 1913: Depth of cover

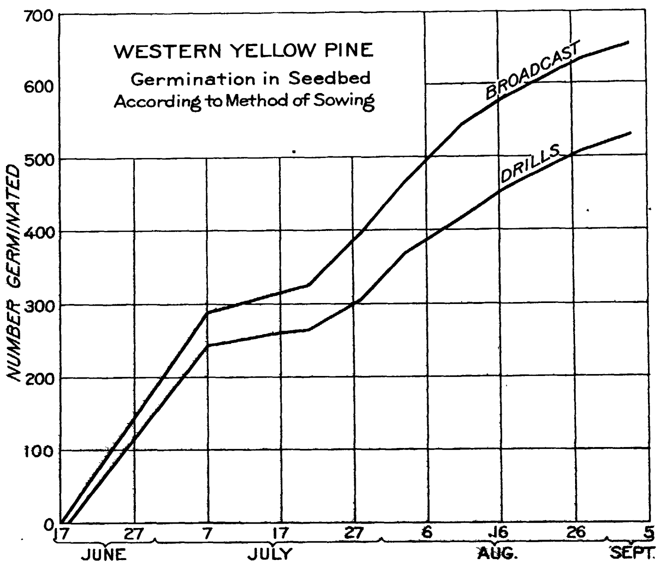

FIG. 2.—Weekly march of germination, 1913: Method of sowing

(2) Germination started five days earlier under the shallowest cover than under the deepest.

(3) The shallowest sowings, ¼ inch and ⅜ inch, showed the most rapid rate of germination.

(4) The period of most active germination occurred in the last half of June and the first half of July, from three to four weeks after sowing.

The survival and development of the stock in the seed bed at the end of the season, and the results in the transplant bed, are shown in Table III.

TABLE III.—*Survival and development of western yellow pine in seed bed and transplant bed, under different depths of cover and methods of sowing, 1913*

Depth of cover	Method of sowing	Seed beds: Total germination	Seed beds: Survival	Seed beds: Average measurements: Length of root	Length of stem	Weight of root	Weight of stem	Transplant beds: Spring, 1915, survival	Transplant beds: Fall, 1915: Survival	Diameter of stem	Height of stem
		Number	*Per cent*	*Inches*	*Inches*	*Grams*	*Grams*	*Per cent*	*Per cent*	*Mm.*	*Mm.*
¼ inch	Drills	714	76.5	9.30	2.20	3.40	5.80	79.0	76.2	4.90	6.00
	Broadcast	702	79.8	9.20	1.80	2.40	3.85	83.0	81.0	4.50	4.90
	Average	708	78.1	9.25	2.00	2.90	4.82	81.5	79.1	4.70	5.45
⅜ inch	Drills	577	79.0	9.30	2.40	3.00	5.43	83.2	82.5	4.90	5.60
	Broadcast	776	83.1	9.50	1.80	2.35	3.60	86.0	83.0	4.90	6.00
	Average	676	81.4	9.40	2.10	2.68	4.52	84.5	83.8	4.90	5.80
½ inch	Drills	656	77.3	9.70	2.40	3.08	5.65	80.0	77.7	4.80	5.90
	Broadcast	565	85.3	10.60	2.10	3.13	4.45	86.5	82.2	4.70	5.70
	Average	610	81.0	10.15	2.25	3.10	5.05	83.9	80.6	4.75	5.80
⅝ inch	Drills	505	59.8	10.10	1.90	3.15	4.20	87.0	84.0	4.90	5.90
	Broadcast	[a] 733	68.2	11.50	2.10	3.25	4.65	89.9	87.3	4.50	5.40
	Average	[a] 619	64.8	10.80	2.00	3.20	4.42	88.9	85.7	4.70	5.65
¾ inch	Drills	449	65.2	9.50	2.00	2.70	4.60	92.7	84.3	4.50	5.80
	Broadcast	694	63.1	11.10	2.00	3.05	4.15	56.5	55.5	4.30	5.00
	Average	572	64.0	10.30	2.00	2.88	4.38	64.5	61.9	4.40	5.40
1 inch	Drills	366	64.8	9.10	1.90	2.55	4.70	83.3	83.3	4.20	4.90
	Broadcast	621	72.3	9.70	2.00	2.50	3.90	85.6	84.6	4.90	5.10
	Average	494	69.4	9.40	1.95	2.52	4.30	85.1	84.5	4.55	5.00
Summary											
Total or average for ¼, ⅜, and ½ inch:											
Drills		1,947	77.5	9.43	2.33	3.16	5.63	80.8	78.9	4.83	5.83
Broadcast		2,043	82.6	9.77	1.90	2.63	3.97	84.9	82.1	4.70	5.53
Total or average for all depths:											
Drills		3,267	71.7	9.50	2.13	2.98	5.06	83.1	80.4	4.70	5.68
Broadcast		4,091	75.1	10.27	1.97	2.78	4.10	80.9	78.3	4.63	5.35

[a] Depth of cover decreased by washing, causing increase in germination.

