RELATION OF QUANTITY OF SEED SOWN AND DENSITY OF SEEDLINGS TO THE DEVELOPMENT AND SURVIVAL OF FOREST PLANTING STOCK [1]

By W. G. WAHLENBERG [2]

Assistant Silviculturist, Northern Rocky Mountain Forest Experiment Station, Forest Service, United States Department of Agriculture

INTRODUCTION

It is obvious that seedlings grown in dense stands can not develop so well as those grown without crowding. Nurserymen naturally wish to avoid injury to their stock from crowding, but they also desire to utilize their soil space as fully as possible. The optimum density of stand for each species and age class of nursery stock can be determined within reasonably close limits only by detailed experiments employing plant measurements, weights, root examinations, and observations of survival in the field.[3] Such experiments were conducted at the Savenac nursery in western Montana. Preliminary tests dealt with the effect on seed-bed density of the amount of seed sown and were followed by observation on the evil effects of crowding.

RELATION OF AMOUNT OF SEED SOWN TO DENSITY OF SEEDLINGS

WESTERN YELLOW PINE (PINUS PONDEROSA)

Once the average percentage of viability of the seed is known it is possible, barring irregularities in germination and loss of seedlings, to regulate the density of nursery stands by varying the amount of seed sown. At the Trapper Creek nursery in the spring of 1914 quantities of seed varying from 5 to 20 ounces were sown in drills. The numbers of 1–0 [4] seedlings obtained varied from 600 to 2,226 in direct proportions. Deaths of seedlings from various causes increased in number with the amount of seed sown, but the percentage of loss did not increase with the density of the stand.

The same year at Savenac nursery a similar experiment was made using the broadcast method of sowing. Eight 4 by 12 foot beds were sown in quantities varying from 12.5 to 50 ounces. The nearly constant relation between quantity of seed sown and density of seedlings is shown in Figure 1 by the inclined and almost straight course of curve 1. In these tests also the variations in numbers of seedlings

---

[1] Received for publication Nov. 2, 1928; issued March, 1929.

[2] Most of the field work on these studies was contributed by E. C. Rogers and P. C. Kitchin, formerly of the Forest Service.

[3] Knowledge of the best density for seedlings is essential, but must be recognized as only a part of the requirements for good seeding practice. In order to obtain the desired density, a nurseryman must also have the results of a germination test of his seed and know how to allow for the difference between germination in greenhouse or laboratory and in the field. Losses from various causes must be anticipated and uniformity in material and methods is essential. The first tests of density of sowing that were made with western white pine failed completely because sowing was done at the wrong time of year and the sand covering for the seeds was not uniform in thickness. Correction of these things in later work led to success of the tests.

[4] In nursery practice the age of plant stock is indicated by figures, the first indicating the number of growing seasons in the seed bed; the second, the number in the transplant bed. Thus 2–0 indicates 2-year-old seedlings; 2–1 indicates 3-year-old stock, 2 years in seed beds, and 1 year in a transplant bed.

lost indicated that although larger numbers of seedlings died, no greater proportion of deaths occurred in the dense than in the less dense beds. Each ounce of seed produced about 260 seedlings.

WESTERN WHITE PINE (PINUS MONTICOLA)

At Savenac nursery in early September, 1919, nine 4 by 12 foot beds were sown broadcast with lots of seed varying from 222.5 to 890 gm. Two years later estimates were made of the number of 2-year-old

