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A comparison of forest canopy transmittance estimators[1]

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Multiple sensors, and alternate statistical estimators, were tested for measuring canopy transmittance in four stands under a variety of sky conditions. On a given day, stand average transmittance estimates were insensitive to degree of synchronization of the sensors used to measure under-canopy and incoming radiation. In comparison to periodic measurement of incoming radiation with a single radiometer, the use of an additional sensor in the open does not automatically improve the estimates of stand average transmittance.

Smith, E.R., et Riitters, K.H. 1994. A comparison of forest canopy transmittance estimators. Can. J. For. Res. **24** : 188–192.

Des capteurs multiples et d'autres estimateurs statistiques furent testés pour mesurer la transmittance du couvert dans quatre peuplements sous une variété de conditions atmosphériques. Pour une journée donnée, les estimations de la valeur moyenne de la transmittance n'étaient pas affectées par le degré de synchronisation des capteurs utilisés pour mesurer la radiation incidente et transmise. Comparée à la mesure périodique de la radiation incidente avec un seul radiomètre, l'utilisation d'un capteur supplémentaire à découvert n'améliore pas automatiquement les estimations de la valeur moyenne de la transmittance d'un peuplement.

[Traduit par la rédaction]

Introduction

Transmittance of solar radiation through forest canopies is a measure of canopy density. Changes in transmittance over time may indicate effects of environmental stresses such as drought, insects, or disease (Burton et al. 1991). One-time measurements of canopy light transmittance provide information that may be used to characterize current growing conditions and productive potential of a forest stand. Transmittance measurements may be combined with diameter increment data to estimate growth efficiency (Russell et al. 1989). Transmittance is related to leaf area index (Monsi and Saeki 1953), and within-stand variation in transmittance provides information about canopy structure (Campbell and Norman 1989).

Local-scale variance of the under-canopy radiation regime is large (Gay et al. 1971; Reifsnyder et al. 1971; Hutchinson and Matt 1977), and transmittance changes with solar zenith angle and cloud cover (Anderson 1966, 1970). The resulting measurement variation has led to a variety of experimental designs (see Pierce and Running 1988; Rich 1990; Welles 1990; Norman and Campbell 1991; Pearcy 1991). Complete accuracy for instantaneous measurements requires exactly synchronized measurements from above and below the

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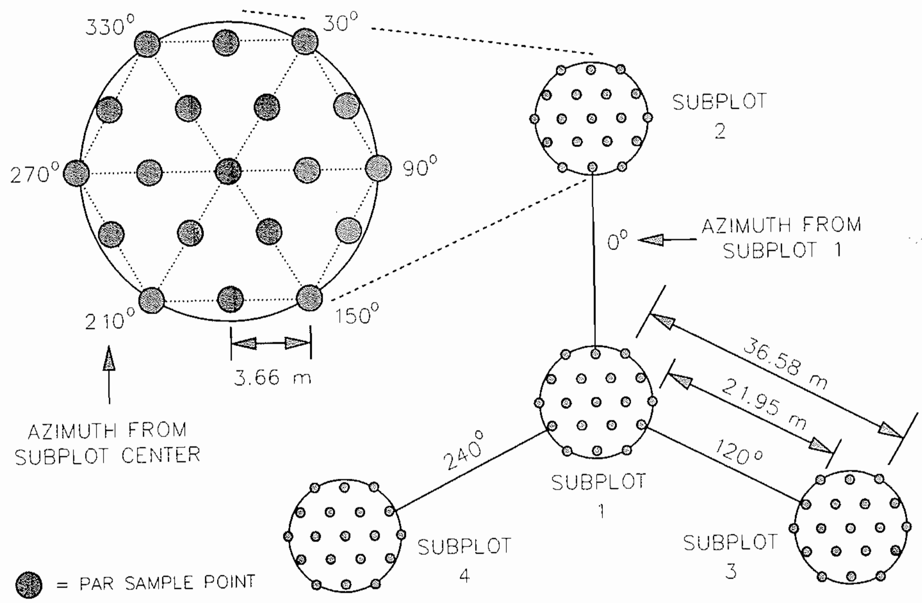

FIG. 1. Plot design for the under-canopy PAR measurements. Each plot consists of four 0.017-ha subplots, each with 19 sample points in a hexagonal arrangement.

canopy at a sample location. In practice, this level of precision is very difficult to obtain for areas as large as whole stands. On clear days, satisfactory estimates of average canopy transmittance have been obtained by using a single integrating radiometer, measuring incoming radiation periodically in canopy openings (Pierce and Running 1988; Bolstad and Gower 1990; Vose and Swank 1990; Burton et al. 1991; Dalla-Tea and Jokela 1991; Smith 1991; Smith et al. 1991; Law et al. 1992). On cloudy days, the direct and diffuse components of total incoming radiation must be measured separately.