The averages for the broadcast and drilled plots shown in Table III bring out the following points:

(1) The survival in the seed bed is highest for the ⅜-inch covered plots, followed closely by the plots with ½-inch and ¼-inch cover.

(2) The seedlings from the plots covered ⅝ inch have the longest roots, those from ¾ inch and ½ inch covers coming next.

(3) The seedlings from the plots covered ½ inch show the largest stems and the heaviest tops.

(4) The heaviest roots were produced on the seedlings from the plots covered ⅝ inch. The comparison between length and weight

of roots is not exact, however, since roots were simply dug in the ordinary way with a spade and it was impossible to obtain the entire root.

(5) The figures for survival in the transplant bed, both after the first year and at the end of the second year, are too irregular to indicate a clearly defined influence of the depth of cover on the survival of transplants.

(6) The transplants from the plots with shallow covers show a slightly better development than those from the more deeply covered plots. This is probably due to the earlier and more vigorous germination in the shallow plots.

The notes taken on the condition of the seedlings when removed from the seed bed are as follows:

Western yellow pine at ¼ inch: Seedlings dark green and thrifty, but apparently many seeds failed to germinate because either entirely or partly on the surface. Radicals of some appear to rise into the air leaving crown in the soil. Practically every germination for several weeks after July 10 was lost through damping-off and drought.

At ⅜ inch: Fine, healthy appearance.

At ½ inch: Good, thrifty appearance.

At ⅝ inch: Fairly healthy appearance. Damping-off very active.

At ¾ inch: Seedlings pale green and inclined to be poor form. Damping-off bad.

At 1 inch: Seedlings rather deformed, pale and unthrifty, tending to damp-off.

Since practically all loss was due to damping-off, the lower survival rate in the deeper covers seems to indicate greater susceptibility to the attacks of damping-off fungi. The root systems of the stock from the lesser depths were more bushy, although perhaps not so long, as those from the ⅝-inch and ¾-inch plots.

Germination and survival figures for the experiment conducted at Trapper Creek nursery in 1914 are shown in Table IV.

Table IV.—*Depth of cover germination and survival percentages, Trapper Creek, 1914*

Depth of cover	Germination at successive observation dates, in percentages of total germination					Total germination of seed sown		Survival of seedlings germinated	
	June 15	July 1	July 15	July 22	Oct. 1				
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*No.*	*Per cent*	*No.*	*Per cent*
¼ inch	12.3	70.5	15.3	0.0	1.9	163	27.2	158	96.9
⅜ inch	2.2	72.5	24.8	0.0	0.5	177	29.5	154	87.0
½ inch	3.0	86.2	7.2	1.8	1.8	166	27.7	157	94.6
⅝ inch	0.0	81.7	15.6	0.7	2.0	148	24.7	135	91.2

The following points are brought out by Table IV:

(1) Although the earliest germination occurred on the plots with shallower cover, the plots with deeper cover showed equal or greater total germination by July 1.

(2) Greatest total germination was under the ⅜-inch cover, with the ½-inch and the ¼-inch next in order, and the ⅝-inch, the deepest, in the last place.

(3) The least depth, ¼ inch, showed the highest percentage of plants surviving at the end of the season, with ½ and ⅝ inch next in order, and ⅜ inch last. In percentage of seed sown, however, survival at ⅜ inch is very much better than at ⅝ inch.

METHODS OF SOWING SEED

SUMMARY

Sowing in long open drills permits pruning of roots in place and facilitates cultivation. Because of the economy of space and time, broadcast sowing has been generally adopted at the Savenac and Boulder nurseries.

The experiments at Priest River in 1913–14 show, from the standpoint of economy of seed, that the evidence is consistently in favor of broadcast sowing. This method produced highest germination, highest survival, and best development of the plants.

Because of the lack of facilities for large-scale production, it was impossible to investigate accurately the difference in economy of time and space between broadcast and drill sowing. These questions have, however, already been worked out at the Savenac nursery, with results in favor of broadcasting for northern Rocky Mountain conditions. It may, therefore, be definitely concluded that for conditions in this region where watering is not possible, and where it is not necessary to cultivate between the rows to conserve moisture, yellow pine seed should be sown broadcast.

PROCEDURE

The principal experiment in this series was identical with that carried on at the Priest River station in 1913 in the depth-of-cover study in the Meadow nursery. It is therefore unnecessary to repeat the description of operation already given.

In order to obtain data on the effect of fall sowing upon methods, two more beds were sown in the Meadow nursery in the fall of 1913. No. 1 was sown broadcast and No. 2 in drills, using the same seed used in the spring-sowing experiment, covered with clean sand to a depth of ⅜-inch after careful spading and preparation of the beds. Protection and watering were as for spring sowing. Six representative areas, 1 foot square in the broadcast bed and one drill in the drilled bed, were selected for intensive counts which were made weekly during 1914.

