CANADA
Department of Northern Affairs and National Resources
FORESTRY BRANCH

SOME EFFECTS OF LIGHT ON GROWTH OF WHITE PINE SEEDLINGS

by
K. T. Logan

Forest Research Division
Technical Note No. 82
1959

Published under the authority of
The Honourable Alvin Hamilton, P.C., M.P.,
Minister of Northern Affairs and National Resources
Ottawa, 1959

THE QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1960

Cat. No. R47-82

CONTENTS

Some Effects of Light on Growth of White Pine Seedlings

(Project P-383)

by

K. T. Logan[1]

INTRODUCTION

The germination period and first few years thereafter are critical in the life of the plant. Innumerable factors—climatic, biotic, and edaphic—which exert their influence on the young seedling must be favourable if the seedling is to survive. Events that may cause little or no harm to an older plant may severely damage or destroy a succulent seedling.

After their first three or four years, seedlings are sturdier and some may be firmly established in the community. Nevertheless their future development is still governed by the main environmental factors—light, temperature, soil moisture, and nutrients. It is important then that we know the effect of these factors on established seedlings as well as on newly germinated plants. Of all these factors, light is the one that can be most readily controlled.

Several workers (4, 6, 11, 12, 18) have determined the effect of light on germination and early survival of white pine (*Pinus strobus* L.) but few have studied the quantity of light required for subsequent good growth. In a virgin stand of red pine (*Pinus resinosa* Ait.), Shirley (15) found that white pine seedlings reached maximum growth at about 36 per cent light, compared with 63 per cent light for red pine and 75 per cent for jack pine (*Pinus banksiana* Lamb.). Gast (3), however, found an increase in the average leader length of 11-year-old white pine with increasing light up to full sunlight. He thought that some of the increase might have been caused by greater availability of nitrogen in the open areas.

The object of this experiment was to determine whether height growth of established seedlings is better in full sun or partial shade, and to measure the effect of light on leader diameter, branch length, needle length, and roots.

METHODS

The experiment was conducted at the Petawawa Forest Experiment Station near Chalk River, Ontario. Four-year-old white pine seedlings of local origin were planted in a well-drained medium sand and grown for 4 years in shelters where they received a known proportion of full sunlight.

In each shelter spherical illuminometers (8) were used to measure the quantity of light in the visible portion of the spectrum received during a given period of time. Table 1 shows the percentage of light in each of the shelters compared with that in the open.[2] These measurements were taken throughout the daylight hours on a clear, sunny day.

Half the seedlings were pruned to equalize the crown size of seedlings within each treatment and reduce the effect of this variable on growth. Less than half of the crown was removed.

---

[1]Forestry Officer, Forestry Branch, Petawawa Forest Experiment Station, Chalk River, Ontario.

[2]For convenience, light treatments are generally referred to in the text as: full light, 55 per cent light, 22 per cent light, 19 per cent light, and 14 per cent light.

76904-2—2½

TABLE 1

LIGHT MEASURED IN EACH SHELTER EXPRESSED AS A PERCENTAGE OF THAT IN THE OPEN

Treatment	Light
L_1—Open	100
L_2—Saran Screen	55
L_3—Lath	22
L_4—Fourdrinier Screen	19
L_5—Lath	14

The experiment had a randomized block design; each of the 10 treatments occurred in 4 replicates (see Figure 1). Fourteen 4-year-old seedlings were planted in each plot in August, 1951. Shelters covering the plots measured 4 x 8 x 4 feet. In 1954 the shelters were raised 4 inches above ground to provide better ventilation and in 1955 some of the L_2 shelters were raised higher to allow for seedling growth.

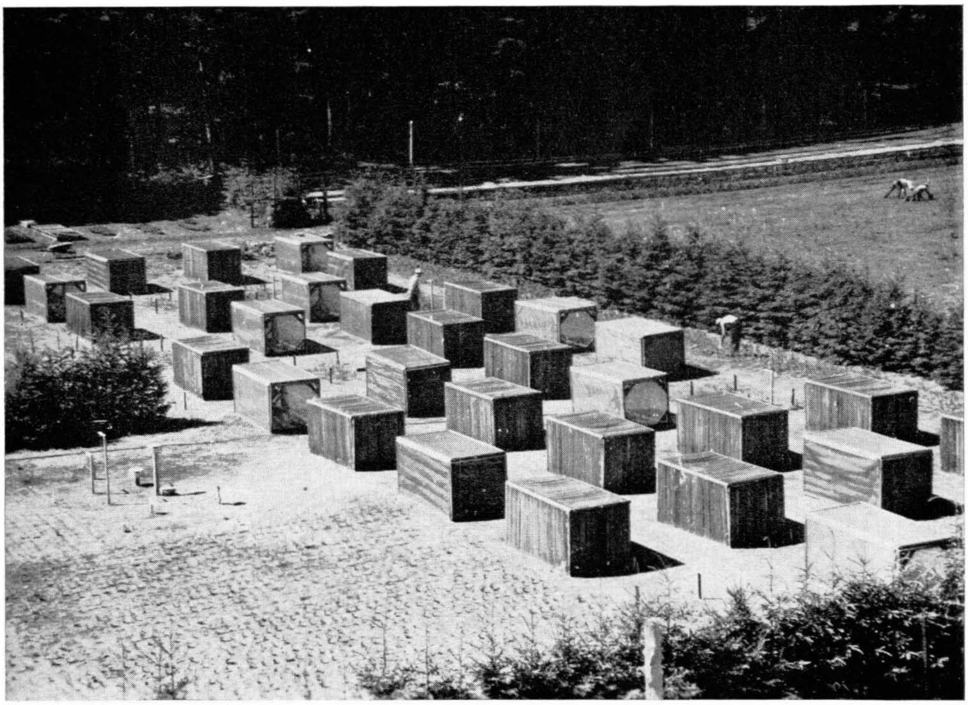

FIGURE 1. General view of the experiment showing the 10 treatments arranged in four blocks. Control post in left foreground.

