A model of radiation interception and use by a maize–bean intercrop canopy

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Received 2 March 2001; received in revised form 6 November 2001; accepted 14 November 2001

Abstract

A modelling study on intercropping was carried out to understand the radiation interception and use. The radiation transmission models on both instantaneous and daily bases were described and validated. For testing the model, photosynthetically active radiation was measured above and beneath a maize–bean intercrop canopy in both north–south (NS) and east–west (EW) rows at Bloemfontein, Free State, South Africa. Both models accurately predicted radiation transmitted through the intercrop canopy throughout the vegetative stage. For the instantaneous model, two methods were compared, namely, the geometrical method versus the statistical method. The geometrical method was equal in radiation transmitted per unit row to the statistical method. The daily amount of radiation intercepted and used by each component crop was estimated. Concerning the radiation utilisation, the intercropping was equivalent in growth efficiency of maize to the sole cropping whereas beans had greater radiation use efficiency in intercropping than in sole cropping, which might explain the intercrop yield advantage.

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Keywords: Modelling, Intercropping, Radiation transmission, Photosynthetically active radiation, Fraction of radiation intercepted, Radiation use efficiency

1. Introduction

Intercropping plays an important role in subsistence and food production in developing countries. Intercropping has been practised traditionally by small-scale farmers in the tropics, in particular, cereal and legume intercropping is recognised as a common cropping system throughout developing tropical countries (Ofori and Stern, 1987). It has been concluded earlier that intercropping systems may be beneficial. In the past, many studies were carried out on analyses of intercrop radiation interception and use (e.g. Sivakumar and Virmani, 1980, 1984; Reddy and Willey, 1981; Natarajan and Willey, 1985; Watiki et al., 1993), however, only a few crop radiation utilisation models for intercropping have been reported (e.g. Wallace et al., 1991; Sinoquet and Bonhomme, 1992; Ozier-Lafontaine et al., 1997).

Radiation transfer models for plant canopies are broadly grouped into two types: the statistical and geometrical methods (Lemeur and Blad, 1974). Plant canopies are described as a turbid layer in the statistical method and as a geometrical figure in the geometrical method. The former method has been discussed in horizontally homogeneous canopies by several authors (e.g. Monsi and Saeki, 1953; Monteith, 1965; Anderson, 1966; Cowan, 1968; Miller and Norman, 1971; Mann et al., 1977). In contrast, the geometrical
method may be used in heterogeneous canopies (e.g. Allen, 1974; Charles-Edwards and Thorpe, 1976; Goudriaan, 1977; Palmer, 1977; Mann et al., 1980; Norman and Welles, 1983; Gijzen and Goudriaan, 1989; Nilson, 1992).

With respect to an intercropping canopy, Wallace et al. (1990, 1991) introduced a one-dimensional radiation transfer model in sugar cane and maize intercropping. The canopy was assumed to be vertically homogeneous. Sinoquet and Bonhomme (1992) introduced a two-dimensional radiation transfer model for an intercrop canopy (intercropping of maize at early vegetative stages and maize at late vegetative stages) based on turbid medium analogy, dividing the space into cells according to horizontal layers and vertical slices parallel to row orientation because of the spatially heterogeneous canopy. Recently, Ozier-Lafontaine et al. (1997) studied radiation interception models in a maize–sorghum intercrop canopy using both models mentioned above. They verified that both models predicted radiation intercepted by the intercrop canopy with high accuracy.

Radiation partitioning in multiple cropping may be necessary to determine radiation interception by each crop. However, it is difficult to distinguish the contribution of each crop to the radiation interception (Ozier-Lafontaine et al., 1997). Several authors have presented models for partitioning radiation intercepted by each plant component (e.g. Marshall and Willey, 1983; McMurtrie and Wolf, 1983; Rimmington, 1984, 1985; Wallace et al., 1990, 1991; Sinoquet and Bonhomme, 1992; Keating and Carberry, 1993). For example, Marshall and Willey (1983) and Wallace et al. (1991) developed radiation partitioning models in millet–groundnut intercrop canopy and a sugar cane–maize intercrop canopy, respectively.

