# A Monte Carlo radiative transfer simulation of rice canopy based on digital stereo photogrammetry

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**ABSTRACT:**

NIR (Near Infra Red) bidirectional reflectance distributions of thirteen kinds of rice canopies are simulated using the 3-D Monte Carlo method and measured in an experimental field. The simulation is carried out under two different field conditions. One is similar to the condition of the experimental field (condition A) and the other is the wide spread field condition under the parallel solar beam (condition B).

The framework of the simulation model is 1cm x 1cm x 1cm sized rectangular solid cell. Each cell has an information on leaf area, inclination, and direction that are calculated using a 3-D digital stereo measurement method. Other than the structural information, the sensitivity of individual leaf reflectance is accounted.

The sensitivity is decided by measuring some kinds of individual leaf reflectance. From the measurement, NIR reflectance and transmittance of rice leaves have low coefficient of variation. On the other hand, VIS (Visible) reflectance and transmittance have high coefficient of variation.

The simulated bidirectional reflectance fit the measured one well under condition A in NIR region. As the result of the simulation, the ratio of the reflectance factors (view zenith: 45deg. to 0 deg. ) in NIR region from wide spread field is suggested to give average inclination of rice canopy.

## 1. INTRODUCTION

Radiative transfer simulation of plant canopy is basic to remote sensing of plant canopy state. A complex scene is hard to model with analytical models. With the simulation models such as Monte Carlo method, one can consider canopy structure that is hard to model with analytical models. Therefore, the simulation has been carried out using the Monte Carlo method.

Ross et al. (1988) modeled plant elements (leaf, stem) as simple geometrical shapes. Round or elliptic leaves are assumed and the difference of bidirectional reflectance factor is estimated under the conditions of different variance of leaf inclination, different deg. of ellipticity, the row effect, and the influence of stems.

Kimes et al. (1982) represented information on plant canopy physical state as 3-D cell matrix and developed a simulation model. A size of one cell is about 10cm. Each cell that corresponds to leaf has information on leaf inclination distribution function and leaf area index. Each cell has the same theoretical or empirical leaf inclination distribution. Simulation is carried out with homogeneous dense canopy (Kimes, 1984), homogeneous sparse canopy (Kimes et al., 1985), and inhomogeneous canopy (Kimes et al., 1986). The results of the simulation are compared with measured value, and bidirectional reflectance characteristics of various vegetation canopy are explained.

However, simulations and validation of their result have hardly carried out from the viewpoint of estimate of canopy physical state of a fixed crop canopy. One of the reasons is thought to be that the structural measurement of canopy has been hardly carried out so that the cells are small enough to correspond to a minute region of an individual leaf. G.V.Menzhulin et al. (1991) also pointed out this as a shortcoming of the simulation model.

Therefore, NIR bidirectional reflectance distribution of thirteen kinds of rice canopy is simulated using the 3-D Monte Carlo method based on cell information given from 3-D structure obtained by the leaf edge matching method (Kushida et al., 1993;

Kushida et al., 1994a; Kushida et al., 1994b) and stereo photogrammetry in this paper. The simulated reflectance factor is compared with measured. Using this model, rice canopy bidirectional reflectance characteristics are analyzed.

## 2. SIMULATION MODEL

### 2.1 Field and light conditions

Basically straight forward method, with which a photon is traced time sequentially is used. A photon comes out of a light, traveling in a canopy, and then absorbed in the canopy or gets out of the canopy. Radiative transfer in canopy and bidirectional reflectance from canopy can be simulated by increasing the number of photon. The fate of a photon is decided by condition of both incident light and canopy physical state. The former is presented using light's incident direction - intensity characteristics as probability density function. The latter are mentioned in **2.2** and **2.3** in detail.

