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Some Effects of Cover over Coniferous Seedbeds in Southern New England

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SOME EFFECTS OF COVER OVER CONIFEROUS SEEDBEDS IN SOUTHERN NEW ENGLAND

BY

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AND

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NEW HAVEN

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SOME EFFECTS OF COVER OVER CONIFEROUS SEEDBEDS IN SOUTHERN NEW ENGLAND

INTRODUCTION

MAY 2, 1922, three coniferous seedbeds, in the School of Forestry Nursery at New Haven, Connecticut, were sown with eleven species of conifers. The seed used was collected the previous autumn. Later results proved all the species viable.[1]

The nursery soil is a garden loam and at the time of seeding had a high content of organic matter, resulting from a thick layer of thoroughly decomposed leaf litter, turned under some weeks before the beds were formed. The beds were approximately 4 by 4 feet with uniform soil conditions and were located side by side. They were treated alike as to the species sown in each bed, the number of seeds of each species sown, and the time and method of seeding. The seeds were sown in drills approximately six inches apart. The three beds differed only in the nature of the protective covering over the soil after the seeds were sown and during the growing season. All the beds after seeding were surfaced with a layer of sandy loam sifted over the rows to a depth of approximately ¼ inch.

The covering soil was prepared as follows:[2] Equal parts of good garden loam and moderately coarse builders' sand were brought together under cover in a well-ventilated shed and passed through a screen having sixteen meshes to the square inch. The soil was slightly moist but not wet. The pile was leveled off after mixing and thoroughly saturated with formaldehyde in water in the proportion of 4 oz. of formaldehyde to 1 gal. of water. The pile, protected from the weather, was thoroughly mixed and turned over each day for a period of two weeks. At the end of this period, it was well

1 The seed was received in February, 1922, from Conyers B. Flue, Germantown near Philadelphia, Pennsylvania.

2 Three years' experience at New Haven in treating the covering soil with formaldehyde has given uniformly excellent success in preventing losses from damping-off parasites in the seedbeds. In 1922, treated coniferous seedbeds protected by half shade suffered no losses while similar, adjacent, untreated seedbeds suffered a loss of 92 per cent from damping-off parasites.

dried out and in condition for use on the seedbeds. The beds were prepared in the usual manner. The seeds were sown and covered to a depth of about ¼ inch by sifting over them a layer of the treated soil.

Foresters have usually drawn an arbitrary line between nursery troubles that arise in coniferous seedbeds and transplant beds, due to damping-off diseases and blights. Thus Hartley[1] states, "Because of the difficulty in finding a natural dividing line between damping-off diseases and the blights, it has become necessary to draw an arbitrary line between them." Nurserymen usually place in the category of damping-off diseases nearly all troubles in seedbeds that result in the early death of the plants whether of parasitic origin or not.

Although most losses in coniferous seedbeds during the first few weeks following germination are usually due to damping-off parasites, other losses may occur which to the casual observer look like the effects from damping-off parasites, but which are non-parasitic in origin and require totally different treatment. Thus, in May, 1922, the authors found seedlings of white and red pine in nurseries in southern New England dying in large numbers from the formation of lesions on the young stems at or near the surface of the soil. The cause of these lesions will be discussed later.

Object of the study. The object of the study as at first conceived was to secure experimental data under the climatic conditions of southern Connecticut:

1. On the effect of shade as compared with full light on the time required for germination, and on germination values in representative conifers, and on survival and growth during the first season.

2. On the effect of mulch as compared with exposed soil on the time required for germination, and on germination values in representative conifers, and on survival and growth during the first season.

In the progress of the study during the warm and dry weather of May, when germination was at its height, it became apparent that losses in the seedbeds, from the plants bending over at the surface of the soil, and in some instances from withering and dying even without bending over, varied greatly in the different beds. On investigation, it was found that the trouble was not due to damping-off parasites. Lesions were apparent on the stems of the injured plants at or near the surface of the soil. In most instances, particularly with very young plants, the transpiration current was cut off a few hours after the lesions were apparent and the top

[1] Hartley, Carl: The blights of coniferous nursery stock, U. S. Dept. of Agr., Bureau of Plant Industry, Bulletin 44, 1913.

wilted and died. Later in the season, after the stem had become somewhat woody, the formation of a lesion on the shoot at the surface of the soil did not, as a rule, immediately cut off the transpiration current. When this was the case, the seedling remained erect and continued to live from one to several weeks. So far as observed, no plant with a pronounced lesion completely surrounding the stem at the surface of the soil was alive on September 30. Due to the early observation of these lesions and the differences in the extent of damage in the several beds and in different species, the original object of the study was expanded to secure experimental data on the cause of the lesions and on the extent of damage from them in different species and when grown under different densities of shade.

Species sown and nature of cover used. Eleven species were used in these studies. The species were selected to give as wide a range as practical in the nature of the habitat in which they naturally grow, in the size of the seed and consequent size of the young seedlings, and in the rapidity of growth during the first season. Table I shows the species sown in each bed, the date of seeding, the number of the row, the order of arrangement of the species, and the number of seeds sown in each row.

TABLE I

DATA ON SPECIES SOWN

Species	*Number of row*	*Date of seeding*	*Number of seed sown*
Pinus canariensis	1	May 2	172
Pinus palustris	2	May 2	198
Pinus taeda	3	May 2	658
Pinus laricio	4	May 2	912
Pseudotsuga taxifolia	5	May 2	936
Pinus insignis	6	May 2	576
Larix laricina	7	May 2	2020
Picea excelsa	8	May 2	1552
Abies balsamea	9	May 2	1810
Cupressus macrocarpa	10	May 2	1956
Pinus pinaster	11	May 2	360

The three beds were treated uniformly until after seeding. A standard seedbed box was placed over bed one. Bed two was left without cover of any kind, the surface soil being directly exposed to full light. Bed three was covered to the depth of 2.5 inches with a partially decayed and broken hardwood leaf litter.

WEATHER CONDITIONS

THE effect of cover over the surface soil of seedbeds is known to be extremely variable depending on weather conditions. Shade and mulch react advantageously on germination and survival during dry weather. Shade reacts disadvantageously on growth during periods of cloudy weather and reduced sunlight, and advantageously during prolonged periods of bright weather. Shade reacts advantageously on survival during extremely hot weather as soon as the surface soil becomes dry, while mulch apparently has but little effect. For these and other reasons any discussion of germination, growth, and survival in seedbeds under different covers must take weather conditions into account. The results obtained during a particular growing season under a given set of weather conditions would likely be quite different from results obtained during another season or in a different locality under strikingly different weather conditions.

Robert Douglas, in establishing the first nursery in this country for growing coniferous seedlings, recounts his early failures as due to ignoring the relation of cover over the seedbeds to weather conditions. After he observed the successful growing of conifers in open seedbeds in the humid and cool climate of England, he attempted to grow them in open beds at his home near Waukegan, Illinois. For a few weeks following the sowing of the seed, the weather was mild and humid with a high percentage of cloudy days. The seed in all the beds germinated and formed full stands of young seedlings, but in late May and early June the weather became hot and dry and soon out of the millions of young trees that appeared above the soil, practically none remained alive.

The data on germination, growth, and survival are preceded by the following analysis of weather conditions for the period over which the study extended. Continuous records of air temperature, humidity, and precipitation are not so important as records of hot, prolonged periods without rain and with low relative humidity, because it is during these periods that the excessive temperature of the surface soil and low moisture content tell most disastrously on survival in open seedbeds.

TABLE II

METEOROLOGICAL SUMMARY OF WEATHER CONDITIONS FROM MAY 1 TO SEPTEMBER 30, 1922[1]

Date		*Maximum temperature (°F.)*	*Relative humidity per cent*	*Precipitation inches*	*Wind max. velocity miles per hour*	*Sunshine per cent*
May	1	60	33	0	17	100
	2	72	34	0	28	100
	3	75	50	0	24	83
	4	62	95	.98	25	0
	5	51	90	1.56	30	9
	6	66	77	0	11	88
	7	78	81	T	28	70
	8	70	24	0	30	99
	9	73	20	0	21	100
	10	78	24	0	24	90
	11	77	24	0	32	83
	12	61	53	0	18	100
	13	71	51	0	14	85
	14	66	56	0	16	100
	15	76	47	T	20	83
	16	70	37	0	19	100
	17	62	52	T	20	70
	18	69	87	1.48	29	25
	19	68	74	.33	28	52
	20	76	69	0	25	100
	21	80	44	.02	22	78
	22	75	62	0	16	88
	23	79	34	0	19	100
	24	73	50	0	14	100
	25	77	44	.28	24	49
	26	82	45	0	19	96
	27	65	58	T	23	64
	28	70	56	0	17	100
	29	83	30	0	20	100

[1] Compiled from the monthly meteorological summary at the New Haven station of the United States Weather Bureau.