DATA

The results of the 1913 spring-sown study at Priest River have already been assembled in Figures 1 and 2 and Table III. The summary of Table III has been prepared to show contrasts due to differences in method of sowing rather than depth of cover. Reference is made to these data, in regard to the essential points brought out, as follows:

(1) Germination in the broadcast plots was consistently greater than in the drilled plots, or 25 per cent more for all depths. For the three shallower depths, however, the average of the broadcast plots was only 5 per cent greater, so that for the depths which will be used in practice the advantage over the drills is very slight. The greater difference in the deeper sowings was due perhaps to the fact that the cover on the three broadcast plots was decreased somewhat by watering, thus probably increasing the germination.

(2) During the first month germination in the drilled plots was more rapid. By the middle of July the broadcast plots were in the lead in point of numbers. It evidently takes the seedlings in the

broadcast plots a little longer to break through the ground, possibly because in the drills the combined lifting force of many seedlings is concentrated along a narrow line. Figure 2 shows graphically the rate and amount of germination.

(3) Survival in the seed bed, in percentage of the number that germinated, was higher for the broadcast plots, both for the average of the three lesser depths (5.1 per cent) and also for the average of all depths (3.4 per cent). The comparatively higher survival in the broadcast plots is due to greater susceptibility of the seedlings along the drills to attack from damping-off.

(4) In general, the stock from the broadcast plots showed a longer root and a shorter top than that from the drills, and the tops and roots were, on the whole, lighter in weight. The broadcast method produced the largest seedlings, except for the 3/8-inch and 1/4-inch depths, and the drill method produced the heaviest plants, except for the 5/8-inch depth.

(5) The stock raised by the broadcast method showed a higher survival in all cases, except for the lot raised with 3/4-inch cover. The latter made such a radically different showing from any of the rest that it can safely be assumed to have been injured either during transplanting or later.

(6) Measurements of both seedlings and transplants show that the stock raised in the drills had longer roots and tops. This is due to greater competition for light and root room in the case of seedlings crowded together in drills. It really means that the drills produced an inferior grade of stock compared to the broadcast plots and is an argument in favor of broadcast sowing.

A comparison of the amount of germination in the fall-sown beds is of no value, for the reason that mice got in during the winter, in spite of protective screens, and did more or less damage. Therefore the germination figures have not been tabulated. The total amount of germination during the season was 25 per cent greater in the drills than in the broadcast beds, but this may only indicate that more of the broadcasted seed was eaten than of that in the drills.

Loss in the drilled bed was almost 50 per cent greater than in the broadcast bed, showing a marked advantage in favor of broadcasting.

Plants from the drills had longer, more spindling tops than those from the broadcast bed, an additional argument in favor of the latter method.

DEGREE OF SHADE

SUMMARY

As earlier nursery experience in other regions had shown that the tender first-year seedlings of many conifers were benefited by being partially shaded from the direct rays of the sun, it was the practice to use shade on western yellow pine beds in the earlier nursery work in this region. By 1913, however, when this study was started, shading had been discontinued for yellow pine at Savenac and Trapper Creek nurseries, for general observations indicated that it was unnecessary. The experiments at Priest River were undertaken to obtain definite information on this point.

The basis for drawing conclusions was the effect of the different degrees of shade upon germination, survival, growth, and development of seedlings, and survival and growth of transplants.

Germination is affected by the influence of shade upon temperature and moisture content of the soil. Shade influences survival by reducing excessive water loss of the young plants in transpiration, by decreasing the surface temperature and evaporation from the soil, and by making conditions more favorable for the growth and spread of damping-off fungi. Shade affects the survival and growth of transplants indirectly through its effect upon the rate of germination, since the seed which germinates earliest produces the largest and most vigorous seedlings for transplanting.

Practically all the evidence from these experiments strongly supports the conclusion that western yellow pine spring-sown seed beds should not be shaded where artificial watering is possible, under the conditions in northern Idaho and western Montana. Duplicate experiments in two successive seasons, one of which was moist and favorable and the other was unusually hot and dry, uniformly show that the largest and most rapid germination, greatest survival, and best growth in the seed bed is obtained without shade, and that the unshaded seedlings make, on the whole, the best record in the transplant beds. There does not even seem to be any advantage in the temporary use of light shade during the hottest and driest part of the season, if water is frequently applied.

The optimum condition for the seedlings of this species appears to be full light and direct exposure to the sun at all times.

PROCEDURE

Two sets of experiments were included in this study, one in 1913 and one in 1914. The 1914 series was intended to check the results obtained in 1913 under different seasonal conditions, and to compare early spring sowing with the late spring sowing. The two seasons represented a wide contrast, 1913 being cool and moist, and 1914 unusually hot and dry. All plots were located in the Meadow nursery in connection with similar shading experiments with Douglas fir and western larch.