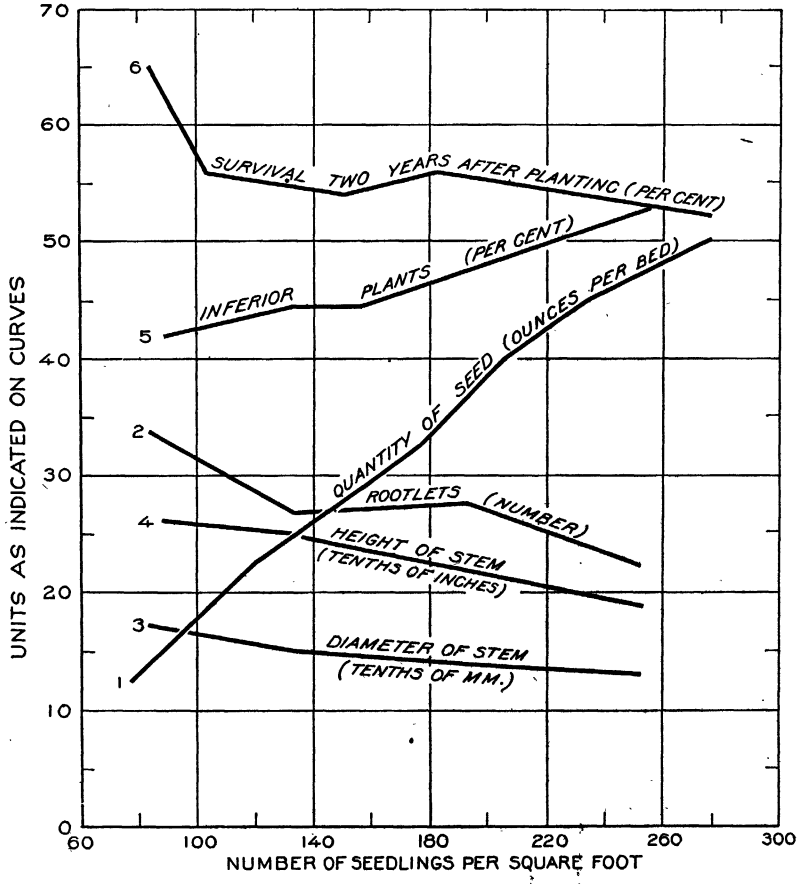

FIG. 1.—Effects of density of seedlings on the development and survival of 2-0 western yellow pine stock when various quantities of seed are sown

seedlings by counting them on strips covering one-quarter of the area. The number of seedlings per square foot varied approximately from 160 to 480 according to the amount of seed sown. Curve 1 in Figure 2 shows a nearly constant relation between the amount of seed sown and the density of the seedling stand.

ENGELMANN SPRUCE (PICEA ENGELMANNI)

Six identical 4 by 12 foot beds were sown at Savenac nursery in the spring of 1915, each with a different quantity of seed. These beds

were prepared in the ordinary manner, sown broadcast, covered with sand one-quarter inch deep, protected by screen frames, shaded alike, and watered quite uniformly. Throughout the summer frequent counts were made of the numbers of seedlings lost from different causes on sample plots in each bed. These observations revealed a fairly constant relation between amount of damping off and density. In September all living plants in these beds were counted, with the results shown in Table 1. The stands corresponded quite closely to the quantities of seed sown, demonstrating that it is possible to control density within fairly close limits by sowing more or less seed.

