

Estimating dew duration on banana and plantain leaves from standard meteorological observations

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(Received 22 February 1991; revision accepted 28 June 1992)

ABSTRACT

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

Black Sigatoka is an important fungal disease of bananas and plantains. Dew duration on the upper leaves of these plants (Leaves 0 and 1) is an important factor in the development of the disease. A general dew estimation scheme, based on an energy budget approach, was adapted to the particular case of banana and plantain upper leaves in order to provide a tool for Black Sigatoka management. This scheme allows the estimation of dew duration from standard weather station measurements of air temperature and humidity, wind velocity, solar radiation and cloud cover. Values of dew duration estimated by this scheme were compared with observed values on plantain during 18 nights. On average, the differences between observed and estimated values were less than 1 h.

INTRODUCTION

Leaf wetness duration is an important aspect of plant epidemiology and protection because it strongly affects the development of many pathogens (Royle and Butler, 1986). The persistence of free water on leaves is often required for spores to germinate and infect the host. It is the case of Black Sigatoka, which is an important disease of banana and plantain in the humid tropics, caused by the fungus *Mycosphaerella fijiensis* (Leach, 1964). In the last two decades the disease has spread from the Sigatoka valley in the island of Fiji, its centre of origin, to Southeast Asia, Africa and the Americas (Stover and Simmonds, 1987). Black Sigatoka has become the most damaging and costly disease of banana and plantain, and represents a serious threat in many tropical countries because banana and plantain are important staples in many people's diets.

A certain duration of wetness is required to initiate ascospore discharge

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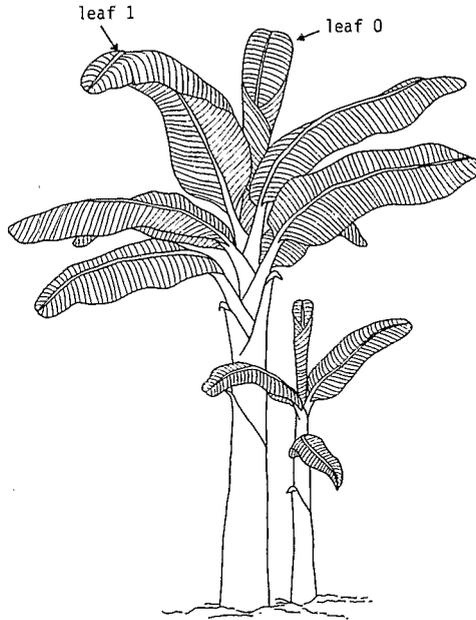


Fig. 1. Typical plantain plant with its sucker before flowering.

from leaves bearing mature perithecia. Rain or dew is also required to dislodge conidia from conidiophores which emerge from stomata. Spores deposited by the wind on a leaf need the presence of a film of free water over the leaf in order to germinate and infect the host. The germination tube produced by the spore penetrates the leaf tissue through the stomata. Since stomata are five times as numerous on the under surface as on the upper surface (Stover and Simmonds, 1987), infection generally occurs on the lower side of the leaves. The upper leaves are the most vulnerable to infection, since, owing to their vertical position, the under sides are directly exposed to the wind which carries the ascospores.

The orientation of leaves on banana or plantain plants varies with age, from vertical at the time of emergence, to nearly horizontal and below for the most mature leaves (Fig. 1). Leaf location is indicated by numbering from the youngest unfurled leaf, which is marked 0 and called the candle leaf, consecutively downward to the oldest leaf. At emergence from the pseudostem, the lamina appears as a tightly rolled vertical cylinder, the right half rolled upon itself, and the left half rolled around the right half with its under side outwards (Fig. 2, Stage 1). Unrolling starts at the leaf tip and progresses downwards (Fig. 2, Stages 2 and 3). The first completely expanded leaf is marked 1 and called the flag leaf. From an epidemiological point of view, the two first leaves are the most important for their vulnerability to an infection by the fungus, and this is the reason why only these two first leaves will be considered in this

