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LIGHT MEASUREMENT
IN A STUDY OF WHITE PINE REPRODUCTION

by
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CONTENTS

	Page
Introduction	5
Review of Literature	6
Instruments Available	7
Techniques	8
Comparison of Norwood Meter and Illuminometer	8
Sampling Intensity	9
Light Variation on Bright and Overcast Days	11
Application	11
Height Growth of Individual Seedlings as Related to Light	13
Height Growth of Seedlings in Stands of Different Densities	14
Discussion and Conclusions	16
Summary	17
References	18

Light Measurement in a Study of White Pine Reproduction

by

E. S. Atkins*

INTRODUCTION

The importance of light to reproduction in forest stands has been well recognized. A number of studies have been made, and all indicate that it is a major environmental factor related to the growth of young seedlings. Unfortunately, acquisition of this knowledge has not been accompanied by definite quantitative data which could be used by the silviculturist. Many difficulties are involved not only in the measurement of light but in the assessment of other factors such as moisture and temperature which may in themselves influence growth and development.

One of the research problems at the Petawawa Forest Experiment Station, Chalk River, Ontario, is to determine the light required by white pine (*Pinus strobus* L.) reproduction. The region now supports important stands of second-growth white pine either pure or in association with red pine (*P. resinosa* Ait.), jack pine (*P. banksiana* Lamb.) and various other species. Abundant seed is released by the white pine and germination is generally very good. Subsequent growth, however, appears to be correlated with the amount of light available, and in numerous cases the regeneration attains a height of only 12 to 18 inches in several decades of growth.

While the problem can thus be stated very simply, methods of study leading to its solution are difficult to conceive. Three main possibilities suggest themselves in so far as general methods are concerned. The first is to select certain forest stands and confine the study to natural growth. It will be apparent that the main disadvantages are instrumentation and the interplay of other factors. On the other hand, this approach has the advantage that environmental features such as root competition and soil structure are retained in a natural condition. A second method is a laboratory approach, in which seedlings may be raised and studied under controlled conditions. The artificial environment may, however, result in conclusions not entirely applicable to field conditions. Lastly, a combination of these two approaches may be adopted. For example, seedlings raised in the nursery may be transplanted under a forest stand and there receive intensive study, trenching around natural seedlings may be effected, or competing underbrush removed.

This report is concerned with empirical field studies in natural stands undertaken at the Petawawa Station during the summers of 1953 and 1954. In the main experiment, light conditions were assessed for white pine reproduction under four stands of different densities. As a subsidiary experiment, available light was recorded for a number of individual pine seedlings showing poor current height growth and for an equal number of seedlings with excellent growth. Projects by other investigators are currently in progress at the Station in which a more fundamental approach is being followed; such work when completed should provide an interesting comparison of results obtained by the two techniques.

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REVIEW OF LITERATURE

Craighead (1) has shown that drought may cause a drastic reduction in height growth of young white pine. Oosting and Kramer (7), however, concluded that "it appears that pine seedlings can survive periods of low available soil moisture and even compete successfully with hardwoods provided they are not too heavily shaded". Shirley (10), quoting other sources, suggested that white pine on heavy soils may show almost as much growth in the shade of hazel, aspen, and birch (10 to 30 per cent light) as in the open. These few examples demonstrate the importance of the growing medium. On lighter, sandy soils water-holding capacity is much less than on heavier, loamy soils. It is possible that minimum light may be partially compensated for by adequate moisture on heavier soils.

Daubenmire (2) stated that with tree seedlings the compensation point, that is, the point at which photosynthesis and respiration are in equilibrium and carbon dioxide is neither absorbed nor evolved, is usually between 2 and 20 per cent of full sunlight. He also mentioned that the compensation point for seedlings of white pine is about 10·4 per cent, but twice this amount is necessary to maintain growth.

Gast (3) undertook an intensive study, over the period June-September, of light received by white pine reproduction under different crown densities. A recording spherical hot-junction thermopile was used to measure light penetration at each of three stations (85 per cent canopy, 40 per cent canopy, and no canopy). The author's main conclusions were as follows: (1) with greater light intensities in the open a smaller percentage penetration results, (2) observation of percentage penetration on clear days only gives too low a value for the average percentage penetration, and (3) a minimum of 40 complete daily records of radiation well scattered throughout the growing season is necessary for adequate determination of the radiation environment under a forest canopy. Annual increment of the pine reproduction was found to be directly proportional to the cumulative radiation intensities of the three sites in which they were growing.

Gustafson (4), experimenting with white spruce and red pine transplants, artificially reduced the light intensity to 75, 50, and 25 per cent of full sunlight for the period 1932-40. Height growth was adversely affected for both species at 25 per cent of full sunlight, but unfortunately budworm attacks confused the results.