Simulation of wide spread canopy is restricted by capacity of computer memories. But, when a canopy can be presented by repeat of a basic unit, the simulation can be carried out with as much memories as necessary for basic unit simulation. Namely, a photon that gets out of a basic unit is equivalent to the one that entered from the opposite surface of the basic unit (Kimes et al., 1982). The conception of the model is shown in Fig. 1.

### 2.2 Cell information

When radiative transfer in canopy is tried to simulate more realistically, more canopy information is necessary. The framework of the simulation model is 1cm x 1cm x 1cm sized rectangular solid cell.

There supposed to be not more than two individual leaves in the space of each cell. Each cell has an attribute of air or leaf or soil. A cell that has attribute of leaf is given information on leaf area, direction, and inclination. These information is obtained as follows. At first, leaf direction and inclination on each leaf edge lines are calculated using a 3-D measurement method, the leaf edge matching method and stereo photogrammetry. The lines are divided into shorter unit lines. A cell that includes each point of a unit line is given information on inclination and direction of the unit line. Vertical resolution of this method is about 1.7 mm, and the perpendicular resolution is about 6.8 mm. Then, the projected leaf area of each cell is calculated from the rectified disparity image obtained by the method. Cells that have only leaf area information are given information on leaf direction and inclination by supplementation. Attribute of soil is given to all the cell situated at 0 cm height.

### 2.3 Cell-photon interactions

1) Air cell: A photon is not forced by this cell. Namely, a photon goes straight forward in this cell.
2) Leaf cell: Let $\rho$ be leaf reflectance factor, $\tau$ leaf transmittance factor. $S_c$ and $S_L$ are projected area of a cell and leaf in the cell respectively to a plane that is perpendicular to incident vector. When a photon enters the cell, the probability of the photon distributing is $(S_L/S_c)(\rho+\tau)$, and that of the absorbed is $(S_L/S_c)(1-\rho-\tau)$, and that of the transmitting is $1-S_L/S_c$. Distribution phase function of the cell obeys Lambertian.
3) Soil cell: When a photon entered this cell, the photon is distributed at the incident point. Distribution phase function obeys Lambertian without the specular reflectance. The specular

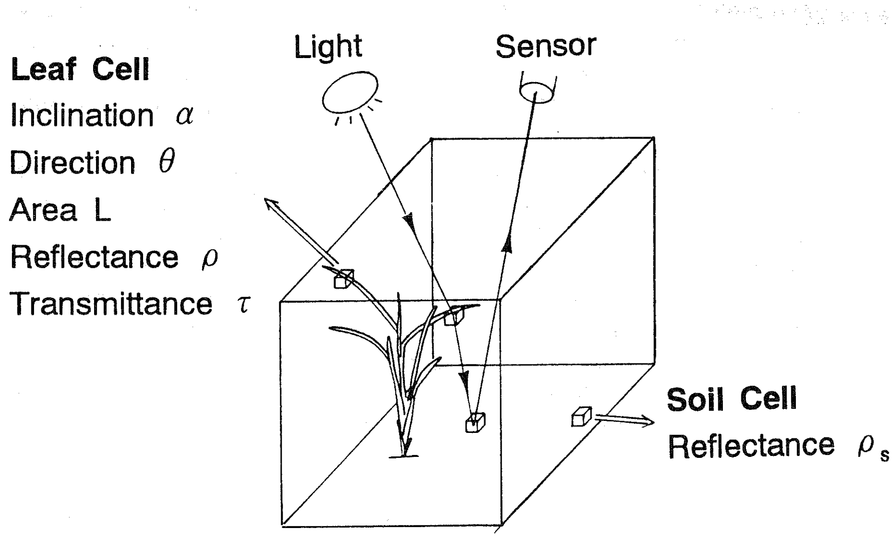


Fig. 1. The conception of the model

reflectance factor caused by the ponding water is 2.1% here.