For the instantaneous radiation transmission in early plant growth stages, or in the wide spacing plant canopies, the geometrical method may be more accurate than the statistical method, as has been reported by many scientists (e.g. Allen, 1974; Charles-Edwards and Thorpe, 1976; Mann et al., 1980; Norman and Welles, 1983; Whitfield, 1986; Gijzen and Goudriaan, 1989; Rührig et al., 1999; Marescal et al., 2000). In contrast, the statistical method may be used for the daily radiation transmission model. In the Ozier-Lafontaine et al. (1997) study, as well as the study of Wallace et al. (1990, 1991), similar plant stands were used, i.e. maize and sorghum, however, few studies on the radiation modelling in cereal–legume intercropping canopies were reported (e.g. Marshall and Willey, 1983). The objective in this study was, therefore, to build and test an instantaneous radiation transmission model for a cereal–legume intercrop canopy using the geometrical method, compared with the statistical method, and the daily model using the statistical method, and then to estimate the daily amount of radiation intercepted and used by each component crop.

2. Materials and methods

2.1. Model description of the instantaneous radiation transmission

In a row crop, the inter-row spacing is much wider than the intra-row spacing. Neglecting the intra-row spacing, the row can be assumed to be a rectangular hedgerow. Radiation turbid mediums between canopy and soil surfaces are crop foliage and the atmosphere (whose turbidity is assumed to be nil). The turbid layer thickness is the hedgerow height, and the vertical boundary between crop foliage and the atmosphere is determined by the hedgerow width and the inter-row spacing. In maize (Zea mays L.) and bean (Phaseolus vulgaris L.) alternative intercropping, the cross-section of rectangular hedgerows is divided into two horizontal layers: (i) between the top of maize and the top of beans (the first turbid layer) and (ii) between the top of beans and the surface of soil (the second turbid layer), because maize hedgerows are taller than bean hedgerows. The horizontal boundaries are determined by the hedgerow heights of maize and beans. The turbid mediums in the layers include maize foliage, bean foliage, maize–bean mixed foliage and the atmosphere. The vertical boundaries are determined by the hedgerow width of maize and beans and its inter-row spacing. The horizontal and vertical boundaries determine a specific turbid medium cell. The maximum turbid mediums are two for the first turbid layer and three for the second turbid layer, while the minimum turbid mediums are one for both layers. In each turbid layer, a vertical stripe of the turbid mediums is formed, and the combination of the stripe layers has a systematic pattern.
Assuming that both maize and beans have black leaves and random leaf dispersion and separating the product of canopy extinction coefficient, leaf area density (LAD) and radiation path length into the four classes of the turbid mediums, the direct radiation transmission on a horizontal surface from canopy surface to soil surface is given by the Beer’s law:

\[ I = I_0 \exp[-g_0 \cdot \Omega_{g,M,B} - g_0 \cdot \Omega_{g,M,B} - g_0 \cdot \Omega_{g,M,B}] \]  

(1)

where \( I \) and \( I_0 \) are the direct radiant flux densities at the surface of soil and the top of canopy, respectively; \( g_0 \) the canopy extinction coefficient (G-function: the average projection area of canopy elements onto a surface normal to the direction of the projection) at a given zenith angle \( \psi \); \( \Omega \) the LAD; \( \psi, \phi \) the total radiation path length from the top of the canopy surface to the soil surface at a given solar position (zenith angle \( \psi \), azimuth angle \( \phi \)), subscripts M, B, M/B and A denote maize, bean, the maize/bean mixture and the atmosphere, respectively. Actually, the product of \( g_0 \), \( \Omega \), \( \psi \) and \( \phi \) is zero, so that the equation is rewritten as follows:

\[ I = I_0 \exp[-g_0 \cdot \Omega_{g,M,B} + \Omega_{g,M,B} + \Omega_{g,M,B} + \Omega_{g,M,B}] \]  

(2)

where \( \Omega_{g,M,B} + \Omega_{g,M,B} + \Omega_{g,M,B} + \Omega_{g,M,B} \) are equal to radiation path length for the maize hedgerow and the bean hedgerow, respectively. The total diffuse radiation transmission can be derived by integrating the direct radiation attenuation function over the hemisphere (all zenith and azimuth angles), assuming a uniform overcast sky (Campbell and Norman, 1998).

In order to compare the geometrical method with the statistical method, the direct radiation transmission model is based on the statistical method. The assumption is made that maize and bean canopies in the intercropping are horizontally homogeneous, and then the model is given by

\[ I = I_0 \exp[-k_{g,M,M} + k_{g,M,B} + k_{g,B,M} + \Omega_{g,M,B} \Omega_{g,M,B} + \Omega_{g,M,B} + \Omega_{g,M,B} + \Omega_{g,M,B}] \]  

(3)

where \( k_g \) is the canopy extinction coefficient (K-function: the average projection area of canopy elements onto a horizontal surface) at a given zenith angle \( \psi \); \( L \) the leaf area index (LAI), and subscripts M and B denote maize and bean.