Shirley has carried out a number of experiments in connection with light intensity. In one of these (8), he found that "measurements of the light intensity under forest canopies show it to be from 0·1 to 20 per cent of full sunlight. Under ordinary continuous canopies the light is usually reduced to below 10 per cent of full light". In another study (9) he concluded that pines require 20 per cent for satisfactory survival (as contrasted with 11 per cent for white spruce) and "maximum height of all species occurred at about 43 per cent light".

In discussing light requirements of tree species, Zon and Graves (11) pointed out that optimum light changes during the life of the tree and is subject to variation even in different parts of the same vegetative season. From a practical viewpoint, a distinction can be made between reproduction and mature trees but present knowledge and techniques are so limited that fluctuations in light requirements over a single vegetative season cannot receive major consideration.

The author has found no literature yielding complete information on the light requirements of different species corresponding to poor, fair, and optimum growth. Such light regimes require study in relation to physiographic site features in order to avoid overlooking the importance of moisture and other factors. Simplified field techniques to determine available light would also be desirable.

INSTRUMENTS AVAILABLE

Various devices such as thermocouples and thermopiles, galvanometers, sensitized paper, and photoelectric meters have all been used, either directly or indirectly, to measure light intensity. There is still no instrument, however, which is wholly satisfactory; the more accurate the instrument the greater its cost, hence it can be used only in very limited quantities.

The Forestry Branch has recently acquired several new instruments for measuring light quantity; these are called "spherical illuminometers" and have been described in detail by Logan (5) and Middleton (6). These illuminometers (Plate 1) measure the quantity of light received through a spherical globe during any period, resulting in cumulative totals which are recorded on a dial gauge. A calibration factor is supplied with each instrument and this factor when multiplied by the reading yields the total light quantity for the period in lumen-hours per square foot. It is necessary, however, to pre-set a switch at either "high" or "low", depending upon the intensity of light.

For instantaneous readings, two "Norwood Director" light meters were obtained (Plate 2). These are equipped with an opal photosphere mounted on a swivel head, and a bright-light slide which is inserted when high light intensities are present. In the low intensity range, direct readings are obtained in foot-candles, and, when the slide is used, the readings are multiplied by 30 to convert into foot-candles. The scale of readings on the instrument is rather coarse but this may be overcome very easily by preparing a small chart showing finer divisions.

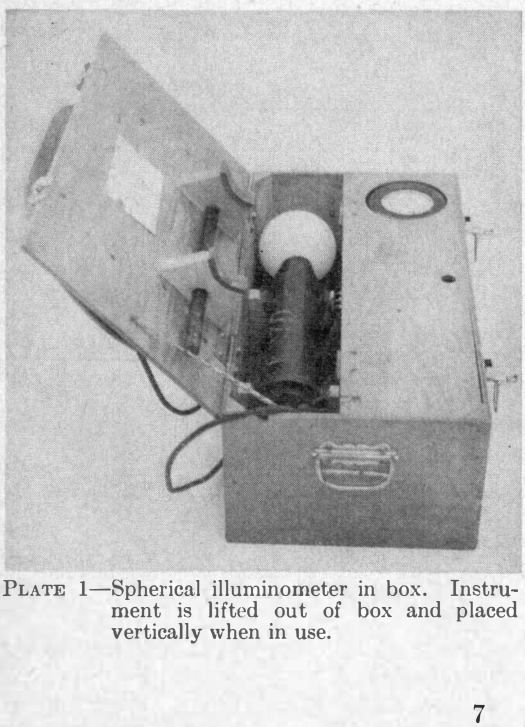

PLATE 1—Spherical illuminometer in box. Instrument is lifted out of box and placed vertically when in use.

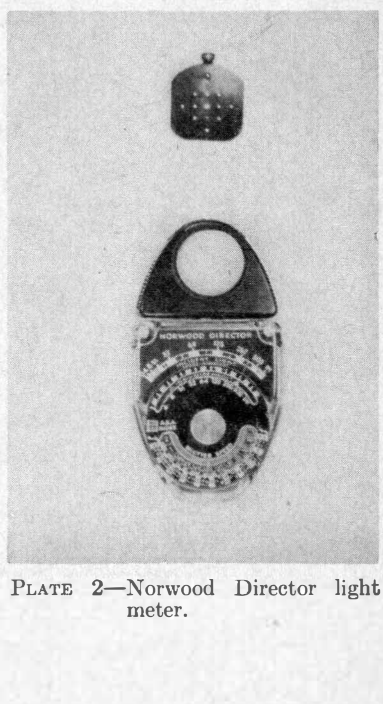

PLATE 2—Norwood Director light meter.