## 3. REFLECTANCE MEASUREMENT

### 3.1 Measurement of canopy bidirectional reflectance factors

Rice crop (Oliza Sativa, variety: koshihikari) is cultivated at an experimental field of University of Tokyo in 1992. Dense plot (15 cm X 15 cm) and sparse plot (30 cm X 30 cm) are set. Reflectance measurement is carried out a week interval under artificial light (450W lump) just after sun set. Reflectance factors are measured with 10 deg. FOV. Data is obtained three times per one object and averaged. The device for reflectance measurement is shown in Fig. 2 shows . Incident angle to the canopy is 15 deg.. View azimuth angle is 0 deg. (the opposite of the light) and view zenith angles are 0, 45, and 60 deg.. Soil reflectance (8 cm water ponding) is also measured.

### 3.2 Measurement of individual leaf reflectance factor

Variation characteristics of spectral reflectance and transmittance of rice individual leaves, which are seldom investigated in canopy reflectance modeling are analyzed. Difference of leaf spectral characteristics due to the difference of leaf situations and fertilizer levels are inquired. And these characteristics in an individual leaf are also inquired.

Rice crop is cultivated in a pot in a green house. The fertilizer levels are high, middle, and no fertilizer. 3 pots are set in each fertilizer level and data is arranged by randomized block design, considering other conditions. Reflectance and transmittance factors are nondestructively measured in 280-2500nm. The incident angle is 45 deg. And reflection angle is 0 deg.

Analysis of variance in two-factor factorial experiment and inspection using least significant difference are carried out. The factors of this factorial experiment are leaf situation on a stem and fertilizer level. In NIR, there are no significant differences of reflectance and transmittance factor due to the leaf situations and fertilizer levels among the fertilizer applied plots. In the visible region, there are significant differences of reflectance factor due to the leaf situations. The coefficients of variations of all the reflectance and transmittance factors (number of samples: 41) are as small as 5% in NIR (Fig. 3). Reflectance and transmittance factors in a individual leaf are in the corresponding ranges of the coefficients of variation in NIR. On the other hand, in the visible region, variation of the factors are rather large.

Thus, NIR is suited for deciding canopy structure from reflectance characteristics, because variations of reflectance and transmittance factors among individual leaves are small. The visible region is suited for states of individual leaves from reflectance characteristics.Reflectance factor $\rho$ and transmittance factor $\tau$ of ten samples of rice individual leaves are measured nondestructively in 1995. Incident angle is 0 deg. and reflection angle is 45 deg..

