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Improving leaf wetness duration modeling with simple physics

Application to apple scab

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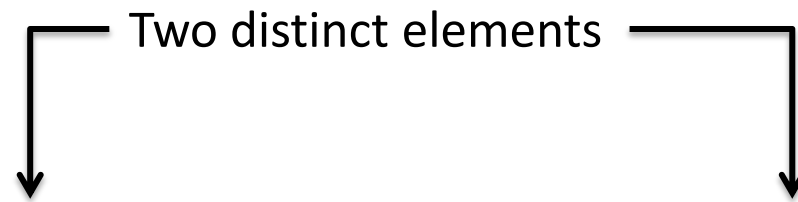
Who are you really, Leaf Wetness Duration ?

LWD = Time during which a leaf is wet



Two phenomena

WD = Liquid Water Deposition + Liquid Water Evaporation



Liquid Water Budget

Evaporation

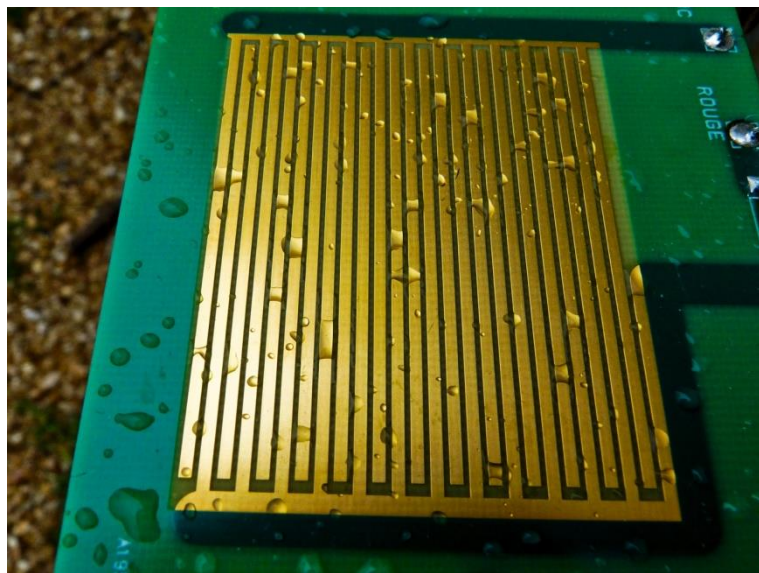
How much water on which leaves?

How fast does it dry?

How do we measure WD?

Many techniques used¹

Mostly used one : **Impedance grid**



BUT

The sensors "*dried when 15-30% of the foliage was still wet*"² : still, we don't know **how susceptible to fungal pathogens** this foliage was

Which inclination?³ Latex painted or not?^{2,3}
Covered or under clear sky?⁴ At which height?^{3,5,6}

**How can we be accurate and progress when there is no standard in WD sensing?
Are drying times really that different from sensors to susceptible apple leaves ?**

¹ Huber, 1992

³ Lau et al., 2000

⁵ Batzer et al., 2008

² Gillespie & Kidd, 1978

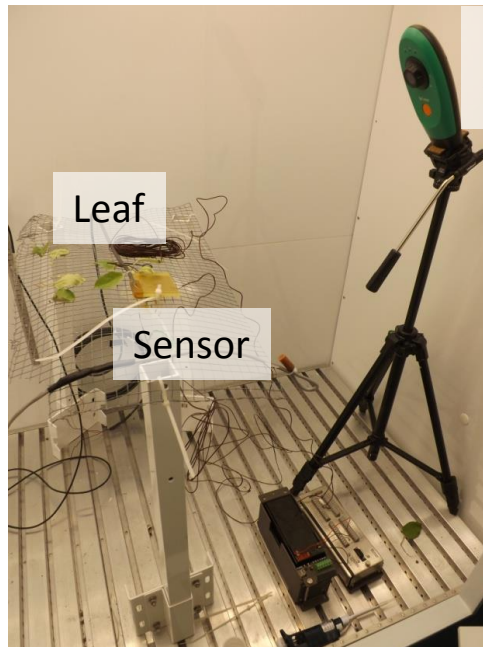
⁴ Leca, 2011

⁶ Sentelhas et al., 2005

A simple WD measurement

Objective : to estimate Δ WD between **susceptible** leaves and sensors

Same volume of water evaporated under controlled conditions
(temperature, relative humidity, radiation)