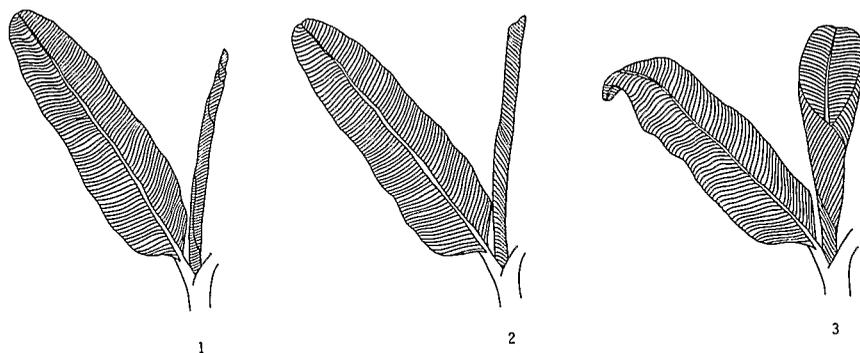


Fig. 2. Different stages in the unrolling of the candle leaf of a plantain plant.

study. Furthermore, since banana and plantain leaves senesce rapidly and fall, the infection of old leaves is not important because lesions do not have time to develop and reduce the photosynthesis rate.

In the humid tropics of Central America most of rainy events are convective rains, which generally occur between 15:00 and 20:00 h. They are only responsible for approximately 25% of the total wetting duration, the rest being as a result of dew. Models have been devised to predict wetting duration by dew deposition on various mid-latitude crops (Pedro and Gillespie, 1982a, b; Gillespie and Barr, 1984), as well as for tropical crops such as cocoa (Monteith and Butler, 1979). This paper describes the adaptation for banana and plantain of a model based on an energy balance approach and originally developed by Pedro and Gillespie (1982b) for mid-latitude crops. It allows one to estimate dew duration on the upper two leaves of banana and plantain (Leaves 0 and 1) from standard weather data.

MODEL OPERATION

General principles governing dew deposition have been described by Monteith (1963). Dew deposition occurs every time leaf temperature T_L is lower than the dew point temperature of the air, i.e. $e^*(T_L) < e_a$, where e_a is the vapour pressure of air and $e^*(T)$ is the saturation vapour pressure at temperature T . Leaf temperature can be estimated from the energy balance concept applied to a unit area of leaf, assuming heat storage is insignificant. The net radiation absorbed by a unit area of leaf is equal to the sensible and latent heat fluxes exchanged between the leaf and the surrounding air. Since, as a first approximation, the candle leaf has the form of a vertical cylinder, we shall assume that there is no energy exchange within the inner part of the cylinder. Only the under or outer side of the leaf is considered to exchange energy. The flag leaf (Leaf 1) will be considered as an inclined plane which makes an angle α with the horizontal plane and exchanges energy from both

sides. If T_L denotes the leaf temperature and T_a the air temperature, by putting $\delta L = T_L - T_a$ and linearizing T_L^4 and $e^*(T_L)$, the energy balance equation can be solved with respect to δT (Kreith and Sellers, 1975; Pedro and Gillespie, 1982) and yields

$$\delta T = \frac{\alpha R_s + \varepsilon R_l - n\varepsilon\sigma T_a^4 - nhD_a/\gamma}{4n\varepsilon\sigma T_a^3 + nh(1 + s/\gamma)} \quad (1)$$

R_s is the incoming short wave radiation and R_l is the incoming long wave radiation (on both sides for the flag leaf; α is leaf short-wave absorptivity, ε is leaf emissivity and σ is the Stefan-Boltzmann constant. $n = 1$ for the candle leaf, assuming radiative balance of the inner side of the cylinder to be nil, and $n = 2$ for the flag leaf. h is the transfer coefficient assumed to be the same for heat and water vapour, γ is the psychrometric constant, D_a is the air saturation deficit ($e^*(T_a) - e_a$) and s the rate of change of e^* with temperature.