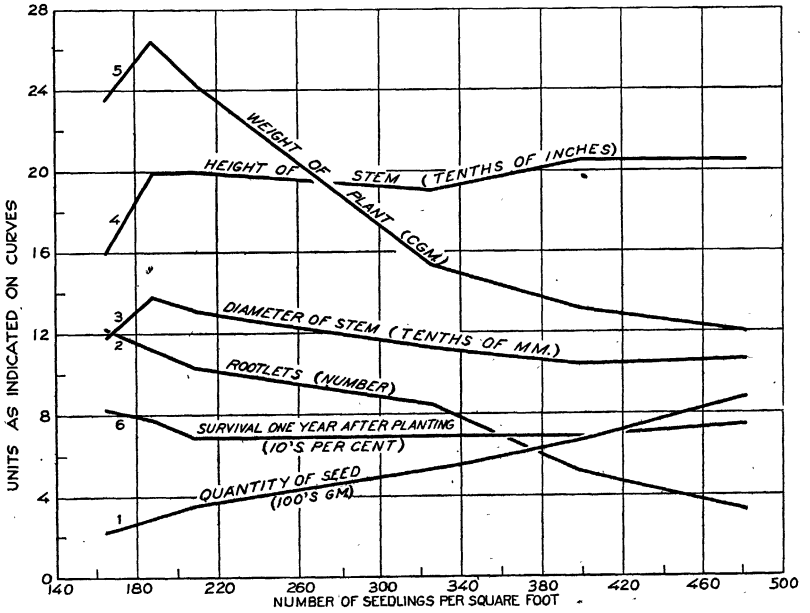

FIG. 2.—Effects of density of seedlings on the development and survival of 2-0 western white pine stock when various quantities of seed are sown. The quantity of seed is shown in hundreds of grams, that is, 4 on the scale equals 400 gm.; survival is indicated in tens per cent, that is, 8 on the scale equals 80 per cent

TABLE 1.—*Density of 1-0 Engelmann spruce seedlings as related to the amounts of seed sown*

[Figures are based on two seed beds of 48 square feet representing each density class]

Amount of seed sown per bed (48 square feet)	Average Density at end of first season by survival count		Theoretical density calculated at a rate of 200 plants per gram of seed
	Per bed (48 square feet)	Per square foot	
Grams	*Number*	*Number*	*Number*
27.18	5,740	120	5,436
36.25	7,177	150	7,250
45.31	9,370	195	9,062
54.37	10,305	215	10,874
63.44	11,100	231	12,688
72.50	13,439	280	14,500

RELATION OF DENSITY OF SEEDLINGS TO ANATOMICAL DEVELOPMENT

WESTERN YELLOW PINE

From each of the eight beds of 1–0 western yellow pine at Savenac, which varied in density from about 80 to 275 seedlings per square foot, 100 plants were removed and measured. Averages from the figures so obtained revealed no significant differences in height of top, but they indicated a gradual decrease in diameter of stem with the increase in density. Curve 3 in Figure 1 marks an average decrease of 0.1 mm. in diameter for each increase of about 44 trees per square foot. The number of lateral roots also diminished steadily with increased density of stand.

Two years later similar results were obtained from measurements of 3–0 stock from the same beds. The tendency for the number of rootlets to be less in the denser stands is apparent in the trend of curve 2 in Figure 1. It indicates an average decrease of one rootlet for each increase of about 14 seedlings per square foot.

Numerous inferior plants were found in these beds when trees were removed for field-planting tests. Although they were 2 years old, these plants either had no needles in fascicles or only two or three bundles of them. The stem of the second year's growth was light green and bore flat straplike leaves of the same color, quite different from the dark green bushy top of a normal seedling. Terminal buds on these plants did not have the brown and mature appearance characteristic of normal plants. In another experiment this type of seedling was found to result from late germination,[5] but there is evidence that plants weakened in other ways may develop the same abnormal form. Thus the percentage of these inferior plants was found to increase with density in the seed bed. Curve 5 in Figure 1 shows this relation. It indicates an increase in distinctly inferior plants equal to 1 per cent of the total stand for every increase of about 15 trees per square foot.

WESTERN WHITE PINE

From the nine beds originally sown with different quantities of seed, two hundred 2–0 seedlings were taken from each of six stands of different density. Averages of weights and measurements of these trees, although not entirely consistent throughout, clearly showed some of the effects of crowding. Although the trees grown in dense stands were slightly taller (fig. 2, curve 4) than those having more room, they were decidely more slender (curve 3), and were of inferior development, as indicated by plant weights (curve 5). The number of lateral roots within 8 inches of the surface decreased quite rapidly with increases in density. (Curve 2.) When trees were lifted from the densest lot it was noticed that their roots had penetrated much more deeply than the others. Such growth is undesirable because roots more than 8 inches long can not be properly planted in the field by present methods.

[5] WAHLENBERG, W. G. SOWING AND PLANTING SEASON FOR WESTERN YELLOW PINE. Jour. Agr. Research, 30: 245–251. 1925.