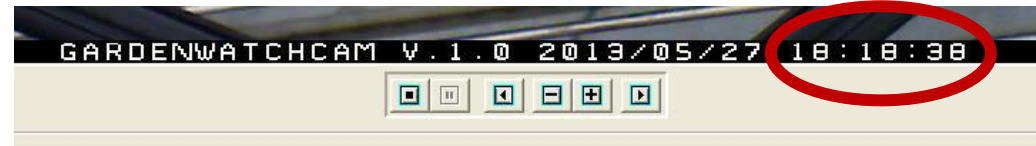
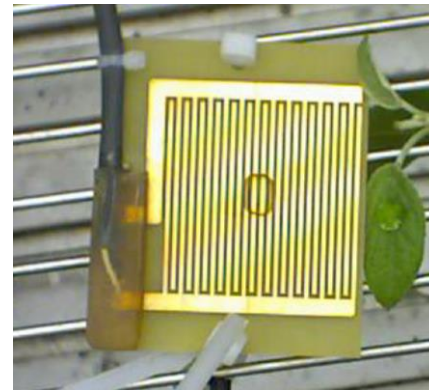
Timelapse
video camera

Leaf

Sensor

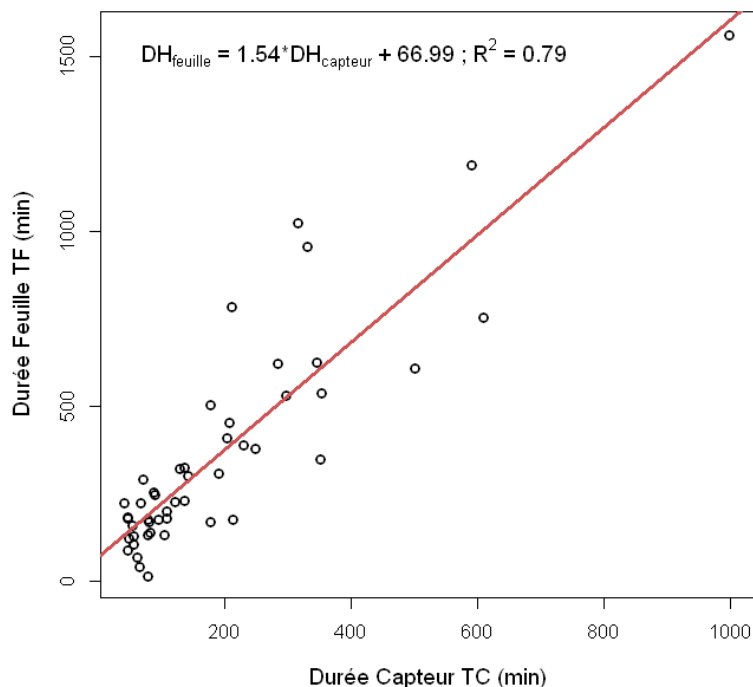
Controlled Environment Chamber

WD = Time dry – Time drop deposition



Still shot from the **timecoded** video

A simple WD measurement



cv McIntosh, apple scab susceptible leaves

- Temperature : 0 – 26 °C
- Relative Humidity : 15 – 91 %
- PAR Radiation : 0 – 510 $\mu\text{Mol.m}^{-2}.\text{s}^{-1}$