TABLE II (Continued)

Date	*Maximum temperature (°F.)*	*Relative humidity per cent*	*Precipitation inches*	*Wind max. velocity miles per hour*	*Sunshine per cent*
30	81	32	0	19	100
31	73	55	0	17	100
Mean	71.6	51.2	Total 4.65		81
June 1	71	84	.02	12	44
2	75	69	.28	17	63
3	68	86	.31	19	25
4	84	52	.03	14	83
5	79	68	T	17	76
6	75	95	.83	13	17
7	88	41	0	12	91
8	90	62	0	20	98
9	90	64	0	15	68
10	78	67	0	14	58
11	86	76	.32	31	43
12	75	38	.03	32	94
13	70	28	0	24	91
14	73	46	0	18	77
15	75	47	.01	21	75
16	72	60	0	14	73
17	68	90	.21	26	19
18	71	92	.98	21	9
19	74	86	.04	13	43
20	72	79	.22	13	19
21	67	95	1.76	17	3
22	76	56	T	18	75
23	75	63	.01	14	71
24	79	58	0	12	90
25	78	81	1.33	31	43
26	75	53	0	16	91
27	70	61	T	12	37

TABLE II (Continued)

Date	*Maximum temperature (°F.)*	*Relative humidity per cent*	*Precipitation inches*	*Wind max. velocity miles per hour*	*Sunshine per cent*
28	80	83	.60	13	43
29	81	79	.34	18	39
30	85	28	0	14	94
Mean	76.7	66.2	Total 7.32		58
July 1	76	95	.34	18	21
2	89	62	.52	22	59
3	80	79	.08	17	48
4	74	65	.17	15	23
5	65	86	.49	14	0
6	80	44	0	15	100
7	81	48	0	25	100
8	82	71	1.52	20	75
9	77	65	0	20	62
10	74	66	0	15	100
11	74	70	0	14	64
12	83	72	0	12	89
13	86	71	.29	16	39
14	78	67	.04	22	70
15	78	54	0	17	89
16	84	48	0	21	100
17	78	77	0	17	67
18	91	56	.08	25	84
19	82	79	.14	13	44
20	75	67	T	15	5
21	85	52	0	16	100
22	86	68	0	22	87
23	82	81	.23	18	27
24	80	68	1.00	13	43
25	74	70	.01	17	47
26	72	64	0	14	83
27	72	72	.05	20	34

TABLE II (Continued)

Date	*Maximum temperature (°F.)*	*Relative humidity per cent*	*Precipitation inches*	*Wind max. velocity miles per hour*	*Sunshine per cent*
28	77	76	.06	20	67
29	80	51	0	15	97
30	79	36	0	19	100
31	84	57	.12	21	74
Mean	79.3	65.7	Total 5.14		64
Aug. 1	78	82	T	13	27
2	74	73	.51	17	19
3	75	67	0	12	80
4	75	65	.33	24	65
5	81	46	0	13	100
6	83	53	0	19	100
7	80	75	T	23	11
8	80	57	T	20	52
9	74	43	T	23	74
10	75	46	0	16	83
11	72	58	0	15	43
12	65	83	.52	16	0
13	77	76	0	11	63
14	87	65	0	14	87
15	89	65	0	15	100
16	91	57	0	16	100
17	88	59	.07	15	85
18	88	60	0	27	100
19	84	55	T	24	60
20	70	48	0	26	90
21	74	43	0	28	100
22	80	63	0	20	89
23	80	58	0	23	83
24	79	71	0	19	72
25	77	82	.06	21	33

TABLE II (Continued)

Date	*Maximum temperature (°F.)*	*Relative humidity per cent*	*Precipitation inches*	*Wind max. velocity miles per hour*	*Sunshine per cent*
26	73	85	.92	16	10
27	68	89	.50	17	7
28	68	82	.10	29	0
29	80	60	0	20	100
30	78	69	0	12	73
31	78	52	0	14	78
Mean	78.1	64.1	Total 3.01		64
Sept. 1	75	81	T	12	72
2	76	71	0	13	64
3	81	77	0	17	58
4	72	85	.27	12	20
5	84	43	0	10	100
6	89	68	.70	32	76
7	70	84	.02	19	0
8	72	61	0	12	61
9	72	80	0	9	29
10	78	78	0	13	54
11	79	64	0	18	76
12	76	72	.85	21	22
13	76	44	0	14	100
14	82	49	0	19	100
15	82	67	0	25	100
16	75	46	0	21	97
17	68	45	0	13	82
18	64	34	0	19	100
19	65	54	0	15	84
20	70	49	0	11	43
21	75	45	0	19	84
22	74	39	0	13	98
23	78	45	0	12	100
24	81	59	.02	20	91

TABLE II (Continued)

Date	*Maximum temperature (°F.)*	*Relative humidity per cent*	*Precipitation inches*	*Wind max. velocity miles per hour*	*Sunshine per cent*
25	61	36	0	23	100
26	62	41	0	19	100
27	73	32	0	16	100
28	65	56	0	14	100
29	75	71	0	12	80
30	82	61	0	14	100
Mean	74.4	57.9	Total 1.86		76

GERMINATION

THE controlling factors in germination are heat, moisture, and air. An environment which supplies these in optimum degree for a given species affords the most complete and uniform germination. Deviations from the optimum reduce germination values. If deviations extend overfar, there is no germination. All species, however, withstand considerable fluctuations in the controlling factors without a serious falling off in germination values. Seedbeds established under ordinary conditions usually find a suitable environment so far as heat and air are concerned. An environment too cold for the time being simply delays germination. Well-tilled seedbeds always have adequate air in the top soil to meet the needs for germination. Free water about the seed cuts off the air supply and reduces the temperature. Too little water stops germination from taking place. If the top soil surrounding the seed becomes overdry after germination starts and this condition continues for several days, the young plants are likely to be killed before the tap roots can strike deep enough to draw upon the soil moisture below the top layer.

Uniform and full germination are much to be desired in nursery practice. Methods of practice that bring up together the largest number of seedlings from a given lot of seed in the shortest period of time are sought after. Table III shows the course of germination in the three beds, but does not show the losses after germination or the quality and relative vigor of the plants, both of which are discussed later in this report.

Analysis of germination data. An analysis of Table III shows that, on the whole, germination was best in the closed bed, and poorest in the open bed, although there was much variation in the different species in this respect. With the large-seeded species such as Pinus canariensis, Pinus palustris, and Pinus insignis, the total gennination attained was not appreciably different in the three beds, while, on the other hand, with the smaller-seeded species such as Pinus taeda, Larix laricina, Picea excelsa, Abies balsamea, and Cupressus macrocarpa, the germination attained was far superior in the closed bed. It appears from these results that the marked difference in the moisture conditions of the top soil in the three beds was a·determining factor in the percentage of germination attained, but that this effect appears to be correlated 'with the size of the seed. The marked fluctuations in the moisture conditions of the top soil in bed two, as contrasted with beds one and three, appeared to affect the percentage of germination only in cases where the seed was small.

It is well known that large seeds like oak and chestnut show a high percentage of germination when sown in open nursery rows or in the open field. On the other hand, experience has established the practice of protecting the top soil of coniferous seedbeds during the period of germination. From the results of this study, it appears doubtful whether the same degree of protection should be given to all coniferous seedbeds alike over the period of germination. We do not seem to have appreciated the apparent variation in different conifers for the need of this protection and the extent to which it appears to be correlated with the size of the seed.

By turning to the table, it will be seen that germination took place earlier in the open seedbed, while there was little difference in the time required for gennination in the closed bed and in the mulched bed. Although, on the whole, germination was earlier in the open bed, Pseudotsuga taxifolia showed the earliest gennination in the closed bed, and Picea excelsa in the mulched bed.

The table shows considerable variation in the time over which germination took place in the different species and in the different beds, but there appears to be no correlation between the first and last germination of the different species under different conditions of cover; thus with Abies balsamea, some germination took place as late as 116 days after seeding in both the closed and open beds, while with Picea excelsa, germination continued longest in the open bed, and in Pseudotsuga taxifolia in the closed bed.

TABLE III

COURSE OF GERMINATION AND GERMINATION VALUES

Date of seeding, May 2.

Species	*No. of bed*	*No. seeds sown*	COURSE OF GERMINATION, DAYS *13*	*15*	*20*	*23*	*27*	*31*	*41*	*44*	*51*	*58*	*83*	*96*	*116*	*Total germination*	*Germination per cent*
Pinus canariensis	1	172	..	..	..	5	20	23	24	24	24	25	..	..	..	25	14.5
	2	172	..	..	1	18	23	24	24	24	26	..	..	..	..	26	15.1
	3	172	..	..	16	24	36	..	..	..	..	..	..	..	..	36	20.9
Pinus palustris	1	198	..	6	99	106	115	121	..	..	..	..	..	..	..	121	61.1
	2	198	16	23	78	115	126	135	138	139	141	..	..	..	..	141	71.2
	3	198	..	18	120	125	127	127	127	127	127	128	..	..	..	128	64.6
Pinus taeda	1	658	..	..	..	..	1	1	57	88	135	160	271	271	278	278	42.2
	2	658	..	..	..	..	6	10	31	33	41	41	57	..	..	57	8.6
	3	658	..	..	..	..	..	..	80	90	118	133	185	185	192	192	29.2
Pinus laricio	1	912	30	144	462	465	567	601	..	..	..	..	..	..	..	601	65.9
	2	912	213	389	475	632	655	655	679	679	679	687	..	..	..	687	75.4
	3	912	..	77	584	625	657	657	657	663	663	663	665	..	..	665	72.9
Pseudotsuga taxifolia	1	936	50	183	387	420	452	465	467	470	473	480	508	..	..	508	54.2
	2	936	7	71	215	233	279	279	319	330	338	..	..	..	..	338	36.1
	3	936	..	14	340	391	430	430	443	444	..	..	..	..	..	444	47.4