The \( G \) - and \( K \) -functions are given by

\[ G_\rho = \frac{\sqrt{2} \cos \psi + \sin^2 \psi}{x + 1.774(x + 1.182)^{1/3}} \]  

(4)

\[ k_\rho = \frac{\sqrt{2} \cos \psi + \sin^2 \psi}{x + 1.774(x + 1.182)^{1/3}} \]  

(5)

where \( x \) is the ratio of vertical to horizontal projections of canopy elements, \( \chi \rightarrow 0 \) for predominantly vertical leaf angle distributions and \( \chi \rightarrow \infty \) for predominantly horizontal leaf angle distributions, and also \( \chi = 1 \) for a spherical leaf angle distribution (Campbell and Norman, 1989). A field experiment was carried out during the 1998–1999 growing season in order to determine the \( G \) - and \( K \) -functions for maize and bean canopies (Tsubo, 2000). The fraction of photosynthetically active radiation (PAR) transmitted, \( \tau \), was measured under cloudless conditions at 9:00, 12:00 and 15:00 h of South African Standard Time (three different \( \psi \) ) during the vegetative stages. The canopy extinction coefficient (\( g_0 \) and \( k_0 \)) was estimated from the linear relationship between LAI and the natural logarithm of \( \tau \). Assuming uniform LAD in the hedgerow, LAD can be calculated weighting LAI by the ratio between the inter-row spacing (\( w_{\text{row}} \)) and the hedgerow cross-section width (\( w' \)), which is less than \( w_{\text{row}} \).
Fig. 1. The canopy extinction coefficient as a function of solar zenith angle.

Fig. 2. The co-ordinate system, \( \theta_a \): the difference between row azimuth and solar azimuth; \( \theta_b \): the angle of the radiation within the plane of a cross-section through the hedgerow perpendicular to the direction of the rows; \( \theta_c \): the angle between a vertical plane through the zenith and the beam and a vertical plane through the zenith and the hedgerow cross-section; \( AC(s_{\psi, \phi}) \): the length of the radiation path from the top to bottom of the hedgerow; \( BC(s_{\psi}) \): the length of the component of \( AC \) in the hedgerow cross-section; \( CD(s_{\psi}) \): the length of the horizontal component of \( BC \); \( s_f \): distance from the left-side of the first unit row traversed by radiation; \( s_l \): the distance from the left-side of the first unit row traversed by radiation; \( w' \): the hedgerow width; \( w_{row} \): the inter-row spacing.
a vertical plane through the zenith and the beam and a vertical plane through the zenith and the hedgerow cross-section. The relationships among angles are as follows:

\[
\cos \psi = \cos \theta_b \cos \theta_c
\]
(7)

\[
\sin \theta_c = \cos \theta_b \sin \psi
\]
(8)

AC \((s_{θc})\) is the length of the radiation path from the top to the bottom of the hedgerow, BC \((s_{θb})\) the length of the component of AC in the hedgerow cross-section, and CD \((s_{θc})\) the length of the horizontal component of BC. The relationships among lengths are as follows:

\[
x_{φ, ψ} = \frac{s_{θb}}{\cos \theta_b} = \frac{s_{θc}}{\cos \theta_b \sin \psi}
\]
(9)

The radiation path length of the horizontal component in the hedgerow cross-section \((s_{θb})\) is calculated by

\[
x_{b} = h \tan \theta_b
\]
(10)

When radiation traverses from the right-side of the hedgerow cross-section, \(θ_b\) is defined as a given distance from the left-side of the last unit row (the range is from the hedgerow to the next hedgerow, \(0 ≤ s_{b} < w_{row}\)) traversed by radiation. The total path length of the horizontal component in the hedgerow cross-section only for the hedgerow \((s'_{θb})\) with the hedgerow width \((w')\) is calculated by

\[
s'_{θb} = \begin{cases} 
(N-1)w' + (w' - s_{b}) + \theta_{l} & s_{b} ≤ w', \theta_{l} ≤ w' \\
(N-1)w' + \theta_{l} & s_{b} > w', \theta_{l} ≤ w' \\
Nw' + (w' - s_{b}) & s_{b} ≤ w', \theta_{l} > w' \\
Nw' & s_{b} > w', \theta_{l} > w' 
\end{cases}
\]
(11)

where \(N\) is the integer number of units of inter-row spacing \((w_{row})\) traversed by radiation and \(s_{b}\) the distance from the left-side of the first unit row traversed by radiation \((0 ≤ s_{b} < w_{row})\), which are calculated by

\[
N ≥ \frac{s_{b} + s_{0}}{w_{row}}
\]
(12)

\[
s_{l} = (s_{b} + s_{l}) - Nw_{row}
\]
(13)