$$DH_{\text{leaf}} = 1,54 * DH_{\text{sensor}} + 66,99 ; R^2 = 0,79$$

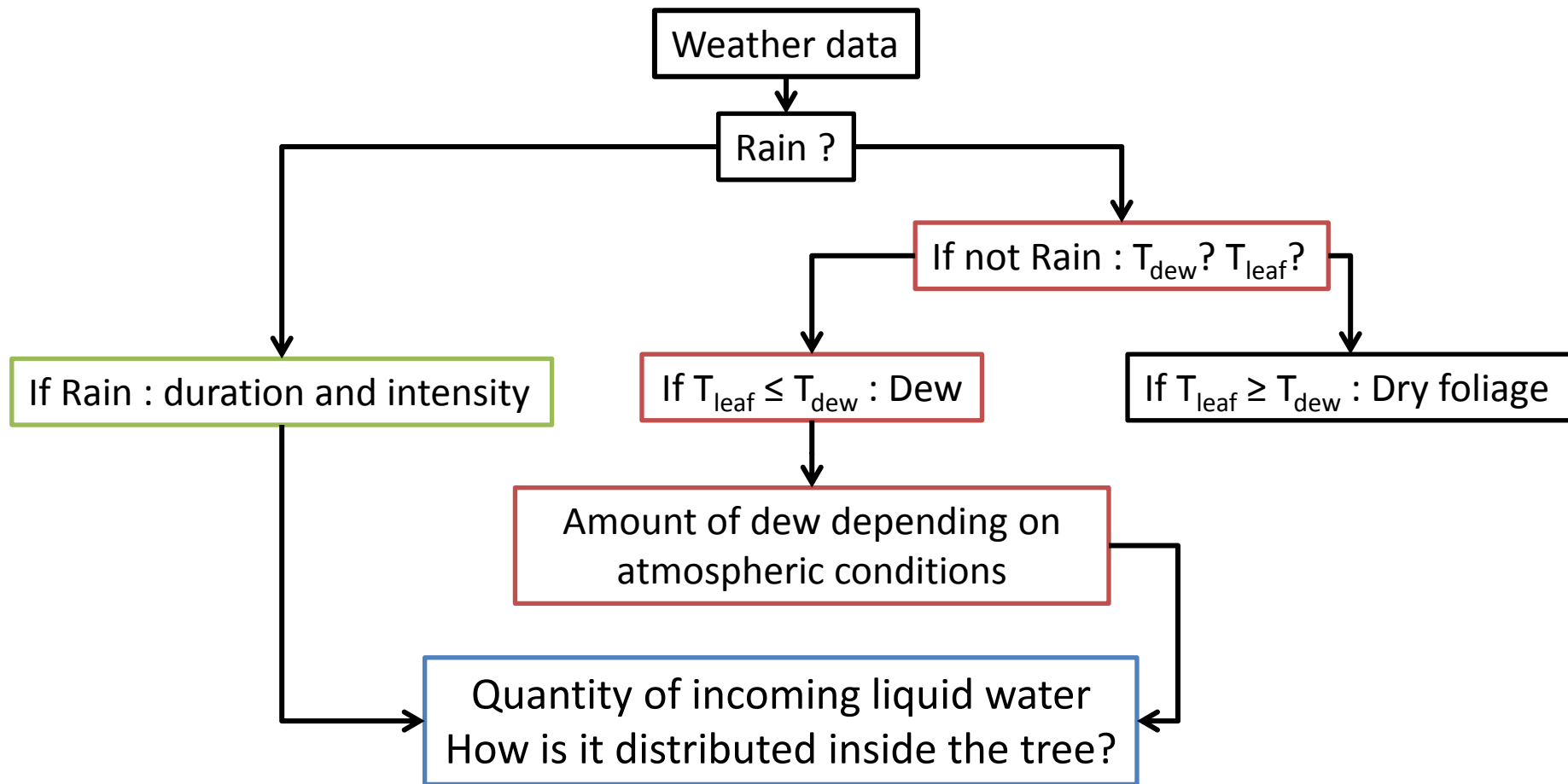
Water drying on leaves is 1.5 times slower than on sensors!

No standard, large discrepancies between leaves and sensors...

What about a physics based modeling approach?

