Rainfall Interception and Radiation Regime in a Plantain Canopy

O.F. Jiménez
J.P. Lhomme
Centro Agronómico Tropical
de Investigación y Enseñanza
(CATIE)
7170 Turrialba
Costa Rica

Fruits, vol. 49, n°2, p. 133-139

Rainfall Interception and Radiation Regime in a Plantain Canopy.

ABSTRACT

The present paper presents experimental results on the microclimate in a plantain plantation relative to black Sigatoka epidemiology. Since this fungal disease is very sensitive to leaf wetness and temperature, data were collected on the amount of water stored by leaves and on the radiation regime within the canopy. Rainfall interception was determined using 65 rainfall events recorded in 1989. Internal precipitation and stemflow were measured in a canopy with a leaf area index (LAI) of about 2. The storage capacity of the canopy was found to be 1.9 mm. Measurements of radiation penetration in another canopy (with a LAI of 3.4) revealed that incoming solar radiation absorbed by the canopy was 61 ± 7%.

KEYWORDS

Plantains, canopy, microclimate, rainwater, solar energy.

La rétention en eau du feuillage et la pénétration du rayonnement solaire dans un couvert de bananier plantain.

RÉSUMÉ

Des données expérimentales sur le microclimat et ses conséquences sur l'épidémiologie de la Sigatoka noire sont analysées dans une plantation de bananier plantain. Le pathogène responsable de cette maladie étant très sensible à la durée d'humectation et à la température de la feuille, la quantité d'eau stockée par le couvert et le régime de rayonnement à l'intérieur de la plantation ont été étudiés. L'interception de la pluie a été déterminée à partir de 65 chutes de pluies enregistrées en 1989. Les précipitations sous le couvert et l'écoulement le long des troncs ont été mesurés dans un couvert d'indice foliaire égal à 2. La capacité de rétention en eau du feuillage est égale à 1,9 mm. Des mesures de pénétration du rayonnement solaire faites dans une autre plantation (avec un indice de surface foliaire de 3,4) montrent que le pourcentage de rayonnement solaire incident absorbé par le couvert est de 61 ± 7 %.

MOTS CLÉS

Banane plantain, couvert, microclimat, eau de pluie, énergie solaire.

Intercepción de la lluvia y régimen de radiación en una cobertura de plátano.

RESUMEN

Esta publicación presenta algunos resultados sobre el microclima dentro de una plantación de plátano en relación con la epidemiología de la Sigatoka Negra. El hongo causante de esta enfermedad es muy sensible a la duración de mojadura y a la temperatura de la hoja. El estudio fue realizado con el propósito de obtener datos experimentales sobre la cantidad de agua almacenada por el dosel y sobre el régimen de radiación. La intercepción de lluvia fue determinada usando 65 eventos de lluvia registrados durante 1989. La precipitación interna y la escorrentía por los tallos fueron medidas en un dosel con un índice de área foliar de 2. La capacidad de almacenamiento del dosel fue de 1,9 mm. Mediciones de penetración de la radiación, realizadas sobre otra plantación (con un IAF de 3,4), muestran que el porcentaje de radiación solar incidente absorbida por el dosel representa 61 ± 7 %.

PALABRAS CLAVES

Plátano, cubierta de copas, microclima, agua de lluvia, energía solar.

introduction

Plantain production is an important activity in the humid tropics of America. Until now, this production has been mainly for subsistence and domestic market supply, but the plantain export potential has increased considerably in recent years. A main factor limiting production is black Sigatoka disease, caused by the fungus *Mycosphaerella fijiensis* (STOVER and SIMMONDS, 1987). In Central America, for instance, black Sigatoka is the most damaging disease of banana and plantain, accounting for 27% of production costs (JACOME and SCHUH, 1992).

All pathogens of plant aerial parts depend to some extent on weather conditions for their development and dissemination. For fungal diseases, and black Sigatoka in particular, leaf wetness and temperature are important factors for development of the pathogen. The duration of surface wetness determines the probability of infection. Studies have been conducted in controlled environments to evaluate the influence of temperature and leaf wetness duration on development of the disease (JACOME *et al.*, 1991; JACOME and SCHUH, 1992). However, very little information is available on the microclimate of plantain plantations, and it would be unsuitable to extrapolate data for other species due to the special structure of plantain canopies. The orientation of leaves on plantain or banana trees varies with age, from vertical at the time of emergence (candle leaf), to nearly horizontal and lower for the most mature leaves. The first completely expanded leaf (flag leaf) is oriented at an angle of about 45° from vertical (Figure 1).