Measurements of average canopy transmittance would be simplified if strict synchronization was unnecessary. Our goal was to explore ways to simplify measuring stand average (i.e., not instantaneous or local-scale) transmittance. We used separate sensors to measure incoming and under-canopy photosynthetically active radiation (PAR) under different stand and sky conditions. For a given set of conditions, we then tested the sensitivity of estimated transmittance to the degree of synchronization of the measurements.

Methods

The measurements were made in four stands during July and August 1991. Two of the four stands were located at the Duke University Forest near Durham, N.C. (36.02°N, 78.98°W). One was a relatively dense and uniform stand of 25-year-old loblolly pine (*Pinus taeda* L.) (plot 1), and the other was a two-story, 60-year-old loblolly pine and sweetgum (*Liquidambar styraciflua* L.) stand with large canopy gaps from periodic thinning (plot 2). The other two stands were mixed-species, upland hardwood stands located at the Tennessee Valley Authority's Norris Reservoir near Norris, Tenn. The major species were white oak (*Quercus alba* L.), chestnut oak (*Quercus prinus* L.), northern red oak (*Quercus rubra* L.), and sugar maple (*Acer saccharum* Marsh.). One of these stands was dominated by 60- and 100-year age-classes with little understory (36.20°N, 84.09°W) (plot 3), and the other was a mature, uneven-aged stand with a denser understory and canopy gaps owing to large tree mortality (36.21°N, 84.07°W) (plot 4). The mensurational characteristics of all four stands are summarized in Table 1.

TABLE 1. Mensuration data for the stands in which canopy transmittance was measured

Plot	Subplot	Basal area ($m^2 \cdot ha^{-1}$)	No. of trees/ha	Quadratic avg. DBH[a] (cm)
1	1	50.5	2140	17.3
	2	39.0	1371	19.1
	3	34.4	1673	22.7
	4	41.3	2661	14.0
2	1	25.3	455	26.7
	2	20.7	544	22.1
	3	27.6	714	22.1
	4	18.4	138	41.1
3	1	16.1	412	22.3
	2	34.4	5107	9.3
	3	23.0	353	28.8
	4	27.6	405	29.4
4	1	18.4	130	42.3
	2	13.8	269	25.5
	3	23.0	159	42.8
	4	16.1	597	18.5

[a]Diameter at breast height (1.3 m) of a tree with average basal area.

The plot layout is illustrated in Fig. 1. Mensuration measurements were made on a set of four circular, 0.017-ha subplots within each stand. On each of those subplots, 19 under-canopy PAR sample points were located and marked with survey flags. Average PAR was measured at each sample point by using a portable integrating radiometer (Model SF-80; Decagon Devices, Inc. Pullman, Wash.).[4] The radiometer was turned in a level circle at waist height, accumulating >2400 individual sensor readings (over ~10^2 m in ~1 min) prior to storing the average

[4]Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the Tennessee Valley Authority or the United States Environmental Protection Agency.

TABLE 2. Average ambient PAR (μmol·m^{-2}·s^{-1}), coefficient of variation (CV, %), average solar zenith angle (Θ, degrees), and average fraction canopy transmittance (T_1) by plot and sample day