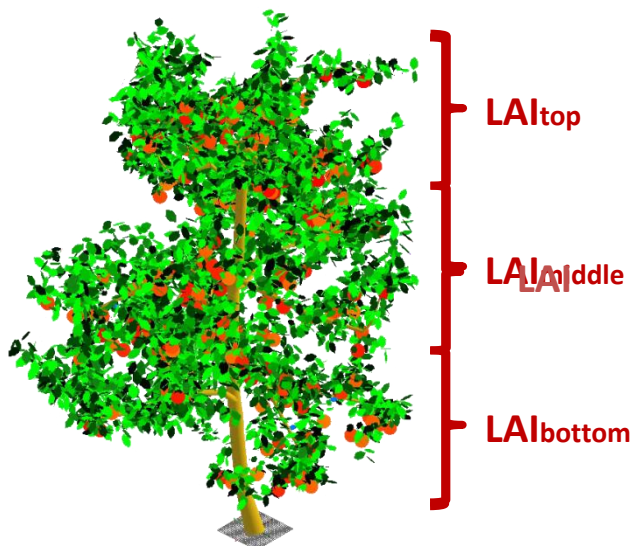
How we model LWD

Water production



How we model LWD

Spatial distribution of water



Water interception

Assuming the "Leaf Area Index proxy" (Magarey, 2005)

Tree's LAI or better : LAI of different layers in the tree

V_p = precipitation water volume

V_0 = intercepted water volume

$$V_0 = (1 - \exp(-0,5LAI)) * V_p$$

Water storage capacity



V_1 = critical water volume before overflowing

V_2 = overflowed water volume

V_3 = remaining water volume

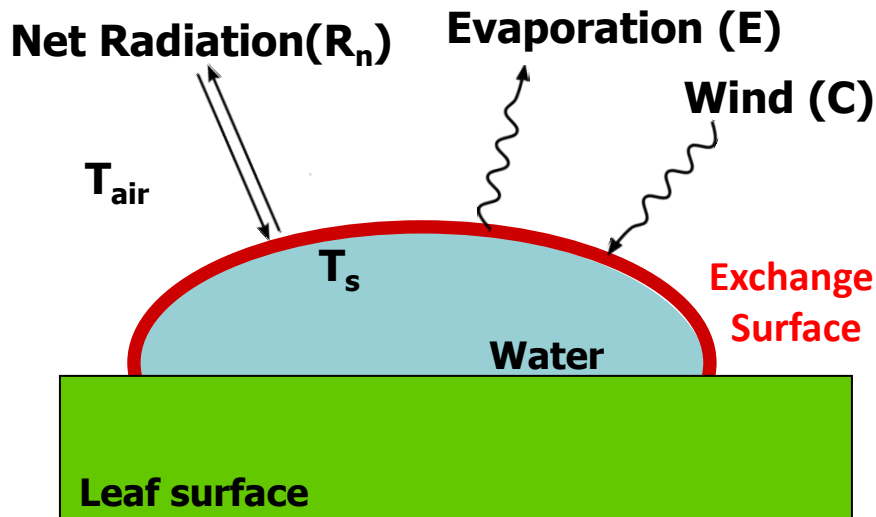
$$\text{If } V_0 \geq V_1 : V_3 = V_1 - V_2$$