The present study on a plantain canopy was conducted to obtain experimental data on rainfall interception and radiation regime, two important factors determining the spread of black Sigatoka disease. Rainfall interception and dew occurrence (LHOMME and JIMÉNEZ, 1992) are responsible for moisture persistence on leaves and thus have to be accounted for in calculating wetness duration. Radiation regime is directly linked with leaf temperature and is also required to estimate the water evaporation rate on leaves.

rainfall interception

theory

For any storm, the interception loss (I) by a canopy can be expressed as the difference between incident rainfall or gross rainfall (P_g) and net precipitation (P_n). P_n is the amount of rainfall reaching the soil surface, i.e. the sum of throughfall (T) and stemflow (S) (RUTTER, 1975):

$$I = P_g - P_n \quad \text{with} \quad P_n = T + S \qquad (1)$$

Throughfall (also called internal precipitation) represents a combination of water dripping from the canopy and that falling directly through gaps. Stemflow is rainfall diverted to the soil along the stems. Interception loss represents water which is either absorbed by aerial parts of the plants, or evaporated from their surfaces. For any rainfall large enough to saturate the canopy, it is possible to express the interception loss as the sum of three terms:

$$I = E + A + C \qquad (2)$$

where E is the amount of intercepted water evaporated during the rainfall, A is the amount of intercepted water absorbed during the same event, and C is the storage capacity, defined as the amount of water remaining on the canopy at the end of the rainfall, if it is completely saturated.

The A variable is usually small in comparison to evaporation (RUTTER, 1975), and thus neglected. The plantain leaf characteristics, particularly their funnel-shaped insertion on the stem of the plant, can increase the storage capacity by retaining water in leaf axils. Interception is generally determined by measuring P_g and P_n simultaneously. If A and E are disregarded, the canopy storage capacity C can be calculated from equation (2), equating C with I.

measurements

The experiment was carried out on a plantain plantation (Horn plantain variety) located at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), in the Turrialba valley (9°53'N), Costa Rica, at about 600 m elevation. The climate of the valley is tropical humid, with mean annual rainfall of 2600 mm and mean temperature of 21 °C. The experiment was conducted from December 1988 to December 1989. The plantation was 2 years old, covering an area of about 1 ha at a density of 1322 plants/ha. The plants were spaced at 2.75 m. The leaf area index (LAI) was determined by measuring the leaf area of each plant on a representative square of 100 m². The length (l) and the width (w) of each leaf were measured, and its area (a) was inferred from the following empirical relationship, a = 0.81 (l.w), previously worked out by digitizing a sample of 40 leaves (JIMÉNEZ, 1994). The LAI obtained by this technique was close to 2, with most of the leaves located between 2 and 5 m above the soil surface. With an individual rainy event defined as a rainfall preceded and followed by at least 6 h without rain (RUTTER, 1967), 65 individual rainfall events were registered and statistically analysed.

Incident and throughfall were measured by means of linear PVC raingauges 3 m long, with a reception area of 4 000 cm², connected to 25 l plastic buckets to collect the water. They were installed at a height of 50 cm to avoid splashing from the soil. Two of these raingauges were located outside the plantation along with a 203 mm siphon raingauge. Ten of them were randomly placed within the plantation to measure throughfall. For each rainfall event, incident rainfall P_g and throughfall T were calculated as means of the values given by the raingauges.

Stemflow was measured on 8 plants. Stemflow was collected in collars made of half plastic hosepipe wound around the stem and attached to the trunk with plasticine. These hoses were connected to plastic buckets to collect the water.

results

Table 1 shows the results obtained from the 65 rainfall events recorded during the experiment. They ranged from 0.3 mm to 33.4 mm. The results were expressed as a percentage of incident rainfall. When the amount of rainfall increased, the percentage of interception tended to decrease from 18% for $P_g < 5.0$ mm to 8% for $P_g > 15$ mm, whereas stemflow remained almost constant at 9%. Throughfall thus increased from 73% to 83% for the same classes. In Table 2, the results (expressed as a percentage) are given for different classes of rainfall intensity (R). The same trends can be noted. Interception tended to decrease as R increased and throughfall remained constant.

Figure 1
Typical plantain plant with sucker before flowering.