Pinus insignis	1	576	..	..	..	4	161	344	444	454	467	467	473	..	..	473	82.1
	2	576	..	..	16	36	111	128	196	209	225	256	335	342	..	342	59.4
	3	576	..	..	..	38	329	329	415	430	..	..	..	..	..	430	74.6
Larix laricina	1	2020	..	..	32	58	128	676	719	739	787	787	787	790	..	790	39.1
	2	2020	..	..	1	3	14	14	16	18	18	100	100	100	101	101	5.0
	3	2020	..	..	10	30	212	212	278	286	287	..	..	..	..	287	14.2
Picea excelsa	1	1552	..	..	90	950	1060	1104	1351	1404	..	..	..	..	..	1404	90.4
	2	1552	..	..	4	21	21	221	700	700	700	721	..	..	..	721	46.5
	3	1552	..	21	212	212	325	325	368	439	..	..	..	..	..	439	28.3
Abies balsamea	1	1810	..	..	..	..	..	8	12	17	30	73	327	339	..	339	18.7
	2	1810	..	..	..	..	..	..	8	8	12	14	14	14	17	17	0.9
	3	1810	..	..	..	1	1	2	22	49	71	79	..	..	..	79	4.4
Cupressus macrocarpa	1	1956	..	..	..	..	31	99	159	179	188	193	..	..	..	193	9.8
	2	1956	..	..	..	2	18	37	53	53	54	56	..	..	..	56	2.8
	3	1956	..	..	..	2	41	42	65	75	..	..	..	..	..	75	3.8
Pinus pinaster	1	360	..	..	32	95	145	266	266	279	296	..	..	..	..	296	82.2
	2	360	2	4	30	140	197	202	202	202	205	205	210	..	..	210	58.3
	3	360	..	12	123	194	206	212	258	261	262	262	265	..	..	265	73.6

From these studies it appears that under weather conditions such as prevailed in southern Connecticut, in May and early June, 1922, the effect of cover over coniferous seedbeds during the period of germination was as follows:

1. With all the small-seeded species like Cupressus macrocarpa, Abies balsamea, Picea excelsa, and Larix laricina, germination was far more complete in the closed than in the open bed, even more so than in the mulched bed. On the other hand, the larger-seeded species like Pinus canariensis, Pinus palustris, and Pinus pinaster showed but little difference.

2. Although germination began somewhat earlier in the open bed, the difference in time sequence for germination in the shaded bed, the mulched bed, and the open bed was of little importance.

Moisture conditions in the top soil during the period of germination. The moisture conditions of the surface soil is a factor of great importance in germination. Soil samples were taken from each of the three beds at irregular intervals over a period of six weeks following the seeding. A point was made to take these samples on days during which weather conditions indicated that the surface three inches of soil was at its lowest as to water content. No samples were taken on rainy days, but as many samples as practical were taken on hot, dry days and on days preceding rainfall. The aim was to find the lowest water content in the upper three inches of soil and the periods of low water content during the time of germination and immediately afterward or until the downward penetration of the tap roots of the young seedlings would reach below the three inches of surface soil.

The moisture content of the samples was determined by drying to a constant weight at 100°C. Table IV shows the dates that the samples were taken, the beds from which taken, the weight in grams when taken, the dry weight, the total moisture in grams, and the percentage of moisture to the dry weight of the soil.

After the soil samples were taken on May 9 and 13, all the beds were irrigated by overhead sprinkling. These were the only dates during the entire season when water was artificially applied. Bed one was entirely enclosed and protected by full shade until May 15, when some of the plants appeared above the soil. On this date, the side protection was removed and the overhead cover reduced to produce half shade. Bed three was uniformly covered with mulch until May 17, when three species were breaking through the soil. As soon as the different species began to germinate, the mulch was carefully removed from over the rows of seedlings, but left intact between the rows. Only as much mulch was removed as

TABLE IV

SURFACE SOIL MOISTURE

Date sample taken	Number of bed	Weight of soil sample	Dry weight of soil sample	Total moisture of soil sample	Percentage of moisture to dry weight
May		Grams	Grams	Grams	
9	1	47.01	43.36	3.65	8.4
	2	55.21	50.53	4.68	9.2
	3	65.89	58.01	7.88	13.6
13	1	42.22	39.45	2.77	7.02
	2	56.65	50.77	5.88	11.5
	3	44.44	40.46	3.98	9.8
17	1	77.73	69.15	8.58	12.4
	2	82.95	76.16	6.79	8.9
	3	55.29	50.60	4.69	9.2
18	1	64.73	57.53	7.20	12.5
	2	82.21	70.08	12.13	17.1
	3	57.53	48.88	8.67	17.7
19	1	70.58	62.29	8.29	13.3
	2	53.24	47.73	5.51	11.5
	3	69.10	58.70	10.40	17.7
20	1	64.15	55.77	8.36	14.9
	2	65.73	56.30	9.43	18.5
	3	61.56	53.29	8.27	15.5
22	1	48.64	43.76	4.88	11.1
	2	47.89	43.66	4.23	9.7
	3	44.16	37.98	6.18	16.2
24	1	95.52	84.54	10.98	12.9
	2	103.59	96.39	7.20	7.2
	3	97.78	86.40	11.38	13.1
25	1	83.96	79.16	4.80	6.06
	2	94.91	91.19	3.72	4.07
	3	79.97	73.76	6.22	8.4
29	1	85.46	79.29	6.17	7.6
	2	105.15	97.29	7.86	8.06
June					
12	1	58.06	53.14	4.92	9.2
	2	64.51	59.86	4.65	7.7
	3	65.61	57.06	8.55	14.9
13	1	57.28	53.53	3.75	7.0
	2	62.12	58.31	4.81	8.2
	3	61.65	57.25	4.40	7.7
14	1	57.11	53.41	3.70	6.9
	2	65.23	61.63	3.60	5.8
	3	54.43	49.64	4.79	9.6
15	1	57.38	52.89	4.49	8.5
	2	76.01	70.38	5.63	7.9
	3	53.39	49.79	3.60	7.2

necessary to permit the seedlings to come up through that which remained over the rows.

Analysis of soil moisture data. Although the above table shows that there was considerable variation in the amount of water in the upper three inches of soil in the different beds during the six weeks following seeding, it does not show the distribution of the moisture in this layer. Thus on May 25 there was but 0.79 per cent of moisture in the upper ¾ inch of surface soil, while below a depth of 1½ inches the soil still held adequate available moisture to sustain growth as shown by its color. The wilting coefficient as determined by the U. S. Bureau of Plant Industry was 9.52 per cent. On several dates the physical water content was much less. Thus on May 25 it was reduced to 4.07 per cent in the open bed, and 6.06 per cent in the bed under half shade. This low physical water content during the driest periods was evidently due to the extreme dryness of the upper portion of the three inches of surface soil. The color of the soil at a greater depth than 1½ inches clearly indicated that available moisture was still present, adequate for plant survival. It is believed, therefore, that where the roots reached a greater depth than 1½ inches during these driest periods following germination, they could still obtain moisture from the soil.

By comparing the soil moisture conditions of the three beds, it will be noted that the retention of surface soil moisture was greatest under the mulch in bed three and least in bed two where the surface soil was unprotected. Furthermore, bed three showed less variation in surface soil moisture than either of the other beds. The greatest fluctuation was in bed two, and this bed showed the most rapid falling off in moisture during clear, dry days. The lowest moisture content of the first three inches of top soil in bed three was 7.2 per cent; in bed one, 6.06 per cent; and in bed two, 4.07 per cent; while the highest moisture content was 18.5 per cent in bed two; 17.7 per cent in bed three; and 14.9 per cent in bed one. In taking the samples particular attention was given to the depth that the surface soil had dried sufficiently to cause a change in color. At no time over which the samples were taken did the soil in any of the three beds show a uniformly lighter shade due to the loss of moisture at a greater depth than 1½ inches. Although the surface soil in each of the beds retained at all times adequate moisture to appear moist to the eye at a depth of 1½ inches or more, the ¾ inch surface layer often became very dry in bed two a day or two after a heavy precipitation when followed by hot, windy weather. Thus a sample taken from the upper ¾ inch of surface soil in bed two on May 25 had but 0.79 per cent of moisture to dry weight, and another similar sample taken from the same bed on May 29 had but 0.64 per cent.

SEEDBEDS

SURVIVAL

AFTER germination takes place in coniferous seedbeds, the percentage of survival is the factor of chief economic importance. Even under the best of conditions some losses occur, while under adverse conditions, such as uncontrolled disease, the losses may be complete.

Differences in survival in the three beds. The first recorded losses in any of the seedbeds, after germination took place, were on May 20. On this date, six species were more or less advanced in germination in bed one, eight in bed two, and seven in bed three. Table V shows the losses in the three beds on different dates and the total losses to September 26.

An analysis of this table shows that there was a striking difference in survival in the three beds. Taking the eleven species together the losses in the open bed were about four times and in the mulched bed more than five times the losses in the bed under half shade. There was but little difference in survival in Pinus laricio and Pinus insignis in the three beds, but in most species, and particularly in Larix laricina, Picea excelsa, and Abies balsamea, while losses were very low in the shaded bed, they were excessive in the open and mulched beds. The greatest losses occurred from May 24 to June 22. The losses in most species were negligible after the end of June. As will be shown later, excessive losses in the open and mulched beds are closely correlated with dry, hot weather. So far as observed, there were no losses from damping-off organisms. The losses shown in the table are believed to have been caused by adverse factors other than biotic, and closely related to weather conditions.