ENGELMANN SPRUCE

In the spring of 1917 about 200 of the 2–0 spruce seedlings grown at each of six different densities were washed out of the beds at Savenac nursery. While stored in a root cellar awaiting laboratory examination the tops of the trees mildewed so badly that no measurements of them could be made, but measurements of the roots are given in Table 2. The decrease in number of rootlets and in diameter of stem with increased density is clearly shown. In September of the same year, when the plants remaining in the nursery beds were 3–0, about 400 were removed by washing from each of six beds of different densities. The average results from measuring both roots and tops of these plants are given in Table 3. With one exception, all the characteristics desired of planting stock seem to decrease with the increase of density in the seed-bed stand. The trees from dense stands are better balanced than those from thin stands, that is, they have a larger portion of their total weight in roots. This is known to be an advantage, but in this case it was gained through puniness of tops rather than through good development of roots, and was completely outweighed by the advantage of better general development attained in the thinner stands.

TABLE 2.—*Measurements, weights, and counts of 2–0 Engelmann spruce roots on seedlings grown at different densities*

[Basis: 200 plants from each different density. Primary lateral rootlets are branches from the central or taproot. Secondary laterals are branches from the primary rootlets.]

Density of seedlings per square foot of seed bed	Diameter of stem at ground line	Primary lateral rootlets		Secondary lateral rootlets		Weight of fresh, washed, air-dried roots
		Diameter 0.5–2 inches	Diameter over 2 inches	Diameter 0.5–2 inches	Diameter over 2 inches	
Number	*Millimeters*	*Number*	*Number*	*Number*	*Number*	*Grams*
116	1.36	20.5	7.0	5.3	0.1	0.08
138	1.29	18.3	5.8	5.0	.1	.06
184	1.24	19.4	6.0	4.6	.1	.06
191	1.23	17.5	6.3	4.6	.1	.06
217	1.14	17.7	4.9	3.0	.0	.05
323	1.12	15.9	4.3	1.8	.0	.05

TABLE 3.—*Measurements and weights of 3–0 Engelmann spruce seedlings grown at different densities*

Density of seedlings per square foot of seed bed	Length of stem [a]	Diameter of stem [b]	Length of needle [c]	Weight air dried [d]			Ratio roots to plant	Plants examined
				Top	Roots	Total		
Number	*Inches*	*Mm.*	*Inches*	*Gm.*	*Gm.*	*Gm.*	*Per cent*	*Number*
116	1.58	1.53	0.48	0.38	0.12	0.50	24.0	428
161	1.37	1.40	.44	.27	.09	.36	25.0	395
206	1.24	1.20	.41	.18	.08	.26	30.8	387
191	1.35	1.31	.40	.18	.08	.26	30.8	399
217	1.17	1.14	.38	.11	.06	.17	35.3	394
323	1.10	1.03	.36	.10	.06	.16	37.5	380

[a] Ground line to tip of terminal bud.
[b] At ground line.
[c] Needle taken from middle of crown.
[d] Fresh washed plants.

RELATION OF DENSITY OF SEEDLINGS TO FROST RESISTANCE

No study was made of frost action on western yellow pine and western white pine because frost does not ordinarily interfere seriously with the growth and survival of these species.

ENGELMANN SPRUCE

Seedlings may be injured by frost in two ways. Frost injures the tops by freezing and killing the tissue. Frost heaving injures the roots by breakage or exposure, the roots being lifted from the soil by the expansion of ice crystals. Spruce seedlings are subject to both of these forms of frost injury in western Montana.

In May, 1918, at Savenac nursery the relation between density of spruce seedlings and frost nipping was investigated on 25 sample plots of 1 square foot each representing average conditions in stands of different density. The results of this examination, as given in Figure 3, indicate a decided advantage in density of stand, for while