Heat transfer coefficient is estimated from the classical relationship which involves the Nusselt number (Nu): $h = k \text{Nu}/d$, where k is the thermal conductivity of air and d a characteristic dimension of the body (width for a flat leaf and diameter for a cylinder). In forced convection the Nusselt number can be calculated from the Reynolds number (Re): $\text{Nu} = A \text{Re}^n$, with $A = 0.6$ and $n = 0.5$ for a flat plate and $A = 0.24$ and $n = 0.6$ for a vertical cylinder (Monteith and Unsworth, 1990). Leaf 1 width was set at 70 cm and for the candle leaf diameter the mean value of 5 cm was used. Wind velocity was directly registered at the level of the leaves within the plantation.

The incoming long wave and short wave radiations are calculated from the standard radiations (received on a horizontal plane) using the relationships given in the appendix. Leaf short-wave absorptivity (α) and canopy albedo (a) were measured using Li-cor sensors. α was found to be equal to 0.3 and a to 0.25 for both plantations. Leaf emissivity ε was assumed to be equal to 0.95. The average value of the inclination angle of Leaf 1 to the horizontal (α) was found to be 50° .

The standard upward and downward long wave radiations have been estimated from air temperature, air humidity and cloud cover by making use of the semi-empirical formulae given by Monteith and Unsworth (1990). Since in this study only the total solar radiation $R_{s\downarrow}$ was measured, the direct beam radiation $R_{b\downarrow}$ and the diffuse solar radiation $R_{d\downarrow}$, needed to calculate the radiation balance of the leaves, were estimated for clear sky using the Campbell's formulae (Pedro and Gillespie, 1982b). Taking the ratio $r = R_{b\downarrow}/R_{d\downarrow}$ we can infer the following relationships: $R_{b\downarrow} = rR_{s\downarrow}/(1 + r)$ and $R_{d\downarrow} = R_{s\downarrow}/(1 + r)$. According to Campbell (1977), for a clear sky, the ratio r is equal to $r_x = 2a^m/(1 - a^m)$, where a is an atmospheric transmission coefficient (0.84) and m is the optical air mass depth ($= 1/\sin \beta$), β being the solar elevation. For a completely covered sky $r = 0$. So, for a partially covered sky, we assume the following simple linear relationship as a function

of cloud cover to be valid $r = r_x(1 - c)$. Cloud cover was visually assessed in the evening and in the morning. But when dew was deposited, during the night, no visual assessment was made until sunrise. Therefore, a simple linear interpolation was used between the last observation of the evening and the first observation of the morning. Sunshine duration was used to determine the presence or not of direct beam radiation. When sunshine duration during each hour was lower than 50%, it was assumed that there was no direct beam radiation during the hour.

Before dew deposition or wetting by rain, when the leaf surface is dry, the latent heat flux can be disregarded because the onset of dew generally occurs during the night when stomata are closed. For a dry leaf without transpiration, Eqn. (1) is simpler, since it does not contain the terms nhD_a/γ and s/γ . The beginning of dew deposition is determined when T_L calculated from (1) ($T_L = T_a + \delta T$) becomes equal to the dew point temperature of air. Then, the rate of dew deposition or of evaporation of free water is given by the classical latent heat flux equation (Pedro and Gillespie, 1982a)

$$\lambda E = (nh/\gamma)[e^*(T_L) - e_a] \quad (2)$$

where λ is the latent heat of vaporization of water. The ending of dew occurs when the condensate accumulated during the night is completely evaporated. It was assumed that this condensate cannot exceed a maximum value which has been experimentally derived using the following procedure. When dew deposit seemed to be maximum, the leaves surfaces were dried up using paper tissues and the leaves dimensions were measured. The tissues were put into plastic bags and weighed before and after the drying operation. The maximum value of dew deposit retained was that corresponding to the maximum value observed during the experiments, i.e. $90 \mu\text{m}$ for one side of a leaf (0 or 1). The model was run on an hourly basis. The estimated times of onset and ending of dew were always rounded to the corresponding half-hour. The data of air temperature and humidity used as input to the model were those of the weather station, assuming that they were close to the values observed at the level of the first leaves.

