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## Modelling of powdery mildew spread over a spatially heterogeneous growing grapevine

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### ► To cite this version:

Agnes A. Calonnec, Jean-Baptiste Burie, Michel Langlais, Youcef Mammeri. Modelling of powdery mildew spread over a spatially heterogeneous growing grapevine. Working Group “Integrated Protection and Production in Viticulture”, Oct 2013, Ascona, Switzerland. 250 p. hal-02739949

**HAL Id: hal-02739949**

**<https://hal.inrae.fr/hal-02739949v1>**

Submitted on 2 Jun 2020

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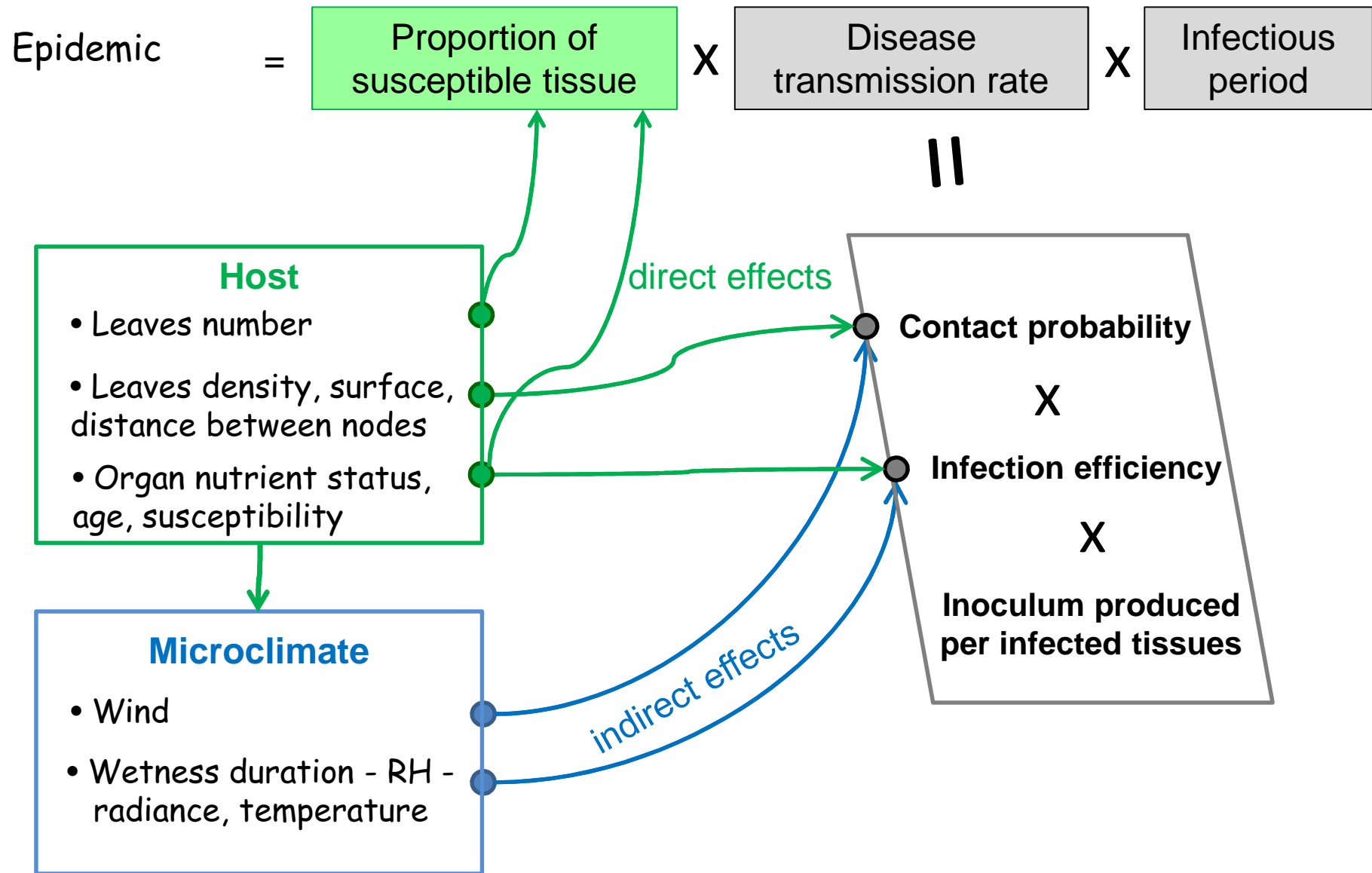


