A Study of Light Distribution within a Red Pine Canopy[1]

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Abstract

A three-dimensional sampling scheme was designed to measure daily solar insolation in a red pine plantation. Because of its economical use and convenient size the athracene-in-benzene chemical light meter was utilized as the energy-sensing device. Fifty-six sampling points were established at each of six height levels on a 1/20-acre plot within the plantation. The variance in light readings obtained between points on each level was used to refine the sampling technique. The pattern of change in solar insolation with increasing canopy depth was then determined.

Introduction

According to Geiger (3) light extinction curves in forest canopies were probably first developed in the 1930's. However, the mathematical relation of light intensity to a foliage parameter was not defined until 1953 when Monsi and Saeki (5) adapted the Beer's-Lambert equation to absorption of light by a plant canopy. During the following decade this basic model was tested primarily on low canopies, such as rice, dwarf fir, and mixed herbaceous systems. Baumgartner (1) found that the light attenuation curves for tree canopies were significantly different from those determined for low canopies. Geiger (3) and Kira *et al.* (4) concluded that tree canopies were a special case.

Few of the models of light attenuation developed up to the present have actually been tested on tree canopies, and the tests which have been made are invariably statistically inadequate. This is due to the extreme difficulty in sampling tree foliage by strata and also due to the economic and physical limitations imposed by most light measurement systems.

Objective

The purpose of this research was to determine the light attenuation curve for a specific tree canopy. It was desired to sample with minimum foilage disturbance and to vary sampling intensity to attain a common error level about the true mean light intensity at each height sampled.

Methods

A 1/20-acre square plot was located in a 22-year old pure red pine (*Pinus resinosa*, Ait.) stand at Cunningham Forest near Linden, Indiana. Crown closure was 100% and the plantation had not been subjected to previous silvicultural treatment. Mean dbh was 5.7 inches, mean height was 35.4 feet, basal area equaled 182 ft^2/acre, and stocking was 1020 stems per acre.

The anthracene-in-benzene chemical light meter was selected as the light-measuring instrument because the small vial size permitted

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sampling with minimum foliage disturbance and the low cost allowed a large number of observations to be made simultaneously. To adapt this light meter to a vertical stratified sampling scheme, copper wire vial holders were devised which could be hooked into 20 cm rings to be placed at each sampling point within the stand. Tests showed non-significant effects of the rings on the light intensity measured by the vials.

Eight, 150 lb-test nylon lines were placed through the canopy at a 5-foot horizontal spacing at each of 6 stratum heights; 11, 15, 19, 23, 27 and 31 feet. A crossbow was used to string the lines through the canopy so as to alter branch geometry only to a very small degree. Double nylon lines, each with 7 rings spaced 5 feet apart, were then pulled through using the initial lines as guides. Finally, the ringed lines were adjusted to strata heights ± 6 inches and to a 5-foot horizontal spacing ± 1 foot. Because of the combined effects of the sag in the nylon lines and the length of the copper wire vial holders the actual strata heights for light sampling were: 10, 14, 18, 22, 26, and 30 feet. This system of lines provided 56 potential sampling points at each stratum height.

Heads for a sectioned aluminum pole were devised to hang and to retrieve the vials in the wire holders. Ground level measurements were made by using burlap covered wood blocks to which vials were wired.

To permit comparisons of light intensities measured on different days, only clear, relatively cloudless conditions were desired. Measurements were made on June 14, July 12, August 4, and August 22. The range of incoming light energy on these days was from 498 to 567 ly. Anthracene concentration was 100 mg/l for all runs except on July 12 when it was varied to 3 g/l, thereby permitting a test of the effect of concentration on energy recorded. The 125-175 vials used for each measurement run were put in place either in the early or late daylight hours and then taken down in the same sequence after a daylength exposure to light. In each run sample points were assigned randomly over the 56 possible points of each stratum. Initially, 25 observations were taken per stratum, but after the first run analysis showed that the 10- and 14-foot strata were not significantly different from the ground level and they were deleted from the third and fourth sampling periods. Also, sample sizes to attain a common 20% error about the mean were calculated, and in succeeding runs strata sample sizes were adjusted as could be accommodated within experimental limitations. In the third run a 34-foot stratum with 24 points was also used.