Extensive instrumentation was set up to measure seedling environment. A minimum-maximum thermometer and a rain gauge were placed in each of the five light treatments and Piché evaporimeters in half of the 40 plots. These instruments were 1 foot above ground. Colman fiberglas soil moisture units (2) were calibrated in samples of the nursery soil and installed in pairs at depths of 6 and 12 inches in each plot of one of the replicates.

In addition, a control post was set up as a reference point in a clear area adjoining the experiment. Instruments at the control post included a minimum-maximum thermometer, rain gauge, Piché and Wright evaporimeters at 1 foot and $3\frac{1}{2}$ feet, and a hygrothermograph at $3\frac{1}{2}$ feet. Fluctuations in Colman units were not great enough to warrant reading the units more frequently than twice a week, but all other instruments were read daily from June to September.

Seedling measurements made each autumn were: leader length, leader diameter (measured at the midpoint), branch length (the average branch in the current year's whorl), and needle length (using needles on the leader). At the conclusion of the experiment, unpruned seedlings in 5 of the plots were excavated and oven-dry top and root weights determined for each treatment. Other root measurements taken were: length of longest root, maximum depth of root, main rooting zone, and diameter and length of a typical growing tip.

RESULTS

The Environment

Data taken at the control post, augmented by sun and wind records from station headquarters one mile away, give a picture of yearly climatic variations during the experiment (see Table 2). Compared with the first two years, 1954 was cool and wet and 1955 warm, sunny and calm.

TABLE 2

YEARLY CLIMATIC VARIATIONS FROM JUNE 1 TO AUGUST 31 DURING THE STUDY.[1]

(All values are means of daily readings except rainfall which is total for the period.)

Year	Temperature (°F)		Evaporation (cc.)				Inches of Rain	Hours of Sun	Wind m.p.h.
	Min.	Max.	Piché 1 ft.	Piché $3\frac{1}{2}$ ft.	Wright 1 ft.	Wright $3\frac{1}{2}$ ft.			
1952........	52	87	5.9	6.3	61	70	8.7	9.1	6.1
1953........	51	87	6.2	6.6	61	67	6.2	9.3	5.8
1954........	52	81	3.8	4.2	41	47	14.0	7.1	5.6
1955........	53	89	5.7	6.2	62	65	6.6	10.1	5.0

[1]Temperature, evaporation, and rainfall measured at control post; sun and wind at Station H.Q.

Mean minimum and maximum air temperatures in the different treatments are presented in Table 3. Maximum temperatures decreased gradually with a decrease in light, contrasted with a slight increase in minimum temperatures. Minimum temperatures were comparable each year but maximums varied

TABLE 3

MEANS OF DAILY MINIMUM AND MAXIMUM AIR TEMPERATURES, JUNE 1 TO AUGUST 31.

Treatment	1952		1953		1954		1955	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
100%	52	87	51	87	52	81	53	89
55%	52	87	53	86	53	80	54	89
22%	53	83	53	84	53	78	54	88
19%	54	84	53	83	53	78	54	88
14%	53	83	53	82	53	77	55	87

widely: differences between years were greater than between treatments. Differences between treatments dropped from 4° in 1952 to 2° in 1955, probably owing to the modifying effect of the seedlings on their environment. Tissue temperatures would vary more than air temperature and this was an unknown variable.

Piché evaporation data are summarized in Table 4. In 1952 daily evaporation varied from nearly 5 cc. in full light to less than half that amount in 19 per cent light. Evaporation dropped steadily with a decrease in light, except that evaporation was less in 19 per cent than in 14 per cent light as a result of poorer ventilation in the wire screen shelter. As the unpruned seedlings in full light and 55 per cent light grew, they gradually closed around the Pichés and by 1954 there was little difference in evaporation between treatments. Evaporation in the other treatments was not affected in this manner because of poor seedling growth. Note that yearly differences were almost as great as treatment differences.

TABLE 4

MEANS OF DAILY PICHÉ EVAPORATION
(Cubic centimeters, June 1 to August 31.)

Treatment	1952		1953		1954		1955	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
100%	4.5	4.7	4.7	4.2	2.8	1.9	4.9	3.0
55%	3.4	3.3	3.5	3.1	2.0	1.4	4.1[1]	3.3[1]
22%	2.9	2.9	3.1	3.1	1.8	1.6	3.1	2.8
19%	2.1	2.2	2.3	2.4	1.5	1.5	2.8	2.6
14%	2.7	2.6	2.9	2.9	1.8	1.7	3.3	3.0

P_1 = Seedlings pruned
P_2 = Seedlings not pruned

[1]Shelters raised to accommodate tall seedlings.

Soil moisture conditions beneath pruned seedlings are summarized in Figures 2, 3, and 4. The logarithm of Colman unit resistance is plotted over time, and the graphs adjusted so that the permanent wilting point for all units falls at a common point. This means that comparisons between units are more accurate for dry soils than wet.

The graphs illustrate the differences in soil moisture between treatments at depths of 6 and 12 inches, the increase in consumption of moisture as seedlings grow, and the close relationship between soil moisture and rainfall. During dry weather, soil moisture at a depth of 6 inches in the L_1 and L_2 plots approached the wilting point several times, especially in the warm dry year of 1955. At a depth of 12 inches there was no shortage of soil moisture in the same plots but the soil was drier each year as more roots penetrated to this depth. Soil moisture in the L_3, L_4, and L_5 plots remained near field capacity at both depths throughout most of the experiment.

Similar trends were apparent beneath unpruned seedlings but the soil was consistently drier owing to the greater transpiring surface and somewhat more interception.