# Modelling of powdery mildew spread over a spatially heterogeneous growing grapevine

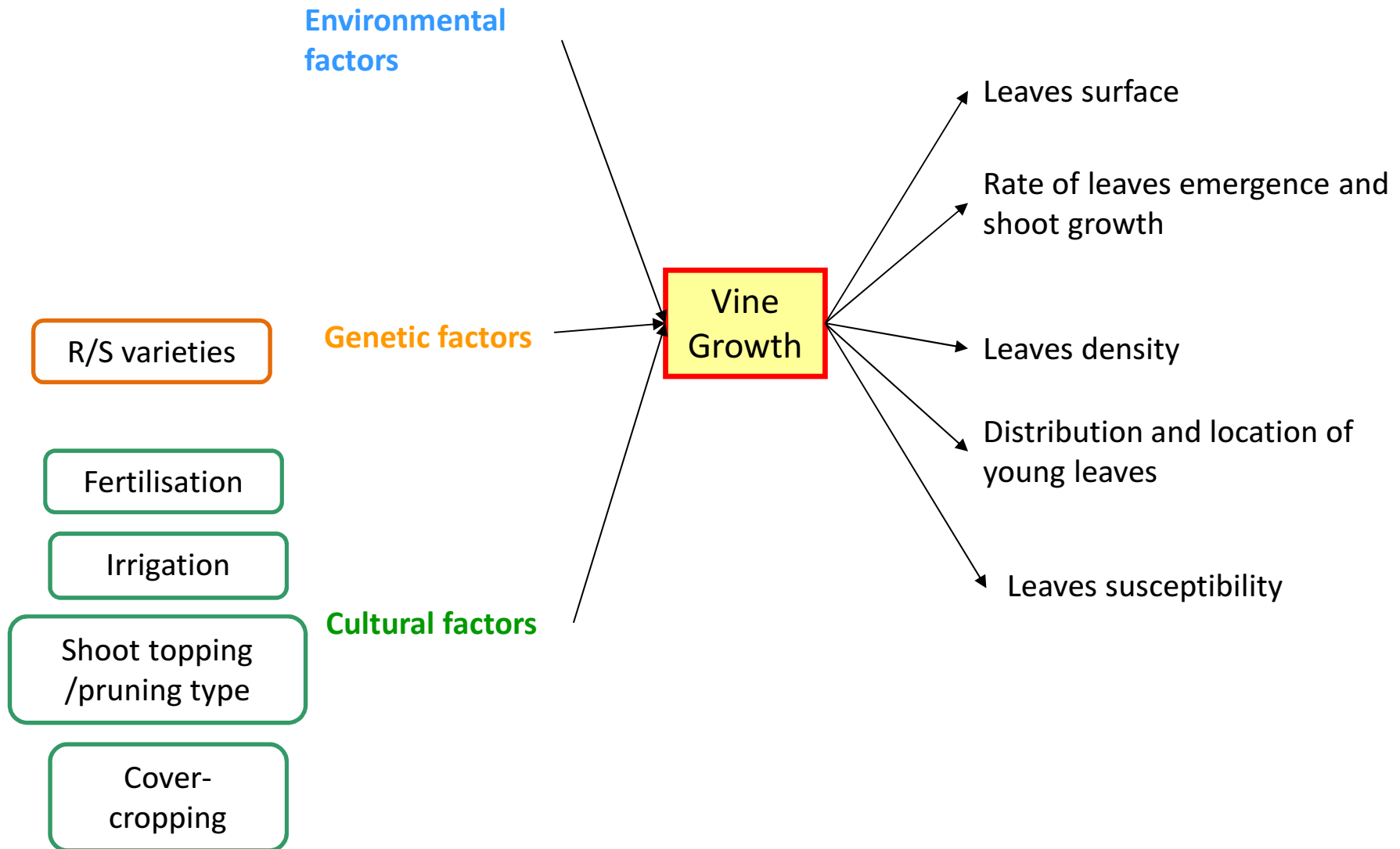
A. Calonnec, J.B. Burie, M. Langlais and Y. Mammeri



# What makes an epidemic?



# What kind of changes in the host can we expect?



# What do we know about grapevine growth - powdery mildew relationships?

- Correlation between vine **vigour** and the powdery mildew dynamics and spread

Calonnec et al., 2009, *Phytopathology* 99:411-422

- The vine growth dynamic impact the disease dynamic **for a partially resistant variety**

Valdes et al., 2011, *Crop protection*, 30:1168-1177

- **Models at the vine scale** are in accordance with those effects

Calonnec et al., 2008, *Plant Pathology*; Burie et al., 2011, *AOB*, 107, 885-95

Can those effects be explored at the plot scale?