For the result, in the NIR region (850nm -

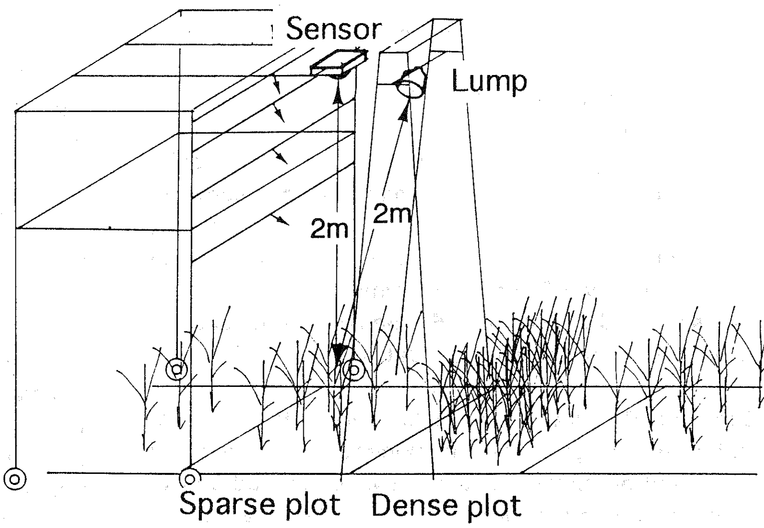


Fig. 2. Canopy reflectance measurement

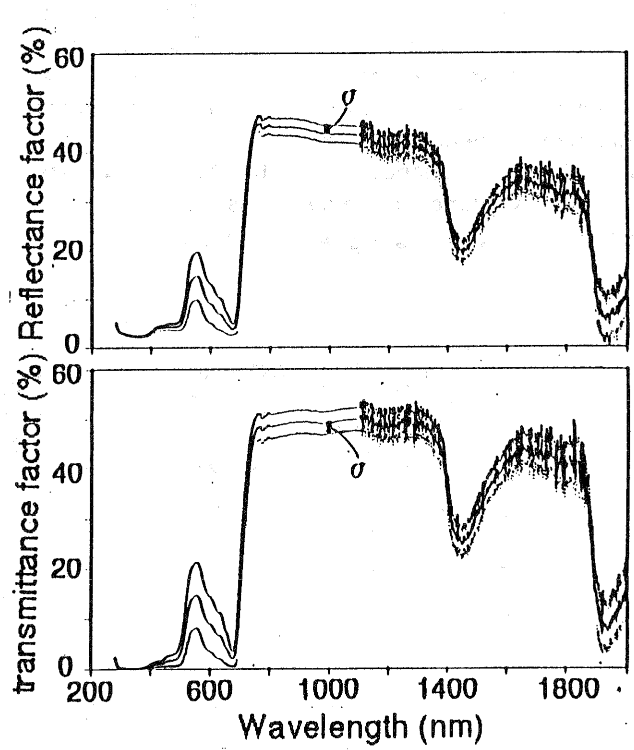


Fig. 3. Spectral characteristics of rice leaves (average±S.D., n=41)

950nm), the average of $\rho$ is 0.45 and that of $\tau$ is 0.49. These values and measured soil reflectance $\rho_s$=0.055 are used for the simulation. Coefficient of variation of $\rho$ is about 5%. In the other regions, coefficient of variation is higher than 15%. This shows that NIR region is the most optimal to use as the indicator of the 3-D structure of rice canopy that is not withered.

## 4. SIMULATION OF CANOPY BIDIRECTIONAL REFLECTANCE

### 4.1 condition of the simulation

The simulation is carried out under the following two conditions.

Condition A. Experimental field: this is the condition that is similar to the experimental field measurement condition. In the other words, direction - intensity characteristics of the incident light is approximated by a function of $y=I(0)\cos^{7.16}\theta$. Where $I(\theta)$ shows the intensity to the direction $\theta$. Basic unit is situated based on the measurement situation.

Condition B. Wide spread field: This is the condition that specular light enters homogeneously to a scene composed of repeat of basic unit which spread enough widely to the vertical direction. IFOV of the sensor can be any combinations of basic unit. In order to account for the air effect, it is necessary to combine air reflectance models with this model. The probability concerning to photon fate remarked in **2.3** is given by causing a suspected random number. Individual leaf reflectance and soil reflectance are given by in situ and field measurement respectively.

B-1. Leaf reflectance $\rho$, absorbance $\alpha$ and transmittance $\tau$ are constants.

B-2. $\rho$, $\alpha$ and $\tau$ are given as follows.

$$\begin{aligned} \rho &= \rho_c + \rho_v \\ \alpha &= \alpha_c + \alpha_v \\ \tau &= 1 - \rho - \alpha \end{aligned} \qquad (1)$$

Where $\rho_c$ and $\alpha_c$ are constants. $\rho_V$ and $\alpha_V$ are $\pm 0.05\rho_c$ and $\pm 0.05\alpha_c$ respectively.

### 4.2 comparison between simulated and measured

NIR bidirectional reflectance distribution of thirteen kinds of rice canopy is simulated under condition A. Fig. 4. Shows the comparison of the calculated reflectance factor to the view azimuth 180 deg., view zenith 0, 45, 60 deg. with the measured one in an experimental field. RMSE means Root Mean Square Error. This shows the simulation is effective for valuating the rice canopy bidirectional reflectance.