Soil temperature data shown in Table 5 are based on readings taken with Colman units. These readings were taken twice weekly between 8:00 and 9:00 a.m. and represent the current soil temperature. A series of readings taken every

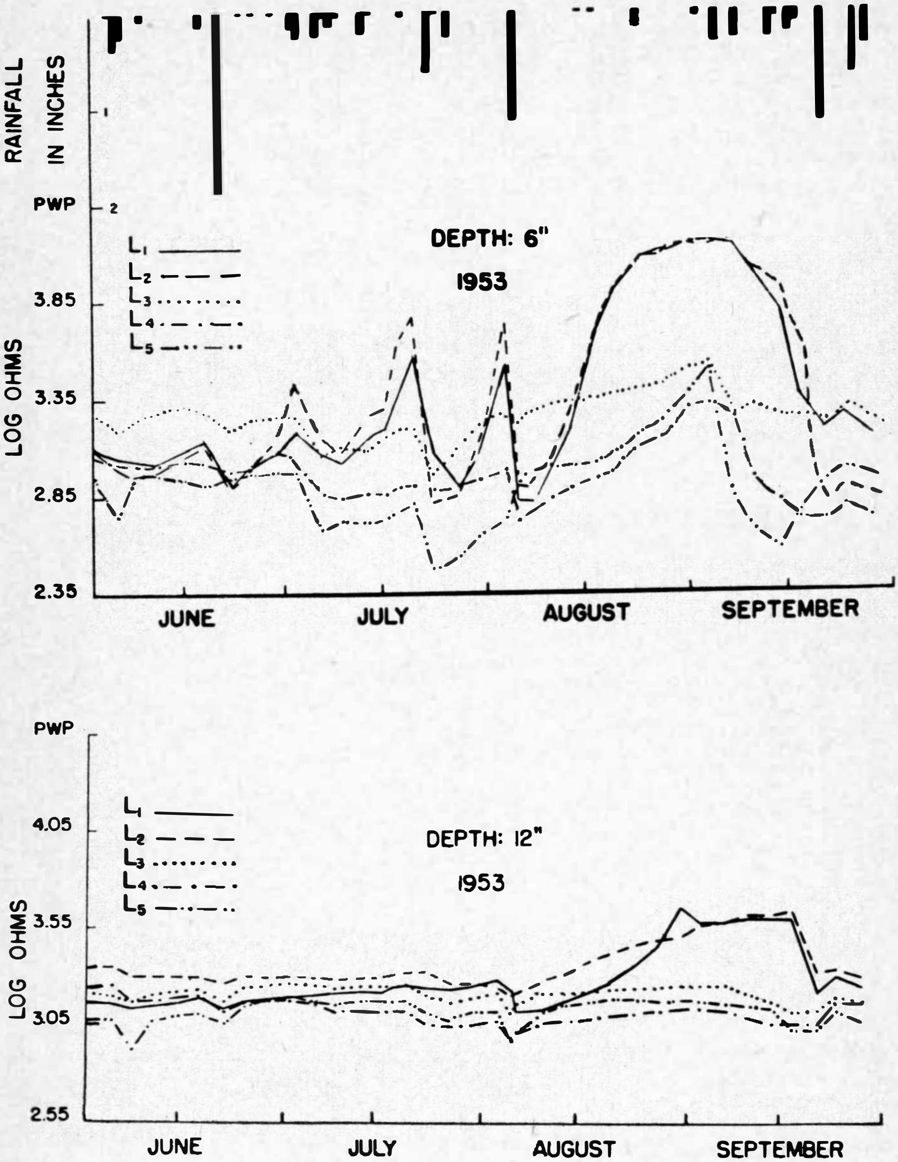

FIGURE 2. Soil moisture trends in 1953 at depths of 6 and 12 inches. The permanent wilting point is marked PWP.