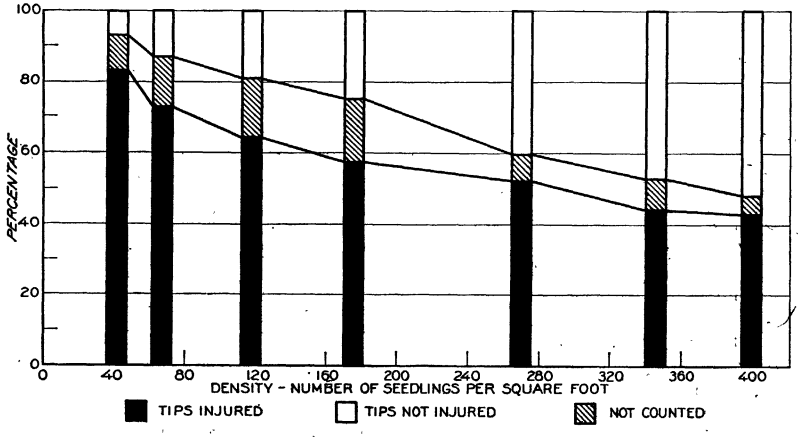

FIG. 3.—Relation of density in seed bed to frosting of tips of Engelmann spruce seedlings

a stand of but 42 seedlings to the square foot had only 6.5 per cent of the tips uninjured, that with 400 seedlings escaped with nearly 52 per cent of the tips untouched by frost.

This single series of observations indicates that the susceptibility of Engelmann spruce seedlings to frost nipping depends upon density in the seed bed, and that the greater the density the less is the injury by frost. This may be due to a layer of comparatively warm air, held in place by a thick mat of plants, tending to equalize air temperature at the surface of the bed and to prevent the freezing temperatures that would occur in more open stands.

More severe damage was caused by frost heaving. This was also studied in 1918, in transplant beds and in field plantations set out the previous year. One thousand 2-0 seedlings were transplanted from each of the beds of different density (as shown in Table 1) early in June, 1917, and in October eight hundred 3-0 seedlings from each bed were planted in the field. The field planting was divided equally between two widely separated areas. When examined in the spring of 1918 the trees were classified as follows:

Class 1. Plant erect, thrifty, and with roots firmly embedded in the soil.

Class 2. Plant heaved by frost, perhaps prostrate, but with some roots firm enough in the soil to withstand a pull of about 2 ounces; having a chance to live, but handicapped.

Class 3. Plant heaved by frost, apparently dead; unable to withstand a pull of about 2 ounces or thrown completely out of the soil; most of the root tips showing no life or having no contact with the soil.

The result of using this classification of transplants is given in Table 4. These figures seem to show that frost heaving of 2-1 Engelmann spruce in transplant rows increases with the seed-bed density at which the trees were grown, especially for densities greater than 150 per square foot. Similarly this same tendency was shown to hold true for the 3-0 stock in both field plantations, one on a northwest exposure near Wallace, Idaho, and the other on a southwest exposure near Haugan, Mont.

TABLE 4.—*Degree of injury by frost heaving sustained by 2–1 Engelmann spruce transplanted from seed-bed stands of different densities*

Density of seedlings per square foot of seed bed	Uninjured	Frost heaved	Fatally frost heaved	Plants examined
Number	*Per cent*	*Per cent*	*Per cent*	*Number*
120	33.6	24.0	42.4	921
150	31.7	31.5	36.8	904
195	12.0	21.3	66.7	841
215	2.9	16.0	81.1	784
231	4.6	21.4	74.0	778
280	2.6	10.6	86.8	774

RELATION OF DENSITY OF SEEDLINGS TO SURVIVAL IN THE FIELD

WESTERN YELLOW PINE

That more of the normal than of the inferior plants survived planting was to be expected. The difference in their behavior is shown in Table 5. Although they constituted but 48 per cent of the aggregate stock, the inferior class of plants furnished 57 per cent of the unthrifty and 59 per cent of the dead plants at the end of the first season in the field. To a large extent the low survival of trees from the dense seed-bed stands (fig. 1, curve 6) was attributed to the presence of numerous inferior plants of the type described. The curve indicates that after two years in the field the percentage of the total number surviving planting decreased about 1 per cent for each increase of 15 trees per square foot in the original seed-bed stands.