Interception loss is generally expressed by a linear regression as a function of incident rainfall (BLAKE, 1975; RUTTER, 1975):

$$I = aP_g + b \tag{3}$$

Table 1
Throughfall (T), stemflow (S) and interception (I), expressed as a percentage of incident rainfall (P_g), with the corresponding standard deviations, for different classes of incident rainfall.

P_g (mm)	Number of events	T (%)	S (%)	I (%)
$P_g < 5.0$	26	73 ± 11	9 ± 3	18 ±13
$5.0 < P_g < 15.0$	24	81 ± 6	9 ± 4	10 ± 4
$P_g > 15.0$	15	83 ± 4	9 ± 3	8 ± 2
all events	65	78 ± 9	9 ± 4	13 ±10

Table 2
Percentage of throughfall (T), stemflow (S) and interception (I) for different classes of rainfall intensity (R), with the corresponding standard deviations.

R (mm/h)	**Number of events**	**T (%)**	**S (%)**	**I (%)**
R < 1.5	25	75 ± 12	9 ± 4	16 ±14
1.5 < R < 3.0	21	82 ± 5	9 ± 3	9 ± 4
R > 3.0	19	80 ± 6	9 ± 3	11 ± 6

In Figure 2, the interception loss for each of the 65 events recorded in the experiment is plotted against gross precipitation. The regression line was calculated as follows: a = 0.0625 and b = 0.249 with $r^2 = 0.81$.

In Figure 3, net precipitation P_n is plotted against gross precipitation P_g. The storage capacity C was estimated according to the method described by LEYTON *et al.* (1967). Using this method, C was considered to be equal to the y-intercept of the regression line, with P_n being a function of P_g, and a slope of 1, since, from equations (1) and (2), $P_n = P_g - C$. Storms must be heavy enough to completely wet the canopy for this derivation to be accurate (RUTTER, 1975). Consequently, only P_g values greater than 15 mm were taken into account. For these values, a regression line was drawn parallel to the bisecting line, and the storage capacity C was graphically determined as the y-intercept of this regression line. The value obtained was approximately 1.9 mm. When C was calculated as the mean of $P_g - P_n$ for $P_g >$ 15 mm, we obtained C = 1.83 mm with a standard deviation of 0.45 mm. There was close agreement between both results, suggesting that the real storage capacity was around 1.9 mm. This value is slightly higher than those generally obtained for coniferous forests in temperate climates: RUTTER (1975) found 1.6 mm for a forest of *Pinus sylvestris* and LEYTON *et al.* (1967) 1.5 mm for a forest of *Picea abies*. In a study of individual trees in a tropical rainforest, HERWITZ (1985) found that between 2.2 and 8.3 mm of water per unit projected crown area were required to completely saturate the canopy (trunks included). However, LLOYD *et al.* (1988) reported a value of 0.74 mm for the storage capacity of the Amazonian rain forest.

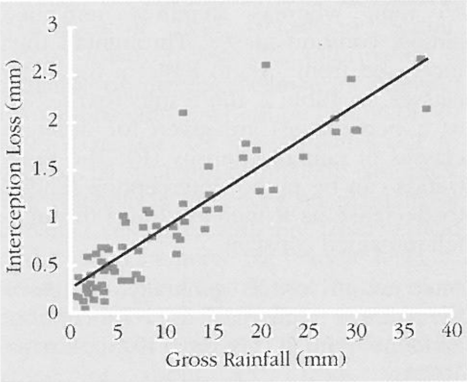

Figure 2
Interception loss (I) as a function of gross rainfall (P_g) and the corresponding regression line ($I=0.0625P_g+0.249$).

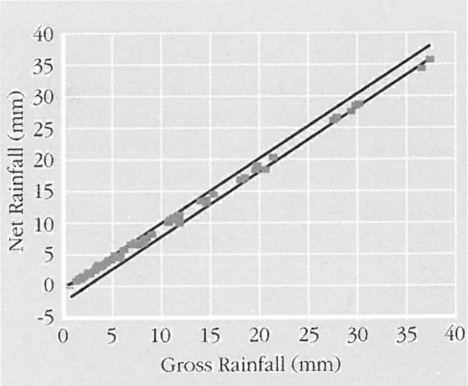

Figure 3
Net precipitation (P_n) as a function of gross rainfall (P_g) with the lines y=x and y=x-1.9 used to determine the storage capacity of the canopy.

radiation regime

theory

The overall solar radiation absorbed by a canopy R_a can be expressed as (ASRAR *et al.*, 1984; VARLET-GRANCHER *et al.*, 1989):

$$R_a = R_i - R_t - R_r + R_{rs} \qquad (4)$$

where R_i is the total downward solar radiation, R_t is the solar radiation transmitted by the canopy, R_r is the solar radiation reflected by the canopy and R_{rs} is the solar radiation reflected by the soil surface. The same equation applies for photosynthetic active radiation (PAR).