Comparison of Norwood Meter and Illuminometer

After initial testing of several illuminometers to ensure that they were operating properly, a test comparison was made between a Norwood meter and an illuminometer to see whether these two instruments, designed for different purposes, could be used to complement one another in certain studies. As mentioned previously, the former provides an instantaneous measure of light intensity whereas the latter indicates the cumulative total light over a specific period.

This test was carried out by taking Norwood readings at 5-minute intervals and illuminometer records at 15-minute intervals, both instruments being placed side by side in the open. The results were plotted on the same scale for the 15-minute intervals (Figure 1) and although differences in values are apparent, the similarity in trends is remarkably uniform. This suggests the possibility of using both types of instruments with a reasonable assurance that the readings can be transformed to a similar base for practical purposes.

The testing of the two instruments was carried out on a clear bright day. How the results would compare on a dull or overcast day is open to question and would be even more so with rapid fluctuations of light values. The sensitivity and accuracy of calibration of the instrument would be important factors under such conditions.

Why the two instruments did not give identical values in Figure 1 is rather puzzling, even in view of the differences in the theory of their construction and use. The calibration of the Norwood meter is one possibility. These meters are adjustable, hence it should be possible, with further experimentation, to make the light values coincide for the two instruments, at least on clear bright days.

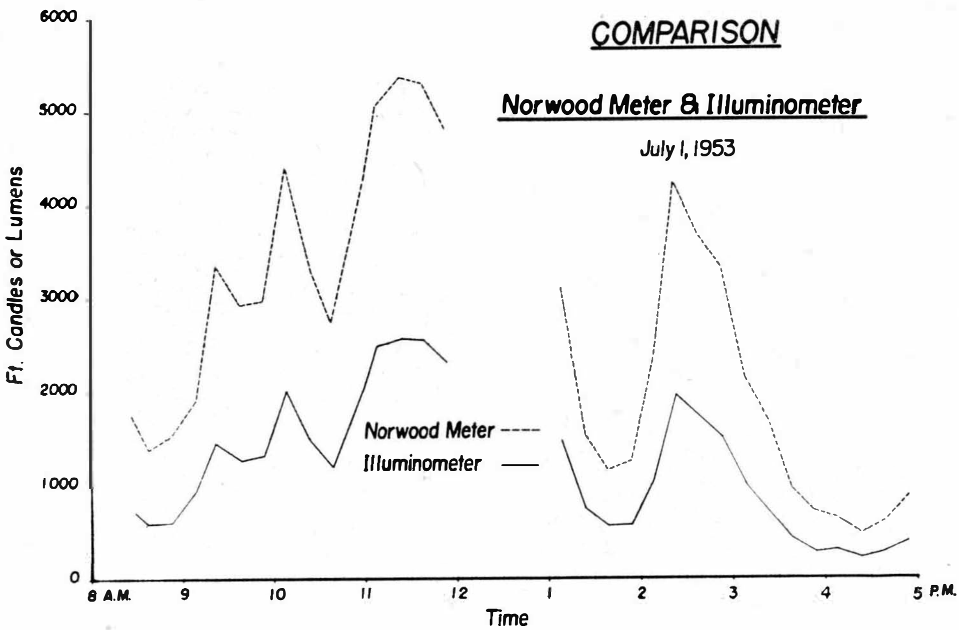

Figure 1—Comparison of light measurement with spherical illuminometer and Norwood light meter during the same day.

Sampling Intensity

In using an instrument giving an instantaneous measure of light such as the Norwood light meter, the accepted procedure for sampling light penetrating through a forest canopy is to take a series of readings in the stand and a simultaneous series in the open. By relating the two, a measure of available light in the stand is obtained. With this method, the question arises of the minimum number of well distributed readings necessary for a reasonably accurate estimate of light conditions.

To gain some information on these points, four fairly uniform pine stands were selected, all about 80 years of age but varying in basal area from 103 to 209 square feet per acre. In each stand, a one-half-acre plot, square or rectangular, was established and pickets were located at 20-foot intervals along the perimeter. Each plot was then sampled for available light, choosing clear or nearly cloudless days for the experiment. Four series of light measurements were taken throughout the day on the first plot and this procedure was repeated for the other plots on successive days or as soon as the weather was suitable. In carrying out the field work the meter was held about waist high, away from the body and as level as possible. To avoid shadow effects, the man using the meter turned towards the sun before taking a reading. Control values were recorded in the open with a second Norwood meter.