Plot	Item	Sample day										
		1	2	3	4	5	6	7	8	9	10	11
1	Avg. PAR	846	1563	1681	1597	923	875	591	652	507	—	—
	CV PAR	19	15	2	8	15	35	10	45	17	—	—
	Θ	30.4	32.0	31.8	32.0	31.9	31.9	31.4	29.1	29.5	—	—
	Avg. T_1	0.073	0.096	0.100	0.094	0.071	0.060	0.058	0.055	0.058	—	—
2	Avg. PAR	1309	1736	1854	1756	931	891	792	710	494	—	—
	CV PAR	24	9	2	2	20	44	12	45	6	—	—
	Θ	23.3	25.1	25.1	25.5	25.7	25.6	25.6	23.9	24.6	—	—
	Avg. T_1	0.158	0.223	0.236	0.229	0.167	0.123	0.138	0.154	0.136	—	—
3	Avg. PAR	1816	1284	1681	1772	1794	1584	1544	1652	1291	995	1075
	CV PAR	3	17	15	3	2	6	4	16	18	36	34
	_	19.3	16.6	18.6	23.9	21.8	26.2	36.0	29.4	32.4	30.5	33.7
	Avg. T_1	0.031	0.035	0.037	0.036	0.034	0.039	0.085	0.095	0.085	0.079	0.096
4	Avg. PAR	1390	1616	1520	1685	1364	930	1304	811	1231	1430	—
	CV PAR	18	6	15	4	4	50	36	30	24	21	—
	Θ	23.6	26.8	21.1	23.7	25.1	28.0	28.0	32.6	31.9	32.4	—
	Avg. T_1	0.059	0.055	0.055	0.064	0.050	0.054	0.073	0.052	0.067	0.056	—

NOTE: The statistics are based on values for the 76 min at which the under-canopy measurements were made on a given plot day. See text for explanation of T_1.

and the time (hour and minute). Between 30 and 60 min were required to complete all PAR measurements on a plot.

Ambient (incoming) PAR was measured (at 0.65-s intervals) in a nearby open area by using a quantum sensor (model LI-190SA; LI-COR Inc., Lincoln, Neb.), millivolt adapter (model 2290S; LI-COR Inc.), signal conditioner, and data logger (models MOD-10 and OM-160; Omega Engineering Inc., Stamford, Conn.). The ambient measurements were initiated before the under-canopy measurements began, and they were continued until after the under-canopy measurements were completed. Proprietary software (Omega Engineering Inc.) was used to generate a per-minute average summary of ambient PAR during the sampling period. In this way, the ambient and under-canopy measurements could be compared on a minute by minute basis.

The comparability of the instruments was tested. Each ambient sensor was supplied with a factory calibration constant to calculate PAR (μmol·m^{-2}·s^{-1}, 400–700 nm) from the data logger output (mV). Each integrating radiometer recorded PAR (μmol·m^{-2}·s^{-1}, 400–700 nm) by using a built-in calibration constant and calculation routine; one of the 80 quantum sensors was factory calibrated, and the built-in routine permitted the other 79 sensors to be field calibrated to that reference sensor (Decagon Devices Inc.). To test comparability, a set of simultaneous measurements were made with all four instruments on a cloud-free day. The 1-min average values obtained from the two ambient sensors differed by 0.7% and were considered to be directly comparable. The average values obtained from the two reference sensors in the integrating radiometers differed from each other by ~14%, and from the ambient sensor values by up to 17%, so additional calibration factors were calculated from the test data to adjust all instrument outputs to a common standard.

Measurements were made on 9 days each for plots 1 and 2, 10 days for plot 3, and 11 days for plot 4. Each plot was sampled under a variety of cloud conditions as indicated by the daily means and the coefficients of variation of ambient PAR (Table 2). The daily average (and range over days) of solar zenith angles during the under-canopy sampling periods by plot was 31.1° (29.1°–32.0°), 24.9° (23.3°–25.7°), 26.2° (16.6°–36.0°), and 27.3° (21.1°–32.6°), respectively.

Four estimates of the transmitted fraction at a given sample point were made by using different denominators in the ratio of under-canopy to ambient PAR. A "synchronized" estimate (T_1) used the ambient PAR value obtained for the same minute as the under-canopy sample point value. A "windowed" estimate (T_2) used the 7-min average of ambient PAR values, centered on the minute of the under-canopy measurement. An "interpolated" estimate (T_3) used the average of the two ambient PAR values that were obtained 3 min before and 3 min after the under-canopy measurement. An "average" estimate (T_4) used the average of all 19 ambient PAR values that were obtained for the minutes corresponding to all under-canopy measurements for a given subplot.

Results and discussion

Summary statistics for the synchronized estimate (T_1) illustrate general differences in transmittance among plots and days (Table 2). The average transmittance over all sample points and days by plot was 0.07 (n = 684), 0.17 (n = 684), 0.06 (n = 836), and 0.06 (n = 760), respectively. Because about 3% of ambient PAR is typically reflected from the top of a forest canopy (Russell et al. 1989), these average values indicate that three of the four canopies intercepted nearly all of the incoming PAR. Transmittance estimates varied among days because of differences in sky conditions and solar zenith angles.

