

Measurements of Radiation Transmittance and Reflectance of Discontinuous Canopies*

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Abstract It is a report of experimental results. By means of the field measurements we obtained the features of variation of radiation reflectance (in wave bands 290—2800 nm and 400—700 nm) of the four components in GO approach in Juniperus tree nursery and the radiation transfer in a single tree crown and in apple tree orchard. At the same time we also obtained the foliage area volume density (FAVD) in three dimensions and the leaf angle distribution (LAD) with the Tree Computed Topography (TCT) method. The measured data of distribution of reflected radiation from sunlit crown of Junipers tree were related very well to the model calculation using the approach of path scattering of light in semi-infinite medium with modification of change the semi-infinite medium to the shape of tree crown.

Key words Field measurements, Variation of brightness of four components in GO approach, Radiation transfer in tree stand, Model validation

1 INTRODUCTION

In research on BRDF both the constructing theoretical model and testing the model validation using the experimental data are very important and closely related to each other. Usually, the experiment design and parameters gathering should be based on the requirement of the purpose of the model validation testing, by which the theoretical model can be modified, improved, and its application will be extended.

In BRDF study, the geometric optical (GO) approach has been successfully used to discontinuous canopies, such as woodland, forest. For pure GO approach, the bidirectional reflectance of a canopy is treated as an area weighted sum of the four brightness of sunlit and shaded crown, sunlit and shaded back-ground. However the brightness of the four components should be provided as input parameters. It

restricts its application. Li, Strahler and Woodcock^[1] used a geometric optical radiative transfer approach to modelling the albedo and bidirectional reflectance of Maine forest with an assumption that the radiation reflectance from sunlit and shaded crown were uniform. This assumption caused a systematic derivation between the modelling and observation. Therefore it is necessary to study the features of the brightness variation of the four components in GO approach by experiment and model calculation. The purpose of this study is that based on the field measurements to study the features of variation of radiation reflectance from the sunlit and shaded crown, sunlit and shaded ground and also to study the radiation transfer in tree stand, especially emphasized on the interactions between light and foliage geometry and foliage optics of tree crown.

The two experiments were made, experiment No. 1—measurement of radiation reflectance from tree crown and ground in Junipers tree nursery and experi-

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ment No. 2—measurement of radiation transfer in apple tree orchard.

2 EXPERIMENT NO. 1

2.1 Experiment Design and Method

2.1.1 Experiment site

The experiment No. 1 was carried out in Juniperus tree nursery at Yucheng Experimental Station ($116^{\circ} 38' E$, $36^{\circ} 57' N$, elevation 23m), Chinese Academy of Sciences, May 25/June 3, 1994. The area of it was $10 * 10 m^2$. The trees were planted with Poisson distribution. A specified tree was selected to be a sampled tree for measuring radiation reflectance from the crown surface. The space between the sampled tree and the others in the NE, S and SW directions were available for the measurement without shadowing on it. Height of the tree was 231cm and the maximum diameter of the tree crown was 75cm.

2.1.2 Measurement and instrument

Two kinds of measurements were made. (i) The radiation reflectance from sunlit and shaded crowns and from sunlit and shaded ground surface with three kinds of instruments. (ii) The three dimensional distribution of the foliage area volume density (FAVD) and leaf angle distribution (LAD) of the sampled tree were obtained by an indirect measuring method named the Tree Computed Topography (TCT)^[2].

The three kinds of instruments were used in radiation measurements, albedometer (290—2800 nm, Model MR-21, EKO, Japan), quantum sensor (400—700 nm, LF-190SA, LF-COR, USA) and SE590 spectrometer (400—1100 nm, Spectron Engineering, Inc., USA).

For the albedometer, there are two sensors, which were fixed together and opposite to each other. As the observation being carried out, one of the sensors was towards to the measured point of the crown and parallel to the tangent plane of this point. The distance between the point and the sensor was about 15cm. Readings of reflected radiation from the sunlit crown was denoted as Q_r . Another sensor was towards to the space to measure ambient incident radiation.