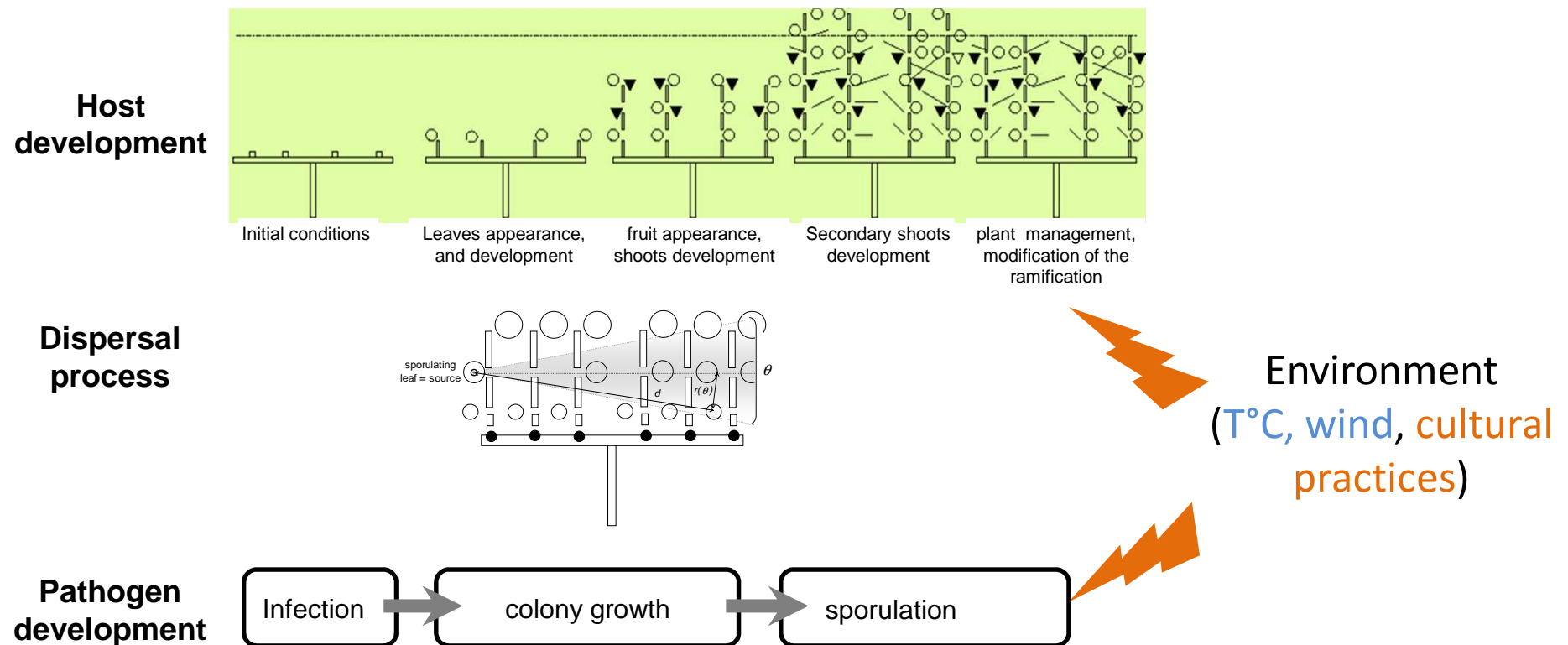
**Can we build a model able to take into account:**

**Vine growth, Evolution of susceptibility, Cultural practices, Fungicide treatments...**

**at the Plot and Vineyard Scales?**

**Can we use this model to test practical disease management?**

# At the vine scale: A deterministic architectural model able to explore the host and pathogen processes involved

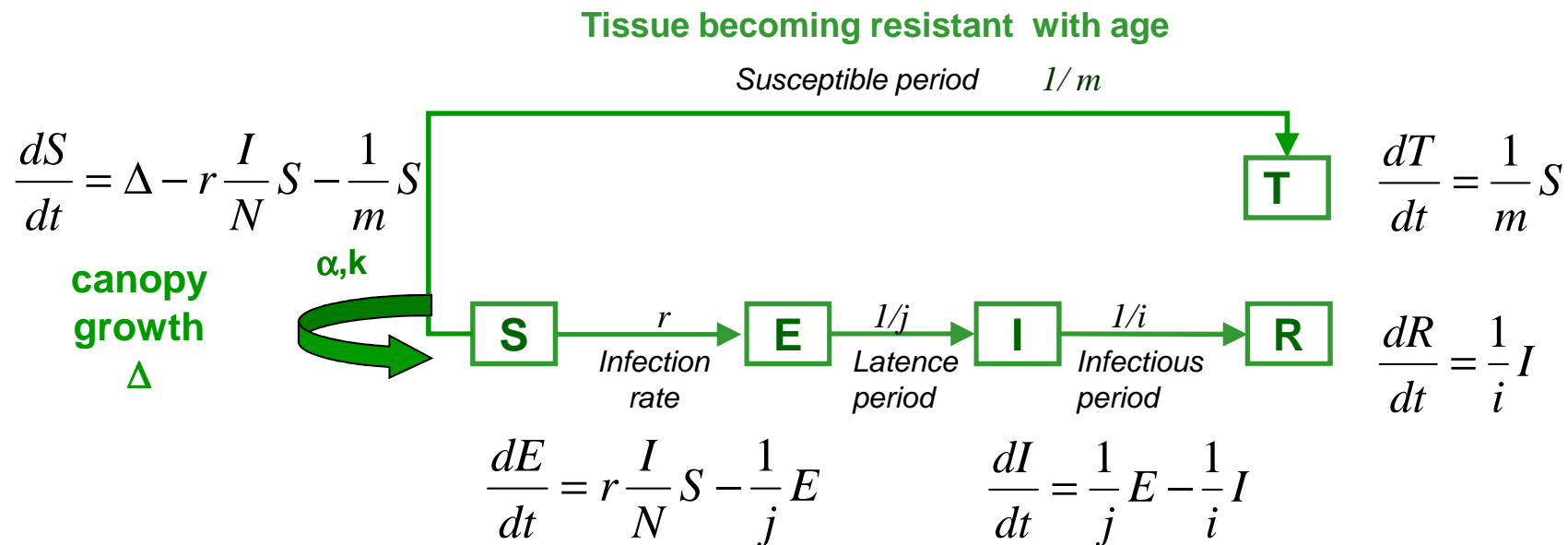


Complex model  
Allow to rank the effects of host development on the disease  
Sensitivity analyses can be cumbersome