FIELD MEASUREMENTS AND MODEL VALIDATION

The model was tested using experimental data obtained on plantain plantations (Horn plantain variety) located at Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), ($9^{\circ}53'N$), in the Turrialba Valley, Costa Rica, at about 600 m above sea level. The climate of the valley is tropical humid with an average annual rainfall of 2600 mm and an average temperature of 21°C . The experiments took place on two plantain plantations located near a standard weather station. The first one, with first generation plants, covered an area of 0.5 ha at a density of 1150 plants ha^{-1} . Its leaf area

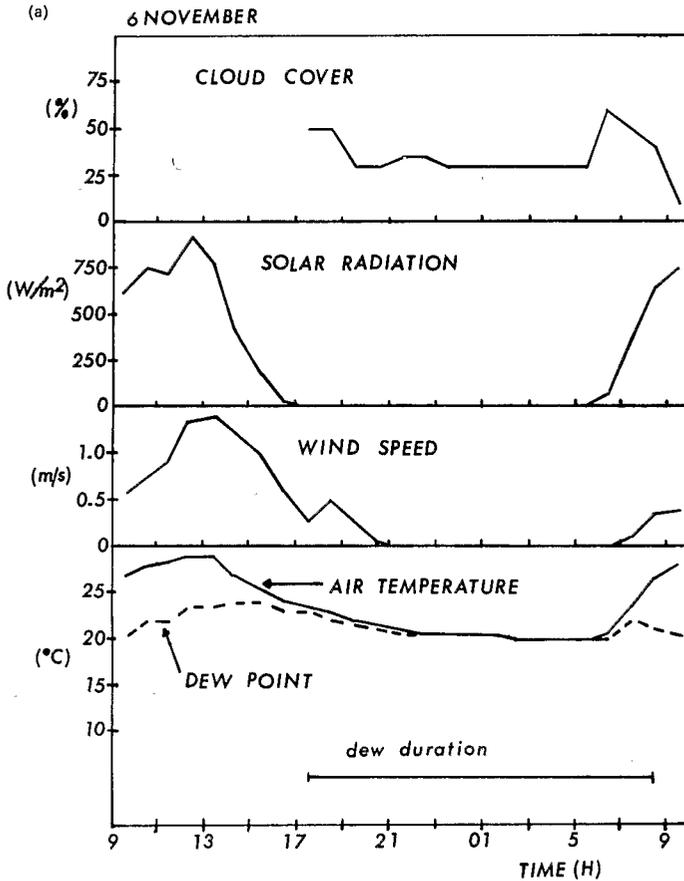


Fig. 3. Meteorological conditions for two contrasting nights. (a) 6 November: dew duration 16:00 h. (b) 10 January: dew duration 09:00 h.

index (LAI) was about 1 and the soil was covered with young coffee plants. The second one, with second generation plants, covered 0.6 ha at a density of 1670 plants ha^{-1} . Its LAI was about 1.8 and the soil was bare. In both cases the mean height of the highest leaf tip was 5.4 m. In the nearby weather station air temperature, air humidity, solar radiation (Kipp and Zonen pyranometer) and sunshine duration were registered. Wind velocity was directly registered by an anemometer (Lambrecht) installed within the crop at the mean level of the first leaves (about 4.5 m). Onset and ending of dew were visually assessed throughout the plantation using a step ladder and an electric torch (for night assessment).