A numerical integration is used to compute the radiation transmission per unit intercrop hedgerow. For the direct radiation transmission, the computation is made with class intervals of 0.1 m in the hedgerow cross-section, and then a simple average of them is computed. For the diffuse radiation transmission, the computation is made with class intervals of 10° for both zenith and azimuth angles at each class interval for the direct radiation.

2.2. Description of the daily radiation transmission model

When both canopy surfaces of maize and beans in the intercrop are assumed to be horizontally homogeneous, the total radiation interception is independent of crop height (Wallace et al., 1991). The daily radiation transmission is simply given by

\[
I = I_0 \exp(-K_M L_M - K_B L_B)
\]
(14)

where \(K_M\) and \(K_B\) are canopy extinction coefficients for maize and beans on a daily basis. The \(K_M\) is 0.43 and \(K_B\) is 0.64 for global PAR, which were determined during the 1996–1999 growing season (Tsubo, 2000).

2.3. Estimation of the daily radiation interception and use

The first turbid layer only includes maize turbid medium while the second turbid layer consists of maize and bean turbid mediums. The fraction of radiation intercepted by maize in the first turbid layer, \(F_{M1}\), is given by

\[
F_{M1} = 1 - \exp(-K_M L_{M1})
\]
(15)

where \(L_{M1}\) is maize LAI in the first turbid layer. Using the equation described by Keating and Carberry (1993), the fraction of radiation intercepted by maize and beans in the second turbid layer \(F_{M2}\) and \(F_{B}\), respectively, is given by

\[
F_{M2} = \frac{K_M L_{M2}}{K_M L_{M2} + K_B L_B} \times [1 - \exp(-K_M L_{M2} - K_B L_B)]
\]
(16)

\[
F_B = \frac{K_B L_B}{K_M L_{M2} + K_B L_B} \times [1 - \exp(-K_M L_{M2} - K_B L_B)]
\]
(17)

where \(L_{M1}\) and \(L_B\) are maize and bean LAI in the second turbid layer. Assuming that leaves are randomly
distributed in the hedgerows, $L_{M1}$ and $L_{M2}$ can be calculated as follows:

$$L_{M1} = h_M - h_B L_M$$  \hspace{1cm} (18)

$$L_{M2} = h_B h_M L_M$$  \hspace{1cm} (19)

where $h_M$ and $h_B$ are the height of maize and bean canopies.

Radiation use efficiency (RUE) of maize and beans ($\varepsilon_M$ and $\varepsilon_B$, respectively) is calculated by

$$\varepsilon_M = \frac{W_M}{I_0 (F_{M1} + F_{M2})}$$  \hspace{1cm} (20)

$$\varepsilon_B = \frac{W_B}{I_0 F_B}$$  \hspace{1cm} (21)

where $W_M$ and $W_B$ are dry matter for maize and beans, respectively.

2.4. Data collection

A field experiment was carried out on a fine sandy soil at the Soil Science experimental site of the University of the Free State (latitude 29°01′S, longitude 26°09′E, altitude 1354 m a.s.l.) during the 1999–2000 growing season. Alternate intercrops of maize and beans were planted on 12 January 2000. The seedling establishment was estimated to be 2 weeks after sowing. Supplemental irrigation and fertiliser were applied. The experimental treatment had row orientations NS and east–west (EW). The plot size was $18 \times 18$ m. The inter- and intra-row spacing for each crop were 1.00 and 0.15 m, respectively, corresponding to 6.67 plants m$^{-2}$.

Above-ground plant samples were harvested weekly from 28 to 49 days after planting (DAP) and the harvest area was $3 \text{ m}^2$. Leaf area of the harvested samples was measured using the L-3100 leaf area meter (LI-COR, Inc., Lincoln, NE, USA). The harvested samples were dried in an oven at 80°C for 3 days. Canopy height and row cross-section width for maize and beans were measured on the same days.