Over all plots and days, the Pearson correlation coefficient of sample point transmittance between any two of the four estimation methods was never less than 0.97 (n = 2964). Average canopy transmittance on a given day was insensitive to the choice of method for obtaining the ambient PAR values (Fig. 2). We concluded that, for a given set of stand and sky conditions, strict synchronization of under-canopy and ambient measurements was unnecessary for estimating stand average transmittance.

The day to day variation in estimated transmittance for a given plot was larger than the variation among the dif-

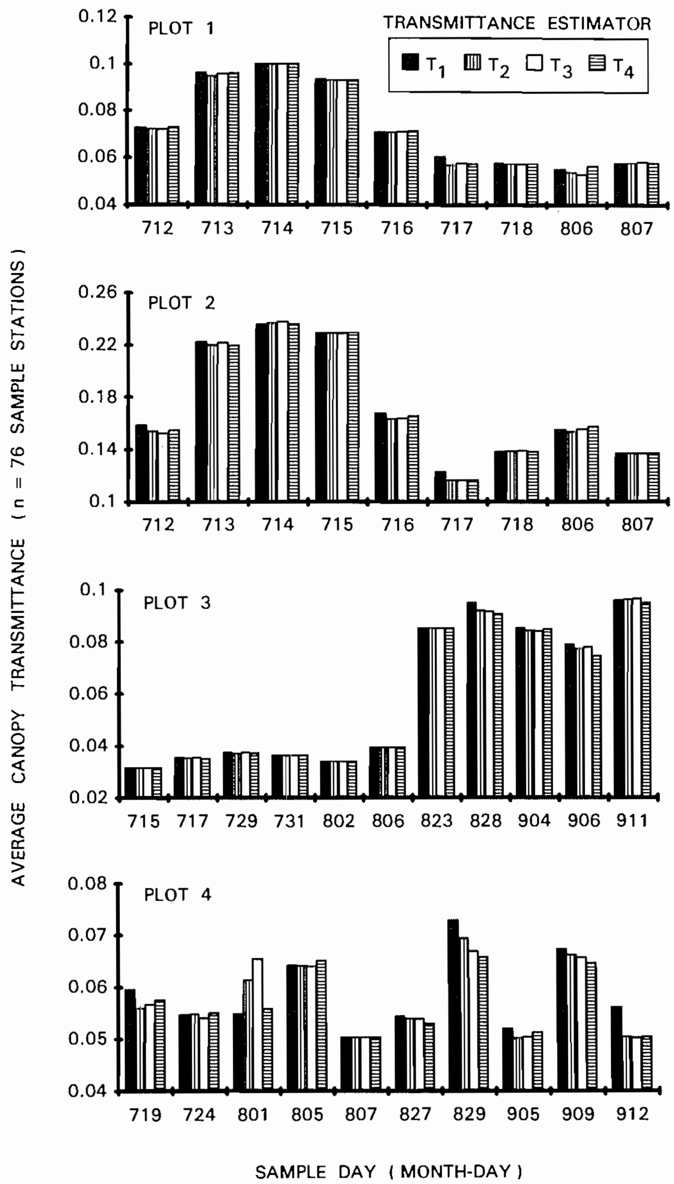

FIG. 2. Average stand transmittance by plot, sample day, and estimation method. Calculation of transmittance for each estimator is described in the text.

ferent estimation methods on any given day (Fig. 2). Thus, if interest centers on measuring stand average transmittance under a variety of sky conditions, it would be more efficient to allocate more resources to account for direct versus diffuse radiation components and solar zenith angle, as opposed to trying to improve the synchronization of measurements. Shaded and unshaded sensors can be used to account for the effects of clouds, and the effects of solar zenith angle are accountable through simple models.

The interpolated estimator (T_3) simulates the popular procedure (after Pierce and Running 1988) of using one radiometer and periodically measuring ambient PAR in canopy openings. The average canopy transmittance obtained by T_3 was never more than 1% different from the estimate obtained by the synchronized estimator (T_1). This result suggests that just one radiometer could be used even on cloudy days, thereby saving the cost of the second sensor. The direct-beam and diffuse components of radiation can be found with one sensor as described by Smith (1991).