Values for incoming light were obtained using 8 vials and an Eppley pyranometer placed on top of a 45-foot tower 200 feet from the light measurement plot. A Rustrak recorder connected to the Eppley provided additionally a permanent record of energy variability.

Results

Energy data were first converted to per cent of incoming light (relative light intensity) so that separate days could be compared successfully. The distributions of observations by stratum within runs were tested using the Kolomogorov-Smirnov test (6) and found to generally fulfill the desired normality assumption although the data of the 22- and 26-foot strata in all four runs were more exponential than normal. The variance values within each run increased with the means, and ranges of values from similar population sizes increased generally with the means. Consequently, a logarithm transformation was done before converting to per cent of incoming light. This had the effect of making variances much more independent of the means and more homogeneous. Coefficient of variation values of each stratum were compared between runs using the Foster-Burr Q test (2) and found acceptably homogeneous by stratum with Run 2 omitted.

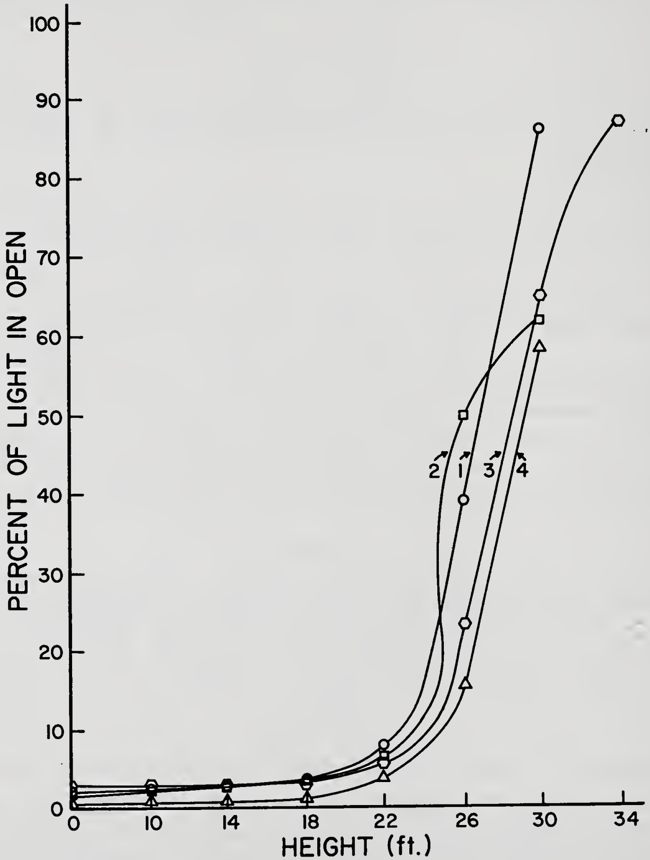

FIGURE 1. *A comparison of mean light intensity for 4 days in the light measurement plot. Run numbers 1-4 are chronological.*

An analysis of variance using the transformed data showed that height in the canopy had a highly significant effect on the light received. A Newman-Keuls sequential range test (7) then showed that stratum means from 26, 30 and 34 feet in all runs were significantly different at the 0.01 level both from each other and from all lower strata. In none of the runs were the ground, 10, 14 and 18-foot levels significantly different at the 0.05 level. When mean light by stratum was graphed as per cent of incoming light (Fig. 1), Runs 1, 3, and 4 showed similar form with possible increase in rate of attenuation with lateness in the growing season. Run 2 represented a higher anthracene concentration and was not considered typical. Runs 3 and 4 when compared using Student's t test (7) showed significant differences in mean light intensities at the 22 and 26-foot heights. Accumulated from the top, per cent light intensity averaged from Runs 3 and 4 plotted against height approximated a smooth sigmoid curve (Fig. 2).