The original plan for the 1913 experiments included only two degrees of shade—one-quarter shade and no shade—since previous nursery experience had indicated that one-half shade was probably too heavy for an intolerant species like yellow pine. The no-shade and one-quarter shade plots were sown June 6, the late sowing being due to the unusually late season that year and unavoidable delays in getting the new nursery ready for sowing. At the end of the season, however, it was thought worth while to make a comparison between these two plots and another plot sown June 6 in a near-by bed which had been given one-half shade. This plot differed essentially from the other plots only in area, position in the bed, and degree of shade. Source of seed, date and method of sowing, depth of cover, character of soil, and other details of treatment were the same for all three plots.

One-half shade was included as a regular feature of the 1914 series, and three plots, one for each degree of shade, were sown May 6 in adjacent beds. Except for the degree of shade, all essential features of treatment were similar for the three plots.

Seed collected and extracted at the experiment station in the fall of 1912 was used for both the 1913 and 1914 experiments. All seed was sown broadcast and covered with clean sifted sand to a depth of

½ inch in 1913 and ⅜ inch in 1914. Sand was spread by one-hand leveling boards and the depth was gauged by numerous toothpicks inserted to project ⅜ inch above the sowing surface.

The one-quarter shade and no-shade plots in 1913 were 4 feet square and occupied one-third of the beds. They were sown with about 375 seed per square foot by distributing as evenly as possible an equal amount of seed over each plot, the seed being weighed out to centigrams. The one-half shade plot was 2 feet square in the ½-inch cover, broadcast plot, and was also sown at the rate of 375 seeds per square foot by weight.

In the 1914 tests all plots were 3⅓ feet by 4 feet, the short dimension being caused by a vacant space left at the ends of each bed so that conditions surrounding the end plots might be similar to those surrounding the plots in the middle of the bed. Three equal quantities of seed, weighed out to centigrams so as to provide about 350 seeds per square foot, were evenly distributed over the plots.

To prevent damping-off, the 1914 plots were sprinkled with dilute sulphuric acid applied two-thirds before sowing and one-third after covering, at the rate of $\frac{3}{16}$ fluid ounce of acid to 1½ pints of water per square foot. The 1913 plots were not sterilized.

Germination and survival counts were restricted to certain parts of each plot because of the limited time available for such work, except for the small one-half shade plot of 1913, which was counted completely. In the other 1913 plots a counting area 2 feet square was marked off in the center by pressing lath into the soil edgewise. In the 1914 plots two areas 1 foot square were used. These were centrally located about 1 foot from either side of the bed and marked by bent telephone wire laid on the surface and fastened by pegs.

Standard shade screens, made by nailing common lath to an outside frame of 2-inch strips at a distance of one lath width apart, were used to furnish one-half shade. One-quarter shade was provided by the use of lath sawed in half lengthwise, and spaced 1½ full lath widths apart. Such a frame distributed the light and shade more uniformly than if full-width laths spaced 3 widths apart had been used. The no-shade plots received full light, except for a little shade along the edges of the south side and ends of each bed caused by the 2-inch bars of the protective frame and the ½-inch mesh wire of the screens.

Beds were laid out in an east-and-west direction so that the lath shadows would move from west to east. During both years shade frames were left on continuously from the time of sowing until the end of September.

Watering was carefully regulated in each season so as to give uniform treatment to all plots. With the nozzle set at a certain point, all beds were sprayed for the same number of minutes at each watering.

The stock raised in 1913 was transplanted May 1 and 2, 1914, and was divided into separate lots according to the degree of shade it had received. Part of the 1914 stock was transplanted in November, 1914, and was kept separate according to degree of shading and months of germination. The rest of this stock, separated only according to degree of shading, was transplanted April 26, 1915. All transplanting was done with a standard Yale board in trenches dug with a spade, and the work was uniform for all lots.

Counts of germination and survival were made about once a week after germination started during both seasons. At the end of the season a count of all living seedlings in the counting areas was made as a check on the total brought forward weekly. Also a final count of the total number of surviving plants outside the counting area was made to determine how closely the counted areas represented the rest of the plot. Survival counts of the transplants were made in the early summer and fall of 1915.

When seedlings were taken up for transplanting in the fall, a sufficient number from each plot in each bed to give a good average were selected arbitrarily, and measurements of length of main tap root and length of stem to tip of bud were taken. The plants were carefully dug to a depth of about 18 inches, and the soil was loosened from the roots with the fingers so as to bring out practically all of the main root system with the plant. In addition, the 1913 samples were washed and surface-dried and divided at the ground line, the two lots of roots and tops being weighed to centigrams. The 1914 samples were not weighed, but were measured to obtain the average length of leaf in the main top and the diameter of the stem at the ground line. In the fall of 1914 measurements were taken separately according to month of germination. Measurement of the length of root was omitted for the stock taken from the 1914 beds in the spring of 1915.

In the fall of 1915 each tenth transplant from each lot in the transplant bed was measured to determine the average height of stem and diameter at ground line.

At the time seedling stock was measured about five plants typical of those with average measurements were selected from each lot and pressed. Photographs were made of typical seedlings from each of the three degrees of shading and also of seedlings from the unshaded bed, to show the relation between month of germination and size of the plants.