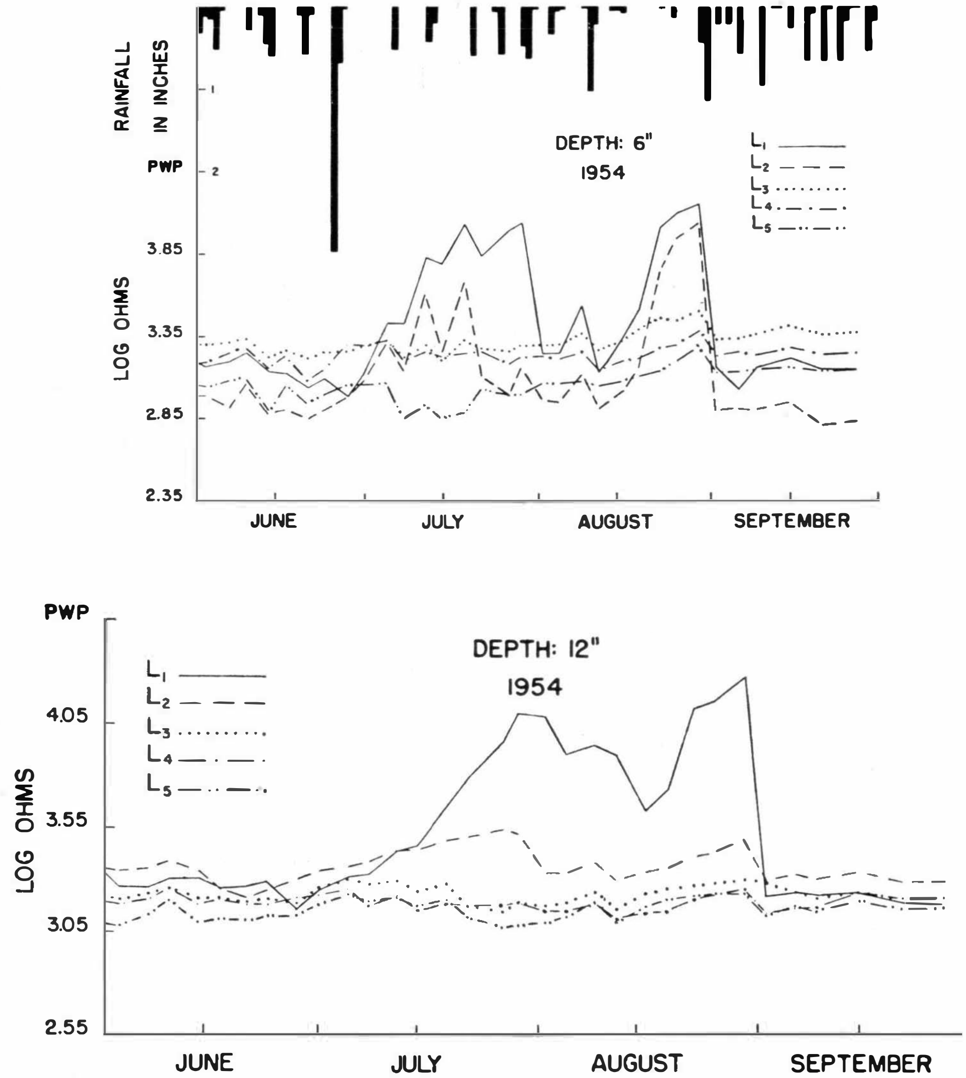

FIGURE 3. Soil moisture trends in 1954 at depths of 6 and 12 inches. The permanent wilting point is marked PWP.

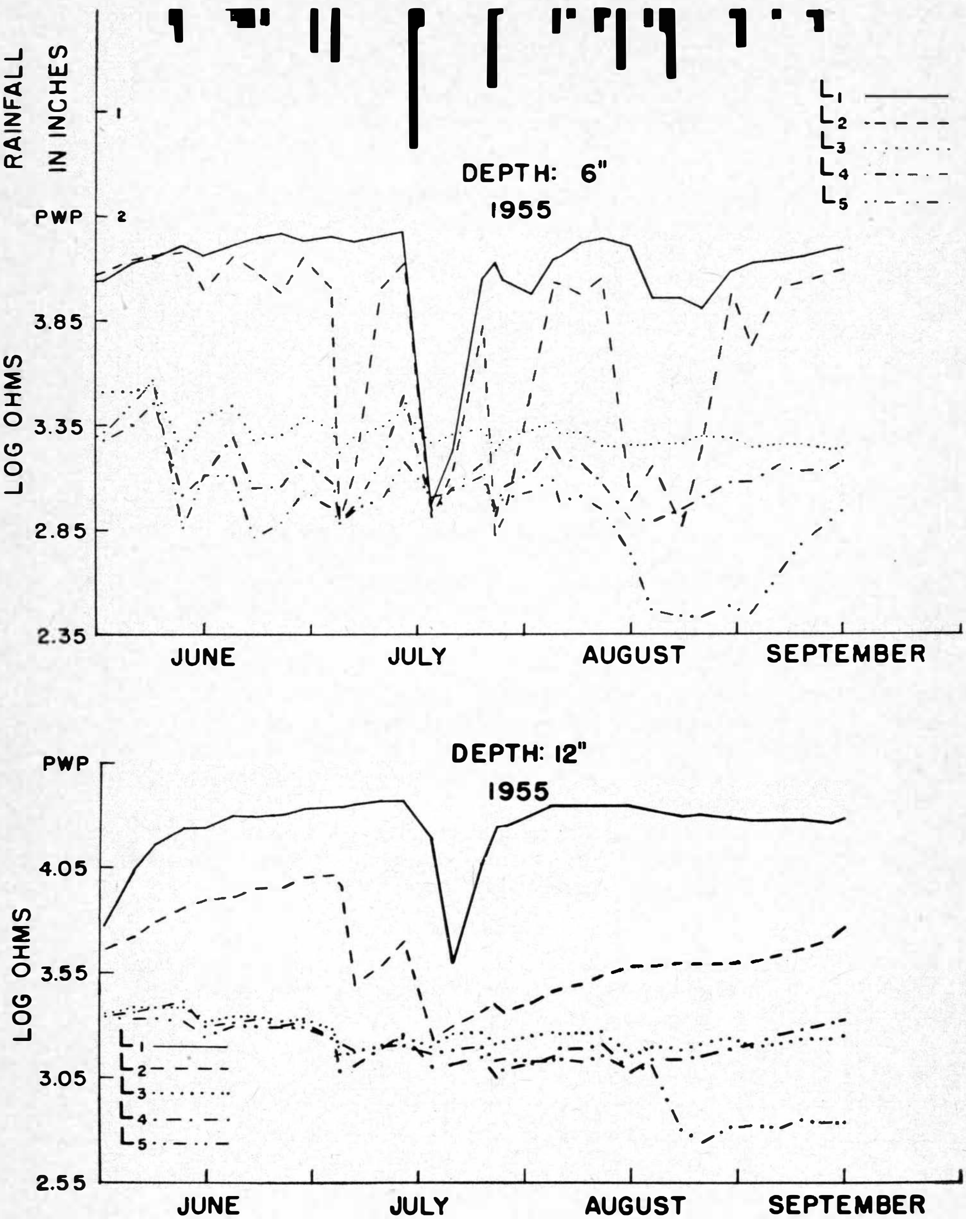

FIGURE 4. Soil moisture trends in 1955 at depths of 6 and 12 inches. The permanent wilting point is marked PWP.

half hour throughout the day showed that at that hour temperature at 6 inches was near the minimum while at 12 inches it was near the maximum for the 24-hour cycle. This explains why temperatures in Table 5 are generally higher at 12 inches than at 6 inches. Mean recorded temperatures differed by 3° to 4°F between treatments during the growing season and on individual days temperatures hardly ever varied by more than 5°F. Mean soil temperatures in 1955 were about 6°F higher than the previous year.

TABLE 5

MEAN SOIL TEMPERATURE READINGS[1] AT DEPTHS OF 6 AND 12 INCHES.