The readings from this sensor was denoted as Q . Therefore the radiation reflectance, R_Q , in wave band 290—2800 nm from the sunlit tree crown was expressed as $R_Q = Q_r / Q$.

For the quantum sensor, the two sensors were tied together and opposite to each other. One sensor was towards to the tree crown and another was towards to the space. The readings of the two sensors were denoted as U_r and U , respectively. Therefore the radiation reflectance in wave band 400—700 nm from the crown was expressed as $R_U = U_r / U$.

The radiation reflectance from sunlit and shaded ground were measured at the height of about 20cm also with the above the two instruments.

The SE590 spectrometer mounted with a 15° FOV was also employed to measure the reflected spectral radiance from the sunlit tree crown.

During the period of the above observations, the incident radiation from the sun and the sky were also measured, respectively, in the opened area using the three kinds of the instruments.

For the measurements of sunlit crown surface, five longitudinal lines were set up along the crown surface. The line in the middle was denoted as 0° , which was in principle plane of the sun light. Others were $\pm 30^{\circ}$ and $\pm 60^{\circ}$. In clockwise direction it was “+”. There were five measured points on each longitudinal line. Therefore there were twenty five measured points for each set of data for the sunlit crown surface.

2.2 Result

2.2.1 Radiation reflectance from sunlit junipers crown

The measurements were carried out on four clear days. Total nine sets of data were collected. The sun zenith (SZ) during these measurements were covered in $20^{\circ} - 52^{\circ}$. The mean of sun zenith was $32^{\circ} \pm 12^{\circ}$.

Because the measurements of the patterns of distribution of radiation reflectance from the sunlit crown of the nine sets data were very similar. Therefore only the mean forms of the nine sets are provided.

The two graphs of radiation reflectance, $R_Q(290$

—2800 nm) and R_U (400—700 nm), from sunlit crown surface are shown in Fig. 1. There was a lower center for each graph and the values of R_Q and R_U were increased gradually from the center to the edge of the sunlit crown surface. Values of R_Q and R_U were in range of 0.16—0.28 and 0.08—0.16, respectively. R_Q was higher than R_U . In generally speaking it was mainly because of the mean reflectance of foliage in 290—2800 nm is higher than the one in 400—700 nm.

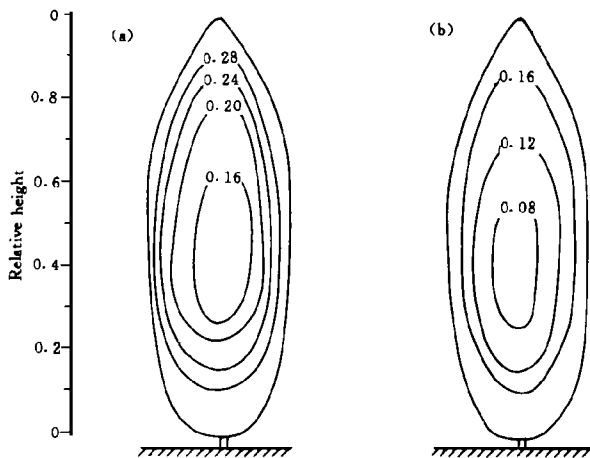


Fig. 1 Distribution of radiation reflectance from sunlit Juniperus tree crown in wave bands (a) 290—2800 nm, (b) 400—700 nm. The height of the tree was 231 cm. The maximum diameter of the tree was 75 cm

The measured data of distribution of reflected radiation from sunlit crown of Juniperus tree were related very well to the model calculation using the approach of path scattering of light in semi-infinite medium with modification of change the semi-infinite medium to the shape of tree crown^[3] (It will be described in another paper).

2.2.2 Radiation reflectance from shaded juniperus crown, sunlit and shaded ground in the juniperus nursery (Fig. 2)

(1) For each of the graphs of wave bands 290—2800 nm or 400—700 nm, on average the values of reflectance from shaded crown were higher than the ones from the sunlit crown.

(2) More sky the shaded crown opened to, the lower the reflectance were.