$$\text{If } V_0 < V_1 : V_3 = V_0$$

How we model LWD

Evaporation

Energy budget at the water – air interface



$$\lambda E + C = R_n$$

- T_{air}
- RH
- U
- R_g
- $V_{water} = V_3$
- Exchange surface

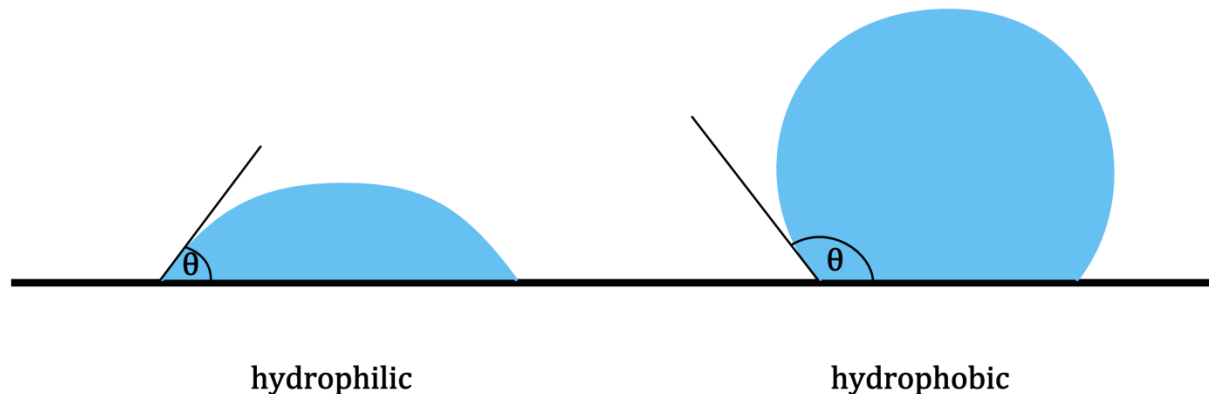
How we model LWD

Exchange surface and wettability

Exchange surface at air-liquid interface = $f(\text{drop shape})$

Drop shape = $f(\text{surface tensions coexistence at } \textit{triple point})$

Quantified by the contact angle θ



How we model LWD

Variables involved

Output

Input required

Quantity of incoming liquid water
How is it distributed inside the tree?

Precipitation rate & intensity

$$V_0 = (1 - \exp(-0,5LAI)) * V_P$$

Tree's LAI(s)

+

If $V_0 \geq V_1$: $V_3 = V_1 - V_2$
If $V_0 \leq V_1$: $V_3 = V_0$

+

$$\lambda E + C = R_n$$

V_3 U
 T_{air} R_g
 RH θ

=

Leaf Wetness Duration

What has been done so far

Data acquisition to define model parameters :

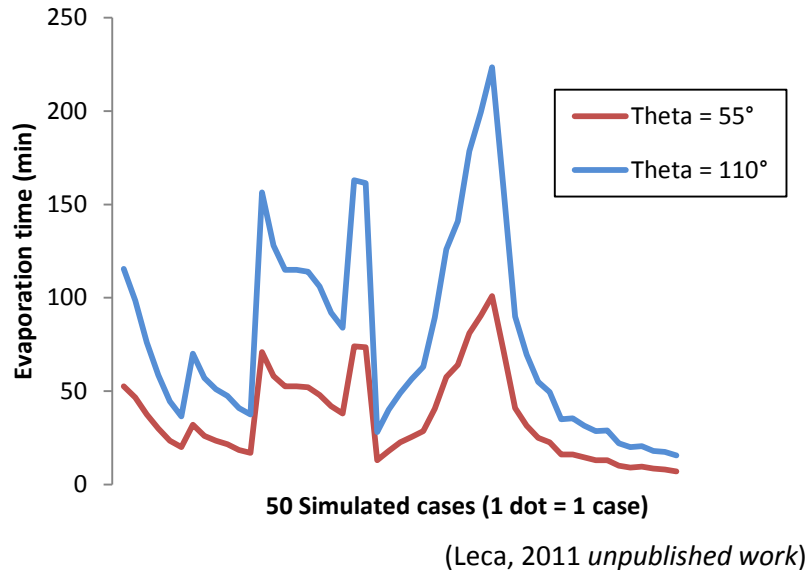
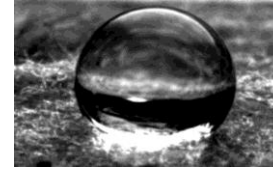
- Meteorological data collection throughout the season
- Wettability Measurements on cv McIntosh susceptible leaves
- Water storage capacity of cv McIntosh susceptible leaves
- McIntosh trees LAI measurement in our experimental orchard

Model programming and development :

- Evaporation module

Why measure wettability?

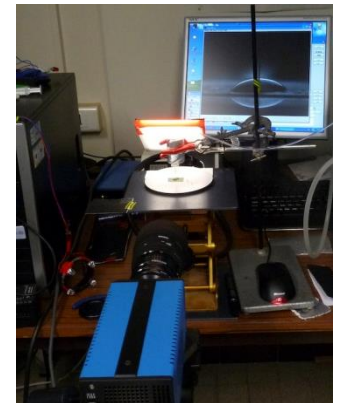
Modeling with the right wettability is **crucial**



Seems to be cultivar dependent (2 cv studied so far) ¹ : requires measures for each cv ?