Treatment	1953		1954		1955	
	6″	12″	6″	12″	6″	12″
100%	62	64	59	60	66	67
55%	60	63	58	60	64	66
22%	59	60	57	57	63	64
19%	60	60	57	58	62	63
14%	59	61	57	57	63	64

[1]Measured twice weekly between 8-9:00 a.m., June 1-Sept. 15.

The Seedlings

Although height of individual seedlings varied somewhat at the beginning of the experiment, treatment means were very uniform: eight treatments had a mean height of 1.2 feet each, and the remaining two treatments averaged 1.1 feet high. The data did not indicate that original height had any material effect on the final results.

Typical seedlings from each of the light treatments are shown in Figure 5, and treatment means of the 1955 measurements are presented in Table 6. An analysis of variance was made wherever possible (see Appendix). In each analysis, light treatments were highly significant and a t-test was made to determine the least significant differences. With one exception, pruning treatments and interactions were not significant.

There was no significant difference in height of seedlings in full light and 55 per cent light (Table 6); nor between those in 22 per cent and 19 per cent light. But when light was reduced from 55 per cent to 22 per cent the drop in

TABLE 6

THE EFFECT OF TREATMENT ON VARIOUS MEASURES OF SEEDLING GROWTH.
(The data are treatment means based on 1955 measurements.)

Treatment	% Light	Total Height (feet)		Leader Diameter (mm.)		Root Collar Diameter (mm.)		Branch Length (inches)		Needle Length (inches)	
		P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
L_1	100	3.2	3.4	4.7	5.0	20.7	24.9	5.8	6.7	2.6	2.5
L_2	55	3.0	3.1	3.8	4.0	14.7	18.7	5.2	5.2	2.6	2.8
L_3	22	2.3	2.5	2.9	3.1	10.5	12.6	3.4	4.1	2.6	2.5
L_4	19	2.4	2.6	2.7	3.1	11.0	13.0	3.9	4.6	3.0	2.9
L_5	14	1.9	2.0	2.4	2.4	6.8	10.1	2.7	3.0	3.0	2.8
L.S.D. $p = .05$		0.5		0.5		—		1.3		0.4	
L.S.D. $p = .01$		0.6		0.7		—		1.8		0.5	

P_1 = Pruned
P_2 = Not pruned
L.S.D. = Least significant difference between treatments.

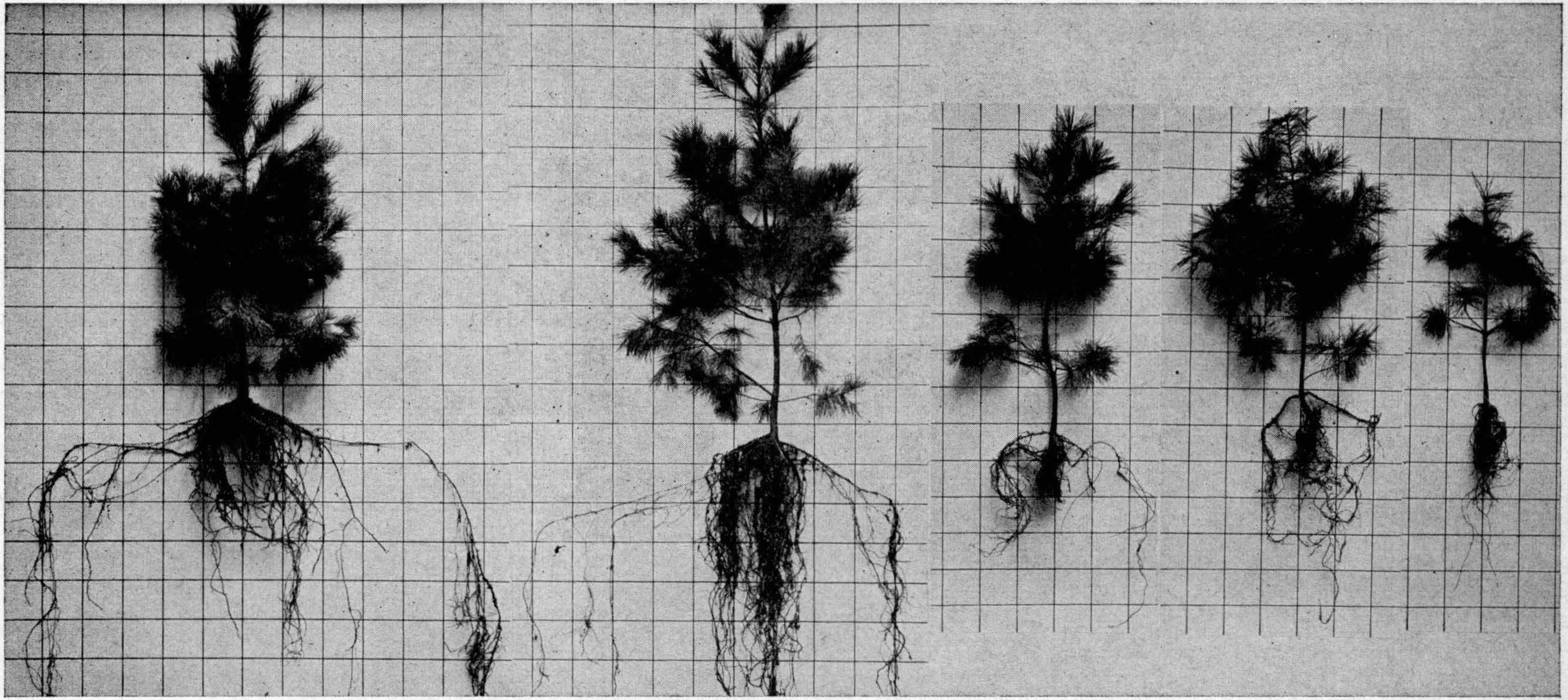

FIGURE 5. Typical seedlings from each of the light treatments. From left to right: 100%, 55%, 22%, 19%, and 14% of full light.

height growth was significant at the 1 per cent level. Seedlings in 14 per cent light were also significantly smaller than those in 19 per cent light. Differences between pruned and unpruned seedlings were not significant in any of the light treatments, although unpruned seedlings were consistently a little taller.