Computations were then made of the average light in the stands if readings were taken at 10, 20, 30 and 40-foot intervals for each of the four series of measurements taken on each plot. The number of readings varied on this basis from 225 at 10-foot intervals to 20 at 40-foot intervals (except for plot 1 where a slightly larger size resulted in more samples). The average error and standard error for each series of readings were computed (Table I).

Before considering Table I, it is well to place the results in a proper perspective with respect to acceptable error. Limitations in the instrument itself, the scale in which it is graduated, and difficulties in taking a reading if the light intensity is changing, make it unrealistic to expect very precise results. A margin of error of 10 per cent is reasonable. For most studies an error of this magnitude is of little practical importance; a plus or minus error of 10 per cent applied to a light value of say 20 per cent of full intensity in a stand will be of small consequence.

In Table I, the main aspects to consider are possible variations between light values with different degrees of sampling, variations between different daily periods, and significance of different light values between plots. For the intensity of sampling, it is apparent, and rather surprising, that reducing the daily number of readings from about 1,000 down to 80 causes little variation in the mean. Even the standard error of the mean is not unduly large with the small number of samples. In the individual series of readings, reducing the number of samples to 30 or 20 does not alter light values too seriously on plots 1 and 2, but on the more open plots 3 and 4, somewhat inconsistent results are obtained. There is a general trend for the standard error to increase on the more open plots but light values increase and consequently the larger standard error is only relative.

The second consideration, variation between periods during the day, is important if only one set of readings is contemplated. While there is a certain fluctuation throughout the day it is more or less parallel on all four plots. Thus identical times of day should be chosen for comparison of light values in different stands.

Finally, the difference between the four plots studied is quite distinct as evidenced by available light. A slight increase in light can be observed between plots 1 and 2 but this may not be significant. Plots 3 and 4, however, are much more open and this is reflected in the light values obtained, around 25 per cent as compared to 7 or 8 per cent on the first two plots.

TABLE I. PER CENT LIGHT AVAILABLE IN FOUR PINE STANDS WITH DIFFERENT INTENSITIES OF SAMPLING

Plot No.	Basal Area sq. ft./acre	Spacing (Feet)	No. Readings	Eastern Standard Time								Daily Average		
				8 A.M.		10 A.M.		1 P.M.		3 P.M.				
				M.	S.E.	M.	S.E.	M.	S.E.	M.	S.E.	M.	S.E.	No.
		10	294	6.7	0.9	6.8	0.7	8.3	0.9	5.4	0.5	6.8	0.4	1,176
		20	77	5.8	1.5	5.0	0.8	9.6	1.8	5.8	1.2	6.5	0.7	308
1	209.1	30	35	7.4	2.4	5.6	1.8	9.6	2.7	9.5	3.2	8.0	1.3	140
		40	24	4.0	1.3	7.8	2.3	10.4	3.5	6.6	2.4	7.2	1.2	96
		10	255	6.1	0.1	8.8	0.6	10.8	0.4	8.9	0.4	8.7	0.2	1,020
2	171.1	20	72	6.5	0.3	10.1	1.5	10.6	0.5	9.3	0.5	9.1	0.4	288
		30	30	6.6	0.4	9.0	1.4	9.8	0.7	9.8	0.9	8.8	0.5	120
		40	20	6.6	0.5	11.7	3.1	11.0	1.2	9.6	1.0	9.7	0.9	80
		10	255	20.3	1.4	29.0	1.6	34.2	1.0	23.8	1.5	26.8	0.7	1,020
3	102.7	20	72	17.3	2.2	27.5	2.7	38.2	2.0	22.9	2.5	26.5	1.3	288
		30	30	16.3	3.7	30.7	5.2	41.7	3.7	21.0	4.7	27.4	2.3	120
		40	20	14.2	3.1	25.5	4.6	39.4	4.3	19.4	2.8	24.8	2.1	80
		10	255	16.4	0.3	28.8	1.3	31.4	1.6	21.9	1.3	24.6	0.6	1,020
		20	72	16.1	0.5	28.9	2.5	35.5	3.2	22.7	2.4	25.8	1.2	288
4	103.4	30	30	17.1	0.9	28.0	3.7	28.5	4.8	22.8	3.9	24.1	1.8	120
		40	20	15.9	0.9	23.1	3.0	33.1	5.8	19.0	3.1	22.8	1.9	80

NOTE:—M. is mean light available for period, S.E. is standard error of the mean.

Light Variation on Bright and Overcast Days

Further information is needed on the variation in light within a forest stand on bright and on overcast days. If, for instance, light conditions are to be compared in two stands and this must be done on different days, the question arises of how comparable the control readings must be in order to compare the two stands.