### 4.3 simulation of rice canopy reflectance in wide spread fields

Fig. 5. shows simulated NIR bidirectional reflectance distribution of thirteen kinds of rice canopy under condition B-1. Incident zenith angle is 15 deg.. 2.5 x $10^6$ photons are traced. Following results are obtained by the simulation.

Basically, reflectance factor inclined to be higher to each direction as rice grows up. This shows that the effect of the total leaf area increasing on bidirectional reflectance is more dominant than that of leaf inclination in each direction.However, comparing the dense plot in July 16th with that of July 21th, the former has higher reflectance to the nadir direction, and has lower reflectance to greater than 30 deg. zenith angle. This is the case of either 0, 45, 90 deg. azimuth angle. This seemed to be caused by the difference of leaf inclination.

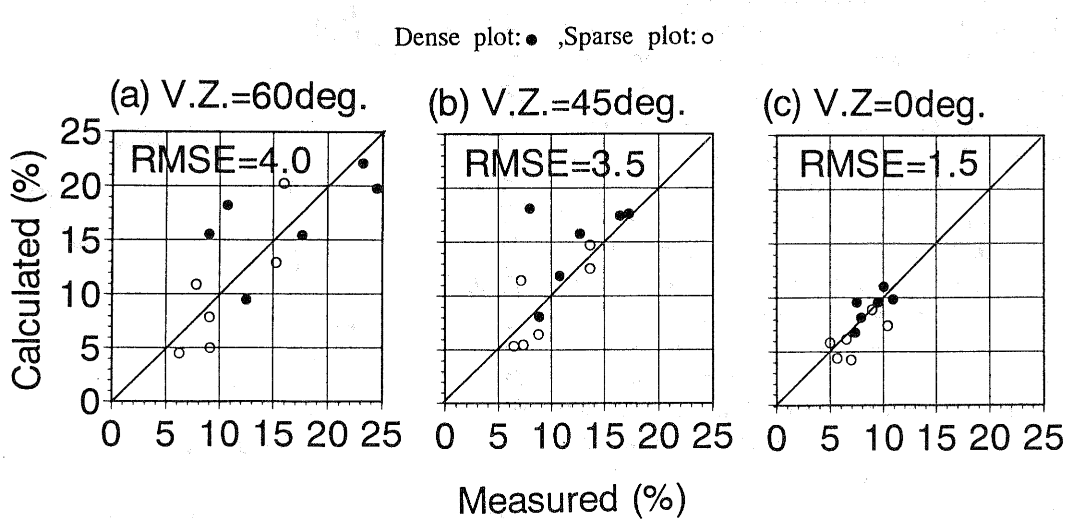


Fig. 4. Comparison between measured and calculated reflectance factors (condition A, view azimuth = 0° )