To describe the vertical attenuation of radiation within the crop canopy, it is common practice to use an exponential function of the Beer's law type (SAEKI, 1963; RUSSEL *et al.*, 1989):

$$R_i(z) = R_i \exp[-kL(z)] \qquad (5)$$

where R_i is the incoming flux of radiation above the canopy, R_i (z) is the flux density of radiation at level z within the canopy, L (z) is the downward cumulative leaf area index and k is the attenuation coefficient, taken as constant for a given canopy. k depends on the geometry of radiation with respect to the architecture of foliage (MONTEITH and UNSWORTH, 1990). Beer's law can be applied to both total solar radiation and photosynthetic active radiation, but it is obviously an empirical relation that is only valid for the conditions under which it is determined.

measurements

The measurements were done in September 1991 on a plantain plantation (Horn plantain variety), also located in CATIE's experimental fields in the Turrialba valley. The plantation was 3 years old, planted in rows at a density of 1600 plants per hectare. The distance between rows and between plants in the same row was 2.5 m, and there was a displacement of 1.25 m (50%) between the plants of two consecutive rows. It was the beginning of the flowering period. The average height of the plantation was 4.6 m (pseudostem height was about 3.1 m), and there were no leaves below the height of 1 m.

Incident (solar and active photosynthetic) radiation was measured outside the plantation with Li-cor radiometers. The radiation reflected by the canopy and by the soil surface was measured by the same types of radiometer, set in an inverted position, respectively 2.5 m above the top of the canopy and 0.8 m above the soil surface. Transmitted radiation was measured at the height of 1 m, since there were no leaves below this height.

To measure the solar radiation profile, four Delta-T linear radiometers (TSL type) were set at 1, 2, 3 and 4 m above the soil surface. For the photosynthetic active radiation, Li-cor linear sensors were used and set at the same heights above the soil surface. The profiles were alternatively measured on each side of the triangle formed by three adjacent plants. The linear radiometers were moved daily. All data were logged as hourly values on a Li-1000 data-logger (Li-cor). All sensors were precalibrated according to reference radiometers.

results

The leaf area index was determined at two different sites, close to where the measurements taken, using the previously described technique (cf. rainfall interception). It was found to be 3.4 (higher than for the canopy investigated for rainfall interception). Table 3 gives the different components of radiation balance (solar and photosynthetic active) of the canopy, expressed as a percentage of incoming radiation. They represent means calculated from 189 hourly measurements for solar radiation, and 121 hourly measurements for PAR. The radiation reflected by the canopy was found to be 20% of the downward incident radiation for total solar radiation, but only 4% for PAR. Figures 4 and 5 show time courses of different radiation balance components for two typical days (one sunny and the other cloudy).

Table 3
Radiation balance components in a plantain canopy, expressed as a percentage of incoming radiation (R_i), with the corresponding standard deviations. R_r: radiation reflected by the canopy; R_t: transmitted radiation; R_{rs}: radiation reflected by the soil surface; R_a: radiation absorbed by the canopy.

	solar radiation	**photosynthetic active radiation (PAR)**
R_i (%)	100	100
R_r (%)	20 ± 1	4 ± 0.5
R_t (%)	29 ± 6	34 ± 8
R_{rs} (%)	9 ± 2	3 ± 0.5
R_a (%)	61 ± 7	66 ± 13

Table 4
Mean attenuation profile for total solar radiation (R_{si}) and photosynthetic active radiation (R_{pi}). z is the height above the soil surface. LAI is the cumulative leaf area index from the top to the bottom of the canopy.

z (m)	**4**	**3**	**2**	**1**
LAI (m^2/m^2)	1.4	2.5	3.1	3.4
$R_{si}(z)/R_{si}$	0.53	0.35	0.33	0.29
$R_{pi}(z)/R_{pi}$	0.52	0.39	0.38	0.34