One approach would be to ascertain the difference in light available within one stand under extremes of light intensity in the open. The difficulty is that while bright days are frequent during normal summer, uniformly overcast days are usually rare. Thus, to compare the two within a short period in one season is not always possible. Unusual weather conditions during the summer of 1954 gave the opportunity of obtaining some interesting data on this aspect.

A 27-year-old plantation of red pine with 7- by 7-foot spacing was chosen because of the uniform canopy. Using Norwood light meters, readings were taken at 7-foot intervals between rows, and in the open for control. A series of five measurements, each comprising 240 readings, was taken during the day. Repetition on both clear and overcast days resulted in the data shown in Figure 2.

It is evident from Figure 2 that while the percentage of light was greater on the overcast day, the reverse is true of actual foot-candles within the stand. The noon readings indicate about 6 per cent light on the clear day and 8 per cent on the overcast day, but the number of foot-candles was more than three times as great on the bright day.

Another apparent trend is the relatively uniform readings on the overcast day, both in percentage of light and number of foot-candles. Much greater fluctuation is evident on the clear day, particularly before 10 a.m. and after 2 p.m.

On the whole, the difference between light available on bright and overcast days was not as great as might be expected. This would indicate that the error introduced by fluctuating intensity of sunlight, or haziness caused by cloud formations, might not be too serious if readings were restricted to the noon period. The present comparison represents extremes which would not usually be encountered.

Evidence that light readings are more constant during the central portion of the day is presented in Figure 3. The data are taken from the four pine stands in which light readings were recorded for each series of measurements. Here it is evident that fluctuations in light intensities are greater under the more open stands and particularly in early morning and late afternoon. This would indicate that if illumination is to be compared in stands with widely different degrees of stocking, then it would be best to confine such work to the mid-day period.

APPLICATION

Practical application is the ultimate objective of most studies on light available in forest stands. It is a twofold problem, entailing first the determination of how much light is necessary for optimum growth and, second, the reduction of overstory density until the right condition is reached. In measuring light, it is essential that the method be simple. Expensive equipment and long, involved studies in each stand would be too costly and impractical in the majority of cases. Basal area of the main stand could be used as a cutting guide but could not be substituted for light measurements. This is so because two stands of similar basal area can have different light intensities under the canopies because of such factors as composition, slope and aspect.

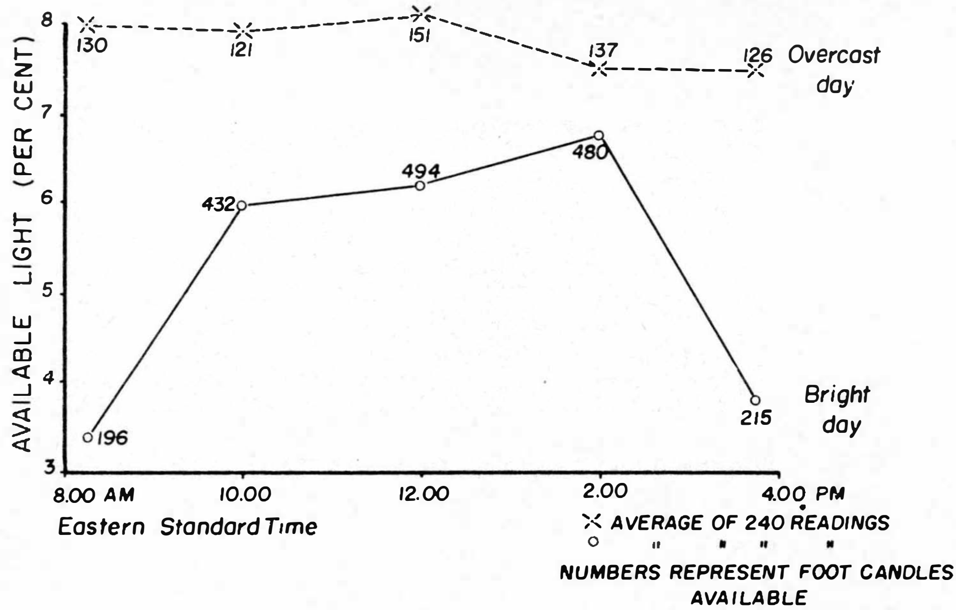

Figure 2—Per cent light available in a plantation on an overcast and on a bright day (Norwood meter).

