Simulation and systems analysis for rice production (SARP)

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Leaf wetness in rice crops caused by dew formation: a simulation study.

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Leaf wetness in rice crops caused by dew formation: a simulation study[1]

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Introduction

Water on leaf surfaces is a necessary condition for fungi spores to germinate successfully and infect the host (Marches et al., 1976; Shoemaker & Lobster, 1977; Hosford, 1978; Boned et al., 1978). In order to forecast the epidemics of fungi diseases and to maximize the efficiency of pesticides used to control these diseases, estimation of daily duration and amount of dew (including dewfall and distillation dew) on crop surfaces is required.

The estimation of dew formation using an energy budget approach has been widely studied. Monteith (1957, 1963) studied the dewfall and distillation dew on grass and the potential dewfall on several other crops. Barrage (1972) studied the duration and amount of dew within different layers of a wheat canopy. Monteith & Butler (1979) used the energy budget concept to determine the amount and duration of dew formation on cocoa pods. Their studies can be considered as a guide line for estimating dew formation in different canopies, such as a grass vegetation, a crop, and trees, etc.. However, as a simulation model was still missing in their studies, their results cannot be directly adapted to a fungi disease epidemic model.

Pedrio & Gillespie (1982a, b) developed a computer model to simulate the dew duration on a single leaf of apple, maize, and soybean by using microclimate data as well as standard weather data from an observation station. Pedrio and Gillespie's model was adapted to onions as well (Gillespie & Barr, 1984). Their model ignored the soil heat flux, and was developed on basis of data from rainfed crops, which makes it hard to apply it to an irrigated rice crop with a water layer on the soil surface. Goudriaan (1977) developed a computer multi-layer crop microweather model in which dewfall and dew duration within different layers of the crop canopy are calculated. This model allows for heat and vapour exchange at the soil surface and can include a water layer on top of the soil. For this reason this model was chosen as the basis for a further study. In order to forecast the epidemic of a fungi disease, the contribution of dewfall and distillation dew to leaf wetness should be considered, as well as the soil surface energy budget.

In this paper, a simple model to predict leaf wetness was derived and tested. Experimental data were used to simulate dew formation, and were used for validation purposes as well.

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Materials and methods

The experiment

Measurements of dew duration and dew amount on a short grass vegetation with a height of 5 cm were carried out at the weather station field of Wageningen Agricultural University (52 °N) during two nights, May 23 - 24 and 24 - 25, 1990. The dew amount (including distillation dew) was measured by weighing two pieces of porous porcelain plate which were put on the top of the grass vegetation (5 cm above the ground). The time interval of weighing the plates was one or two hours. Dew was considered to be present when the dew amount was more than 0.01 mm. Cloudiness was observed at the same time during the two nights. The other hourly weather data including the soil temperature were automatically recorded at the station.

The model

Dew duration for an overnight period was calculated as follows: dew begins when the upward latent heat flux (LE) is less than zero and ends when the condensation accumulated by the models during the night has been evaporated in the morning. The maximum value of the amount of dew typically occurs at sunrise. It will be indicated by the term 'maximum dew amount'.

Simulation of dew amount and its duration requires an estimation of the components of the energy budget of the soil-canopy system in interaction with the atmosphere.

In the model, the theory of Chen (1984) was used, which enables a much faster solution of the matrix equations, so that the model can be run on a PC (Goudriaan, 1989).

To estimate the distribution of net radiation (Rn) within the canopy, the distribution of global radiation, thermal radiation from the sky, the leaves, and the soil surface, and the extinction coefficient of the canopy should first be calculated. Not only does this result in a large computing program, also daily global radiation data are not always available. These two problems can be avoided by simulating dew duration and dew amount just during the night.

Dew formation is normally concentrated in the top layer of the canopy. Therefore, the canopy (with leaf area index, LAI) was divided in two layers, a top layer with leaf area index of unity, and a remaining layer with leaf area index LAI - 1. Simulation of dew formation was only done for the top layer of the canopy. The following two assumptions were adopted for the night period:

- the leaf temperature of the two layers is the same as far as thermal radiation is concerned;
- the leaf surface resistance to water vapour of the two layers is the same.

Based on these simplifications and assumptions, the comprehensive model could be made much smaller and simpler, at least for the night period. This simplified model ('SIMPLE') was used to simulate night dew period (DEWTN) and maximum dew amount (DEW). Also the comprehensive model ('MICROWEATHER89' (Goudriaan, 1989)) was used to simulate daily dew period (DEWTD) as well as DEWTN and DEW to verify whether the introduced simplifications are justified.