Root penetration and survival. The most frequently assigned non-parasitic cause for losses in coniferous seedbeds immediately following germination has been the inability of root penetration to keep pace with the downward desiccation of the surface soil during periods of dry weather. It is often stated that the greater survival of seedlings under partial shade is entirely due to the favorable effect of the cover on the moisture in the surface soil. We say, "We shade the seedbeds to keep the top soil moist." In order to prove or disprove the assumption that shade is necessary to keep adequate moisture in the surface soil to sustain normal growth after germination takes place, a study was made of the rapidity of juvenile root penetration in each of the eleven species. The study was made of plants growing in the open bed, because it was believed that losses due to inadequate root penetration coupled with excessive downward desiccation of the top soil would be more evident than in the covered and mulched beds. The period of study of root penetration in each species was

TABLE V

LOSSES IN SEEDBEDS

Species	*No. of Bed*	*May 24*	*May 29*	*June 2*	*June 12*	*June 15*	*June 22*	*June 29*	*July 24*	*Sept. 6*	*Sept. 26*	*Total germination*	*Total losses*	*% loss after germination*
Pinus canariensis	1	..	..	..	2	..	..	..	..	..	..	25	2	8
	2	..	..	4	..	..	7	..	..	8	..	26	8	30.8
	3	..	..	3	14	..	15	..	17	..	..	36	17	47.2
Pinus palustris	1	..	..	..	3	5	8	..	..	..	..	121	8	6.6
	2	2	..	10	12	14	..	18	28	34	..	141	34	24.1
	3	..	..	10	13	14	..	..	..	..	..	128	14	10.9
Pinus taeda	1	..	..	..	1	..	..	..	..	..	..	278	1	.4
	2	..	3	4	..	5	..	10	..	..	..	57	10	17.5
	3	..	..	..	..	..	..	7	..	8	..	192	8	4.16
Pinus laricio	1	..	..	16	29	..	..	33	..	35	..	601	35	5.8
	2	3	6	11	16	18	20	26	28	31	..	687	31	4.5
	3	..	..	12	21	..	22	24	..	25	..	665	25	3.7
Pseudotsuga taxifolia	1	..	..	17	..	19	22	26	..	28	..	508	28	5.7
	2	..	..	13	21	35	37	43	54	63	..	338	63	18.6
	3	..	..	20	23	24	29	..	43	46	..	444	46	10.3

Pinus insignis	1	..	..	5	9	13	20	..	..	24	..	473	24	5.1
	2	..	..	10	11	..	16	24	..	25	26	342	26	7.6
	3	..	..	..	44	48	..	50	..	..	..	430	50	11.6
Larix laricina	1	..	..	5	12	20	34	..	..	38	..	790	38	4.8
	2	1	9	..	..	..	10	..	89	92	..	101	92	91.08
	3	..	..	212	16	36	38	50	..	51	..	287	247	86.06
Picea excelsa	1	..	..	..	12	18	22	25	..	26	..	1404	26	1.9
	2	21	..	50	114	210	231	243	251	267	..	721	267	37.02
	3	23	135	189	203	287	297	306	317	320	..	439	320	72.8
Abies balsamea	1	..	..	..	1	..	..	..	..	3	..	339	3	.8
	2	..	..	..	..	..	2	3	13	..	..	17	13	76.4
	3	..	..	..	1	25	..	77	79	..	..	79	78	98.7
Cupressus macrocarpa	1	..	..	..	..	..	..	..	..	..	2	193	2	1.5
	2	..	..	..	..	..	1	..	..	4	..	56	4	7.1
	3	..	..	..	2	16	40	49	..	50	..	75	50	66.6
Pinus pinaster	1	..	..	..	1	..	2	..	..	..	..	296	2	.67
	2	..	..	..	..	1	19	..	32	..	..	210	32	15.2
	3	..	..	..	7	10	13	14	..	..	..	265	14	5.2

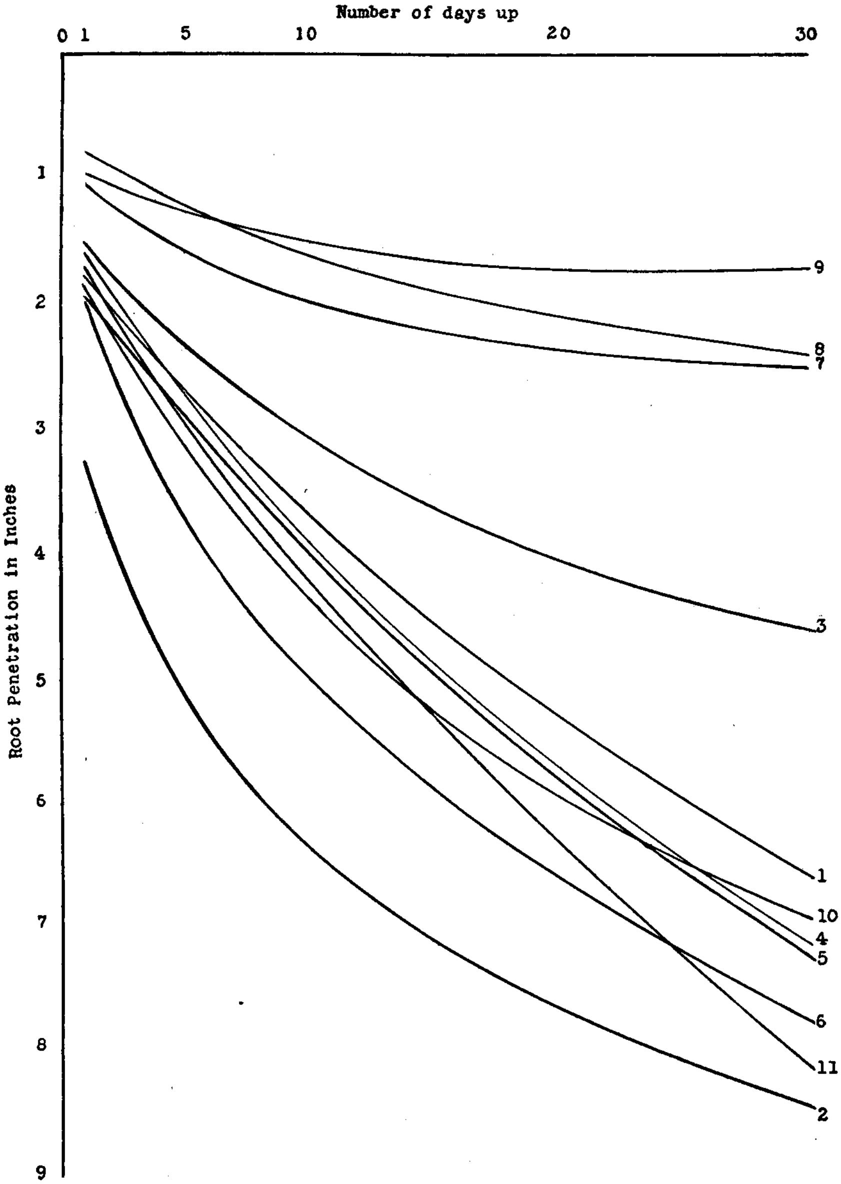
thirty days following germination. By referring to Table V, it will be seen that this was the period over which the greatest losses occurred in the open and mulched beds.

The following graphs show the rapidity and depth of root penetration in each of the eleven species over the period of thirty days following gennination. The four points used in establishing the graph for each species are the average depth of root penetration in 1, 5, 10, and 30 days following the appearance of the shoot at the surface of the soil.

The most striking feature brought out in these graphs is the remarkable variation in the depth of early root penetration in the different species when grown under uniform soil conditions. The numbers of the graphs refer to the different species as follows:

1. Pinus canariensis.
2. Pinus palustris.
3. Pinus taeda.
4. Pinus laricio.
5. Pseudotsuga taxifolia.
6. Pinus insignis.
7. Larix laricina.
8. Picea excelsa.
9. Abies balsamea.
10. Cupressus macrocarpa.
11. Pinus pinaster.

The graphs show that with the species studied, the downward growth of the root the day following the appearance of the shoot at the surface brought the root tips in contact with soil from ¾ to 3¼ inches below the surface, depending on the species. The root tip of Pinus palustris reached a depth of 3¼ inches the day following the appearance of the shoot at the surface. On the other hand, in Larix laricina, Picea excelsa, and Abies balsamea, the root tips reached a maximum penetration of but one inch in the same length of time. Five days later the average root penetration of all eleven species exceeded 2½ inches with the exception of Picea excelsa, Abies balsamea, Larix laricina, and Pinus taeda in which it was 1.2, 1.3, 1.6, and 2.3 inches respectively. At the expiration of thirty days the range in the average depth of root penetration in the eleven species was as follows: 8.4 inches in Pinus palustris, 8.1 inches in Pinus pinaster, 7.7 inches in Pinus insignis, 7.2 inches in Pseudotsuga taxifolia, 7.1 inches in Pinus laricio, 6.9 inches in Cupressus macrocarpa, 6.6 inches in Pinus canariensis, 4.6 inches in Pinus taeda, 2.5 inches in Larix laricina, 2.4 inches in Picea excelsa, and 1.7 inches in Abies balsamea. It would appear from the above data that surface soil desiccation below the point of available moisture even to a depth of one inch might be the limiting factor in survival in spruce, balsam, and larch over a period of several days following germination, and that desiccation to a depth of 2.5 inches below the point of available mois-


Number of days up
0 1 5 10 20 30
Root Penetration in Inches
1
2
3
4
5
6
7
8
9
9
8
7
3
1
10
4
5
6
11
2

ture at any time during the first month following germination would be fatal. On the other hand, Pinus palustris has its root tips in soil 5.2 inches below the surface five days after the shoot appears at the surface.