Are there average values on susceptible apple leaves? Reps would tell!

Once the device is set, measurements are quite fast !



$$WD_{\theta_{110}} \approx 2 * WD_{\theta_{55}}$$

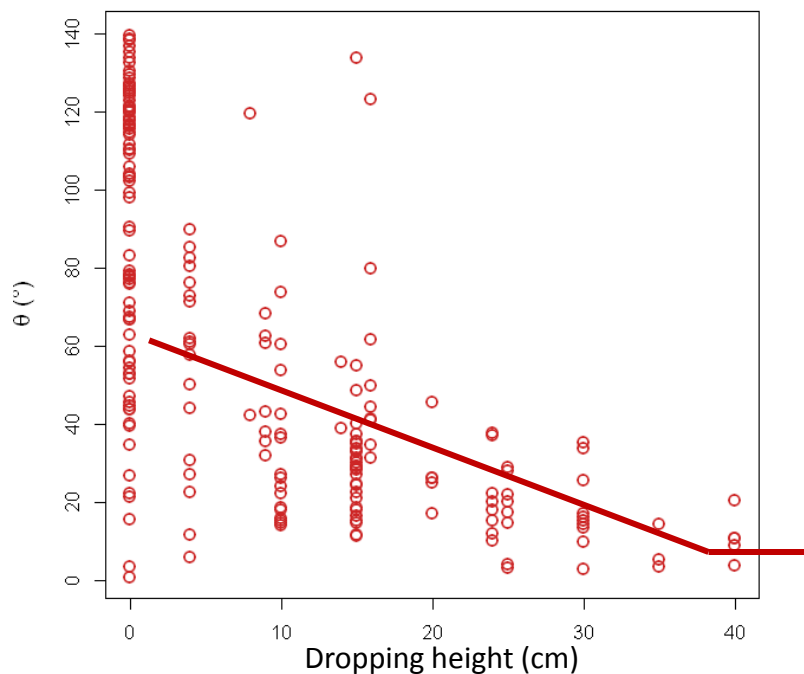
First step : **McIntosh** (64% of apples produced in Quebec)

¹ Leca, 2011

McIntosh wettability

Contact angle value depends on initial conditions :

- leaf's initial wetting (wet or dry?)
- dew water forming on the leaf or dripping?
- raindrops falling at which speed?



In laboratory conditions : different falling speeds reproduced by varying falling height

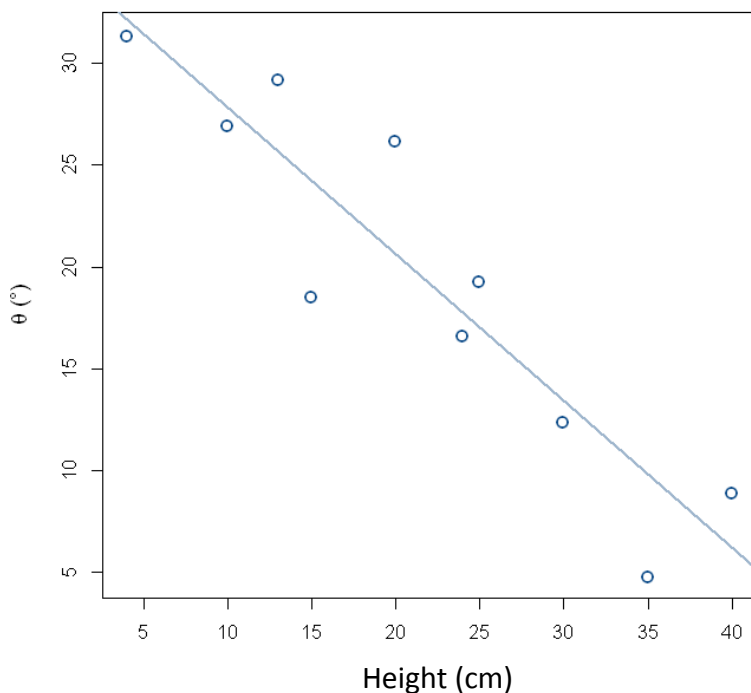
Contact angle correlated with falling height
→ Correlated with drop speed at the impact

What about the initial wetting of leaf ?