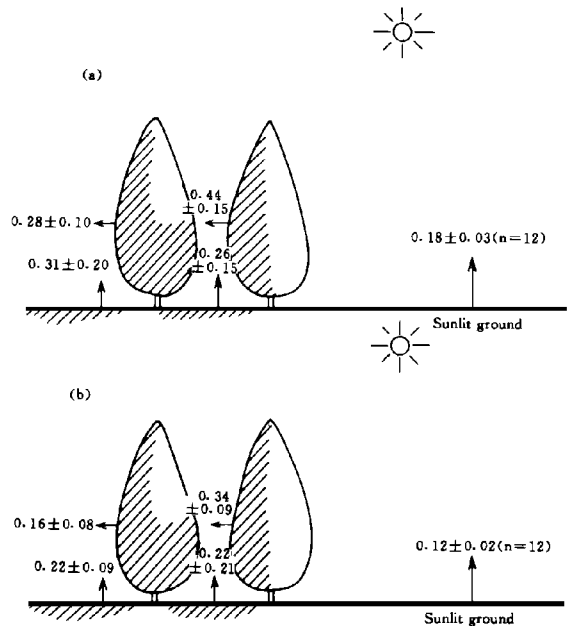


Fig.2 Radiation reflectance from shaded crown, sunlit and shaded ground in Juniperus tree nursery, in wave bands (a) 290—2800 nm, (b) 400—700 nm

(3) The mean square deviation of reflectance from sunlit ground in the fairly opened area was smaller than the ones from the shaded ground. During the measurements, the wetness of ground surface was changed from wet to drier in the area of sunlit ground. It means that the variability of the reflectance from shaded ground was large compared with the ones from the sunlit ground.

3 EXPERIMENT NO. 2

3.1 Experiment Design and Method

3.1.1 Experiment site

The experiment No.2 was carried out in apple tree orchard (116°24'E, 40°00'N, elevation 45m), Changping, Beijing. Area of the experimental plot was 10 * 12 m², in which 3 * 3 trees were latticed planted (Fig. A3). Distance between the two trees

were 5 m and 6 m in directions of NS and WE, respectively. The tree located in the middle of the plot was selected as a sampled one for measuring the radiation transfer in the crown and measuring the geometry and optics of the foliage. And in the lower part of the Fig. 3 it was the distribution of measured points for measuring transmitted and reflected radiation near the ground surface. All the radiation measurements were made in eight azimuth directions. The measured points in the sampled tree crown are also shown in Fig. 3.

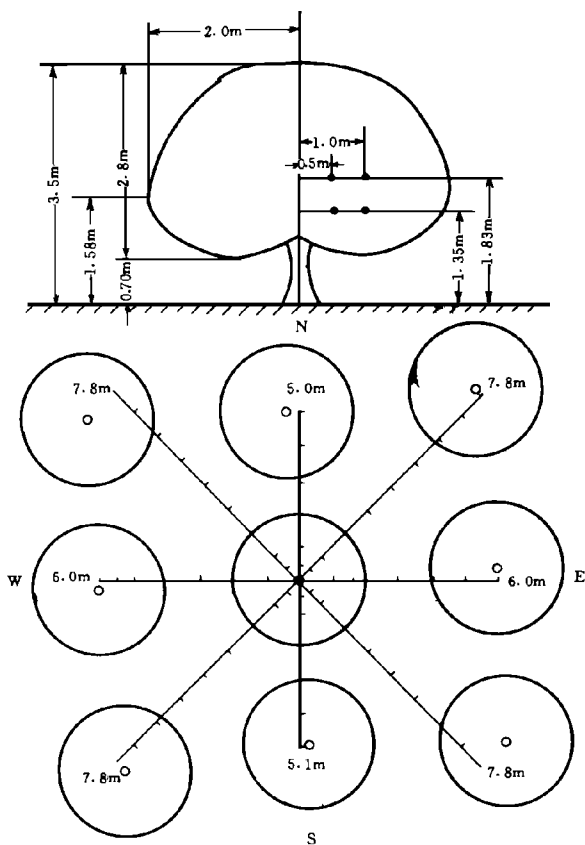


Fig. 3 Measured positions in apple tree orchard, Changping, Beijing, 1995

3.1.2 Measurement and instrument

The field measurements were carried out on 26 (clear) and 27 (overcast) July, 1995. On overcast day the cloud layer was thick and uniform, the incident sky diffuse radiation was quite stable during the measurement period.