Soil moisture investigations made during the period of root penetration studies show that at no time were the root tips of any of the eleven species out of reach of moist soil. Even the root tips of Picea excelsa, Abies balsamea, and Larix laricina were within reach of some available water during the driest period in the open seedbed, namely on May 25 and on May 29. Although on the former date the top ¾ inch of soil contained but 0.79 per cent and on the latter but 0.64 per cent of moisture, the soil at a depth of 1½ inches and deeper was still moist as shown by its color.

Although the rapidity and depth of root penetration may determine survival in open seedbeds, the roots of most species sown in spring quickly reach depths that bring their root tips below the zone of non-available moisture. It would appear that only during seasons of prolonged dry weather following germination are excessive losses likely to occur from non-available water in the surface soil in southern New England, and then only with such shallow-rooted species as Picea excelsa, Abies balsamea, and Larix laricina.

Temperature of the surface soil and survival. Critical periods from high temperature occur in open seedbeds or in the field only at such times as the temperature in a plane which coincides with the soil surface or is slightly above it exceeds from 122° to 130°F. These periods in New England are at irregular and infrequent intervals. The highest temperature at or near the surface of the soil is difficult to determine, due to the rapid falling off in temperature immediately above and below the plane of greatest heat. Munch[1] used a special thermometer with a small bulb and obtained much higher maximums than are obtainable with an ordinary standard thermometer.

In the readings taken at New Haven a standard thermometer with a cylindrical bulb was used, which was supported vertically, with the top of the bulb level with the surface of the soil. This does not record the temperature at the plane of greatest heat, but at approximately ¼ inch below this plane. The following table shows that critical temperatures are not likely to be reached at this depth. The data were obtained during a period when the air temperature records at the New Haven weather station showed

[1] Miinch, E.: Beobachtungen iiber Erhitzung der Bodenoberflache im Jahr 1914. (Naturw. Zeitschr. Forst. u. Landw., 13, s. 257, 1915.)

a maximum daily range of from about 70° to 80°F. and when the relative humidity varied from 28 to 60 per cent.

TABLE VI

SOIL TEMPERATURE DATA

Day of month	*Hour of day*	*Air temp. 6 in. above surface Degrees F.*	*Soil temp. Bed I Degrees F.*	*Soil temp. Bed II Degrees F.*	*Soil temp. Bed III Degrees F.*
June 13	1 p.m.	73.8	78	103.8	88.2
	3 p.m.	75.2	86	105.4	90
	5 p.m.	72.7	79.2	98	83.4
June 14	9 a.m.	67.1	68.9	78.1	73.6
	11.30 a.m.	72	79.2	100	86
	2 p.m.	77.9	83.8	108.7	92.1
	4 p.m.	75.9	86.9	104	89.6
June 15	1 p.m.	75	74.3	86	82.4
	2 p.m.	79.5	84.9	103.3	99
	4 p.m.	73.9	81.5	93.2	88.5
June 16	10 a.m.	70.7	68.9	78.8	77
	12 m.	83.8	81.5	95	90.5
	2 p.m.	75.2	80.6	98.6	92.3

On June 16, a standard thermometer with cylindrical bulb was exposed in each bed in a nearly horizontal position, with the bulb partly above and partly below the surface level, and the exposed part just covered by sprinkling soil over it. At 2.30 p.m., when the air temperature six inches above the surface was 75.9°F., the thermometer in bed one recorded a temperature of 104°F., in bed two 122°F., and in bed three 118°F. By exposing the bulb of the thermometer more nearly in the plane of the surface of the soil, rather than in erect position, the reading was increased for the different beds by from 20° to 25°F. When we consider that on a day when the air temperature six inches above the soil was but 75.9°F. and that recorded by the ordinary standard thermometer with cylindrical bulb, when exposed with the bulb as nearly as possible in the plane of the surface soil, was 122°F., it can be inferred that there are many days during the summer when high air temperature, low relative humidity, and dry surface soil bring the temperature at or near the surface above the critical point for the survival of young seedlings.

High temperature and dry top soil. By referring to Table I, it will be observed that the seeds in all the beds were sown May 2. The first seedlings appeared above the ground on May 14. On May 17, five species had germinated in considerable numbers. Table II shows that the above dates cover a period of relatively low maximum daily temperatures, followed on the 18th and 19th by considerable precipitation and little sunshine. The 20th was a clear day and the 21st experienced a rise in maximum temperature to 80°F. with low relative humidity, a wind of 22 miles per hour, and full sunshine except in the morning hours. The 22d, 23d, and 24th had a somewhat lower temperature, but the weather continued dry with no clouds except for a short time on the 22d. On May 24, stem lesions were apparent on many seedlings in the open beds. Two lesions were found on Pinus palustris, three on Pinus laricio, one on Larix laricina, and one on Picea excelsa in bed two. There were no lesions recorded on the same date on the plants in bed one, but a loss of 23 plants was recorded in Picea excelsa in bed three. There was a precipitation of .28 inch in the afternoon of May 25 followed by almost a week of warm, clear, dry weather. On May 29, the air temperature reached a maximum of 83°F. The relative humidity was 32 per cent, there was a fair wind and 100 per cent of sunshine. It will be observed by referring to Table V that on this date the losses in the open beds were excessive. All the plants of Picea excelsa in bed two showed well-marked lesions and were dead or dying. The loss in this species in bed three was 135 plants, or more than one-third of those above ground. Twelve plants of Larix laricina were just breaking through the soil in bed three on June 2. Not one was alive five days later. June 8 and 9 were two of the hottest, driest days of the month. The temperature reached a maximum of 90°F. The relative humidity was low and the percentage of sunshine was high. An examination of the beds on June 12 showed well-developed lesions on the following species in the open beds: Pinus canariensis, Pinus palustris, Pinus taeda, Pinus laricio, Pseudotsuga taxifolia, Pinus insignis, Larix laricina, Picea excelsa, Abies balsamea, and Pinus pinaster. *No lesions were in evidence on any of the seedlings in the bed protected by half shade.*

Although most of the losses occurred immediately after germination, before the cotyledons spread out and partially shaded the ground, they continued more or less throughout the summer. The losses, however, during July, August, and September were with most species of little moment, due possibly to the well-distributed precipitation.

Cause and nature of the injury. The light-colored, sunken lesions which appeared, particularly during late May and early June, on the seedlings of most of the species in beds two and three were correlated, apparently, with the high temperature of the top soil. During periods of hot, dry weather with a high percentage of sunshine the larch and balsam were practically all severely injured or destroyed, and the damage to the other species in open seedbeds was much greater than at other times. No lesions were observed as forming during hot weather when the top layer of the soil was moist, probably due to the cooling effect of evaporation. It is well known that the temperature of the air may be and usually is much cooler than that of the surface soil when the weather is warm and dry and the soil exposed to the direct rays of the sun. Not infrequently, there is a difference of from 40° to 50°F. The plane of highest temperature, in reference to the soil surface, may coincide with the surface or be somewhat above or below the surface. It is likely for this reason that the point of injury in the seedling is at the surface or immediately above or below the surface. The point of injury in relation to the soil surface is clearly shown in the illustrations accompanying this study and is also shown by Hartley.[1] Münch[2] has shown that the heat of the surface soil varies with its dryness, looseness, and color. The drier, looser, and darker the soil, the higher its temperature, other factors being equal. The highest temperature of moist top soil recorded by him was 100.4°F., while the highest temperature of similar soil when thoroughly dry was 145.4°F. On a given day when the temperature of dry, loose soil reached a maximum of 140°F., that of a similar but compact soil was 132.7°F. A thin, dark litter of partially decomposed organic matter collects the heat in a plane of considerable thickness above the mineral soil and may become a hazard for young seedlings coming up through it.

Münch,[3] in 1913, attributed the lesions on seedlings as due directly to heat at the soil surface. In his study of surface soil temperatures where damage was taking place, he recorded temperatures of 140°F., and in some cases even higher. He found by incubator tests, in which coniferous seedlings survived for two to three hours at temperatures not exceeding

1 Hartley, Carl: Stem lesions caused by excessive heat. (Jour. Agrl. Res., Vol. 14, No. 13, p. 598, 1918.)

2 Münch, E.: Beobachtungen über Erhitzung der Bodenoberfläche im Jahr 1914. (Naturw. Zeitschr. Forst. u. Landw., 13, s. 257, 1915.)

3 Münch, E.: Hitzeschaden an Waldpflanzen. (Naturw. Zeitschr. Forst. u. Landw., 11, s. 557-662, 1913.) Nochmals Hitzeschaden an Waldpflanzen. (Naturw. Zeitschr. Forst. u. Landw., 12, S. 169-188, 1914.)

12S.6°F., that they were quickly killed when the temperature was raised to from 129.2° to 131°F. De Vries[1] exposed a number of different species of plants to various temperatures, the roots being in the soil and the tops in the air. He found that the various species under investigation were killed in fifteen minutes when subjected to temperatures of from 124.7° to 131°F. Although ultra-maximal temperatures, beyond which the death of succulent tissue ensues, vary between considerable limits depending upon the species, the stage of development, and external conditions, a temperature of from 122° to 131°F. is recognized by authorities as fatal for most growing plants. It would appear, therefore, that subjecting any part of the soft, succulent tissue of a young tree seedling, even for a comparatively short time, to a temperature exceeding 122°F. is likely to cause serious injury or death.