Incident global and diffuse PAR (0.4–0.7 μm wavelength) was measured above plant canopies using the LI-190SB quantum sensors (LI-COR Inc., Lincoln, NE, USA). For the diffuse component, a shade ring 15 mm in width and 70 mm in radius was mounted above the sensor. Transmitted PAR through the crop canopy was measured beneath the crop canopy using the LI-191SA line quantum sensors (LI-COR Inc., Lincoln, NE, USA). The linear quantum sensor was set perpendicularly to the crop row orientation at the soil surface. All PAR were recorded at intervals of 10 s. The readings were averaged hourly and stored in the CR10X datalogger (Campbell Scientific Inc., Logan, UT, USA). This radiation data was collected from 14 to 49 DAP.

2.5. Model evaluation

For comparison of the calculated value with the measured value, the correlation-based statistics were used with the deviation-based statistics (Willmott, 1981, 1982). The correlation-based analysis includes the coefficient of determination ($R^2$) and $F$-test. The deviation-based analysis includes mean bias error (MBE), root mean square error (RMSE) and the index of agreement ($d$)

$$\text{MBE} = \frac{1}{n} \sum_{i=1}^{n} (y_i - x_i)$$  \hspace{1cm} (22)

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - x_i)^2}$$  \hspace{1cm} (23)

$$d = 1 - \frac{\sum_{i=1}^{n} (y_i - x_i)^2}{\sum_{i=1}^{n} (y_i) + \sum_{i=1}^{n} (x_i)^2}$$  \hspace{1cm} (24)

where $x_i$ and $y_i$ are the measured and calculated values; $n$ the number of the paired set data; $x'_i = x_i - \bar{x}$; $y'_i = y_i - \bar{y}$; and $\bar{x}$ is the measured mean (Willmott, 1981, 1982).

3. Results and discussion

3.1. The geometrical method versus the statistical method

The geometrical method was compared with the statistical method. For example, the direct PAR transmission was computed near solar noon (12:30h South African Standard Time) on 28, 35, 42 and 49 DAP. Fig. 3 presents horizontal profiles of the fraction of
Fig. 3. Horizontal profiles of direct PAR transmission through the maize-bean alternate intercrop canopy at 12:30 South African Standard Time at the Soil Science experimental site of the University of the Free State, South Africa (latitude 29°01′ S, longitude 26°09′ E, altitude 1354 m above sea level). NS: north-south row orientation; EW: east-west row orientation.
The instantaneous total radiation transmission was evaluated on 28, 35, 42 and 49 DAP. Fig. 4 shows diurnal changes in the model output based on the geometrical method and the actual measurement. Reduction of the total PAR transmission was observed from 28 to 49 DAP. The total PAR transmission was greater at midday than in the early morning and late afternoon on all 4 days. Overall, the model harmonised with the measurement. For example, on 28 DAP (Fig. 4a), the model estimated the total PAR transmission well from sunrise to sunset in both NS and EW orientations. However, on 35 and 42 DAP (Fig. 4b and c), the total PAR transmission was underestimated at midday by 15% on average, and on 49 DAP (Fig. 4d) it was also underestimated in NS row direction. The underestimation may have resulted from sunflecks (Ozier-Lafontaine et al., 1997). Fig. 5 shows the model output based on the geometrical method against the measurement of the instantaneous total PAR transmission. With respect to the deviation-based analysis, MBE was 30 \( \mu \text{mol m}^{-2} \text{s}^{-1} \), RMSE was 81 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) and the index of agreement \((d)\) was 0.99. With reference to the correlation-based analysis, the slope \((=0.94 \mu \text{mol} \mu \text{mol}^{-1})\) and the intercept \((=2.59 \mu \text{mol m}^{-2} \text{s}^{-1})\) were not significantly different from 1 and 0, respectively, at \( P \)-value = 0.01 \((R^2 = 0.97)\). From these statistics it was evaluated that the geometrical model accurately predicted the measured total PAR transmitted.