The following measurements were made.

(1) Transmitted and reflected radiation (400–700 nm) at 4 positions in each azimuth, $h=135$ cm, $r=50$ cm and 100 cm; and $h=183$ cm, $r=50$ cm and 100 cm, in the sampled tree crown, h was height and r was distance between measured position and the center of sampled tree.

(2) Transmitted and reflected radiation (400–700 nm) at about $h=10$ cm in the apple tree orchard. The distance between the measured position and the center of the sampled tree was 0.5 m, 1.0 m, 2.0 m, 3.0 m, 4.0 m ... up to the under of another tree.

(3) Radiation (400–700 nm) from the sun and of the sky arrived at the top of the canopy and reflected radiation from the ground in opened area.

The quantum sensor (in 400–700 nm) and SE590 (in 400–1100 nm) were used in the above radiation measurements.

(4) FAVD and LAD of the sampled tree were obtained also with the indirect measuring method, TCT method^[2]. These measurements were carried out after sun set on 27 July 1995.

(5) Optics of leaves and trunk surface of apple trees, and grass leaves at the ground were measured with external integrating sphere (Model 1800-12, LI-COR, USA) mounted on the detector of SE590 on 28 July. The samples of leaves and trunks were collected in the evening on 27 July, 1995 and kept in fresh.

3.2 Some Early Results

3.2.1 Optics of leaves and trunks of apple trees

Spectrum of optics of two sides of three kinds of color leaves, light green, yellow green and dark green, and surface of trunks of apple trees were obtained. Light green leaves were distributed around the crown surface mostly, especially around the top part of the crown. Yellow green and dark green leaves were the main part of the leaves in the crown. The mean transmittance and reflectance of leaves and trunks in visible (400–700 nm) and near infrared (750–1000 nm) are shown in Table 1, in which T_L , T_Y and T_D denote the transmittance of light green, yellow green and dark green leaves, respec-

tively, and R_L , R_Y and R_D denote the reflectance for the three kinds of color leaves.

Table 1 Optics of apple tree foliage

	Transmittance			Reflectance				
	Leaves			Leaves			Trunks	
	T_L	L_Y	L_D		R_L	R_Y	R_D	R
Visible (400—700 nm)	0.08	0.02	0.02	ad	0.13	0.08	0.07	0.10
				ab	0.23	0.14	0.17	
Near infrared (750—1000 nm)	0.40	0.26	0.34	ad	0.51	0.51	0.44	0.48
				ab	0.48	0.37	0.47	

* ad—adaxial of the leaf, ab—abaxial of the leaf

3.2.2 Radiation transfer in apple tree crown on overcast day

Normally for obtaining representative values of transmitted radiation through a homogenous canopy in horizontal, the data collection has to be carried out in a certain distance. For the case here we use the mean transmittance, $\bar{T}_{h,r}$, of eight azimuth directions to show the representative values of transmittance at the position (h, r) in the crown. $\bar{T}_{h,r} = \frac{\sum_i U_i}{\sum_i U_{0,i}}$ ($i = 1-8$ directions), U_i and $U_{0,i}$ are the transmitted radiation in the crown and the radiation arrived at the top of the crown on overcast day. For the radiation reflectance, it can be calculated by the same way. The mean transmittance, T , and mean reflectance, R , at position (h, r) are shown in Table 2. It shows that:

(1) The mean transmittance, T , is higher than the mean reflectance, R , at each position (h, r) and at each time.

(2) At a same height (h), the mean T at $r=100\text{cm}$ is higher than the mean T at $r=50\text{cm}$; and at the same r, the mean T at $h=183\text{cm}$ is higher than the mean T at $h=135\text{cm}$. It depends on the amount of foliage along the path length of the light through in the tree crown.

