5.1 Leaf Wetness within a Lily Canopy

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INTRODUCTION

Rain, fog, drizzle, mist and dew are meteorological phenomena, which cause leaf wetness, i.e. free liquid water on plant leaves. When water is deposited on leaves for a certain critical period together with a certain temperature level, fungal diseases and other pathogens can develop which can be extremely harmful for the health of plant canopies. To fight these diseases growers protect their crops by frequent spraying with fungicides. With increasing environmental awareness and the high cost of fungicides, however, there is now a requirement to curb excessive use of chemical control measures. Here, an estimate of reliable leaf wetness duration is pursued to use these fungicides efficiently.

The objectives of the present paper are to get a better insight into the dew forming process during nighttime in different layers within a lily canopy. Second, to get better insight into the early morning drying process in different layers within the canopy. To attain these goals, a relatively simple physical model has been developed to simulate the wetting and drying processes. A field experiment was carried out to verify this model.

MODEL DESCRIPTION

The model used is a simple multi-layer crop model and is an extension of the model proposed by Pedro and Gillespie (1982). In an arbitrary air layer within the canopy, the energy budget is:

$$\Delta Q_l^* + \Delta H_l + \Delta\lambda_v E_l = 0 \qquad (1)$$

where ΔQ^*_l is the absorbed net radiation, ΔH_l is the released sensible heat and $\Delta\lambda_v E_l$ is the released evaporation. If the above canopy net radiation is Q^*, the within the canopy net radiation flux can be parameterized by (Lowry, 1989):

$$Q_l^*(L(z)) = Q^* e^{-(0.622L - 0.055L^2)} \qquad (2)$$

where $L(z)$ is the integrated leaf area index from the top, h, of the canopy. The absorbed net radiation, ΔQ^*_l, within the layer now is:

$$\Delta Q_l^* = \Delta Q_l^*(L_t) - \Delta Q_l^*(L_b) \qquad (3)$$

with index L_t is integrated leaf area index until the top of the layer and L_b at the bottom.

The released sensible heat, ΔH_l, in the layer is simulated as:

$$\Delta H_l = -2\alpha(T_l - T_a)(L_b - L_t) \qquad (4)$$

with T_l is the mean leaf temperature, T_a the mean ambient air temperature and α the convective heat transfer coefficient of a one-sided leaf in this layer The convective heat coefficient is calculated using the Nusselt number for forced convection (Gates, 1980):

$$Nu = \frac{\alpha D}{\lambda} = 0.60\,\mathrm{Re}^{0.5}\ \mathit{if}\ \mathrm{Re} > 2\cdot 10^4$$
$$Nu = \frac{\alpha D}{\lambda} = 0.032\,\mathrm{Re}^{0.8}\ \mathit{if}\ \mathrm{Re} < 2\cdot 10^4 \qquad (5)$$

with *D* is a characteristic leaf diameter, λ is the molecular conductivity of air and *Re* the Reynold number. For free convection the convective heat transfer coefficient, α, is calculated by using (Gates, 1980):

$$Nu = \frac{\alpha D}{\lambda} = 0.50 Gr^{0.25} if T_l > T_a$$
$$Nu = \frac{\alpha D}{\lambda} = 0.13 Gr^{0.33} if T_l < T_a \qquad (6)$$

with *Gr* the Grashof number, *g* gravity, β the expansion coefficient, T_l is leaf and T_a ambient temperature.

The released latent heat, ΔLE_l, in the layer is simulated as:

$$\Delta LE_l = -2\rho\lambda_v\alpha'(q_{sl} - q_a)(L_b - L_t) \qquad (7)$$

with ρ is density, λ_v is vaporization energy, *a'* is convective mass exchange coefficient, q_{sl} is the saturated specific moisture contents at leaf level and q_a is the specific moisture of the ambient air. From similarity analogy between heat and mass it can be shown that (Gates, 1980):

$$\frac{\alpha}{\alpha'} = (\frac{a}{D_i})^{0.667} = Le^{0.667} = 0.93 \qquad (8)$$

with D_i molecular mass diffusivity and *Le* is the Lewis number.