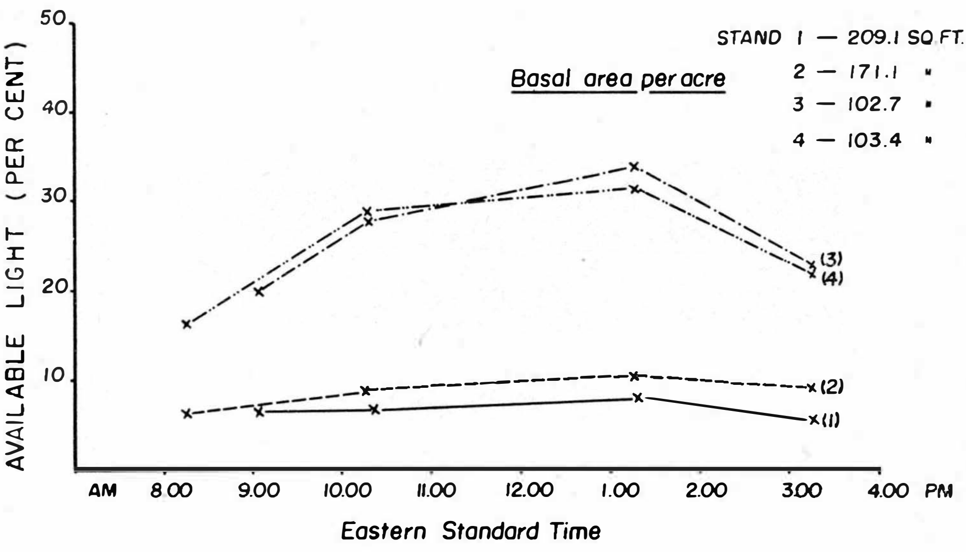

Figure 3—Comparison of Norwood light meter readings in four pine stands.

Two studies were carried out at Petawawa to obtain further information on the amount of light required by white pine reproduction. In the first, current height growth of individual seedlings was studied to find the difference in light available to suppressed as compared to vigorous stems. In the second, the growth of reproduction, in terms of the stocking to various height classes, was related to available light in the several stands comparable in site but with different densities.

Height Growth of Individual Seedlings as Related to Light

A pine stand, well stocked with white pine reproduction from one to three feet in height, was chosen for this study. Work was confined to a small, gently sloping area of loamy sand, thus avoiding as far as possible differences in soil texture and structure which might influence the results.

Pairs of white pine seedlings 10 to 15 years of age were selected, one of which showed vigorous height growth in the previous year and the other suppressed growth. In the selection, care was taken to avoid those which had suffered physical damage such as deer browsing. Later measurements of current annual height growth indicated an average of 10·6 inches for the vigorous and 1·8 inches for the suppressed seedlings. In general, these samples represented the extremes of current height growth.

Three spherical illuminometers were then set up, one in the open and the other two in the spaces occupied by the seedling leaders. This was accomplished by bending and tying the stems to one side of their normal position. One illuminometer was placed to record light received by a vigorous seedling and the other light received by a suppressed seedling. All three instruments were left in position for about an 8-hour period (8:30 a.m. to 4:30 p.m.), and the cumulative light obtained for this period. This procedure was repeated for different pairs of seedlings, alternating the illuminometers to compensate for any discrepancy between instruments. Data were thus obtained for 18 pairs of seedlings during July and August, but at this point one of the illuminometers was accidentally broken and the work was therefore discontinued.

The differences between light received by vigorous as opposed to suppressed seedlings was less than might be expected (Table II). On the whole, light received by the suppressed seedlings averaged 20 per cent of the control as opposed to 28 per cent for the vigorous seedlings. Comparison of seedlings on a paired basis is doubtful validity, but a general trend may be discerned for individual vigorous seedlings to have more light available than the adjacent suppressed seedling. This relationship is inconsistent, however, and there may have been cases where other environmental factors apart from light were limiting or of major importance. In this connection, it should be mentioned that since it was not possible to remain in constant attendance, the illuminometers were left on the high scale, and consequently errors may have been introduced if light decreased below the range covered by the high scale. Aside from the differences between light received by vigorous and suppressed seedlings on an averaged or paired basis, it is interesting to note that only two of the vigorous seedlings were receiving less than 21 per cent light.

A t-test, carried out to investigate the significance of the difference between mean values of available light for the suppressed and vigorous groups of seedlings, was significant at approximately the two per cent level. Although it cannot be stated with certainty that the difference in available light was solely responsible for the difference in height growth, the significance found above cannot be ignored.