# At the vine scale: Mathematical compartmental ODE model

## SEIRT type model

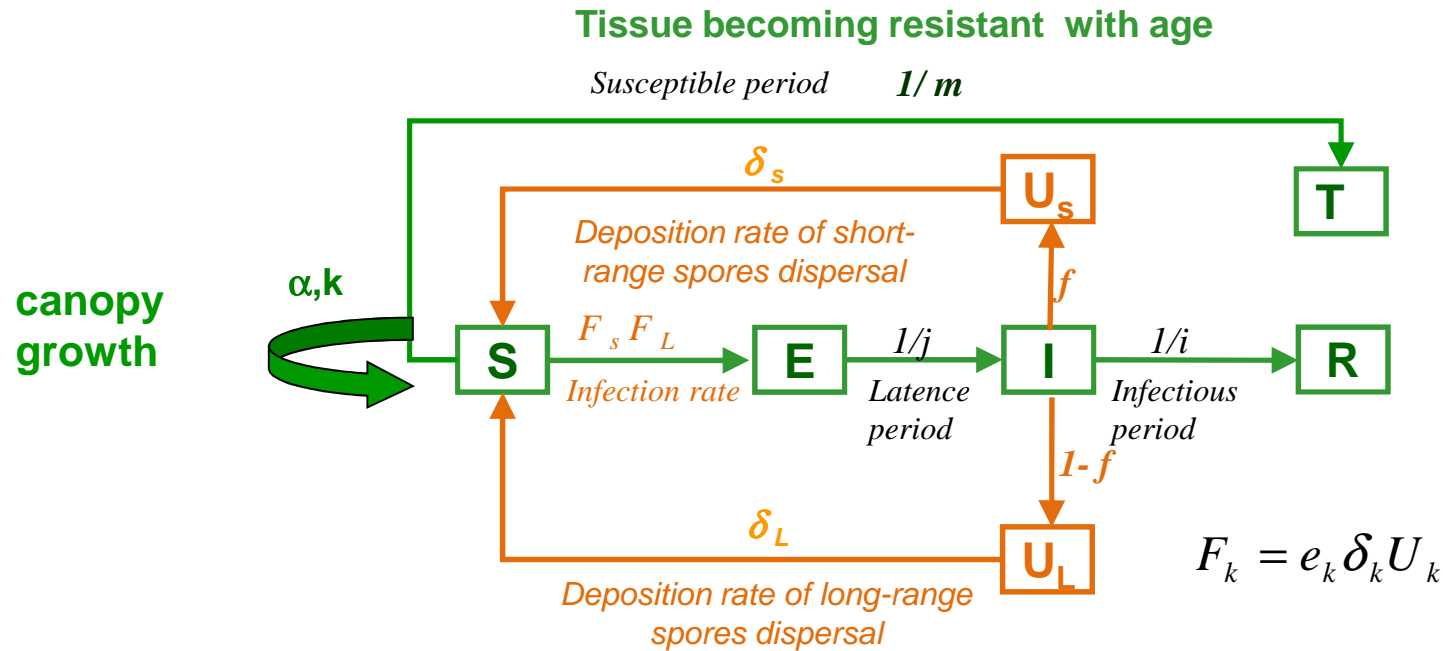
Ordinary Differential Equations describe the Time evolution of the surface area of tissue



**Susceptible Exposed Infectious Removed** on **T** ogenic resistant



# At the plot scale: The ODE model is coupled to Partial Differential Equations model including spore dispersal



$$\frac{d}{dt} E(x,t) = a \left( e_s \delta_s U_s(x,t) + e_L \delta_L U_L(x,t) \right) \frac{S(x,t)}{N(x,t)} - \frac{1}{j} E(x,t)$$

rate of infected tissue is function of the infection efficiency ( $e$ ), deposition rate ( $\delta$ ), density of spores ( $U$ ) coming from short ( $s$ ) or long distance ( $L$ )

Density of spores  $U_S$  and  $U_L$  in the air follows advection-reaction-diffusion equations, giving the amount of spores dispersed at **short vs long** distance

$\gamma$ : rate of spores produced /infectious unit/day

$f$ : proportion of spores dispersed at short distance

$I$ : amount of infectious tissue

$$\frac{\partial U_S(x,t)}{\partial t} - \nabla \cdot (D_S \nabla U_S(x,t)) + \delta_S U_S(x,t) = \gamma f I(x,t)$$

$$\frac{\partial U_L(x,t)}{\partial t} - \nabla \cdot (D_L \nabla U_L(x,t)) + V(x,t) \cdot \nabla U_L(x,t) + \delta_L U_L(x,t) = \gamma (1-f) I(x,t)$$