Table 2 Mean transmittance and mean reflectance of Radiation (400—700 nm) in apple tree crown

Time	h	r	T	R
13:01	183	50	0.47	0.06
16:55	183	50	0.54	0.05
13:01	183	100	0.64	0.05
16:55	183	100	0.57	0.05
12:31	135	50	0.17	0.13
16:38	135	50	0.17	0.13
12:31	135	100	0.27	0.07
16:38	135	100	0.27	0.08

4 CONCLUSION AND DISCUSSION

The objective of this study was that based on the field measurements to study the features of variation of radiation reflectance of the four components in GO approach and radiation transfer in tree stand for model development and validation testing especially emphasized on the interactions between light and the foliage geometry and optics of the tree crowns.

Based on the detailed field measurements, a pattern of distribution of radiation reflectance from the sunlit crown of Junipers tree was observed. The patterns for the two wave bands, 290—2800 nm and 400—700 nm, were very similar (Fig. 1). For each case of the wave bands, there was a low center in the middle of the sunlit crown. The values of the radiation reflectance were increased from the middle to the edge of the sunlit crown. The radiation reflectance in wave band 400—700 nm from the sunlit crown were simulated by means of the approach of path scattering of light in semi-infinite medium^[3] with the modification of changing the semi-infinite medium to a shape of tree crown and using the incident radiation of the sun and the sky to the crown surface and the FAVD in three dimensions as input parameters. It showed that the model calculation related to the measured data very well. This work provided an experimental sample for the validation testing of this approach and showing the application of the work made by Li, Ni *et al.*^[3].

The variation of radiation reflectance of the other three components in GO approach were also observed. But it was better that besides the observations of radiation reflectance of the four components, the observations of bidirectional reflectance from the tree canopy should be carried out in a synchronous way for BRDF study and also for the model validation testing

for the radiation reflectance of the four components.

The radiation transmittance in wave band 400—700nm in a single apple tree crown was simulated by means of KM equation^[4] and using the measured data of sky diffuse radiation arrived at the top of tree canopy on overcast day and the FAVD in three dimensions of the tree crown as input parameters. It showed that the model calculation was also related to the measured data very well.

The optics of the foliage of vegetation in near infrared are different from the ones in visible significantly. Therefore it is necessary that besides the above measurements and model validation testing in visible, the similar works in near infrared should be made as well.

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不连续植被冠层辐射透过率和反射率的测量

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摘要 在植被二向反射的研究中, 构建理论模型和进行实验验证需要协调进行, 该文是按此原则进行的一项野外实验工作, 并突出在树冠尺度上的测量和研究。该文包括两项野外实验: 1. 桧柏树苗圃内树冠承照面、阴影面、地表承照面和阴影面辐射反射率的测量; 2. 苹果园单棵树冠内不同位置和果园内地面辐射透过率和反射率的测量。在进行辐射测量的同时, 还用树冠断层成像法(TCT)得到了树冠内叶面积体密度的三维分布和叶角分布, 在实验2中还同时测量了苹果树叶片及枝条的光谱特性。在实验1中, 辐射测量用了3种仪器: ①反照率表(290—2800nm, 称全波段太阳辐射波段); ②光子量子传感器(400—700nm, 为可见光波段); ③SE590光谱仪(大约为400—1100nm)。在实验2中的辐射测量用后两种仪器。从实验数据得到: ①对桧柏树冠承照面, 在可见光波段和全波段太阳辐射反射率的分布形势非常相近, 在承照面中心部位出现一反射率低中心, 向两侧逐渐增大, 且等值线密度也逐渐加大。对此结果进行了模拟计算, 将光在有限厚度介质中路径散射求解的解析近似方法应用于更复杂的树冠层, 计算出的树冠承照面反射率与观测数据在分布形式上有很好的—致性。②文中给出并分析了桧柏树冠阴影面、地表承照面和阴影面反射率的变化特征。③对阴天条件下苹果树冠内4个测点, 每个测点在8个方位上的辐射透过和反射观测数据的平均值, 用KM方程对辐射透过率进行了模拟计算, 结果表明模拟计算值与实测结果间也有很好的相关性。

关键词 野外测量, GO模型中四分量变化, 树林的辐射传输, 模型验证