These studies indicate that in the climate of southern New England the better survival in coniferous seedbeds under partial shade is largely due to the effect of the cover *in lowering the temperature of the top soil and only secondarily to increasing the surface soil moisture.*

EFFECT OF COVER ON GROWTH

THE foregoing discussion indicates that partial shade over the seedbed influences survival by reducing the maximums of temperature at the soil surface during hot, dry periods having full or nearly full sunshine. It also indicates that mulch between the rows, although more effective than partial shade in maintaining moisture in the top soil, has little effect on survival, probably due to its not reducing the maximums of temperature at the surface. Although partial shade appears to be more or less essential in obtaining a high percentage of survival in coniferous seedbeds, due to its effect in lowering the temperature of the soil surface rather than its effect on soil moisture, it appears in most cases to react unfavorably on growth. The surviving plants in the beds exposed to full light were heavier and larger by the end of September than the plants similarly spaced in the shaded bed. In general, shading the seedbed reacted favorably on survival but unfavorably on growth.

The following table shows the average differences in root and shoot growth in the eleven species when grown under partial shade and when grown in open seedbeds.

1 See Pfeffer's Physiology of Plants, translated by A. }. Ewart. Vol. II, p. 231, 19°3·

TABLE VII

MEASUREMENTS OF ROOT AND SHOOT IN INCHES

Species	*Bed no.*	*No. of seedlings measured*	*Average height of shoot*	*Maximum height of shoot*	*Average root penetration*	*Maximum root penetration*
Pinus canariensis[1]	1	17	5.0	8.0	13.0	16.0
	2	17	7.0	9.4	14.0	16.0
	3	14	8.0	11.1	14.0	16.0
Pinus palustris[2]	1	36	8.5	12.5	10.5	12.0
	2	8	3.2	4.6	5.6	10.0
	3	16	9.5	13.0	11.0	16.5
Pinus taeda[3]	1	7	5.7	7.8	5.4	10.6
	2	11	6.6	10.3	12.6	16.5
	3	9	6.9	8.10	8.1	15.4
Pinus laricio[4]	1	9	3.2	4.5	8.1	14.2
	2	13	4.9	4.8	11.2	16.4
	3	11	4.7	6.5	13.2	16.6
Pseudotsuga taxifolia[5]	1	13	3.2	4.4	6.2	8.4
	2	14	5.2	8.5	9.4	13.4
	3	8	4.9	7.1	8.3	10.6
Pinus insignis[6]	1	17	6.8	9.5	11.2	14.8
	2	13	10.2	13.5	13.9	18.5
	3	18	10.5	13.0	12.8	17.1
Larix laricina[7]	1	12	4.2	6.4	5.1	7.0
	2	4	2.8	3.2	5.8	8.2
	3	1	4.4	4.4	9.1	9.1
Picea excelsa[8]	1	26	1.9	2.4	3.6	5.4
	2	8	2.3	3.0	3.9	6.2
	3	5	2.2	2.9	4.1	6.5
Abies balsamea[9]	1	20	1.1	1.4	2.9	4.1
	2	..	..	..	..	..
	3	..	..	..	..	..
Cupressus macrocarpa[10]	1	16	6.7	11.4	7.6	12.4
	2	14	8.7	12.4	11.2	14.6
	3	4	6.0	9.5	8.0	12.6
Pinus pinaster[11]	1	17	8.8	11.6	11.3	15.4
	2	15	9.6	12.8	12.2	16.2
	3	17	10.0	13.2	12.0	15.9

NOTES ON TABLE VII

1 Maximum root penetration was deep in all beds. The plants were taller and heavier in the open beds and had more short growths (needles).

2 This pine showed the poorest growth in bed two. The leaves were much shorter and much lighter colored than in bed one and in bed three. The roots at 8 inches or more below the surface were much more subject to decay in bed two than in the shaded and mulched beds. On the whole, the plants averaged much more uniform in the shaded bed, but they were much larger, stockier, and better rooted in the mulched bed. Longleaf pine does not appreciably elongate the shoot the first year. The height of this species as given in the above table is the vertical extension of the longest leaves above the shoot.

3 The tap roots and ends of the lower latent roots in bed one partly decayed, possibly due to overwet soil under partial shade. Most of the tap roots in bed two undecayedat ends, which probably accounts for the greater average depth of root penetration.

4 Plants in open beds very stocky, many with one or more lateral branches and with numerous short growths (needles). Numerous lateral buds at the base of the primary leaves.

5 Some of the more vigorous plants with one or more lateral branches. Plants under half shade much more slender than in open beds, also the roots much shorter and showing greater tendency to decay at the ends.

6 The tap roots in this species entirely free from decay in all three beds. Plants in shaded bed much more slender than in open bed.

7 This species was more uniform and taller in the shaded bed, but the plants were much more slender and had fewer buds. The root system was more compact with fewer long, rambling surface roots.

8 Many of the surface lateral roots were larger than the tap roots in all three beds. The maximum length of lateral root was 8.3 inches. The plants were much stockier and taller in the open beds than in the shaded bed.

9 This species continued to germinate in all beds until the beginning of October. There was no survival in either of the open beds of plants that germinated prior to September 1. Both the shoot and the root grew very slowly and at the end of the growing season were very short as compared with the other species.

10 This species exhibited great variation in size of shoot and root in all three beds. Both the shoot and root have numerous branches. Depth of root penetration is less than in many pines.

11 The seedlings were large in all beds with little differences in height and in root penetration. They were, however, stockier and heavier in the open bed and had more lateral branches and short growths (needles).

An examination of the above table shows that with few exceptions there was greater maximum and average height growth in each species in one or the other of the open beds than there was in the shaded bed.

Although root and shoot elongation in the three beds show well-marked differences, the great difference in growth in the open and mulched beds as compared with the shaded bed is best brought out by comparing the average green and dry weights of the several species in the three beds. The difficulty experienced in removing the plants from the beds without leaving considerable parts of the root systems in the soil induced the comparison of weights of the shoots rather than of the entire plants. The species in the three beds were removed and the roots severed at the union of the root and shoot. The shoots were weighed green and later dried to a constant weight at 100°C. Table VIII shows the number of plants of each species and in each bed upon which averages were based.

Although it was observed at the time the plants were lifted that they were much stockier and of greater diameter in the open beds, the table brings out in a most striking manner the extent to which shade over the seedbed reduced the percentage of dry matter formed as compared with that formed in the open beds. This remarkable difference in growth in the shaded as compared with the unshaded beds was attained during a season of well-distributed, abundant precipitation, and a relatively high percentage of cloudy weather. It is not to be expected that there would be as great a difference in a season having a lower and less uniformly distributed precipitation and a higher percentage of sunshine. It would appear, however, that in seedbeds in which soil moisture is under control, *partial shade reduces the size attained by the seedlings irrespective of species.* On the other hand, when soil moisture is inadequate in open beds, the advantageous effect of shade on soil moisture may more than offset its disadvantageous effect on growth.

THE BEARING OF THIS STUDY ON NATURAL REGENERATION

THE natural regeneration of conifers on exposed, unshaded soil and successful regeneration by direct seeding in the open are very largely controlled by the heat and moisture of the top soil. The rapidity and depth of root penetration following germination appears to be an important factor in survival, in that the downward growth of the root must keep in advance of the progressive drying of the surface soil to the point of water non-availability during periods of drought.

TABLE VIII

GREEN AND DRY WEIGHTS OF SEEDLINGS

Species	*Bed no.*	*No. of specimens*	*Green weight*	*Dry weight*	*Average green weight*	*Average dry weight*	*Proportion of moist to dry weight*
Pinus canariensis	1	17	20.5	3.5	1.2	0.2	5 : 1
	2	17	61.5	15.2	3.6	0.89	3.4 : 1
	3	14	50.5	13.0	3.6	0.93	2.8 : 1
Pinus palustris	1	36	55.2	11.2	1.5	0.31	3.8 : 1
	2	8	10.0	2.6	1.25	0.325	2.9 : 1
	3	16	74.0	16.5	4.63	1.031	3.5 : 1
Pinus taeda	1	85	47.9	11.2	0.56	0.13	3.3 : 1
	2	37	80.2	17.5	2.44	0.47	4.2 : 1
	3	68	135.2	29.0	1.98	0.42	3.7 : 1
Pinus laricio	1	82	37.0	9.5	0.45	0.11	3.1 : 1
	2	50	62.5	16.7	1.25	0.334	2.7 : 1
	3	37	58.5	15.2	1.58	0.41	2.6 : 1
Pseudotsuga taxifolia	1	47	13.2	4.5	0.28	0.095	1.9 : 1
	2	28	17.5	5.3	0.624	0.18	2.5 : 1
	3	25	18.22	5.2	0.728	0.208	2.5 : 1

Pinus insignis	1	60	71.0	16.7	1.18	0.278	3.3 : 1
	2	53	173.0	39.0	3.26	0.73	3.4 : 1
	3	58	207.4	46.0	3.575	0.79	3.5 : 1
Larix laricina	1	60	17.1	4.7	0.285	0.078	1.4 : 1
	2	..	..	..	....	....	....
	3	5	4.1	1.5	0.825	0.30	1.7 : 1
Picea excelsa	1	167	17.1	6.0	0.102	0.039	1.6 : 1
	2	82	15.35	5.5	0.187	0.067	1.8 : 1
	3	20	3.85	1.5	0.192	0.075	1.6 : 1
Abies balsamea	1	67	2.9	1.0	0.043	0.015	1.9 : 1
	2	..	..	..	....	....	....
	3	..	..	..	....	....	....
Cupressus macrocarpa	1	58	25.3	5.5	0.436	0.095	3.6 : 1
	2	39	70.0	15.0	1.78	0.385	3.6 : 1
	3	12	15.5	3.3	1.291	0.275	....
Pinus pinaster	1	118	152.5	32.0	1.28	0.27	3.7 : 1
	2	72	311.0	66.2	4.32	0.93	3.6 : 1
	3	67	218.0	48.0	3.25	0.71	3.6 : 1

These studies indicate that the rapidity and depth of root penetration following germination on open sites are such that most conifers are able to withstand the ordinary droughts that are likely to occur in southern New England. It would seem, therefore, that losses in coniferous reproduction on open sites during the first season following germination cannot with most species be caused by the lack of available moisture in contact with the roots, because a few weeks after germination they reach depths where the soil is continuously moist. Only the most shallow-rooted species in the early stages of growth are likely to have their roots in soil layers having non-available moisture. The initial root habit of Abies balsamea, Picea excelsa, and certain other species is such, however, that they are extremely sensitive to the ordinary fluctuations in available water in the upper two or three inches of top soil. The observations recorded in this paper suggest that the heat relation much more than the water relation is the limiting factor in the survival of most coniferous seedlings in the open in southern New England.