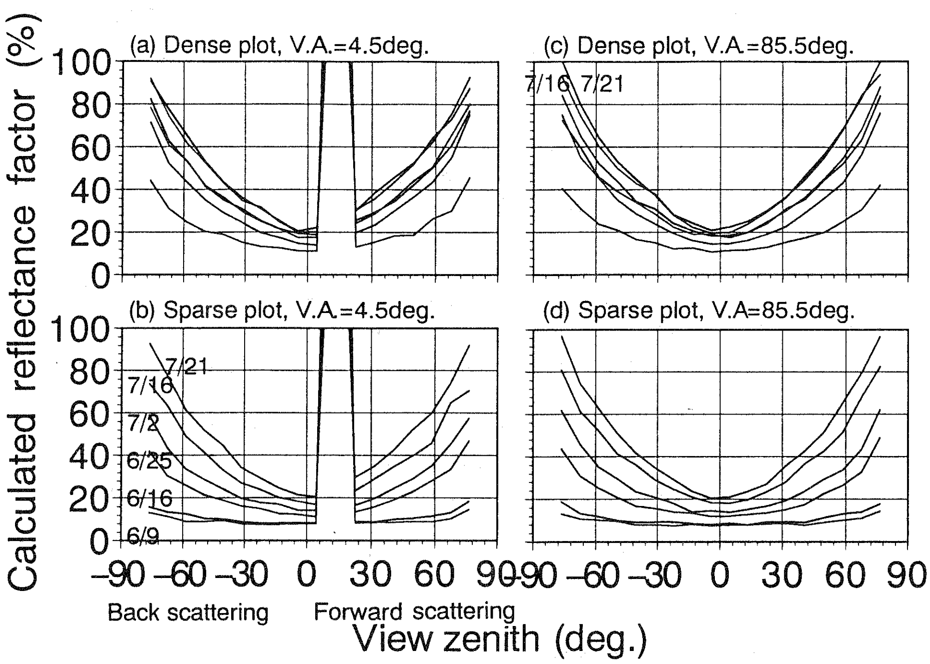


Fig. 5. Bidirectional reflectance characteristics obtained by the simulation (condition B-1)

Therefore, relation between leaf average inclination and R(45° )/R(0° ) is analyzed. Where R($\phi$) is the reflectance factor to view zenith angle $\phi$, azimuth angle 180° . Without earlier growth stages (without data of sparse plot in june 9th and june 16th), the two parameters are adequately correlated. The correlation coefficient is 0.84.

## 5. CONCLUSION

In this paper, NIR bidirectional reflectance distributions of thirteen kinds of rice canopies are simulated using the 3-D monte carlo method and measured in an experimental field. The simulation is carried out under two different field conditions. One is similar to the condition of the experimental field and the other is the wide spread field condition under the parallel solar beam. The simulated reflectance factors under the former condition fit the measured one well. As the result of the simulation, the ratio of the reflectance factors (view zenith: 45deg. to 0 deg. ) from wide spread field is suggested to give average inclination of rice canopy.

In consequence of this research, bidirectional reflectance characteristics of rice canopy should be analyzed using this model under some kinds of physical conditions.

## REFERENCES

Kimes,D.S., J.A.Kirchner (1982) : Radiative transfer model for heterogeneous 3-D scenes. Applied Optics 21 (22), pp.4119-4129

Kimes,D.S. (1984) : Modeling the directional reflectance from complete homogeneous vegetation canopies with various leaf-orientation distributions. J. Opt. Soc. Amer.A1, pp.725-737

Kimes,D.S., J.M.Norman, C.L.Walthall (1985) : Modeling the radiant transfers of sparse vegetation canopies. IEEE Trans. Geosci. Remote Sens. GE-23( 5), pp.695-704

Kimes,D.S., W.W.Newcomb, R.F.Nelson, J.B.Schutt (1986) : Directional reflectance distributions of a hardwood and pine forest canopy. IEEE Trans. Geosci. Remote Sens. GE-24 (2), pp.281-293

Kushida, K., K.Yoshino, E.Yamaji, T.Tabuchi (1993) : Modeling of 3-D structure for analysis of canopy reflectance from rice crop. Proc. of International Geoscience and Remote Sensing Symposium (IGARSS), pp.1991-1992

Kushida,K., K.Yoshino, E.Yamaji (1994a) : A matching algorithm for rice plant images. J. Japan Soc. Photogrammetry and Remote Sens. 33 (3), pp.33-40 (In Japanese)

Kushida,K., K.Yoshino, E.Yamaji (1994b) : Analysis of rice 3-D structure with digital stereo photographs. J. Japan Soc. Photogrammetry and Remote Sens. 33 (3), pp.41-47 (In Japanese)

Menzhulin,G.V., O.A.Anisimov (1991) : Principles of statistical phytoactinometry. In "Photon -vegetation interactions. " (R.B.Myneni, J.Ross Eds.) Springer-Verlag, p.121

Ross,J.K., A.L.Marshak (1988) : Calculation of canopy bidirectional reflectance using the Monte Carlo method. Remote Sens. Environ. 24, pp.213-225