TABLE II. LIGHT RECORDED FOR VIGOROUS AND FOR SUPPRESSED SEEDLINGS
(per cent of control)

Vigorous seedlings		Suppressed seedlings	
current height growth	per cent light	current height growth	per cent light
(inches)		(inches)	
11.1	34	1·0	25
10.2	21	0·9	20
10.3	34	1.0	11
9·4	29	1·6	29
10.3	35	1.8	35
12.0	25	1.9	6
8.1	38	1.8	33
14.4	28	2.7	25
9·6	34	2.5	6
14.0	25	4.8	29
11.2	13	1.5	10
13.8	32	1.2	21
7.7	42	2.5	32
10.3	8	1.7	7
10.2	22	1.3	13
9.6	32	2.2	16
8.0	27	1.3	17
9.7	25	1.3	18
Av. 10.6	28	1.8	20

Height Growth of Seedlings in Stands of Different Densities

In the preceding section, a study of individual pine seedlings was reported. In the following section a study concerning the stocking of pine reproduction, as related to light, in stands of different densities is described.

The four pine stands used for the Norwood light meter studies at different spacings had basal areas ranging from 103 to 209 square feet per acre. Light conditions appeared to be much more favourable on the more open plots and height growth of reproduction correspondingly better. To check the relationship, five reproduction strips, each containing 105 milacre quadrats, were therefore established in each of the one-half-acre plots sampling these stands to determine if height growth of reproduction was correlated with light conditions. On each quadrat, all reproduction was recorded by one-foot height classes, thus providing a tally not only of species but of individual height classes within each species.

When the regeneration was compiled on a stocked-quadrat basis, it was apparent that higher intensities of light favoured the growth of white pine seedlings. The difference is readily seen in Table III, not only with respect to white pine but to other species as well. All the quadrats show good stocking with class "O" white pine reproduction but successively higher height classes are scarce in the denser stands.

There are evident differences between plots in the stocking of reproduction in the taller height classes. If only the stocking to trees 2 feet in height and over is considered, the following trend is apparent. In plots 1 and 2, with low light intensities, no white pine were present and only 5 per cent and 7 per cent of the quadrats were stocked with other species. In plot 3 with 24·6 per cent light, 45 per cent of the quadrats were stocked with white pine, and plot 4 with 26·3 per cent light had 66 per cent of the quadrats stocked with white pine.

It is recognized that available light might vary with month of year and from one season to another; even continuous measurements over one entire season would therefore yield no absolute values. Despite these considerations, the relationship of light values found between plots was quite definite and demonstrates that the comparison of light in different forest stands could be of practical value in the silvicultural management of pine stands.

TABLE III. REGENERATION IN FOUR PINE PLOTS AS RELATED TO BASAL AREA AND LIGHT INTENSITY

(area of plots: 0.5 acre each)

Plot No.	Light Intensity[1]	Basal Area sq. ft./acre	Species	Regeneration: Percentage of quadrats which were stocked by seedlings of the height class indicated[2]										Class 2+[3]
				0	1	2	3	4	5	6	7	8	12	
1	7	209·1	wP	100	3									—
			bF	22	16	5	1							5
2	9	171.1	wP	98	10									—
			wS	1	2									—
			bF	46	43	7								7
3	25	102.7	wP	88	77	36	19	2	1					45
			rP	2	2									—
4	26	103.4	wP	88	70	50	33	20	13	3	2	1	1	66
			rP	3	19	10	3	2						11
			jP		1	5	5	4	2			1		13
			wS		5	5	4	2		2	2			8
			bF	1	1	2	1							3

[1] Norwood readings—per cent of light in open.

[2] Height classes: 0—up to 0.5 ft. high
1—0.6 ft. to 1.5 ft. high
2—1.6 ft. to 2.5 ft. high
3—2.6 ft. to 3.5 ft. high

[3] Presence of two or more seedlings of different height classes on the same quadrat is the reason why this column does not balance across.

DISCUSSION AND CONCLUSIONS

From the work carried out and observations made in this study, tentative conclusions may be drawn as follows.

A light meter such as the "Norwood Director" may be used to good advantage in taking spot readings through a forest stand and relating the average to a control in the open. The results should compare favourably with those obtained by the use of a recording meter, such as the illuminometers used in this study. In the work undertaken, it was found that on a clear day the control readings remained quite constant on the Norwood light meter. It would suffice, therefore, to record the light at 5-minute intervals in the open under such conditions. The sampling intensity study showed that reducing the number of readings from 255 at 10-foot intervals to as low as 20 at 40-foot intervals did not introduce too much error in well-stocked stands, but in understocked stands the results may be unreliable with a small number of readings.

A comparison of Norwood readings in a 27-year-old pine plantation on both bright and overcast days indicated that while there were more foot-candles of light within the stand on the bright days, the percentage of light penetrating through the canopy in relation to that in the open was greater on the overcast day. Another point illustrated was that on bright days, considerable fluctuation may be expected in light values within a stand from early morning to mid-day and throughout the afternoon. On overcast days, relatively constant values may be expected within the stand. It might seem from this that overcast days would prove more suitable for light studies, but overcast days are rarely uniform in the degree of illumination throughout the day and from one day to another. Bright, cloudless days of comparable illumination in the open occur much more frequently.