The observations took place during 18 nights from November 1990 to January 1991. These months correspond to the end of the rainy season and the beginning of the dry season. The transition period generally takes place in

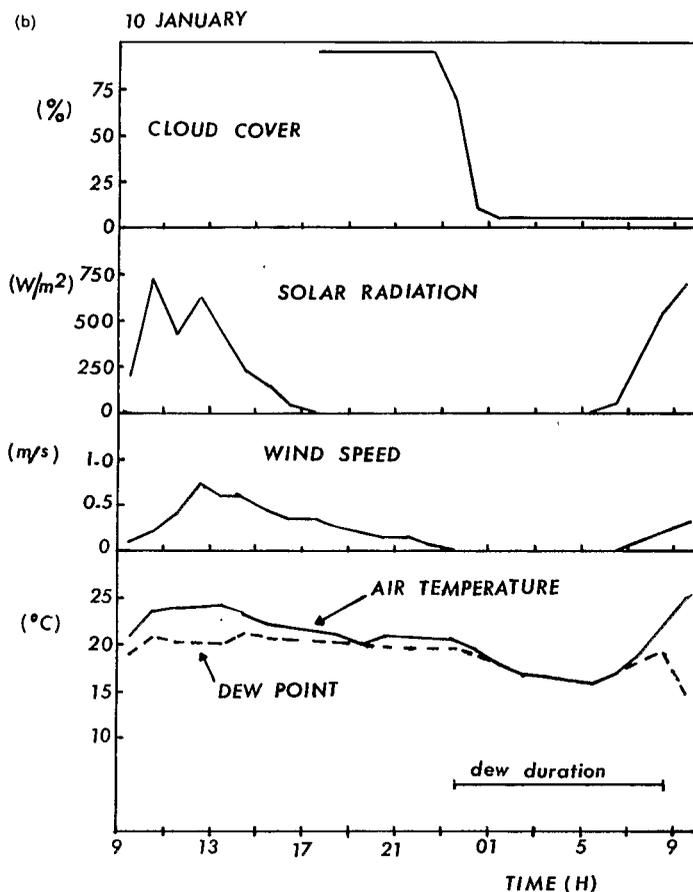


Fig. 3. Continued.

December. More nights than these 18 nights were tested, but nights with rain were not taken into account in this comparison in order to consider only wetness caused by dew. As it generally occurs in the humid tropics, the meteorological conditions are fairly identical from 1 night to another. During the period corresponding to the experiment, air characteristics just after sunset (18:00–19:00 h), when dew generally falls, did not vary significantly: air temperature was around $21 \pm 1^{\circ}C$, air humidity was about 24 ± 1 h Pa and wind velocity was always very low, less than $0.5 m s^{-1}$. This is the reason why, on 16 out of the 18 nights studied, dew duration was similar, i.e. $14(\pm 2)$ h. The main factor explaining the onset of dew is always the radiative deficit which occurs at sunset, at around 18:00 h. During 2 nights (6 December and 10 January) the onset of dew took place very late (23:00 h or later), which is explained by the fact that, during these 2 nights and the previous afternoons,