It is well known that the natural reproduction of white pine is seldom successful on bare soil when fully exposed to the sun. It is usually much better when the soil is protected from the full effects of the sun by natural or artificial shade if not continuous or overdense. Seedlings show better survival when the seeds are carried into and germinate in a field of oats or other grain than when they germinate on a recently ploughed but bare field. Yet in the latter case there is more available soil moisture than in the former.

The mortality of longleaf pine during the first season is usually excessive on bare sites. Yet this species has a deeply penetrating tap root three inches or more in length when the shoot first appears at the surface of the soil, which reaches a depth of eight or more inches within thirty days after germination. The results obtained in growing this species in open seedbeds in New Haven indicate that its survival is closely correlated with ground cover adequate to give partial shade. The tall scattered growth of grass so characteristic of longleaf pine lands is apparently beneficial to the natural reproduction of this species rather than detrimental, due most likely to the effect of the grass in lowering the temperature at the surface of the soil.

To what extent insolation is the limiting factor in inhibiting natural regeneration of various coniferous species in the open is not known from carefully planned and executed research. It seems certain, however, that it is of far greater importance than is generally recognized.

DESCRIPTION OF PLATES

The horizontal unbroken lines in plates I, II, and III represent the surface of the soil, and the broken lines parallel with them and below represent the points of union of root and shoot.

PLATE I

1. *Pinus pinaster* showing seedlings in various stages of early growth and injury from insolation. D, seedling showing depth of root penetration on June 19, thirty days after the shoot appeared above the soil surface; E, ten days after; F, five days after, and G, one day after the shoots appeared above the soil surface. H and I show two seedlings two and five days after the shoots appeared each with a conspicuous lesion (m).
2. *Pinus laricio* showing seedlings in various stages of early growth and injury from insolation. C, seedling showing depth of root penetration on June 21, thirty days after the shoot appeared above the soil surface; D, ten days after; E, five days after, and F, one day after. G shows a short lesion exactly at the soil surface five days after the shoot appeared. H and I show two seedlings two days after the shoots appeared each with a large lesion (m) and with the tops wilted.

PLATE II

1. *Pseudotsuga taxifolia* showing seedlings in various stages of early growth and injury from insolation. A, seedling showing depth of root penetration on June 13, thirty days after the shoot appeared above the soil surface; B, ten days after; C, five days after, and D, one day after. E, F, and G show seedlings with well-marked and extensive lesions (0) on May II, one to five days after the shoots had appeared above the soil surface. H shows a seedling fifteen days old with a lesion (0) on one side of the shoot only. This plant was thrifty and growing rapidly. K shows a seedling 117 days old, on which a lesion (0) appeared in late July. This plant was still green at the top on September 6 when the drawing was made.
2. *Larix laricina* showing seedlings in various stages of early growth and injury from insolation. A, seedling showing depth of root penetration on June 23, thirty days after the shoot appeared above the soil surface; B, ten days after; C, five days after, and D, one day after. E shows a seed-

ling with an extensive lesion (o) when the shoot was one day old and F before the seedling had broken through the surface soil.

3. *Abies balsamea* showing three seedlings with extensive lesions (o) on May 21, one to three days after the shoots appeared above the soil surface. A shows the entire shoot above ground (o) affected while that part of the shoot below the surface was normal.

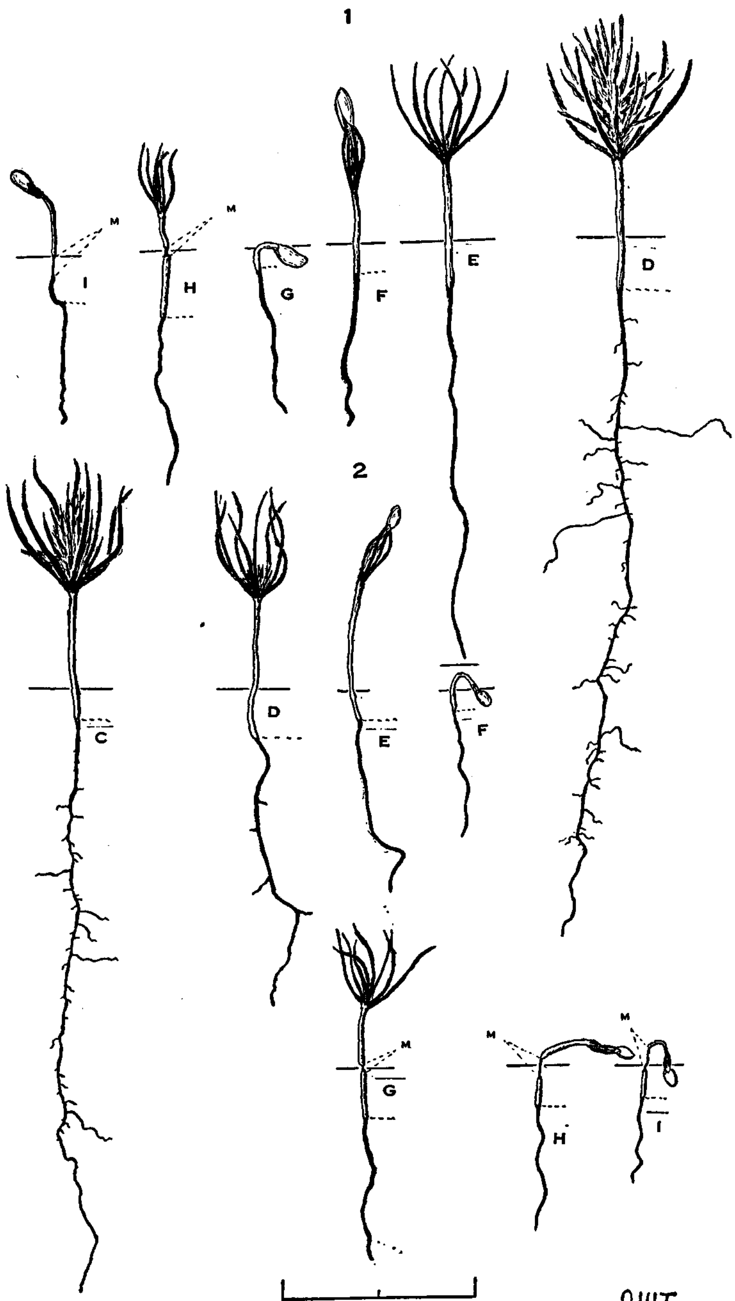
PLATE III

1. *Pinus palustris* showing seedlings in various stages of early growth and injury from insolation. C, seedling showing depth of root penetration on June 12, thirty days after the shoot appeared above the soil surface; D, ten days after; E, five days after, and F, one day after. G shows lesions (n) at the base of the cotyledons and on the shoot just above the origin of the cotyledons. In this case the entire plant above ground was withered and dead.
2. *Picea excelsa* showing seedlings in various stages of early growth and injury from insolation. C, seedling showing depth of root penetration on June 15, thirty days after the shoot appeared above the soil surface; D, ten days after; E, five days after, and F, one day after. H shows a large lesion (n) on a seedling four days after the shoot appeared. The plant is bent over and withered, characteristic of seedlings on which lesions appear soon after germination takes place. I shows three plants from one to three days old with large lesions (n). The shoots are already withered and dead.
3. *Pinus canariensis* showing a seedling six days after the shoot appeared above the soil surface, with a large lesion (n) on one side of the shoot, at and just below the surface of the soil.

PLATE IV

1. *Pinus taeda* grown in open and shaded seedbeds. A, an average plant of one season's growth grown in shaded seedbed. B, an average plant of one season's growth grown in unshaded seedbed. Both plants appeared above the ground in early June and were removed from the seedbeds on September 30 and photographed.
2. *Pinus laricio* grown in open and shaded seedbeds. A, an average plant of one season's growth grown in shaded seedbed. B, an average plant of one season's growth grown in unshaded seedbed. Both plants appeared above the ground in late May and were removed from the seedbeds on September 30 and photographed.

3. *Pinus insignis* grown in open and shaded seedbeds. A, an average plant of one season's growth grown in shaded seedbed. B, an average plant of one season's growth grown in unshaded bed. Both plants appeared above the ground on May 20 and were removed from the seedbeds on October 8 and photographed.
4. *Picea excelsa* grown in open and shaded seedbeds. A, an average plant of one season's growth grown in shaded bed. B, an average plant of one season's growth grown in unshaded bed. Both plants germinated in late May and were removed from the seedbeds on October 8 and photographed.



INCHES.