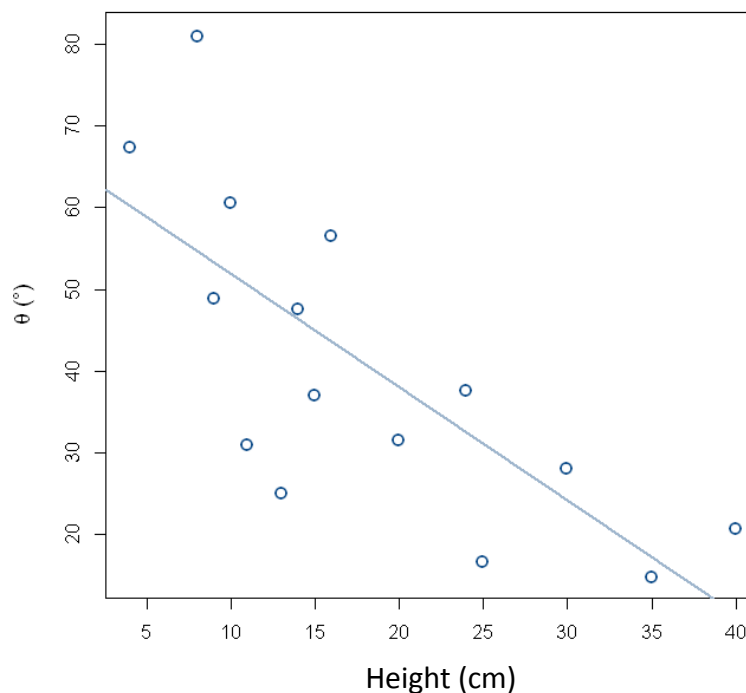
McIntosh wettability

Wettability in function of falling speed for different wetting initial conditions

θ on an initially wet leaf in function of drop height



θ on an initially dry leaf in function of drop height



McIntosh wettability

Weber number links impact velocity to spreading of the drop (further utility as a splashing descriptor¹)

$$W_e = \frac{m v^2}{\sigma}$$

m : mass of raindrop

v : raindrop terminal velocity

σ : water surface tension

Using Weber number to model contact angle of falling droplets :

In the case of falling droplets :

$$\theta_{dry}(\text{°}) = -1,59 * \alpha + 73,02 ; R^2 = 0,74$$
$$\theta_{wet}(\text{°}) = -0,69 * \alpha + 33,92 ; R^2 = 0,84$$

$$\alpha = \frac{W_e \sigma}{2 m g} \quad g : \text{earth gravity constant}$$

**In the case of formed dew
(no falling speed) :**

$$\theta_{dry} = (110,2 \pm 3,2) \text{°}$$
$$\theta_{wet} = (56,4 \pm 5,8) \text{°}$$

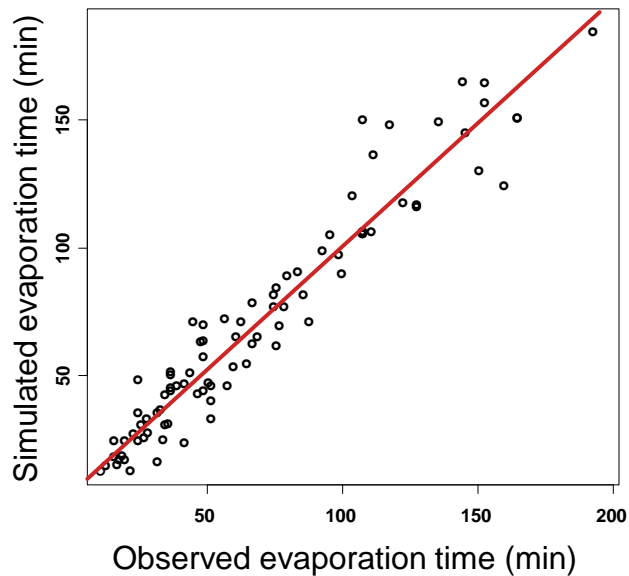
¹ Saint-Jean et al., 2006

Evaporation module

Evaporation module fully coded

Accuracy evaluated by using controlled conditions drying durations ^{1,2,3}

Evaporation module accuracy test



Variations range :