TABLE 1

Comparison of estimated (e) and observed (o) onset and ending of dew duration

Date	Onset time		Ending time		Dew duration	
	Leaf 0	Leaf 1	Leaf 0	Leaf 1	Leaf 0	Leaf 1
6 Nov	e 17.30	e 16.30	e 7.30	e 8.30	e 14.00	e 16.00
	o 17.30	o 17.30	o 8.00	o 8.30	o 14.30	o 15.00
7 Nov	e 18.30	e 17.30	e 7.30	e 8.30	e 13.00	e 15.00
	o 18.00	o 18.00	o 7.30	o 8.00	o 13.30	o 14.00
21 Nov	e 18.30	e 17.30	e 8.30	e 9.30	e 14.00	e 16.00
	o 18.30	o 18.30	o 8.30	o 9.00	o 14.00	o 14.30
3 Dec	e 18.30	e 18.30	e 9.30	e 9.30	e 15.00	e 15.00
	o 18.00	o 18.00	o 10.00	o 10.15	o 16.00	o 16.15
6 Dec	e 22.30	e 22.30	e 7.30	e 7.30	e 9.00	e 9.00
	o 23.00	o 23.00	o 6.30	o 6.30	o 7.30	o 7.30
13 Dec	e 19.30	e 19.30	e 9.30	e 9.30	e 14.00	e 14.00
	o 19.30	o 19.30	o 8.15	o 8.30	o 12.45	o 13.00
17 Dec	e 18.30	e 18.30	e 8.30	e 8.30	e 14.00	e 14.00
	o 18.00	o 17.45	o 7.45	o 8.00	o 13.45	o 14.15
20 Dec	e 20.30	e 20.30	e 8.30	e 8.30	e 12.00	e 12.00
	o 19.15	o 19.00	o 9.00	o 9.15	o 13.45	o 14.15
21 Dec	e 19.30	e 19.30	e 8.30	e 8.30	e 13.00	e 13.00
	o 19.15	o 19.00	o 8.15	o 8.45	o 13.00	o 13.45
27 Dec	e 20.30	e 20.30	e 8.30	e 8.30	e 12.00	e 12.00
	o 20.00	o 19.30	o 8.45	o 9.15	o 12.45	o 13.45
30 Dec	e 17.30	e 17.30	e 8.30	e 8.30	e 15.00	e 15.00
	o 18.45	o 18.30	o 8.45	o 9.15	o 14.00	o 14.45
1 Jan	e 17.30	e 17.30	e 8.30	e 8.30	e 15.00	e 15.00
	o 18.15	o 18.00	o 8.00	o 8.15	o 13.45	o 14.15
3 Jan	e 18.30	e 18.30	e 8.30	e 9.30	e 14.00	e 15.00
	o 19.15	o 18.45	o 8.15	o 9.15	o 13.00	o 14.30
6 Jan	e 19.30	e 19.30	e 9.30	e 9.30	e 14.00	e 14.00
	o 19.30	o 19.15	o 9.00	o 9.15	o 13.30	o 14.00
8 Jan	e 18.30	e 18.30	e 8.30	e 9.30	e 14.00	e 15.00
	o 18.30	o 18.00	o 8.45	o 9.15	o 14.15	o 15.15
10 Jan	e 0.30	e 23.30	e 8.30	e 8.30	e 8.00	e 9.00
	o 23.30	o 23.30	o 8.15	o 8.45	o 8.45	o 9.15
13 Jan	e 18.30	e 18.30	e 8.30	e 8.30	e 14.00	e 14.00
	o 19.00	o 18.45	o 8.15	o 8.30	o 13.15	o 13.45
14 Jan	e 18.30	e 18.30	e 8.30	e 8.30	e 14.00	e 14.00
	o 18.45	o 18.45	o 7.15	o 7.30	o 12.30	o 12.45

the sky was completely covered by clouds, preventing the radiative balance from decreasing so rapidly. Figure 3 gives examples of the meteorological conditions for 2 contrasting nights with regard to dew duration.

Table 1 shows the comparison of estimated and observed times of onset and ending of dew on Leaves 0 and 1. Observation seems to indicate that dew appears on Leaf 1 before Leaf 0, and dries first on Leaf 0, the difference

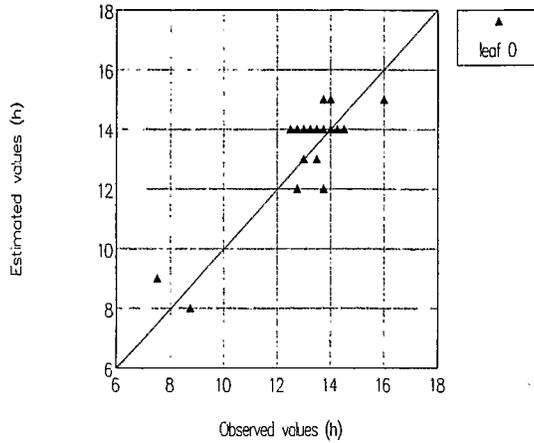


Fig. 4. Comparison of estimated and observed wetting durations on the plantain candle leaf (Leaf 0).