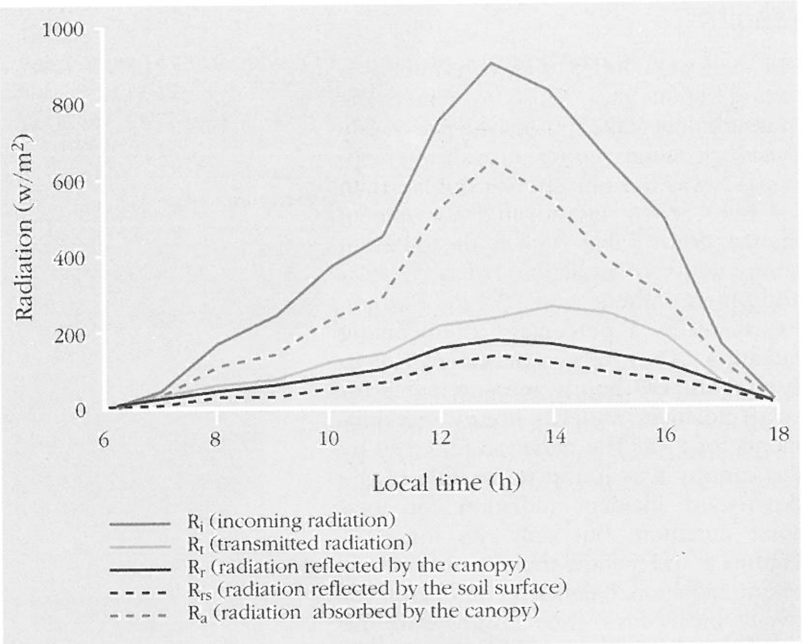

Figure 4
Diurnal variations of the different solar radiation balance components (hourly values) during a sunny day (25 August 1991).

Figure 5
Diurnal variations of the different photosynthetic active radiation balance components (hourly values) during a cloudy day (6 September 1991).

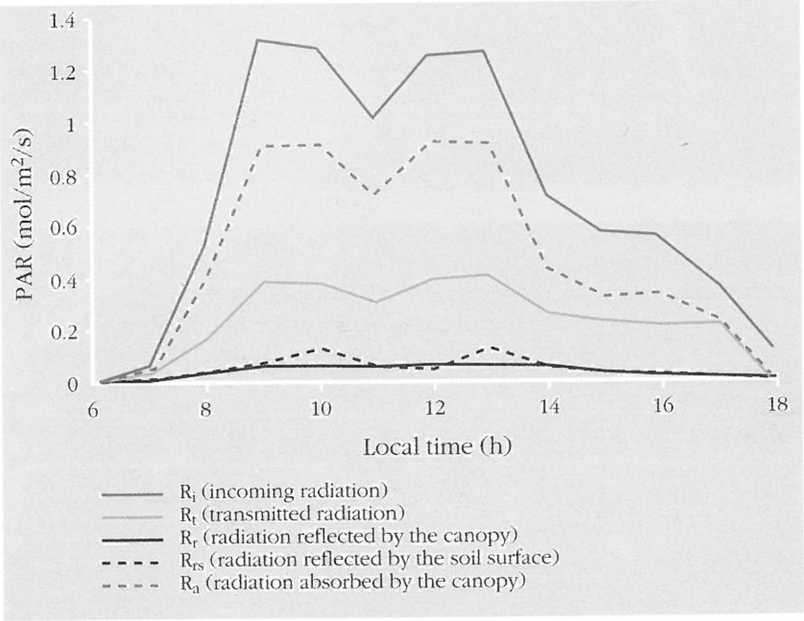

Table 4 shows the mean leaf area profile, measured in the plantation, and the mean attenuation profile for the two types of radiation, expressed as a fraction of incoming radiation. The Beer's law k coefficient (equation (5)) was determined using the hourly profiles (189 and 121, for solar and photosynthetic active radiations respectively). For each hourly profile, a k value was calculated by linear regression, and the mean of all of these values was retained. For solar radiation, $k = 0.36$ with a standard deviation of $\sigma = 0.06$. In previous reports, k generally varied from about 0.2 for plants with mainly vertical leaves (*Gladiolus*) to about 1 for stands with predominantly horizontal leaves, e.g. sunflower (MONTEITH and UNSWORTH, 1990). For photosynthetic active radiation, $k = 0.33$ with $\sigma = 0.07$.