Leader diameters ranged from about 5 mm. on seedlings in full light to less than 2½ mm. in 14 per cent light. Differences were significant for virtually all light treatments.

Root collar diameters also decreased sharply with decreasing light. No statistical analysis was made because only half the seedlings were measured.

Table 6 shows that branches were shorter as light was reduced, especially at levels of 22 per cent light or less. In 55 per cent light, branches of unpruned seedlings were significantly smaller than in full light but there was no significant difference between pruned seedlings in these treatments.

The effect of light on needle length was less pronounced. Needles of pruned seedlings in 19 and 14 per cent light were significantly longer than those in 22 per cent or more light. For unpruned seedlings there was no consistent trend; the longest needles were on seedlings in 19 per cent light.

Root measurements in Table 7, which were made while excavating the roots, indicate a very definite response to light. In 22 per cent light and less the longest roots were less than half the size of roots in the plots with more light, and maximum depth of roots was only 2 feet compared with 6 to 9 feet. In all plots, roots were concentrated near the bottom of the cultivated layer which was about 6 inches deep. Roots appeared one inch below the surface in the shaded plots whereas in the open there were no roots within 3 inches of the surface. This is attributed to an air-dry layer of soil about 2 inches deep which formed during warm, dry periods in exposed parts of the experimental area owing to the absence of a humus layer. Roots of seedlings growing in full light had larger growing tips than shaded plants. On seedlings growing in 55 per cent light, roots were slightly smaller but more fibrous than those on plants in full light. Mycorrhizae were observed on roots in all treatments, but no measurements were taken.

TABLE 7

EFFECT OF TREATMENT ON ROOT MEASUREMENTS OF UNPRUNED SEEDLINGS.[1]

Treatment	Length of Longest Roots	Max. Depth	Main Rooting Zone	Growing Tip	
				Diameter	Length
	ft.	ft.	ins.	mm.	mm.
100%	10.2	8.8	3-7	3.4	24.1
55%	8.3	5.9	1-6	2.7	20.7
22%	3.2	1.8	1-5	2.0	18.6
19%	4.2	2.0	1-8	2.0	22.0
14%	4.7	1.7	1-6	2.1	10.2

[1]Based on 14 seedlings per treatment.

In terms of oven-dry weights, growth of tops and roots decreased progressively (with one exception) with each decrease in light (Table 8). The greater weight of seedlings in full light than those in 55 per cent light is attributed to diameter and branch growth since heights were comparable in these two treatments.

TABLE 8

OVEN-DRY WEIGHT OF TOPS AND ROOTS IN GRAMS.[1]

Treatment	Top	Root
100%	227.1	85.7
55%	131.8	51.2
22%	48.5	20.2
19%	69.2	16.6
14%	31.8	13.2

[1]Average weight per seedling based on 14 unpruned seedlings per treatment.

DISCUSSION

The shelters caused a major change in the quantity of light and a relatively minor change in temperature and soil moisture. Under field conditions, these latter factors are often vastly modified in the shade of an overstorey and several workers have pointed out that they may have a greater effect on growth than low light (13, 19). However, in this experiment, it is doubtful whether the relatively minor variations in temperature and moisture between treatments have had much effect on growth compared with those of light. Using a similar technique, Shirley (16) also concluded that growth responses were primarily the result of light variations.

In contrast to many field conditions, soil moisture was more plentiful in the shaded plots than in full light. It is unlikely that any of the seedlings experienced drought during the experiment. Seedlings in the two driest treatments, full light and 55 per cent light, had the largest root systems and roots were exploiting soil at depths where moisture was adequate.

Adequate moisture in the experimental area was largely due to low evapotranspiration. As already mentioned, an air-dry blanket about 2 inches deep formed on the bare surface soil during a drought which greatly reduced further evaporation. Also there were very few plants using soil moisture other than the experimental seedlings.

Pruning affected moisture consumption and may have affected root growth but this was not studied. Top growth was slightly smaller on pruned seedlings but differences were not significant at the 5 per cent level. An earlier study (9) showed that pruning probably had little effect on top growth of white pine seedlings up to 13 years old, providing at least two branch whorls or half the crown were left.

Figure 6 shows the effects of light treatments on growth as measured by height, diameter, and oven-dry weight. The curves show that seedlings in 19 per cent light were larger than those in 22 per cent light. These differences were not significant, but they were consistent. They may be due to differences in the two shelters. One was built of wire screening (19 per cent light) which resulted in less evaporation and ventilation than in the lath shelter (22 per cent light). In addition, light beneath the wire screening was diffuse rather than