generally being less than 30 min. This fact can be easily explained if we consider that the radiative balance is the main factor which determines the onset of dew. When night begins and short-wave radiation becomes nil, the radiative balance of leaves is negative, which induces a temperature decrease below dew point temperature. Using Eqn. (1), in which R_1 is replaced by its value as a function of $R_1 \downarrow$, one can notice that the radiative deficit is twice as important for a flag leaf as for a candle leaf, which explains why dew appears first on the flag leaf. The candle leaves generally dry more rapidly than the flag leaves. This can be explained by the fact that, during the first hours of the day,

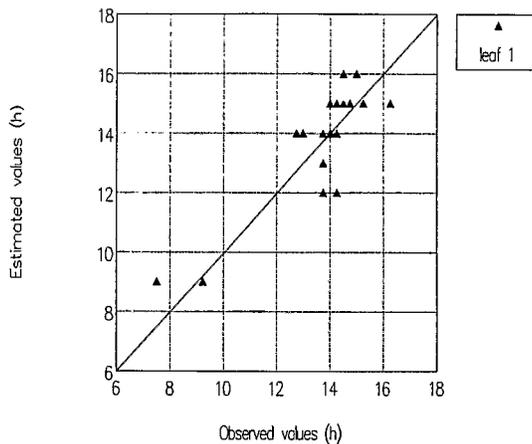


Fig. 5. Comparison of estimated and observed wetting durations on the plantain first expanded leaf or flag leaf (Leaf 1).

when direct beam radiation is still very inclined to the horizon, the vertical candle leaf receives more energy than the inclined flag leaf.

Figures 4 and 5, plotted from Table 1, show the scattering of estimated values with respect to observed values of dew duration. The agreement between estimated and observed values is fairly good if we consider that the standard radiations ($R_b \downarrow$, $R_d \downarrow$, $R_1 \downarrow$, $R_1 \uparrow$) were estimated from weather station data by means of fairly empirical relationships. Most of dew duration values are estimated with an error less than 1 h. We can conclude, thus, that the model described in this paper provides practical estimates of dew duration on the upper leaves of plantain plants. Since plantain and banana have a very similar architecture we may assume this model, tested only with plantain, also works with banana.

CONCLUSION

This model has been developed for operational use in the management of Black Sigatoka, either with past weather data, in order to look for correlations with fungal infection, or in real time, from the data of an automatic weather station, to forecast infection risks (Ganry et Laville, 1983). This is the reason why only readily available data from a standard weather station are used as input to the model. If wind velocity measurements inside the plantation are not made or not available it is always possible to establish a semi-empirical relationship linking wind speed near the crop top with wind speed at the weather station (Pedro and Gillespie, 1982b). The accuracy of such a model is essentially limited by the empirical relationships used to estimate the standard radiations received on a horizontal plane, and the lack of practical means of recording cloud cover during the night in order to estimate downward longwave radiation. More accurate relationships adapted to each region have to be designed to improve the transferability of this dew estimation method for plantain and banana leaves.

ACKNOWLEDGEMENTS

The study was partly supported by a EEC/Sigatoka project. The authors thank Dr. Jean-Vincent Escalant, head of this project, for financial support and numerous useful discussions.

REFERENCES

- Campbell, G.S., 1977. *An Introduction to Environmental Biophysics*. Springer, New York, 159 pp.
- Ganry, J. and Laville, E., 1983. Les cercosporioses du bananier et leurs traitements. Evolution des méthodes de traitement. *Fruits*, 38(1): 3-20.
- Gillespie, T.J. and Barr, A., 1984. Adaptation of a dew estimation scheme to a new crop and site. *Agric. Forest Meteorol.*, 31: 289-295.