$V$ : wind velocity

Simpler models that do not take into account the climate but taking into account the plant growth and to some extent the canopy structure

r I

$$\frac{d}{dt} S(x,t) = \Delta - \overbrace{a(e_S \delta_S U_S(x,t) + e_L \delta_L U_L(x,t))}^{r I} \frac{S(x,t)}{N(x,t)} - \frac{1}{m} S$$

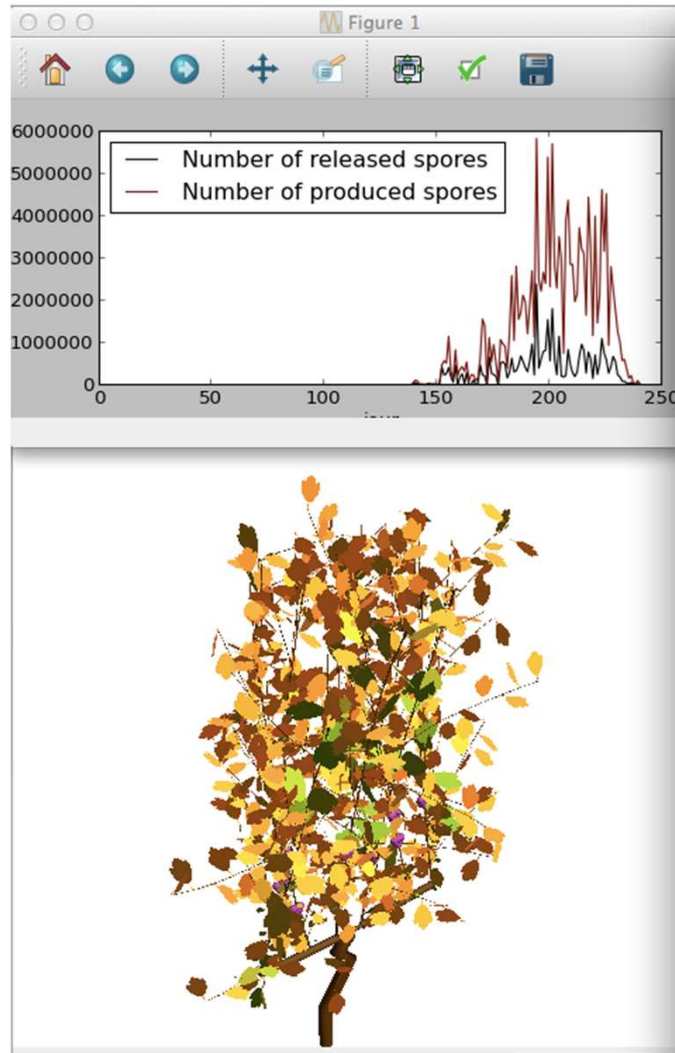
$$\frac{d}{dt} E(x,t) = a(e_S \delta_S U_S(x,t) + e_L \delta_L U_L(x,t)) \frac{S(x,t)}{N(x,t)} - \frac{1}{j} E(x,t)$$

$$\frac{d}{dt} I(x,t) = \frac{1}{j} E(x,t) - \frac{1}{i} I(x,t)$$

$$\frac{d}{dt} R(x,t) = \frac{1}{i} I(x,t)$$

$$\frac{d}{dt} T(x,t) = \frac{1}{m} S(x,t)$$

**The PDE-ODE model :** takes into account plant growth and the canopy structure by using the output of the process based model for calibration

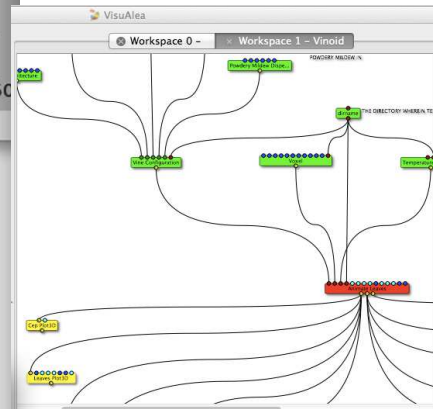


**Architectural model :**

$\alpha, k$  parameters of canopy growth

$\gamma$  rate of spores produced /infectious unit

$S$  evolution of susceptible tissue



**Experimental data at plot scale :**

$f$  proportion of short range dispersal (0.8)

$e_s, e_L$  infection efficiency of short range spores (0.07 %) vs long range (0.06 %)