3.3. Validation of the daily radiation transmission model

The daily radiation model was studied between 28 and 49 DAP. Because LAI was measured at 28, 35, 42 and 49, unknown LAI was estimated by the model outputs followed the measured values and the total PAR transmission decreased during the period. The fraction of total PAR was on average 0.72 on 28 DAP, 0.55 on 35 DAP, 0.37 on 42 DAP and 0.12 on 49 DAP. The model was made in the 1998–1999 growing season and validated in the 1999–2000 growing season. Concerning the deviation-based statistics, MBE and RMSE were 0.16 and 2.32 \( \mu \text{mol m}^{-2} \text{s}^{-1} \), respectively, and the index of agreement \((d)\) was 0.99. In the correlation-based statistics, the slope \((=0.96 \mu \text{mol} \mu \text{mol}^{-1})\) and the intercept \((=0.61 \mu \text{mol m}^{-2} \text{s}^{-1})\) were not significantly different from 1 and 0, respectively, at \( P \)-value = 0.01 \((R^2 = 0.94)\). From these statistics the conclusion is therefore drawn that the model results were valid.

3.4. Evaluation of the daily radiation interception

Fig. 7 shows the changes in the fraction of PAR intercepted by maize and beans during the early
vegetative growth stage. Estimated PAR interception by maize dramatically increased during the period whereas estimated PAR interception by beans gradually increased. This re-emphasises that canopy growth reflects crop radiation interception, and that maize is the dominant crop in the maize–bean intercropping. Difference in the global PAR interception between maize and beans was greater in the NS row than in
the EW row at 35, 42 and 49 DAP. This may be explained by the relationship of LAI and radiation interception. The NS row-oriented maize intercepted more PAR at the upper canopy (only maize forage) than the EW maize, because the NS maize had 60% greater LAI than the EW maize, in this study, (Table 1) although Tsubo (2000) and Tsubo et al. (2001) reported there was no difference in radiation interception by a maize-bean intercrop canopy between NS and EW row orientations. In other words, the upper maize canopy in the EW row transmitted more PAR than that in the NS row. More PAR reached the lower canopy (both maize and bean forage) in the EW row than in the NS row, and the NS-oriented bean crop was equivalent in LAI to the EW-oriented beans. So, the amount of PAR intercepted by the EW beans was higher than that by the NS beans.

Table 1

<table>
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<th>DAP</th>
<th>Maize</th>
<th>Beans</th>
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<tbody>
<tr>
<td></td>
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<td>EW</td>
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<td>LAI (m² m⁻²)</td>
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<td>Biomass (g m⁻²)</td>
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</table>

*NS: north–south row orientation; EW: east–west row orientation.
3.5. Evaluation of the daily radiation use

Fig. 8 presents PAR use efficiency of each component crop. RUE was 0.58 g mol\(^{-1}\) for maize and 0.33 g mol\(^{-1}\) for beans. This was equivalent to 4.7% and 2.7% of incident PAR for maize and beans, respectively, using the conversion factors of 17.5 kJ g\(^{-1}\) and 4.6 μmol J\(^{-1}\) (Sivakumar and Virmani, 1980).

Comparing the present growth efficiency with the growth efficiency, 4.7% for sole maize and 2.4% for
sole beans (see Chapter 3), the intercropping was equivalent in growth efficiency of maize to the sole cropping, whereas beans had 12.5% greater RUE in intercropping than in sole cropping. This could lead to a yield advantage of the intercropping in this region (Tsubo, 2000). A similar result was reported by Marshall and Willey (1983) in millet–groundnut intercropping. In their study, intercropped millet had a similar RUE to sole cropped millet, but groundnut had 45% greater RUE in intercropping than sole cropping. This explained that the intercrop yield advantage resulted from the increased RUE of groundnut (Keating and Carberry, 1993). In the study of Harris et al. (1987) on sorghum–groundnut intercropping, intercropped sorghum had 20% lower RUE than sole cropped sorghum, though by contrast intercropped groundnut had about 20% higher RUE than sole cropped groundnut. The decreased RUE of sorghum and the increased RUE of groundnut resulted in no intercrop yield advantage under that situation (Keating and Carberry, 1993).

4. Conclusions

Both instantaneous and daily models for radiation transmission were validated with high accuracy through the alternate intercrop canopy. In the geometrical method, the different instantaneous radiation transmission was computed at different locations between rows, however, the method was similar in the transmitted radiation per unit area to the statistical method. F and RUE of each component crop in the intercropping were determined assuming that the canopy included two crop turbid layers. The estimated PAR intercepted by maize was greater than that by beans because maize was the dominant crop. Concerning RUE, no difference between intercropping and sole cropping was found on RUE of maize, whereas the intercropped beans had greater RUE than the sole cropped beans, which might explain the yield advantage.

References