DATA

The evidence brought out by the experiments is, briefly, as follows:

The unshaded bed in 1913 produced much the largest total germination for the season, one-quarter shade being 20 per cent less, and one-half shade 50 per cent less. The same marked relation is shown by the 1914 beds, although the decrease in germination in the shaded beds is proportionally not so great.

The rate of germination was most rapid in the unshaded beds in both years. In 1913 the ratio was 45 for no shade, 35 for one-quarter shade, and 20 for one-half shade. The relation in 1914 is shown graphically by the curves in Figure 3. The general form of the curves is the same, but the curve for the unshaded bed rises more rapidly than those for the shaded beds.

Percentage of germinated seedlings surviving at the end of the season is greatest in the unshaded beds in both years, both for the individual months of germination and for the plots as a whole. Expressed in percentage of plants germinated, the proportion in the 1913 beds was 94.6 per cent for no shade, 78.4 per cent for one-quarter shade, and 85.9 per cent for one-half shade. In the 1914 beds the percentage of germinated seedlings surviving was practically the same for no shade and one-quarter shade (85.3 and 85.7), but was distinctly less for one-half shade (78.5).

The total number of surviving plants at the end of the season, in the entire beds in 1913, including those in the germination-count plots, when expressed in terms of the percentage of seed sown, made a distinct showing in favor of no shade. The percentage for

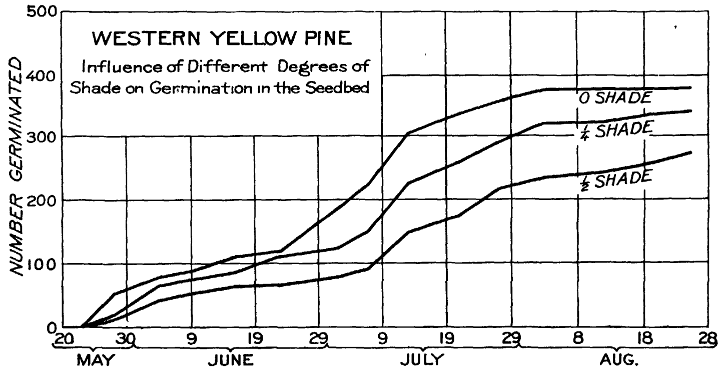

FIG. 3.—Weekly march of germination, 1914: Degree of shade

no shade was 64, for one-quarter shade next at 51 per cent, and one-half shade least with 48 per cent. Losses in the 1914 beds are shown in detail in Table V.

TABLE V.—*Losses by months under different degrees of shade, 1914 beds*

Month	Loss, no shade			Loss, ¼ shade			Loss, ½ shade		
	Dead seedlings	Percentage of germination to date	Percentage of season loss	Dead seedlings	Percentage of germination to date	Percentage of season loss	Dead seedlings	Percentage of germination to date	Percentage of season loss
June	23	12. 2	58. 9	18	6. 1	46. 1	12	15. 4	20. 0
July	14	3. 7	35. 9	17	3. 4	43. 6	22	9. 3	36. 7
August	1	0. 3	2. 6	1	0. 2	2. 6	9	3. 2	15. 0
September–October	1	0. 3	2. 6	3	0. 6	7. 7	17	5. 9	28. 3
Season loss	39	10. 1	100. 0	39	7. 5	100. 0	60	20. 8	100. 0

The largest and best developed plants were obtained from the unshaded bed, the second best from the one-half shaded bed, and the smallest from the one-quarter shaded bed.

The fact that there is a marked difference in size of seedlings according to month of germination, as shown in Figure 4, is an additional argument in favor of no shade. As the earliest germination occurs without shade it should naturally follow that a greater proportion of large, well-developed plants will be produced without shade than when either one-quarter or one-half shade is used.

For the 1913 beds, stock given one-half shade shows the greatest percentage of transplants alive both in the spring count (after one season) and the fall count (after two seasons), with one-quarter shade second and no shade last. The percentages were 95, 92, and 83, respectively. The better survival for the one-half shade stock possibly may be accounted for because of the lesser density of plants in the one-half shade plot, or because of some unknown variable in the transplant bed.

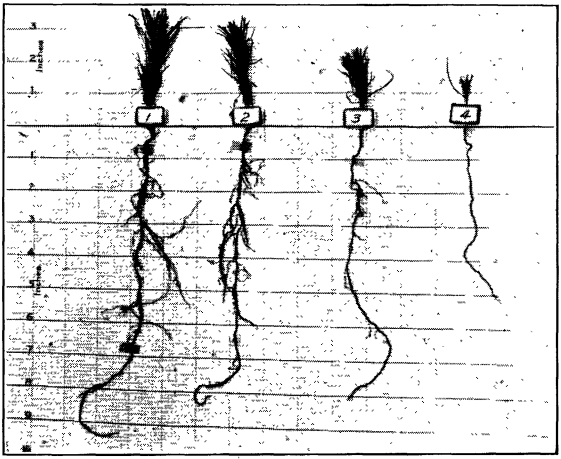

FIG. 4.—Effect of early germination on size of seedlings (*Pinus ponderosa*). Comparison, at end of season, of seedlings germinating in May (1), in June (2), in July (3), and in August (4)

Survival of transplants from the 1914 beds given in Table VI corresponds in the spring count of 1915 with the development of the seedlings and shows 63 per cent for no shade, 61 for one-quarter shade, and 59 for one-half shade. Survival in the fall, in percentage of the number transplanted, was greatest for the one-quarter shade stock (56), with no shade next (52) and one-half shade lowest (47).