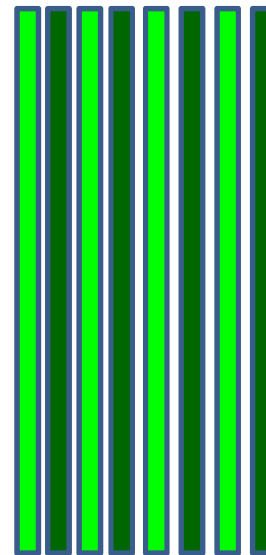
**Literature :**

$\delta$  deposition rates  $50 \text{ days}^{-1}$

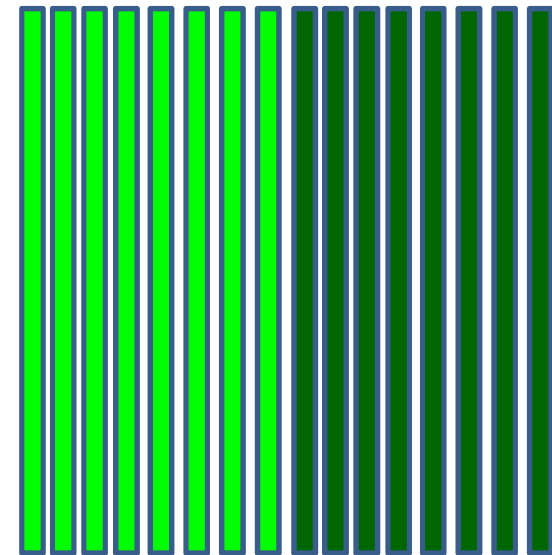
$\sigma_L$  (20 m),  $D_L$  ( $20000 \text{ m}^2\text{day}^{-1}$ ), diffusion coefficients

# The PDE-ODE model used to explore some practical questions

- Do heterogeneities of phenology between adjoined varieties/plots can favor the disease?
- Can the management of plant vigour help having a better control of the disease?
- Can varietal mixture with various levels of resistance reduce the disease spread?
- What is the better timing to apply a fungicide?



rows



patches

# Various simulations performed

Effect on disease spread of :

**Plant growth**



high vigour  
vs  
low vigour

1 plot = 6150 vines  
50 rows of length 98.4 m

**Plant-Pathogen Synchronism**



early budbreak - late budbreak  
primary inoculum early or late side

**Plant growth Heterogeneities**



high vigour - low vigour  
in patches or  
in rows

**Heterogeneities of plant Susceptibility**



susceptible variety - resistant variety  
in patches or  
in rows

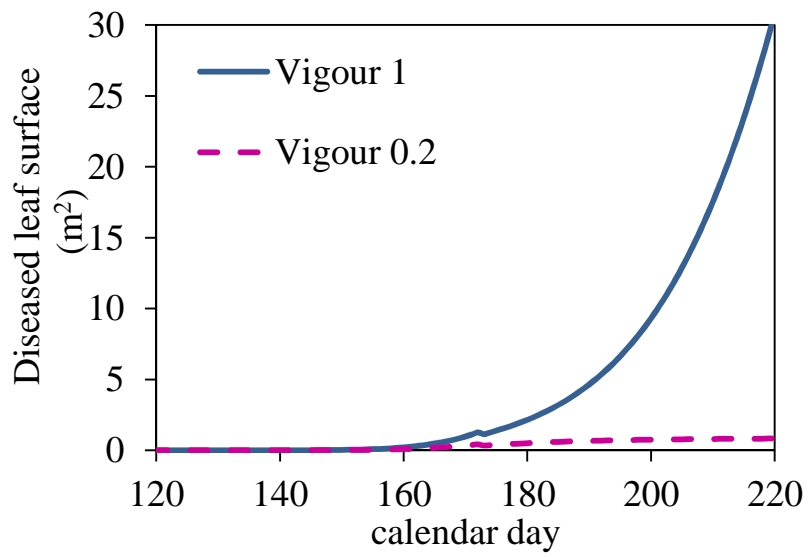
**Disease control with Fungicide**



fungicide at  
flowering or  
at shoot topping

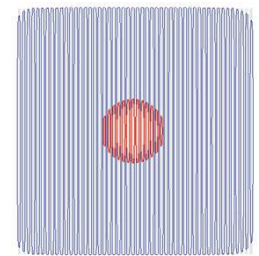
# Effect on disease spread of plant growth and fungicide treatments