T_{air} : 10 – 35 °C

RH : 14 – 90 %

U : 0,025 – 5 m.s-1

R_g : 0 – 875 W.m-2

V : 1 – 50 μ L

$$D_{sim} = 0,96 * D_{obs} + 4,17$$
$$R^2 = 0,93$$

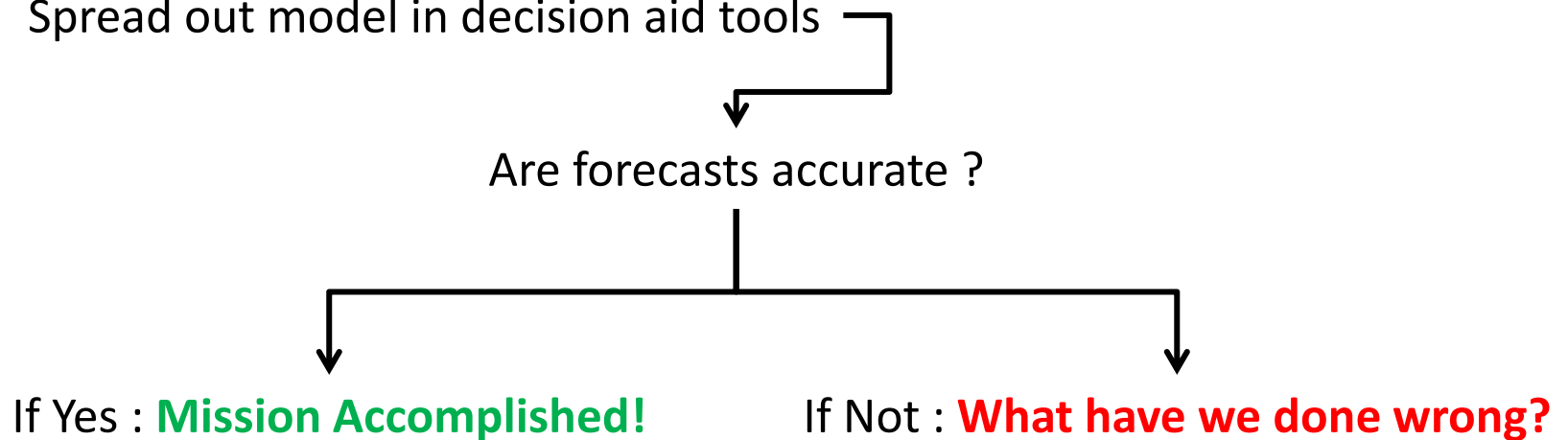
¹ Leclerc et al., 1985

² Magarey et al., 2005

³ Leca, 2011 *unpublished work*

What is left to do

- Develop the water input module to finish LWD model
- Use the measured data (T_{air} , RH, U, R_g , LWD) to validate and adjust model
- Spread out model in decision aid tools



Leads for the future ?



LWD for other species

- not much to change (wettability, boundary layer)
- might be of interest for several pathosystems



FWD : Fruit Wetness Duration?

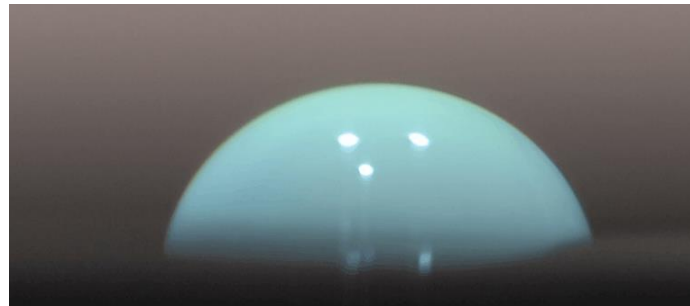
- Great fruits temperature model exists ¹
- Useful to estimate sooty blotch flyspeck
- water dynamics (wettability, droplets sliding, etc.) are a nice and realistic challenge



Any other idea ?

¹ Saudreau et al., 2011

Thank you for your attention !!



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