If the available light is to be compared between two or more forest stands, it would be advisable to adopt certain standards to make the control as uniform as possible. The three major variables involved are month of year, time of day, and intensity of sunlight in the open. For practical purposes, any time during the period June to August would be satisfactory. If all readings were taken during the noon hour, the sun would be closest to its zenith and light values in the open relatively constant. The third factor could be taken into account by taking spot readings only on clear days when the control is 7,500 foot-candles, plus or minus 10 per cent. This figure is suggested for the Petawawa area from experience and observations of the author, since the control reading on clear days remained within these limits and seemed fairly constant. In other regions, suitable standards could be established with very little effort.

By combining the results of the two regeneration studies, i.e. light as related to individual seedling growth and to reproduction within stands of different densities, a fairly definite pattern can be discerned. Relating the height growth to increasing degrees of light intensity, the trend is as follows. The lowest light intensities recorded were 7 and 9 per cent of full sunlight in plots 1 and 2. Here all pine reproduction was very suppressed and less than 1·5 feet high. Even the tolerant balsam fir could not thrive, evidenced by only 5 and 7 per cent quadrat stocking on the two plots. The next highest light intensity, 20 per cent, was the average received by the suppressed seedlings in the illuminometer study. Current annual height growth for these individuals averaged less than 2 inches. At 25 and 26 per cent light, recorded on plots 3 and 4 respectively, good development of the reproduction was evident. In these two plots, 45 and 66 per cent of the quadrats were stocked with white pine reproduction more than 1·5 feet in height. Other species were also developing well on plot 4. The highest light intensity was that recorded for individual vigorous seedlings. Here an average of 28 per cent light corresponded with 10·6 inches in height growth.

A correlation may thus be noted between plot 3, plot 4, and the group of vigorous seedlings. Light intensity ranged from 25 to 28 per cent and the growth of white pine seedlings was very satisfactory in all three cases. In summary, the indications were that up to 20 per cent light intensity, as related to that in the open, was unsatisfactory for development of white pine reproduction, whereas 25 per cent or more resulted in satisfactory growth.

In practice, it would be preferable to open up the stand until 30 to 35 per cent light would be available to the reproduction. In the stands studied, about 25 per cent light was available where the basal area was slightly more than 100 square feet per acre. If 30 to 35 per cent light were desired, the corresponding basal area would probably be around 75 square feet per acre. On a south slope, less reduction in basal area would be necessary but on a north slope the opposite would hold true.

The conclusion that at least 25 per cent light is desirable for satisfactory development of white pine reproduction was derived from data obtained on a fairly dry site. Light requirements might be different on a moister site and, if this is so, recognition and classification of moisture regime should accompany light studies.

On sites with similar growth potentialities, practical use might be made of light measurements in forest stands. Optimum light requirements for reproduction of various species can probably be established most readily through fundamental studies under controlled conditions. With this knowledge, it should then be possible to carry out treatments in the field which would provide the opportunity for seedlings to develop and provide a new stand in a minimum of time. Economically, this would be highly desirable since seedling suppression for a decade or more increases the rotation, and consequently reduces revenue.

SUMMARY

Several experiments were carried out during the summers of 1953 and 1954 in the measurement of light available to white pine seedlings in forest stands. Preliminary experiments with a Norwood Director light meter and a recording illuminometer indicated very similar trends with both instruments.

Spot readings were taken on four one-half-acre plots to provide information on sampling intensity. The number of readings ranged from 255 at 10-foot intervals to 20 at 40-foot intervals. Results indicated that in a fairly uniform pine stand of normal density the average of only 20 readings will give a reasonable indication of available light. However, in stands of lower density, somewhat erratic values may be obtained with such a small number of samples.

Spot readings taken in a young red pine plantation on both overcast and bright days indicated that while the number of actual foot-candles was greater on the bright day, the percentage of light transmitted into the stand in relation to light in the open was greater on the overcast day. It is therefore suggested that instantaneous light readings be taken only at mid-day on clear bright days and when the control reading is at a prescribed standard such as 7,500 foot-candles, plus or minus 10 per cent.

From studies on individual seedlings and on regeneration within stands, the results suggest that a minimum of around 25 per cent light, as compared to that in the open, is required for satisfactory growth of white pine seedlings on a sandy site. This assumes that other factors are not limiting. The optimum light may be higher than this figure. Where the available light was very low (less than 10 per cent), the current height growth of regeneration was correspondingly poor.

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