high vigour  
 vs  
 low vigour

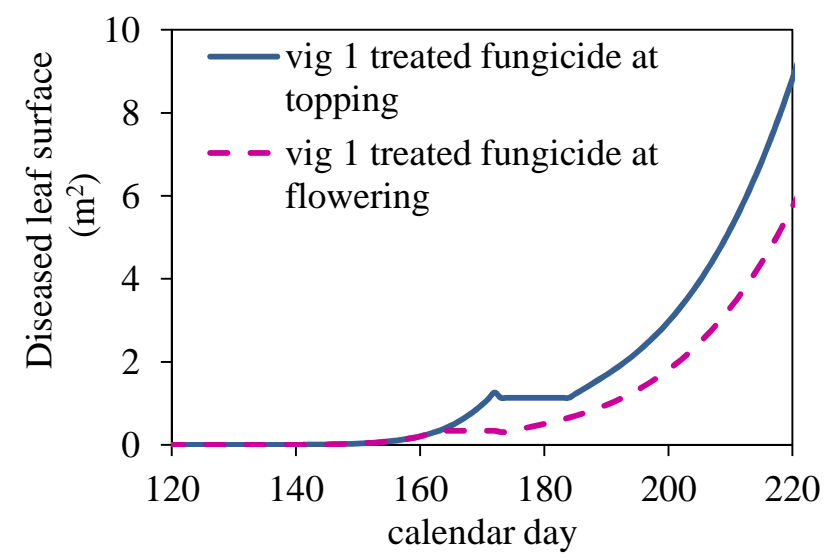


Disease reduction  
 vig 0.2 / vig 1  
 65% at shoot topping  
 97% at day 220

disease spread



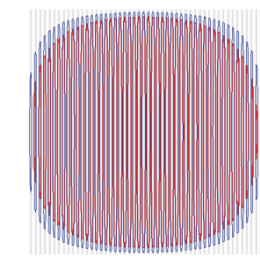
fungicide at flowering or at shoot topping



Disease reduction  
 fungicide flowering / Untreated  
 69% at shoot topping  
 81% at day 220

Disease reduction fungicide  
 shoot topping / Untreated  
 71% at day 220

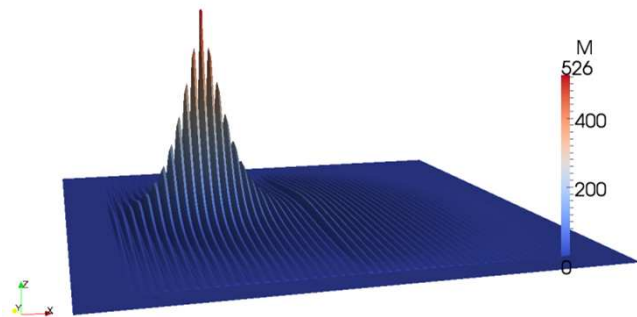
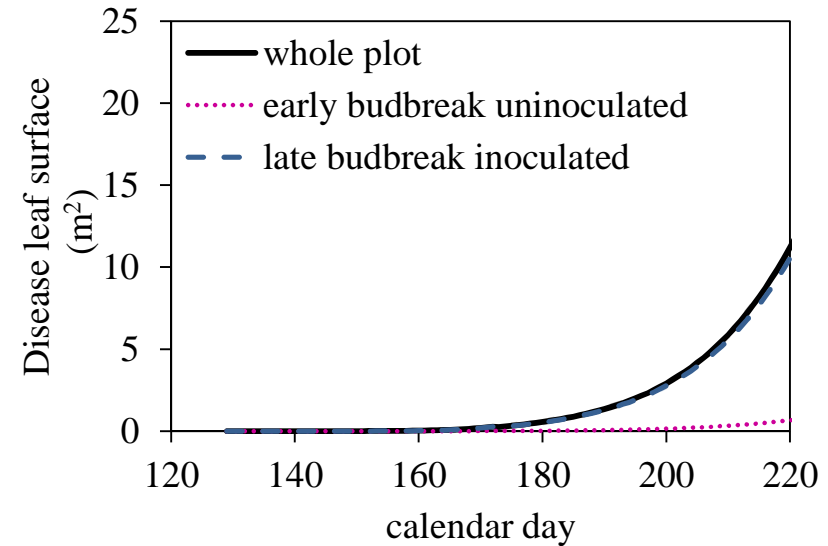
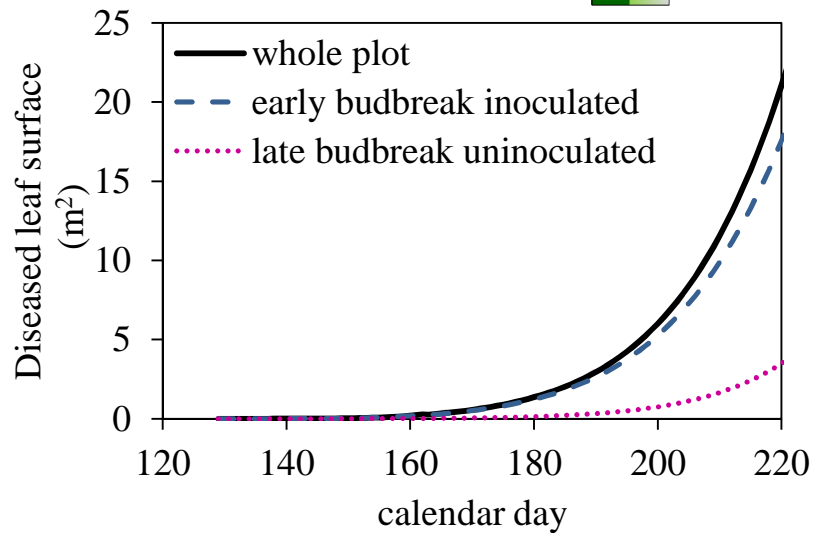
disease spread