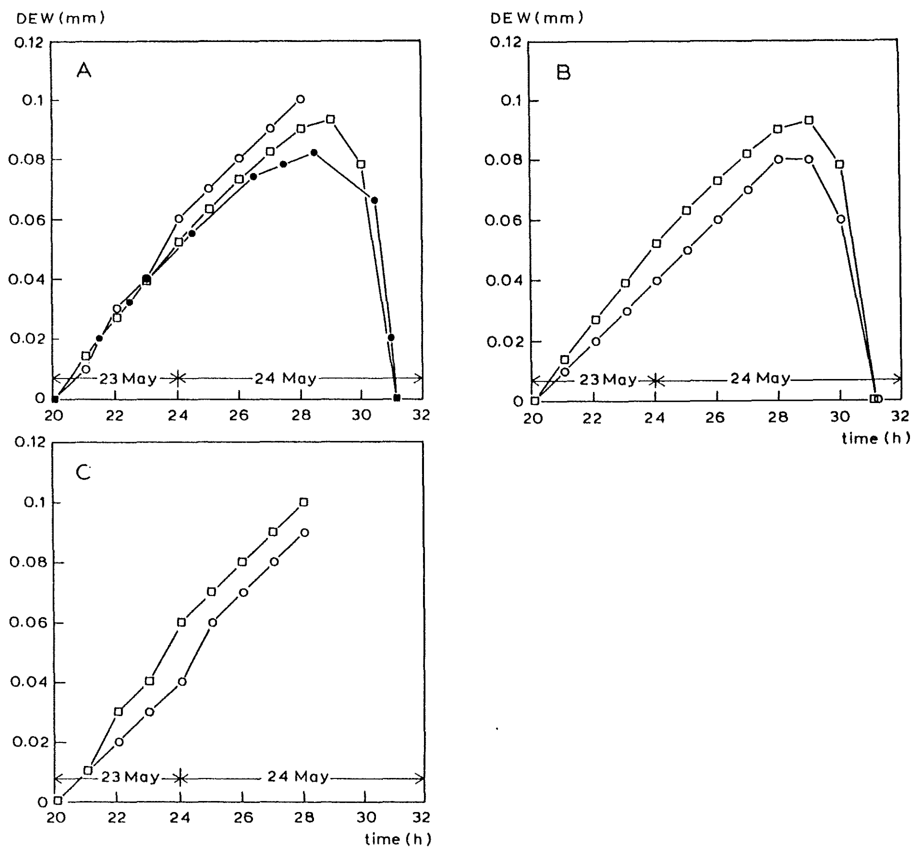

Figure 1. Time course of accumulated hourly dew amount (DEW, mm), May 23 - 24, 1990, location: 52 °N. (A) Based on hourly weather data; observed dew amount (•), simulated dew amount by the comprehensive model based on hourly weather data (□), simulated dew amount by the simple model based on hourly weather data (o). (B) Simulated by the comprehensive model; based on hourly weather data (□), based on daily weather data (o). (C) Simulated by the simple model; based on hourly weather data (□), based on daily weather data (o).

Results and discussion

Time course of dew amount and relative air humidity

The accumulated hourly dew amount simulated by the simple model was quite similar to the results simulated by the comprehensive model during the two sample nights (see Figures 1a and 2a). During the night of May 23 - 24 (with clear sky), the results of both models agreed to those measured on a short grass vegetation (Figure 1a). During the night of May 24 - 25 (clouds appearing after midnight) the simulated values deviated from the measurements after midnight (Figure 2a). Also, relative humidity of the air at reference height (see Figure 3) did