- Kreith, F. and Sellers, W.D., 1975. General principles of natural evaporation. In: D.A. de Vries and N.H. Afgan (Eds), Heat and Mass Transfer in the Biosphere. Scripta Books, Washington, DC, 207-227.
- Leach, R., 1964. Black leaf streak, a new form of banana leaf spot in Fiji. *World Crops*, 16: 60-64.
- Monteith, J.L., 1963. Dew: facts and fallacies. In: A.J. Rutter (Ed), *The Water Relations of Plants*. Blackwell, London, pp. 37-56.
- Monteith, J.L. and Butler, D.R., 1979. Dew and thermal lag: a model for cocoa pods. *Q.J.R. Meteorol. Soc.*, 105: 207-215.
- Monteith, J.L. and Unsworth, M.H., 1990. *Principles of Environmental Physics*. Second edn. Edward Arnold, London, 291 pp.
- Pedro, M.J. and Gillespie, T.J., 1982a. Estimating dew duration. I. Utilizing micrometeorological data. *Agric. Meteorol.*, 25: 283-296.
- Pedro, M.J. and Gillespie, T.J., 1982b. Estimating dew duration. II. Utilizing standard weather station data. *Agric. Meteorol.*, 25: 297-310.
- Reeve, J.E., 1960. Appendix on derivation of formulae (in *Inclined point quadrats*, by J. Warren Wilson), *New Phytol.*, 59: 1-8.
- Royle, D.J. and Butler, D.R., 1986. Epidemiological significance of liquid water in crop canopies and its role in disease forecasting. In: P.G. Ayres and L. Boddy (Eds), *Water, Fungi and Plants*, CUP, pp. 139-156.
- Stover, R.H. and Simmonds, N.W., 1987. *Bananas*. Tropical Agriculture Series, Longman Ed., London, 468 pp.

APPENDIX: ESTIMATING THE RADIATION BALANCE OF THE UPPER LEAVES

Diffuse radiation

The flag leaf (Leaf 1) is considered as a flat inclined plane which receives short-wave diffuse radiation from the sky and from the ground. The diffuse short-wave radiation received on a unit area (both sides) of a flat inclined plane is simply the sum of the downward diffuse radiation and upward diffuse radiation received on a horizontal plane (Monteith and Unsworth, 1990): $R_d = R_{d\downarrow} + R_{d\uparrow}$. The upward diffuse radiation is equal to the total downward solar radiation ($R_{s\downarrow}$) multiplied by the albedo (a) of the surface beneath the leaf: $R_{d\uparrow} = aR_{s\downarrow}$. The long-wave diffuse radiation received on the inclined leaf (on both sides) is simply the sum of upward and downward long-wave radiations as for the short-wave diffuse radiation.

The candle leaf (Leaf 0) can be considered as the curved surface of a vertical cylinder. The diffuse short-wave radiation and the long-wave radiation received on one side of a vertical surface ($\alpha = \pi/2$) are half the radiation received on a horizontal plane.

Direct beam radiation

Direct beam radiation is more complicated to calculate. The mean flux of direct beam radiation received on any solid object per unit area of surface can be written

$$R_b = f \cdot R_{b\downarrow} \quad (A1)$$



where $R_b \downarrow$ is the direct beam radiation measured on a horizontal plane and f a shape factor which can be calculated from geometrical principles.

The first leaves in a plantain plantation are assumed to be flat plates at an elevation of α , sloping non-preferentially towards all points of the compass (personal observation). They can be rearranged on the curved surface of a cone and the shape factor can be calculated in the following way (Reeve, 1960; Monteith and Unsworth, 1990). When $\alpha \leq \beta$, β denoting the solar inclination, only the upper surface of leaves is illuminated and

$$f = \cos \alpha \quad (\text{A2})$$

When $\alpha > \beta$ either the upper or the lower surface of a leaf is illuminated depending on its azimuth and

$$f = [(\pi - 2\theta_0) \cos \alpha + 2 \sin \alpha \sin \theta_0 \cot \beta] / \pi \quad (\text{A3})$$

where θ_0 is the value of θ between 0 and $\pi/2$ which satisfies the equation $\cos \theta = \cot \alpha \tan \beta$. If this value does not exist, f is given by Eqn. (A2).

The shape factor of a vertical cylinder is irrespective of inclination and azimuth, but only depends on solar elevation. Its value is simply (Monteith and Unsworth, 1990)

$$f = \cot \beta / \pi \quad (\text{A4})$$

Solar elevation β was calculated using the classical astronomical formula relating β with latitude, solar declination and solar time.