TABLE VI.—*Seedling measurements and transplant data by month of germination, fall transplanting, series of 1914*

Degree of shade	Month of germination	Seedling measurements: Length root	Length stem	Length leaf	Diameter stem	Transplant data: Survival: First spring	First fall	Height stem	Diam-stem
		Inches	*Inches*	*Inches*	*Mm.*	*Per cent*	*Per cent*	*Inches*	*Mm.*
No shade	May	11.6	2.7	1.19	1.9	94.9	93.1	4.3	3.4
	June	10.2	2.4	1.07	1.8	75.8	62.8	3.6	3.0
	July	9.2	1.7	0.82	1.3	53.5	44.5	3.4	2.8
	August	5.4	1.1	0.48	1.2	10.0	0.0		
	Mixed					70.2	57.9	3.5	3.0
Weighted average		9.1	1.7	0.89	1.5	63.1	51.7	3.7	3.0
One-quarter shade	May	9.5	2.1	0.90	1.5	92.8	91.0	3.2	2.8
	June	8.7	1.8	0.87	1.3	85.0	70.0	3.1	2.6
	July	8.1	1.6	0.78	1.2	63.7	54.8	2.8	2.0
	August	5.6	1.2	0.48	1.2	40.0	35.0	1.8	1.9
	Mixed					74.0	57.0	2.8	2.5
Weighted average		7.9	1.6	0.75	1.3	60.8	56.5	2.7	2.4
One-half shade	May	10.5	1.9	0.99	1.4	97.8	97.0	3.4	2.6
	June	10.5	1.5	0.86	1.3	70.4	58.2	2.6	2.3
	July	8.7	1.4	0.71	1.2	70.4	45.4	2.8	2.2
	August	6.5	1.0	0.50	1.2	4.3	3.3	1.7	1.7
	Mixed					62.8	56.5	3.1	2.8
Weighted average		9.0	1.4	0.86	1.2	58.9	47.3	2.7	2.3

The survival figures for the transplants are rather contradictory and seem to show that the influence of shading in the seed bed has at least partly disappeared and given place to other and more direct influences in the transplant bed itself. The fact that the shaded stock made a slightly better showing may indicate that shade helps to fit the plants to withstand the shock of transplanting. This does not seem reasonable, however, as the more probable effect of shade would be to make them less resistant to severe conditions.

The size of the transplants in the first test did not vary in accordance with the shade received, those receiving one-half shade being much the largest, and the others about equal. The unshaded transplants obtained next year were distinctly the largest, however, with one-quarter shade stock slightly larger than that from one-half shade.

AMOUNT OF WATER WITH OR WITHOUT CULTIVATION

SUMMARY

It was to obtain some definite information as a basis for the standardization of watering western yellow pine that the following experiment was undertaken, bringing out the effect of the different kinds of watering and cultivation upon the growth and development of the stock, first as seedlings and later as transplants.

It is evident that the cheapest method of watering is to water heavily at rather infrequent periods. If water is more difficult to obtain in large quantities, lighter and more frequent watering, with cultivation to conserve the moisture, might be most profitable. Or, if the watering became very expensive, it might pay better to cultivate frequently enough to maintain a good dust mulch and retain in the soil as much as possible of the natural rainfall.

While the combination of moderate watering with cultivation produced the best results in this experiment, the difference in favor of this treatment was comparatively small. In order to cultivate it was necessary to sow in drills. In the second section of this report it was demonstrated that there was a material saving of seed, labor, and space when seed was sown broadcast. The slightly increased growth of the plants due to cultivation would hardly justify the lack of economy due to drill sowing where plenty of water was available. The cost of cultivating between drills, which has to be done with great care in order to avoid injury to the plants, would be an additional argument against cultivation. Broadcast sowing, with rather heavy watering at frequent intervals sufficient to maintain an average water content of more than 50 per cent of dry weight, is therefore unquestionably the best method for use at large nurseries where an abundance of water under pressure is to be had.

In small ranger nurseries where water is scarce or it is inconvenient or expensive to apply it, very good results may be obtained in the western part of the northern Rocky Mountain region on moderately heavy moisture-retentive soil, by raising the stock in drills and cultivating the surface either without artificial watering or with a moderate amount of water applied at times of special need.