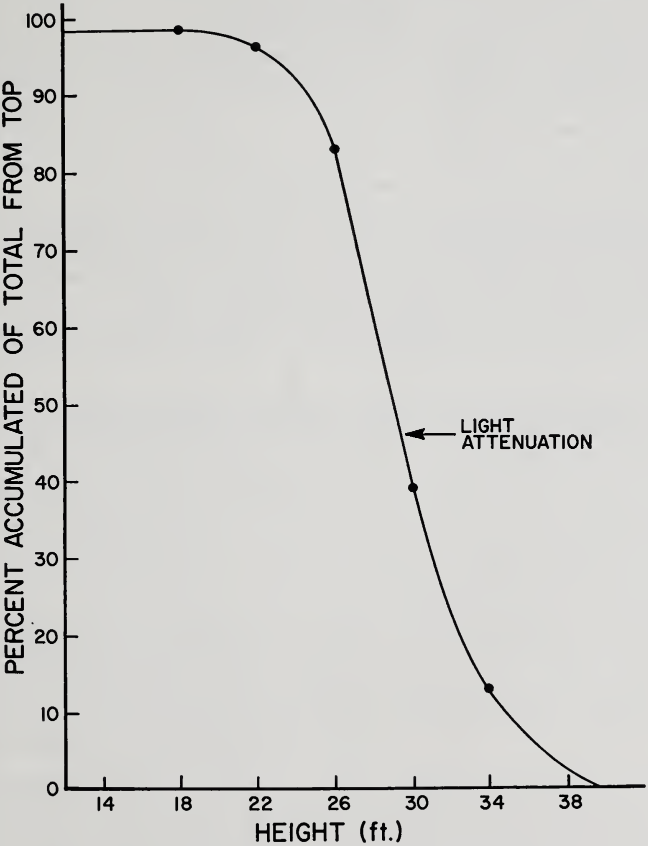

FIGURE 2. *The light attenuation summary curve for Runs 3 and 4.*

Using coefficient of variation values in an iterative procedure to determine sample sizes, the 22-foot strata invariably required more than 56 points to achieve a 20% error about the mean. Because of limitations in time and labor and a desire to sample all strata proportionately, a maximum of 37 points was used at the 22-foot level.

Conclusion

Given a light attenuation curve for a canopy, extinction coefficients for the rate of light decrease could be determined for each height stratum. A beam of light with a given angle of canopy penetration would therefore pass through calculable path lengths for each stratum and be attenuated to a determinable degree. Consequent predictions of the amount of incoming solar energy received for a day or a season through measureable depths of canopy could be useful in estimating forest energy balances.

Literature Cited

1. BAUMGARTNER, A. 1955. Licht und Naturverjungung am Nordrand eines Waldbestandes. Forstw. C. 74:59-64.

2. BURR, I. W., and L. A. FOSTER. 1972. A test for equality and variances. Purdue Univ. Dep. Stat. Mem. Set No. 282. 4 p.

3. GEIGER, R. 1965. The climate near the ground. Translated by Scripta Technica, Inc. (from the 4th German ed.) Harvard Univ., Cambridge, Mass. 611 p.

4. KIRA, T., K. SHINOZAKI, and K. HOZUMI. 1969. Structure of forest canopies as related to their primary productivity. Plant and Cell Physiol. **10**:129-142.

5. MONSI, M., and T. SAEKI. 1973. Über den Lichtfaktor in Pflanzengesellschaften und seine Bedeutung für die Stoffproduction. Jap. J. Bot. **14**:22-52.

6. SOKAL, ROBERT R., and F. JAMES ROHLF. 1969. Biometry: The principles and practice of statistics in biological research. W. H. Freeman and Co., San Francisco, Cal. 776 p.

7. STEEL, R. G. D., and J. H. TORRIE. 1960. Principles and procedures in statistics. McGraw-Hill, New York, N.Y. 481 p.