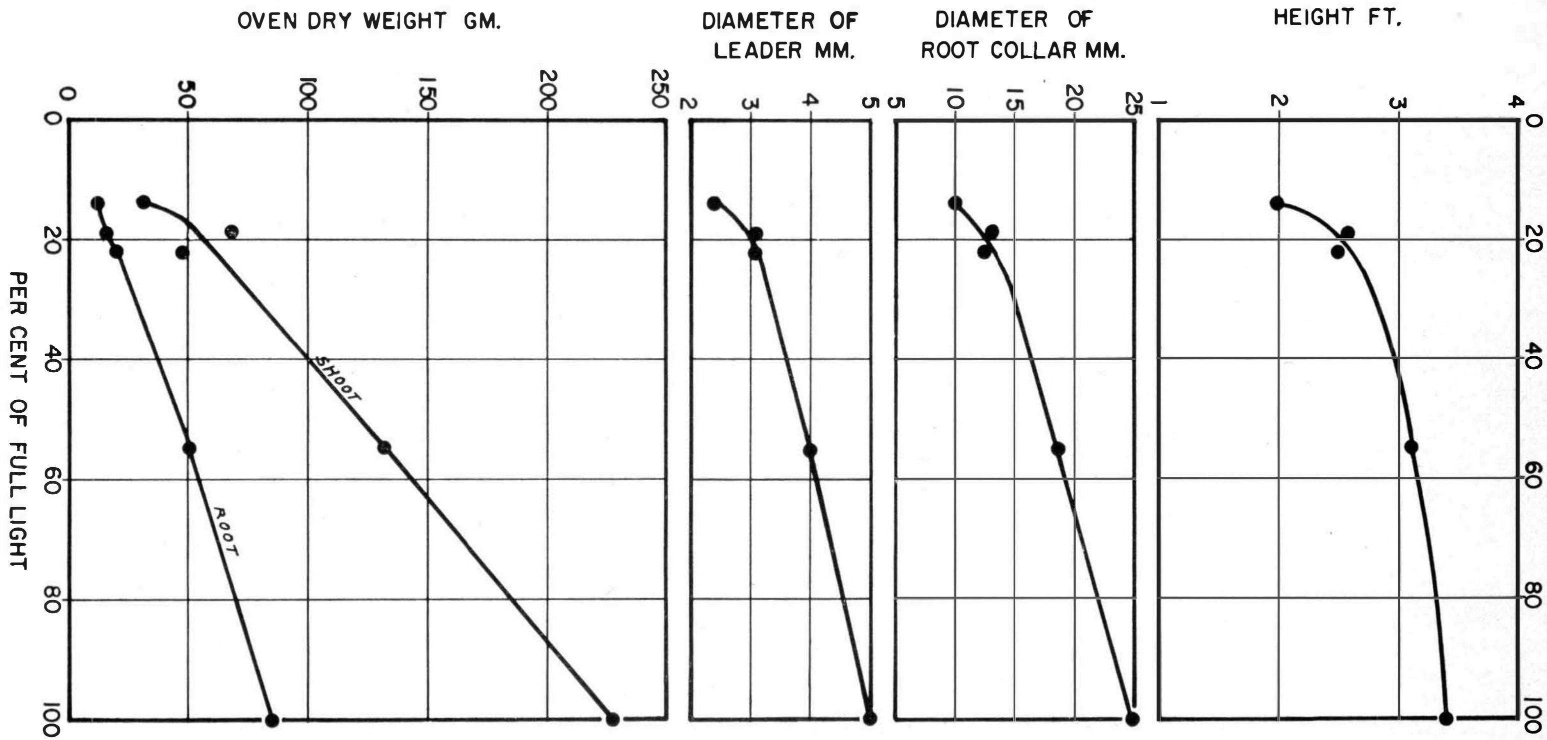

FIGURE 6. Effect of light on height, diameter, and oven-dry weight of unpruned seedlings.

composed of alternate strips of light and shadow. There may also have been differences in the absorption spectra of the two shelters which would affect light quality.

Light had its greatest effect on height growth at levels below 55 per cent of full light; seedlings in 55 per cent and full light differed little. On the other hand, diameter growth of leader and root collar continued to increase up to full light, but as with height growth, the greatest effects were at low levels of light. Oven-dry weight of both roots and shoots increased with increments in light up to full light. Root weight increased in direct proportion to light over the range studied. The increase in shoot weight at full light is due largely to diameter and branch growth rather than to height.

These results are similar to findings of other workers. Shirley (16) found in both controlled experiments and field observations that height growth of white pine increased with light up to 45 per cent of full light. Pearson (14) reported that height growth of ponderosa pine seedlings was only slightly less in 50 per cent light than in full light, whereas diameter growth was reduced by one-half. Gast (4) found that with adequate nitrogen, growth of Scots pine as measured by dry weight increased up to full light. Mitchell and Rosendahl (11) related dry weight of one-year-old red and white pine to solar radiation. They showed that dry weight of shoots and roots increased with increments of radiation over the entire range of intensities studied, but that responses were greatest below 57 per cent of full radiation. They found that seedlings in full light had a larger root/shoot ratio than those in shade. That was not the case in this experiment.

The fact that seedlings in 55 per cent light were comparable in height growth to those in full light but smaller in diameter, is significant from two points of view. First, Smith (17) and other workers have shown that white pine regeneration is more readily established in partial shade than in direct sunlight. Results of this experiment show that limited shade is not detrimental to height growth under the experimental conditions for seedlings 4 to 8 years old. Whether these results hold for conditions in the forest where root competition may be intense remains to be seen, but they do suggest that light requirements for initial establishment and subsequent satisfactory growth may be similar.

Second, the results have a bearing on weevil control. Several workers (5, 10) have pointed out that the white pine weevil (*Pissodes strobi* Peck) prefers the thick healthy leaders found in full sun to the thinner leaders in shade. Kriebel (7) caged weevils on white pine terminals and found that the number of eggs laid increased with diameter of leader; no eggs were laid on leaders 3 mm. in diameter or smaller. Belyea and Sullivan (1) suggested that weevil preference may be affected by the warmer bark temperature in the open as well as by the size of leader. Sullivan[3] believes that approximately 50 per cent light marks the dividing line between severe weevil damage and moderate attack. One of the most significant conclusions to be drawn from the present experiment is the possibility of growing seedlings at a level of light such that danger of weevil damage is reduced without greatly sacrificing height growth.

SUMMARY AND CONCLUSIONS

1. Four-year-old white pine seedlings were planted and grown for 4 years in shelters passing 14, 19, 22, and 55 per cent of full light, and compared with seedlings in full light. Half the seedlings were pruned to reduce the variation in crown size of seedlings, but this had little effect on their growth.

[3]Personal communication.

2. Shelters were built of lath, fourdrinier wire cloth, and aluminum saran. The effect of the shelters on air and soil temperature, soil moisture, and evaporation are discussed. Variations in these factors are considered to have had a minor effect on growth compared with those in light.