PROCEDURE

Beds in the Meadow nursery were carefully prepared for sowing by spading the surface and mixing in sharp sand to loosen the top soil. Seed was sown in drills June 6, 1913, the late sowing being due to the unusually late season and unavoidable delay in getting the beds ready. About 375 seeds (as determined by weight) were used per drill, that number being sufficient to produce an estimated stand of 200 plants per drill four feet long. Drills were 3 inches apart. One-half inch of clean sand was used for covering seed.

The beds were given one-half shade from time of sowing to the end of the season, except when frames were removed for short periods to check damping-off. Protection from birds and rodents was provided by a Pettis seed-bed frame.

Counts of germination and loss were made about once a week from the time of first germination until September, with a final count in mid-October. Plants were left in the beds for two seasons and were counted again at the end of the second season.

All beds were watered equally during the period of heaviest germination up to August, in order to establish a fairly complete stand before differentiation in treatment began, since it was not desired to include in this study the effect of watering upon germination.

After the first week in August the different beds were given the following kinds of watering treatment:

(1) No artificial watering was done, and the surface was cultivated every fourth day and as soon after every rain as the ground could be worked. A uniform dust mulch was maintained in this way.

(2) Two quarts of water were applied per square foot every fourth day. Surface was cultivated after every rain and as soon after watering as the ground could be worked.

(3) One quart of water was applied per square foot every other day. No cultivation was given.

The differentiation in treatment was delayed because of the slow germination due to the late sowing. Although the treatment was kept up during the last three weeks in August and throughout September, the period was not long enough to affect the plants materially. It was therefore decided to continue the experiment through a second season and to make the contrast between treatments great enough to cause differences in growth in spite of the tendency of the plants to adjust themselves to changed conditions.

The following different treatments were given the second season:

(1) No artificial watering was done. Surface was cultivated as soon after every rain as the ground could be worked. It was also cultivated often enough between rains to maintain a dust mulch.

(2) A moderate amount of water was given at the end of each week, the amount being regulated so that the sum of the rainfall and artificial water made a total of 0.75 inch per week. The water applied artificially was reduced to inches by timing the flow with the nozzle set at a certain point and measuring the cubic inches of water discharged per minute. The surface was cultivated after each watering and each rain.

(3) The bed was heavily watered, enough water being applied to make a total, when combined with rainfall, of 0.75 inch for each one-half week. Watering was done on alternate Tuesdays and Wednesdays, as representing the middle of the week and again on Saturdays, thus given an interval of approximately one-half week between applications, not counting rains.

When the precipitation during the week amounted to more than 0.75 inch in the case of bed 2, or to more than 0.75 inch for the semiweekly period in the case of bed 3, the total amount of precipitation was noted, but the surplus was not carried forward into the next period, as the amount of the surplus was the same for all beds.

During the growing season soil samples were taken regularly each week from each of the three beds, as follows: Surface inch, 2 to 6 inch core, 7 to 12 inch core, and 13 to 18 inch core. The moisture content of each core was determined.

About one-half of the stock was transplanted in November and one-half in April. In the fall, at the time of transplanting, measurements were taken of 100 plants to show length of root in inches, length of stem in inches, diameter of stem at ground line in millimeters, and length of leaf in inches.

A survival count was made in the early summer and in the fall of 1915, at which later time measurements of height and diameter of stem were made.

When the stock was transplanted, five seedlings, typical of average measurements, were selected from each bed and pressed. One of each of these lots of samples, photographed in order to illustrate the difference in development due to watering treatment, is shown in Figure 5.

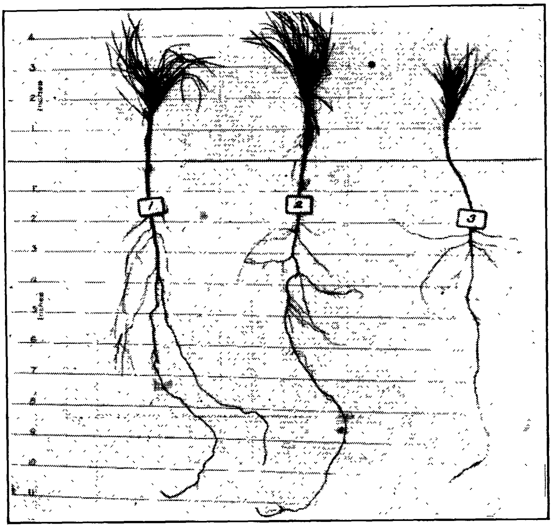

FIG. 5.—Watering versus cultivation. Average seedlings from three beds which received heavy watering only (1), watering and cultivation (2), and cultivation only (3)

DATA

Seed-bed germination and survival have little bearing on the study, because most of the germination was purposely allowed to take place before differentiation in watering treatment began. The relative merits of the three methods of treatment must, therefore, be judged by their effects upon the development of the seedlings and the growth and survival of the stock in the transplant beds. The essential records are included in Tables VII, VIII, and IX.