PLATE I

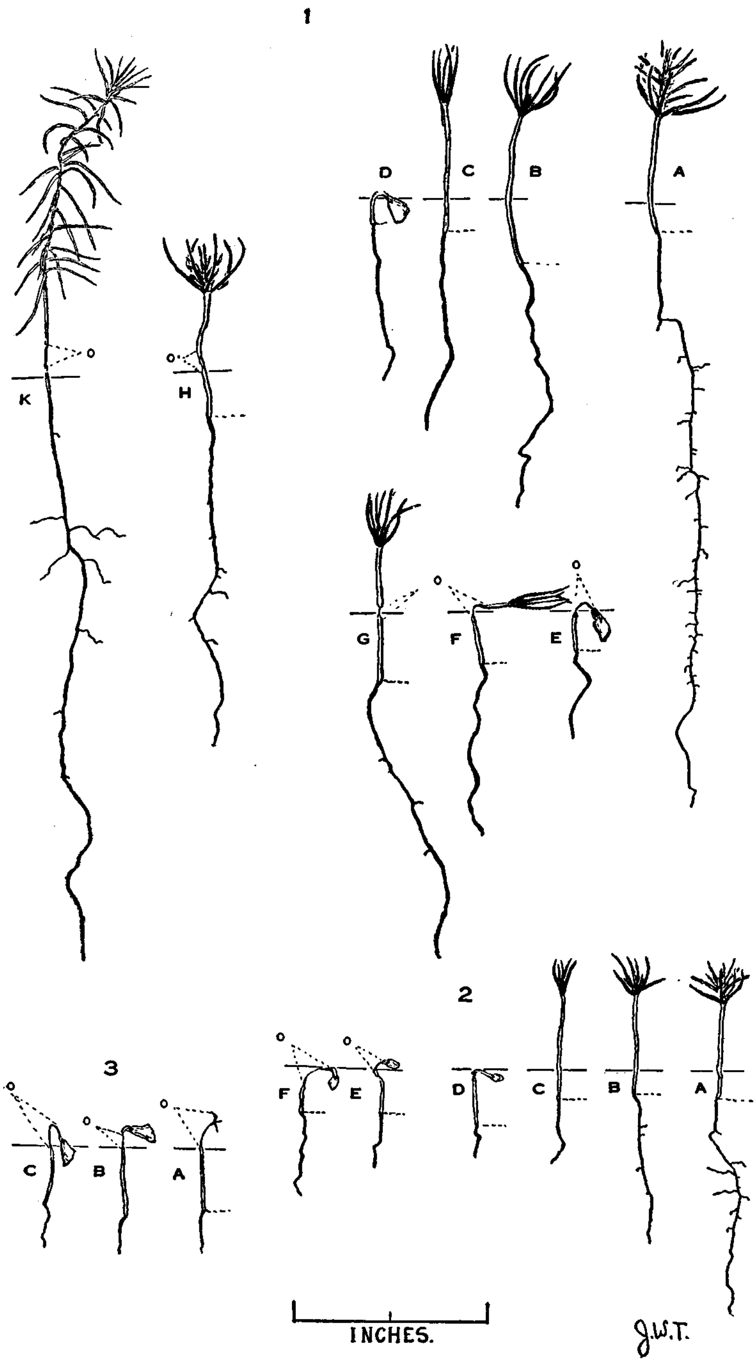


PLATE II

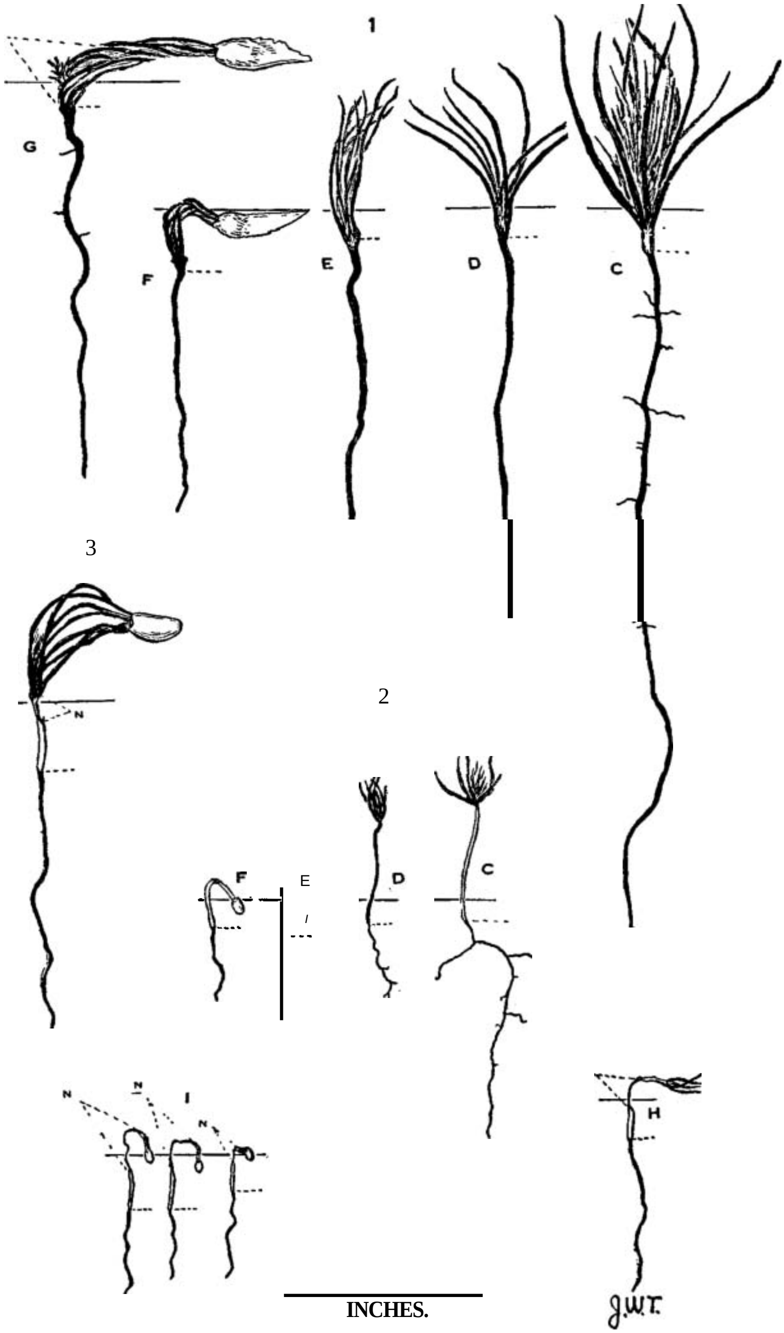


PLATE III

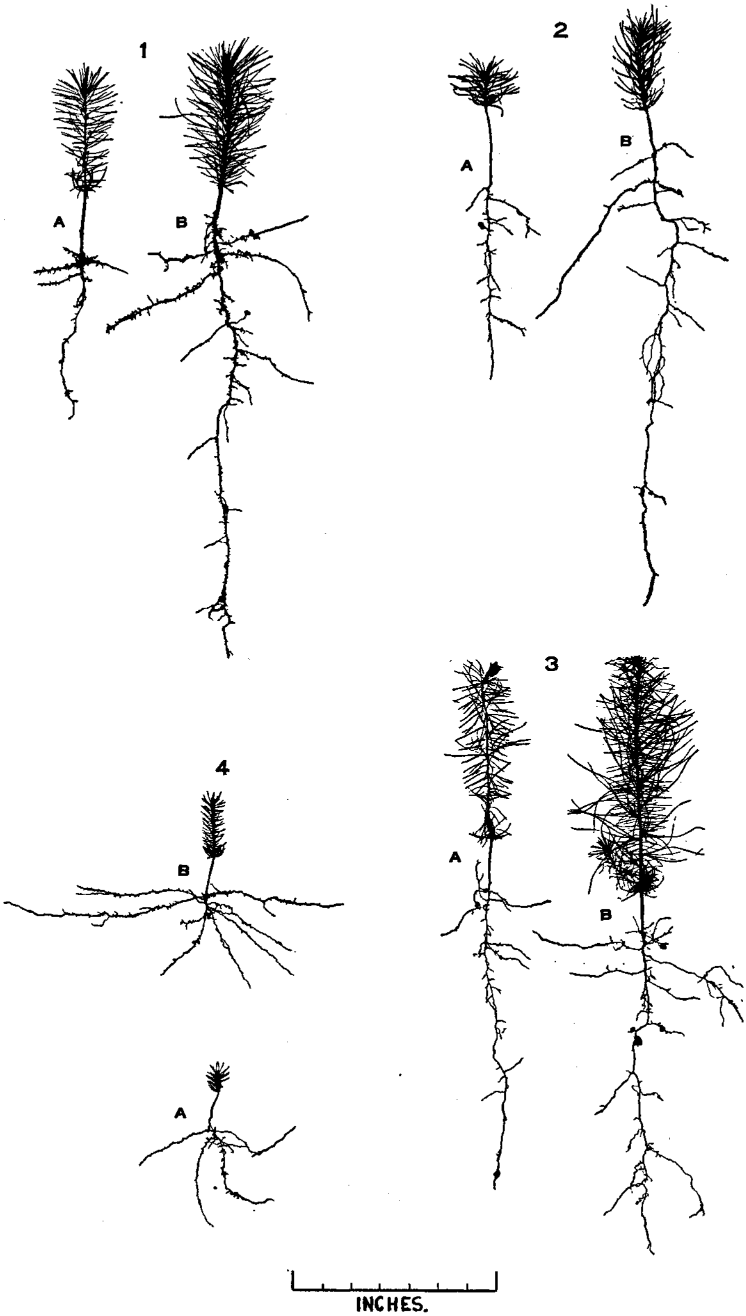


PLATE IV

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