3. Height growth increased with increasing light up to 55 per cent of full light. The increase was most rapid at the lower levels of light. Seedlings in full light were not significantly taller than those in 55 per cent light.

4. Both leader diameter and root collar diameter increased with increasing light up to full light.

5. Branch length increased with light up to full light, although differences between 55 per cent and full light were not significant for pruned seedlings.

6. Effect of light on needle length was not consistent, but needles were usually longest in least light.

7. Oven-dry weight of both tops and roots increased with increments in light up to full light. Increases in weight of seedlings beyond 55 per cent light were due to diameter and branch growth rather than to height.

8. Within shelters built of lath and wire respectively and passing similar quantities of light, there were differences in amount of evaporation, ventilation, type of light (direct or diffuse), and perhaps in light quality. Seedlings were larger in the wire shelter but differences were not significant.

9. It is concluded that white pine seedlings can probably be grown at a level of light (approximately 50 per cent) that will discourage weevil activity without sacrificing height growth.

REFERENCES

1. BELYEA, R. M., and C. R. Sullivan. 1956. The white pine weevil: a review of current knowledge. For. Chron. 32: 58-67.

2. COLMAN, E. A. 1948. Manual of instructions for use of the fiberglas soil moisture instrument. Berkley Scientfic Co., Richmond, Calif.

3. GAST, P. R. 1930. A thermoelectric radiometer for silvical research. With preliminary results on the relation of insolation to the growth of white pine. Harvard For. Bul. No. 14.

4. GAST, P. R. 1937. Studies on the development of conifers in raw humus. III. The growth of Scots pine (*Pinus silvestris* L.) seedlings in pot cultures of different soils under varied radiation intensities. Meddel. Statens Skogsfors. 29: 587-682.

5. GRAHAM, S. A. 1918. The white-pine weevil and its relation to second-growth white pine. J. For. 16: 192-202.

6. GRASOVSKY, A. 1929. Some aspects of light in the forest. Yale Univ. School For. Bul. No. 23.

7. KRIEBEL, H. B. 1954. Bark thickness as a factor in resistance to white pine weevil injury. J. For. 52: 842-845.

8. LOGAN, K. T. 1955. An integrating light meter for ecological research. Canada, Dept. of Northern Affairs and National Resources, Forestry Branch, For. Res. Div. Tech. Note No. 13.

9. LOGAN, K. T. 1958. Some effects of pruning on white pine seedlings. For. Chron. (in press.)

10. MACALONEY, H. J. 1930. The white-pine weevil (*Pissodes strobi* Peck.). Its biology and control. N.Y. State Coll. For. Bul. No. 3.

11. MITCHELL, H. L., and R. O. ROSENDAHL. 1939. The relationships between cumulative solar radiation and the dry weight increase of nursery-grown white pine and red pine seedlings. Black Rock Forest Papers 1: 88-93.

12. MOORE, B. 1926. Influence of certain soil and light conditions on the establishment of reproduction in northeastern conifers. Ecology 7: 191-220.

13. PEARSON, G. A. 1929. The other side of the light question. J. For. 27: 807-812.

14. PEARSON, G. A. 1936. Some observations on the reaction of pine seedlings to shade. Ecology 17: 270-276.

15. SHIRLEY, H. L. 1932. Light intensity in relation to plant growth in a virgin Norway pine forest. Jour. Agr. Res. 44: 227-244.

16. SHIRLEY, H. L. 1945. Reproduction of upland conifers in the Lake States as affected by root competition and light. Am. Mid. Nat. 33: 537-612.

17. SMITH, D. M. 1951. The influence of seedbed conditions on the regeneration of eastern white pine. Conn. Agr. Exp. Sta. Bul. No. 545.

18. SMITH, L. F. 1940. Factors controlling the early development and survival of eastern white pine (*Pinus strobus* L.) in central New England. Ecol. Mon. 10: 373-420.

19. TOUMEY, J. W., and R. KIENHOLZ. 1931. Trenched plots under forest canopies. Yale Univ. School For. Bul. No. 30.

APPENDIX

TABLE 9

ANALYSIS OF VARIANCE: TOTAL HEIGHT IN 1955.

Source of Variation	Degrees of Freedom	Sum of Squares	Variance	F. Ratio
Blocks	3	0.18	0.06	<1
Light (L)	4	9.62	2.40	24.00**
Pruning (P)	1	0.29	0.29	2.90
L × P	4	0.05	0.01	<1
Error	27	2.76	0.10	
Total	39	12.90		

**Significant at the 1% level

TABLE 10

ANALYSIS OF VARIANCE: LEADER DIAMETER IN 1955.

Source of Variation	Degrees of Freedom	Sum of Squares	Variance	F. Ratio
Blocks	3	0.30	0.10	<1
Light (L)	4	31.98	8.00	66.67**
Pruning (P)	1	0.51	0.51	4.25*
L × P	4	0.17	0.04	<1
Error	27	3.13	0.12	
Total	39	36.09		

*Significant at the 5% level
**Significant at the 1% level

TABLE 11

ANALYSIS OF VARIANCE: BRANCH LENGTH IN 1955.

Source of Variation	Degrees of Freedom	Sum of Squares	Variance	F. Ratio
Blocks	3	0.67	0.22	<1
Light (L)	4	55.98	14.00	17.07**
Pruning (P)	1	2.70	2.70	3.29
L × P	4	0.82	0.20	<1
Error	27	22.16	0.82	
Total	39	82.33		

**Significant at the 1% level

TABLE 12

ANALYSIS OF VARIANCE: NEEDLE LENGTH IN 1955.

Source of Variation	Degrees of Freedom	Sum of Squares	Variance	F. Ratio
Blocks	3	0.10	0.03	<1
Light (L)	4	1.12	0.28	4.67**
Pruning (P)	1	0.01	0.01	<1
L × P	4	0.19	0.05	<1
Error	27	1.64	0.06	
Total	39	3.06		

**Significant at the 1% level