TABLE VII.—*Water content of seed-bed soil under different methods of watering, second season, 1914*

Method of treatment	Percentage of average moisture content				Maximum at 1 to 6 inches	Minimum at 1 to 6 inches
	Surface inch	1 to 6 inch core	7 to 12 inch core	13 to 18 inch core		
					Per cent	*Per cent*
Cultivation only	23.5	39.0	42.1	43.5	54.3	14.5
Cultivation and watering	33.4	54.1	57.8	54.7	69.0	40.4
Watering only	42.0	56.1	57.5	60.3	67.8	46.2

TABLE VIII.—*Survival, and growth of seedlings under different methods of watering, 1913–14*

Condition of seed			Survival of seed germinating				Measurements, second fall			
Method of treatment	Germination		First fall		Second fall		Root length	Stem length	Leaf length	Stem diameter
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Inches*	*Inches*	*Inches*	*Mm.*
Cultivation only	759	63.2	509	67.1	331	43.6	11.7	2.3	1.9	1.8
Cultivation and watering	943	78.6	622	66.0	441	46.8	14.4	3.0	2.3	2.3
Watering only	753	63.2	484	64.3	298	39.6	13.6	2.8	2.1	2.1

TABLE IX.—*Survival and growth in the transplant bed under different methods of watering, 1915*

Season transplanted	Treatment	Survival of transplants		Measurements (fall)		
		Spring	Fall	Height	Diameter	Size factor [a]
		Per cent	*Per cent*	*Inches*	*Mm.*	
Fall	Cultivation only	95.4	82.0	3.5	3.2	5.60
	Cultivation and watering	91.8	82.5	3.7	3.2	5.92
	Watering only	90.2	78.6	3.4	3.1	5.27
Spring	Cultivation only	96.0	88.2	4.0	3.1	6.20
	Cultivation and watering	92.8	88.2	3.6	3.3	5.94
	Watering only	95.0	88.8	3.3	2.9	4.78

[a] One-half diameter multiplied by height.

The points brought out by the tables may be summarized as follows:

The largest plants were produced in the artificially watered beds. The beneficial effect of cultivation is clearly seen in the fact that the bed which was both watered and cultivated, even though it received only half as much water as the bed which was watered and not cultivated, produced noticeably larger plants than did the latter.

The soil moisture figures in Table VII show that the watered and cultivated bed had at all times practically as high a water content in the root zones as had the more heavily watered bed. The cultivating evidently helped to preserve moisture, but the greater growth in the cultivated bed must have been primarily due to the stirring of the soil rather than to the preservation of moisture. The exact effect of this stirring of the soil is not known, but it may have helped in aerating the soil and liberating plant food. One point indicated by the moisture-content data is that when the surface is cultivated, only half as much water is needed to maintain the soil moisture at a desirable point as when cultivation is not done.

The minimum moisture content figures show that soil moisture, even in the cultivated and unwatered bed, never approached a critical point. The hygroscopic moisture for similar soil in the vicinity is less than 4 per cent, and the lowest percentage reached was only 14.5.

Table VIII shows the measurements of the average 2-year-old seedlings from the three differently treated beds. The greater average size of the plants in the moderately watered and cultivated bed could not have been due to more growing space, as there was a decidedly smaller number of plants in the other two beds throughout both years in the seed bed.

The stock from the moderately watered and cultivated bed maintained the lead attained in the seed bed and produced slightly larger and better developed transplants than that from the other beds. The most interesting point brought out by the transplants, however, as shown in Table IX, is the relative increase in size of the plants from the unwatered cultivated bed. In distinctly third place in the seed bed, as transplants they surpassed those from the heavily watered bed and almost attained first place, being practically as large as plants from the watered, cultivated bed. This seems to indicate that small size in the seed bed is not necessarily an undesirable feature for transplanting, if the plants are hardy.

The survival figures in the transplant bed show no clearly defined distinctions among the different treatments.

CONCLUSIONS

The following conclusions were reached from the results of the experiments:

(1) When clean, sharp sand is used and plenty of water is available, yellow pine seed in spring-sown beds should be covered to a depth of from ¼ to ⅜ inch.

(2) Where an abundance of water can be applied, highest germination and survival in the seed bed and best development of the plants can be obtained if seed is sown broadcast rather than in drills. Broadcast sowing is also more economical of labor and space.

(3) Shade is not only not necessary for western yellow pine seedlings in spring-sown beds in this region, but has a distinctly undesirable effect on the amount and rate of germination, the amount of survival, and the development of the plants. Shade should not be used at any time. The optimum condition for seedlings of this species seems to be direct exposure to the sun.

(4) In large nurseries where plenty of water can be applied, seed should be sown broadcast and the beds watered rather heavily at intervals frequent enough to maintain an average soil-water content of more than 50 per cent of dry weight.

(5) In small ranger nurseries where water is scarce or it is too inconvenient or too expensive to apply, very good results may be obtained in this region on moderately heavy moisture-retentive soil by sowing in drills and cultivating between the rows, either without artificial watering or with a moderate amount of water applied at times of special need.