The wind profile within the canopy has been derived by extrapolating the measured wind speed at a reference level via a log-linear profile to canopy height and next to apply the within canopy extinction wind speed as suggested by Goudriaan (1977):

$$u(L) = u_c \exp(-M \tfrac{L}{LAI}) \qquad (9)$$

with u_c is wind speed at canopy height, *LAI* is the one-sided leaf area index of the canopy and *M* is the extinction coefficient for momentum depending on the canopy architecture and has for most agricultural crops with erectophile leaves the numerical value of about 0.3 (Goudriaan,1977).

During nighttime the within canopy air becomes well mixed which results in a within canopy temperature profile which is more or less linear with height (Jacobs *et al.*, 1992). This means that the air temperature profile can be estimated by two within canopy temperature measurements

Combination of Eqs (1), (4) and (7) and by using Penman's elimination procedure the temperature difference between leaf and ambient air, $\Delta T = T_l - T_a$, is:

$$\Delta T = \frac{\Delta Q^*{}_l - 2_v \frac{\lambda_v}{c_p} \alpha'(q_{sa} - q)(L_b - L_t)}{2\alpha(L_b - L_t) + 2s \frac{\lambda_v}{c_p} \alpha'(L_b - L_t)} \qquad (11)$$

Following Pedro and Gillespie (1982), dew is accumulated when $T_a > T_l$ and the amount of dew is calculated using Eq. (7). Ending of dew occurs when all accumulated free water is evaporated.

EXPERIMENTAL SET-UP

During the summer period of 1996 measurements were made within and above a lily canopy in Lisse, located in the west of the Netherlands, just behind the costal dunes. The lilies were planted in rows with a row distance of 0.4 m with 67 plants per square meter. During the experimental period the mean crop height was 0.35 m with a leaf area index of 3.6. The underlying soil consisted of fine sand and the mean water table was at a depth of 0.5 m. Other lily fields surrounded the experimental site only.

A 4 m mast was placed in the center of the field between the lilies to which at 1.5 and 3.0 m height aspirated psychrometers were connected. At 4 m wind speeds were measured by two cup anemometers with a stalling speed of 0.2 m s^{-1}. At the top of the mast two global radiometers (Kipp & Zonen) measured the incoming and reflected short wave radiation. At 1.5 m a net radiometer

(Schulze Drake) measured the total incoming and outgoing radiation terms separately. Two infrared thermometers (Heimann KT15) at a height of 1.5 m measured the leaf temperatures of the top of the canopy. Sensor 1 was facing south while sensor 2 was facing north.

Within the canopy, at 0.08 and 0.28 m, air temperatures were measured with Pt100's and the relative humidity with capacitive humidity sensors (Vaisala). At 0.07 m a resistance grid measured the leaf wetness (Campbell). At 3 and 5 cm depth soil heat fluxes were estimated with heat plates (TNO, Ws 31Cp).

All measured quantities were sampled at 1 min with a portable logger (21X, Campbell) and the calculated 10-min averages were stored.

RESULTS AND DISCUSSIONS

An arbitrary dewy night, 26 to 27 August, has been selected and will be analyzed. Most other nights during the experimental period behaved more or less the same.

The lily canopy has been divided into three layers, the top layer, the centre layer and the bottom layer, with each an equal leaf area index per layer of 1.2. From field observations by eye it appeared that the drop coverage of the leaves was about 50%. In the model simulations this coverage value has been used. The lily crop consisted of relatively stiff stems and leaves. This means that this crop is not much affected by droplets draining caused by fluttering leaves (Jacobs and Nieveen, 1995). Consequently the model calculations need not to be corrected for these effects.