TABLE 5.—*Relative survival of 2–0 western yellow pines of the normal and inferior types planted in the spring of 1916*

Date of examination and type	Thrifty	Unthrifty	Living	Dead
July, 1916:	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Normal	67.7	24.0	91.7	8.3
Inferior	60.3	21.1	81.4	18.6
November, 1916:				
Normal	70.0	13.6	83.6	16.4
Inferior	57.9	18.1	76.0	24.0

WESTERN WHITE PINE

Three hundred plants representing each of six densities were planted on a north slope in the fall of 1921. After one year, survival was somewhat higher for densities of less than 210 seedlings per square foot. (Fig. 2, curve 6.)

ENGELMANN SPRUCE

Four hundred seedlings from each of six different densities of 3–0 stock were planted on a southwest slope and a duplicate plantation was set out on a northwest slope in the fall of 1917. The figures obtained in observing survival during the next three years were neither striking nor entirely consistent, but they indicated the tendency toward higher survival of the trees grown at the lesser densities.

RELATION OF DENSITY OF SEEDLINGS TO GROWTH IN THE TRANSPLANT BED AND IN THE FIELD

WESTERN YELLOW PINE

In the spring of 1915 about one thousand five hundred 1 year-old western yellow pine seedlings from each of the eight seed beds of different density were transplanted. In the fall of 1916 the growth in height during the year and the total height of the plants were measured on 200 trees in each of the different lots. Curve 4 in Figure 1 shows the decrease in height growth of the transplants with the increase in their density as seedlings and with the increase in number of inferior plants. Average height growth decreased about 0.1 inch for each increase of 24 seedlings per square foot of seed bed.

Similar figures were obtained from measurements of height growth of 2–0 yellow pine stock two years after field planting in the spring of 1916.

No growth measurements were made of western white pine.

ENGELMANN SPRUCE

Height growth during the second and third seasons in the field was measured on 100 or more trees from each of the various lots grown at different densities in the seed bed. The growth averages obtained, like those of survival, were neither striking nor entirely consistent, but indicated the tendency toward faster growth of the trees grown at the lower densities.

CONCLUSIONS

Density of 1-year-old western yellow pine seedlings varied directly as the amount of seed sown per square foot. Working with seed-bed densities varying approximately from 80 to 275 seedlings per square foot, the following average results were attained:

The stem diameter of 1–0 seedlings decreased 0.1 mm. for each increase of about 44 trees per square foot. The height growth of 1–2 transplants in the nursery decreased one-tenth inch for each increase of about 24 seedlings per square foot of seed bed. The number of rootlets on 3–0 stock decreased by one for each increase of about 14 seedlings per square foot. The percentage of distinctly inferior 2-year-old plants increased by one for every increase of about 15 trees per square foot. These differences in anatomical

development, as a result of differences in seed-bed density, had their effect on the survival of 2–0 stock in the field. Two years after planting, survival was observed to be 1 per cent lower for each increase of about 15 trees per square foot of the original seed bed. Height growth in the field also decreased with increases in density of the seed beds.

Working with densities varying approximately from 160 to 480 seedlings per square foot, the following results were attained with western white pine:

Two-year-old trees grown in dense stands were much smaller, more slender, and slightly taller than those having more room. The crowded trees also possessed fewer lateral rootlets. Field survival was distinctly higher for trees grown at densities of less than 210 seedlings per square foot.

With 3–0 Engelmann spruce ranging in density from 116 to 323 seedlings per square foot, increases in density were accompanied by decreases in characteristics desirable for planting stock. Decreases in length and diameter of stems and in length of needles were observed as well as decreases in the weight of the tops and roots. Such decreases in general development overshadowed the advantage from an increase in the portion of total plant weight contained in roots of densely grown plants. Frost nipping in spruce seed beds at Savenac nursery decreased with increases in density, but the more severe damage from frost heaving acted differently. Frost heaving of 2–1 spruce in transplant rows and 3–0 spruce in field plantations increased with the density at which the trees were grown in seed beds. The field plantations showed a tendency toward increased survival and growth with decreases in the density of original seed beds.

For the best development of seedlings at Savenac nursery, there should be less than eighty 2-year-old western yellow pines, less than one hundred and sixty 2-year-old western white pines, and less than one hundred and twenty 3-year-old Engelmann spruce per square foot of seed bed surface.

36263—29——3