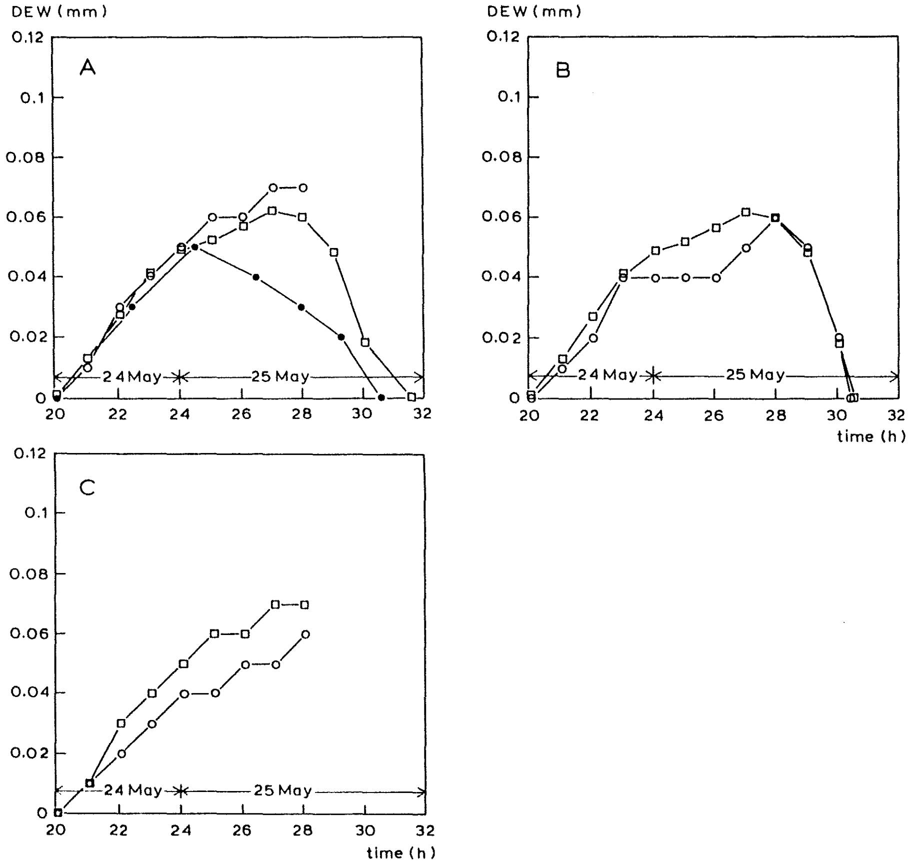

Figure 2. Time course of accumulated hourly dew amount (DEW, mm), May 24 - 25, 1990, location: 52 °N. (A) Based on hourly weather data; observed dew amount (•), simulated dew amount by the comprehensive model (▫), simulated dew amount by the simple model (∘). (B) Simulated by the comprehensive model; based on hourly weather data (▫), based on daily weather data (∘). (C) Simulated by the simple model; based on hourly weather data (▫), based on daily weather data (∘).

not rise further after midnight. The maximum dew amount (dew amount at sunrise) simulated by both models was 0.01 to 0.02 mm higher than the measured values.

For both models, the time course of simulated dew amount based on *daily* weather data followed the one based on *hourly* weather data (see Figures 1b and c, 2b and c), but the amount was a little less. Either simulation result was close to the measured data (see Figures 1a and 2a).

The above results indicate that simulated dew formation at night was not sensitive to the simplifications and assumptions utilized, and that daily weather data instead of hourly weather data could be used as input to simulate the maximum dew amount.

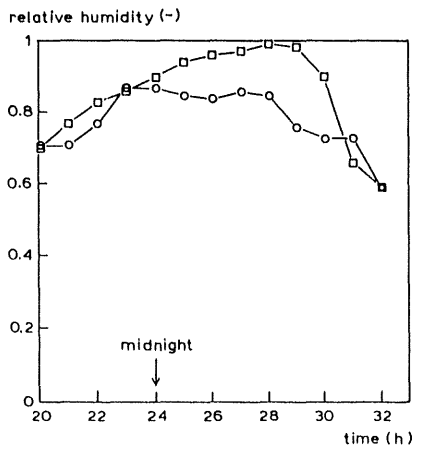

Figure 3. Time course of relative humidity of air at the reference height of 150 cm, location: 52 °N; (□) data of May 23 - 24, 1990; (○) data of May 24 - 25, 1990.

Simulation of the night dew duration (DEWTN) and the maximum dew amount (DEW)
The night dew duration (from sunset to sunrise) and the maximum dew amount (dew accumulated from sunset to sunrise) simulated by the simple model were very close to those simulated by the comprehensive model. This was verified by simulations based on daily weather data under different weather as well as soil conditions (dry, wet, and with a layer of water on the soil surface) (see Figures 4 and 5). Therefore, the simple model instead of the comprehensive model can be used to simulate the night dew duration and the maximum dew amount.