In Figure 1, the accumulated dewfall simulations and early morning drying results have been plotted. Moreover, the results of the wetness sensor in arbitrary units have been depicted as well. From Figure 1 we can infer that the top layer collects most of the dew and moreover that the lower layer is situated in the canopy the less dew is collected. Also it can be observed that the dewfall process starts earliest in the top layer, followed with a short time delay by the centre layer and next by the bottom layer. The wetness sensor was located at a height of 8 cm and the results of this sensor can be best compared with the accumulated dew within the bottom layer. Comparing the wetness results with the dew accumulation of the bottom layer we conclude that both results agree well except that the wetness results show a small time lag of the order of minutes.

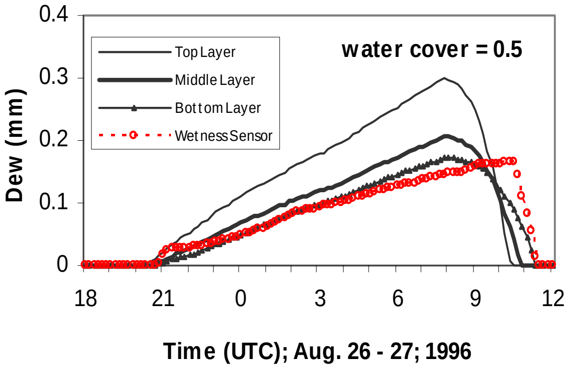

Figure 1: Course dew amounts in three layers with equal leaf area index of 1.2.

The reason for this small delay in time is that the wetness sensor consists of an electrical resistance grid covered with a porous latex paint. It takes some time for the accumulated free water on the sensor to infiltrate into the porous paint layer at the onset of dew formation and, at the end of the drying period, to diffuse out of the paint layer into the ambient air. Also it must be noted that the wetness sensor indicates the presence of free water only and that the shape of the output signal needs not to be an exact indication of the accumulated amount of dew on the sensor. Still it can be observed from Figure 1 that the output signal of the wetness sensor follows reasonably well the pattern of the amount of dew within the bottom layer.

Next, a relatively dry night is analyzed with hardly any dew. In Figure 2 the calculated and measured dew results have been plotted. From this result we conclude that the accumulated dew during this night is very low and that the calculated accumulated dew amount in the lowest layer mimics perfectly the measured one. This means that not only for dewy conditions the model performs well but also for dry conditions.

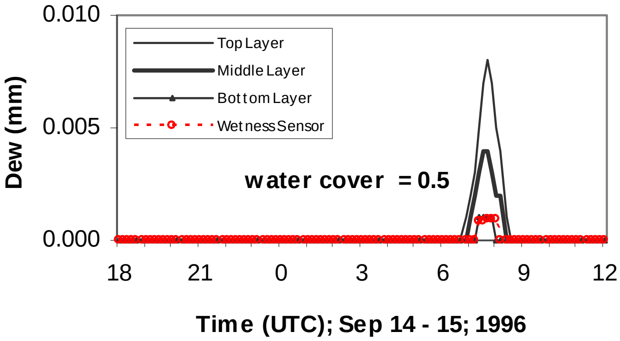

Figure 2: Course dew amounts in three layers with equal leaf area index of 1.2.

CONCLUSIONS

From the above, the following conclusions can be drawn:

a) The leaf wetness duration in the bottom layer is well simulated by the multi-layer model. Within two times the averaging time interval the simulated wetness durations agree with the observations made with the electrical grid leaf wetness instrument.

b) Under extreme wetness as well as under relatively dry conditions the agreement between model simulations and observations was good.

c) The model results suggest that the leaf wetness period in the canopy starts at the top of the canopy and from there penetrates into the canopy. Also the early morning drying process starts in the top of the canopy and follows more or less the same pattern as the wetting process.

d) The model suggests also that the accumulated dew amounts are highest in the top of the canopy, followed by the centre layer and next by the bottom layer.

e) The model simulations suggest also that the longest leaf wetness duration occurs at the bottom of the canopy. This means that the lower region of the canopy is most sensitive to fungal diseases.

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