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Nutrient concentration and acid–base status of leaf litter of tree species characteristic of the hardwood forest of southern Quebec

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CÔTÉ, B., and FYLES, J.W. 1994. Nutrient concentration and acid–base status of leaf litter of tree species characteristic of the hardwood forest of southern Quebec. Can. J. For. Res. **24**: 192–196.

Leaf litter of 15 tree species characteristic of the deciduous and mixed forest of southern Quebec were analyzed for pH, directly titrable acids and bases in water extracts, ash bases, excess bases, excess ash bases, and for levels of N, P, K, Ca, and Mg. We hypothesized that many tree species typical of the climax of sugar maple (*Acer saccharum* Marsh.) dominated forest have leaf litter with a higher base status than sugar maple and red maple (*Acer rubrum* L.) leaf litter, and that the base status of leaf litter would be lower on wet sites. Mean differences among species were highly significant ($p < 0.0001$) for all variables related to acidity or bases, but the effect of drainage was not. Red and sugar maple leaf litter was very acid and low in N concentration. American beech (*Fagus grandifolia* Ehrh.) and red oak (*Quercus rubra* L.) leaf litter was not very acidic but was low in nutrient concentrations. White pine (*Pinus strobus* L.) was lowest in all nutrients and ash bases but was low in titrable acidity. Directly titrable bases in leaf litter extracts were correlated positively with leaf litter N and Mg, and ash bases were positively correlated with leaf litter Ca and Mg. Many species typical of the sugar maple climax may have better soil ameliorating potential than sugar and red maple.

CÔTÉ, B., et FYLES, J.W. 1994. Nutrient concentration and acid–base status of leaf litter of tree species characteristic of the hardwood forest of southern Quebec. Can. J. For. Res. **24** : 192–196.

Les litières foliaires de 15 espèces d'arbre caractéristiques de la forêt feuillue et mixte du sud du Québec ont été analysées pour le pH, les acides et les bases directement titrables dans les extraits aqueux de litière, les bases des cendres, l'excès de bases, l'excès de bases dans les cendres et pour les taux de N, P, K, Ca et Mg. Nous avons émis l'hypothèse que plusieurs espèces typiques de la forêt climacique dominée par l'érable à sucre (*Acer saccharum* Marsh.) ont des litières foliaires plus riches en bases que la litière de l'érable à sucre et de l'érable rouge (*Acer rubrum* L.) et que le statut en bases serait plus bas sur stations humides. Les différences entre espèces étaient très significatives ($p < 0.0001$) pour toutes les variables reliées à l'acidité ou aux bases mais l'effet du drainage n'était pas significatif. La litière foliaire de l'érable rouge et à sucre était très acide et pauvre en N. Les litières foliaires du hêtre américain (*Fagus grandifolia* Ehrh.) et du chêne rouge (*Quercus rubra* L.) n'étaient pas très acides mais étaient pauvres en éléments nutritifs. Le pin blanc (*Pinus strobus* L.) avait la litière foliaire la plus pauvre en éléments nutritifs et en bases des cendres mais quoique pas très acide. Les bases titrables dans les extraits de litière foliaire étaient corrélées positivement avec N et Mg, et les bases des cendres étaient corréles positivement avec Ca et Mg. Plusieurs espèces caractéristiques du climax de l'érable à sucre pourraient avoir un meilleur potentiel d'amélioration des sols que l'érable à sucre ou l'érable rouge.

Introduction

The concept that some tree species may ameliorate a forest site has long been established in the forestry literature (Plice 1934; Miles 1985; Howard and Howard 1990). European forest researchers discovered quite early the strong relationships existing between the acidity of leaf litter and its rate of decomposition (Broadfoot and Pierre 1939; Mattson and Koutler-Andersson 1941). Most conifers, through their leaf litters, have been considered to decrease soil fertility by producing acidic mor humus (Messenger 1975; Brand et al. 1986). Complex interactions with soil fertility (Staaf 1987), soil moisture (Taylor and Parkinson 1988) and forest species composition (Blair et al. 1990; Gustafson 1943) do, however, exist and make predictions of rates of litter decomposition very difficult. Recently, Howard and Howard (1990) have rejuvenated the concept of leaf litter acidity by using the concept of excess bases in litter. Excess bases of leaf litter extracts correlate better with the rate of litter decomposition and the type of humus formed than total acidity of litter (Howard and Howard 1990). The concept of excess bases in leaf litter appears to be a simple integrating concept

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