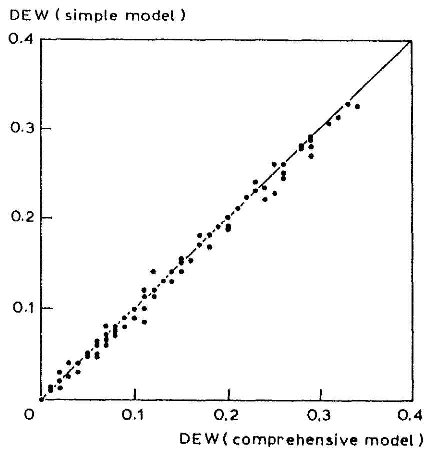

Figure 4. The relation between the maximum dew amount (DEW, mm) simulated by the comprehensive model (x-axis) and by the simple model (y-axis).

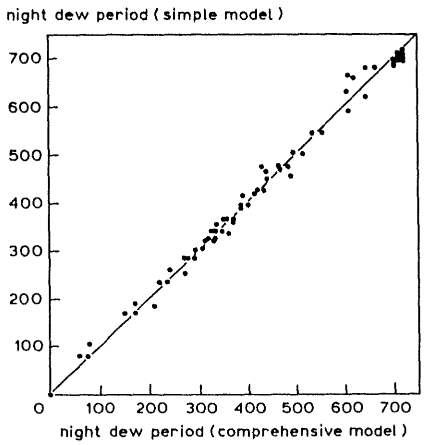

Figure 5. The relation between the night dew period (DEWTN, min.) simulated by the comprehensive model (x-axis) and by the simple model (y-axis).

Simulation of the dew duration after sunrise (DEWTS) and the daily dew duration (DEWTD)

Dew duration after sunrise (from sunrise to the moment when dew disappeared) and the daily dew duration (from sunset to the moment when dew disappeared) could only be simulated by the comprehensive model. The following relation between DEWTS (in hours, comprehensive model) and DEW (mm, both models) (see Figure 6) could be derived:

$$DEWTS = \begin{cases} 44.5 \times DEW & \text{when } DEW < 0.03 \text{ (mm)} \\ 9.2 \times DEW + 1.06 & \text{when } DEW \geq 0.03 \text{ (mm)} \end{cases} \quad (1)$$

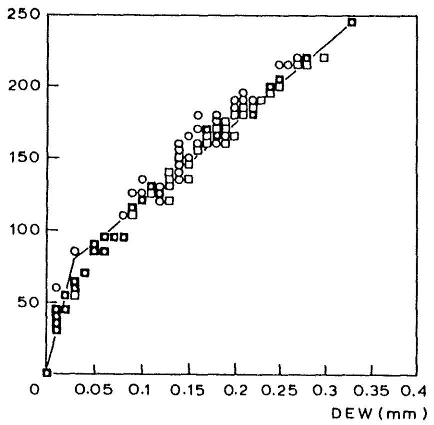

Figure 6. The relation between the dew period after sunrise (DEWTS, min.) simulated by the comprehensive model and the maximum dew amount (DEW, mm) simulated by the simple model (o) and by the comprehensive model (□).

The daily dew duration (DEWTD) is the sum of the night dew duration and the dew duration after sunrise:

$$DEWTD = DEWTN + DEWTS \tag{2}$$

Both nightly dew duration DEWTN and total dew amount DEW can be simulated by the simple model, and so Equations 1 and 2 permit a simulation of the total daily dew duration DEWTD, using the simple model only.

Conclusions

When the comprehensive MICROWEATHER89 model (Goudriaan, 1989) was used to simulate dew formation in crops, the maximum dew amount and the daily dew duration simulated by the model agreed with the measured data on a short grass vegetation, both when based on the input of hourly as well as on daily weather data. So daily weather data instead of hourly weather data can be used as model input. It makes it possible to use the standard meteorological data. However, in view of the small number of validations, a further test of the models is still needed.

The agreement of the night values of dew formation simulated by the simple model to those simulated by the comprehensive model shows that the night values were only little influenced by the simplifications and assumptions. The relationship between dew duration after sunrise (DEWTS) and amount of dew at sunrise (DEW) makes it possible to use a simplified model to simulate daily dew duration, without the need for having data about global radiation. Whatever model is used, observations about cloudiness at night are required as inputs for predictions of dew formation. Our preliminary attempts to simulate dew formation in the tropics (Los Banos, Philippines) confirmed this: due to lack of night time cloudiness observations, only a poor correspondence between simulation and observed dew formation could be obtained in this environment. Further evaluation of our model is planned.

The simplified model will make it easier to add simulation of dew formation into fungi disease epidemic models and into basic crop growth models (such as the MACROS model, module L1D, as developed by Penning de Vries et al., 1989).

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