● ● ● ● conclusion

Incident rainfall, throughfall and stemflow were measured on a plantain canopy with a LAI of 2, during 65 rainfall events in 1989. Mean throughfall and stemflow were 78% and 9% of incident rainfall, which means that interception loss was 13%. The canopy storage capacity (defined as the maximum amount of water stored by the canopy) was determined using two different methods and found to be about 1.9 mm. The plantain canopy radiation regime was studied using a canopy with a LAI of 3.4. The percentage of incoming radiation absorbed by the canopy was found to be 61% and 66% for solar radiation and photosynhetic active radiation (PAR) respectively. The Beer's law attenuation coefficients were 0.36 ± 0.06 and 0.33 ± 0.07 for solar radiation and PAR respectively.

Wetness duration depends upon the amount of water stored on the leaves after rainfall and upon the evaporation rate, which is linked with the radiation regime. Since the risk of infection by black Sigatoka is closely correlated with wetness duration, the present results should help in formulating risk forcasting and disease management models. ●

references

ASRAR G., HIPPS L.E., KANEMASU E.T., 1984.
Assessing solar energy and water use efficiencies in winter wheat: a case study. *Agric. For. Meteorol.,* 31, 47-58.

BLAKE G.J., 1975.
The interception process. In: *Prediction in Catchment Hydrology,* Canberra (Australie): T.G. Chapman and F.X. Dunin (eds.) Australian Academy of Science.

HERWITZ S.R., 1985.
Interception storage capacities of tropical rainforest canopy trees. *J. Hydrol.,* 77, 237-252.

JACOME L.H., SCHUH W., STEVENSON R.E., 1991.
Effect of temperature and relative humidity on germination and germ tube development of *Mycosphaerella fijiensis* cv. *difformis. Phytopathology,* 81, 1480-1485.

JACOME L.H., SCHUH W., 1992.
Effects of leaf wetness duration and temperature on development of black Sigatoka disease on banana infected by *Mycosphaerella fijiensis* cv. *difformis. Phytopathology,* 82, 515-520.

JIMÉNEZ O.F., 1994.
Etudes agrométéorologiques appliquées à la lutte contre la Sigatoka noire (*Mycosphaerella fijiensis*) du bananier plantain (*Musa AAB*). Paris (France) : Institut National Agronomique Paris-Grignon, mémoire de thèse.

LEYTON L., REYNOLDS E.R.C., THOMPSON F.B., 1967.
Rainfall interception in forest and moorland. In: *International Symposium on Forest Hydrology.* Oxford (UK): W.E. Sopper and H.W. Lull.

LHOMME J.P., JIMÉNEZ O.F., 1992.
Estimating dew duration on banana and plantain leaves from standard meteorological observations. *Agric. For. Meteorol.,* 62, 263-274.

LLOYD C.R., GASH J.H.C., SHUTTLEWORTH W.J., MARQUES F.A. DE O., 1988.
The measurement and modelling of rainfall interception by Amazonian rain forest. *Agric. For. Meteorol.,* 43, 277-294.

MONTEITH J.L., UNSWORTH M.H., 1990.
Principles of Environmental Physics. London (UK): Edward Arnold, 291 p.

RUSSEL G., JARVIS P.G., MONTEITH J.L., 1989.
Absorption of radiation by canopies and stand growth. In: *Plant Canopies: their Growth, Form and Function.* Cambridge (UK): G. Russel, B. Marshal and P.G. Jarvis (eds.). Cambridge University Press, 21-39.

RUTTER A.J., 1967.
An analysis of evaporation from a stand of Scotts pine. In: *International Symposium on Forest Hydrology.* Oxford (UK): W.E. Sopper and H.W. Lull.

RUTTER A.J., 1975.
The hydrological cycle in vegetation. In: *Vegetation and the Atmosphere,* vol. 1. Londres (UK): Academic Press, J.L. Monteith (ed.).

SAEKI T., 1963.
Light relations in plant communities. In: *Environmental Control of Plant Growth,* L.T. Evans (ed.). New York (USA): Academic Press, 79-94.

STOVER R.H., SIMMONDS N.W., 1987.
Bananas. London (Angleterre) : Longman (ed.), 468 p., Tropical Agriculture Series.

VARLET-GRANCHER C., GOSSE G., CHARTIER M., SINOQUET H., BONHOMME R., ALLIRAND J.M., 1989.
Mise au point : rayonnement solaire absorbé ou intercepté par un couvert végétal. *Agronomie,* 9, 419-439.