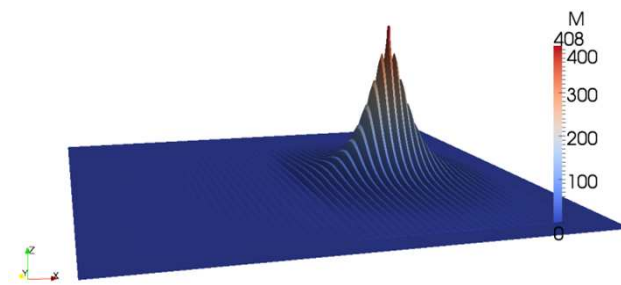
# Effect on disease spread of Plant-Pathogen Synchronism



early budbreak - late budbreak  
primary inoculum early or late side



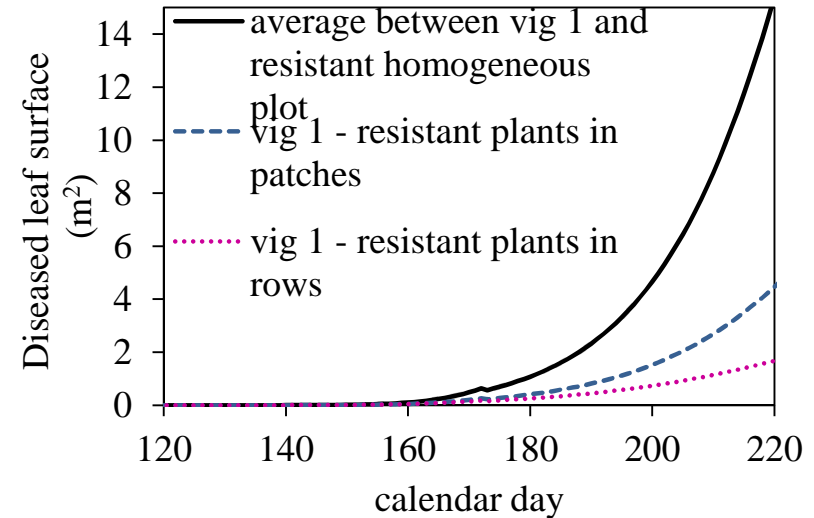
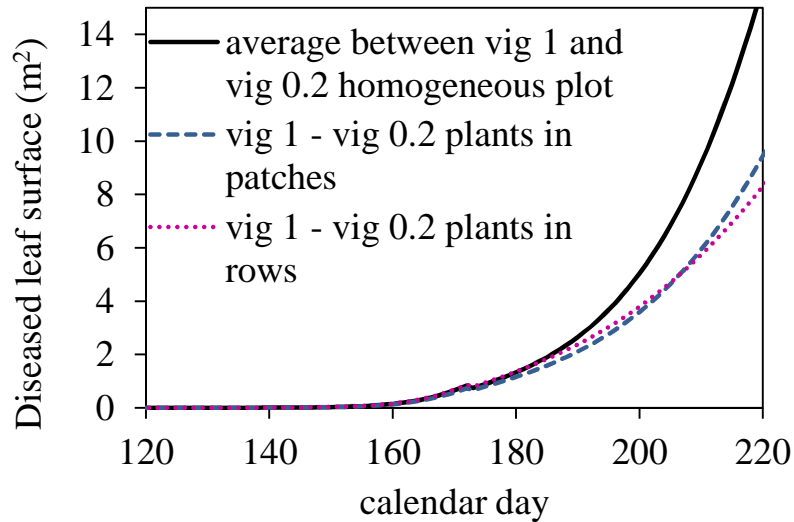
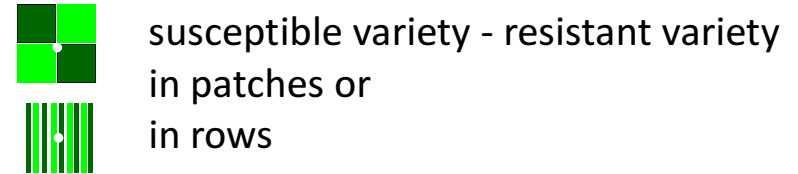
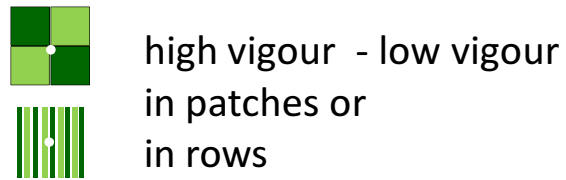
Disease reduction  
Early bud break side inoculated  
44% at shoot topping  
31% at day 220



Disease reduction  
Late bud break side inoculated  
79% at shoot topping  
64% at day 220



# Effect of plant growth or plant susceptibilities heterogeneities



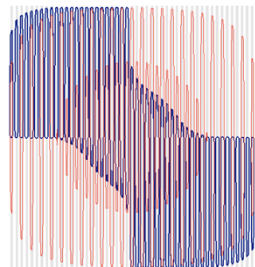
Disease reduction  
heterogeneities for **plant growth**

**47% rows**  
**40% patches**  
at day 220

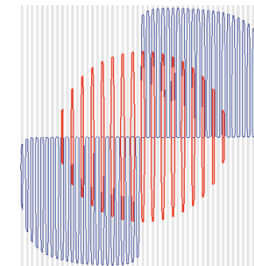
Disease reduction  
heterogeneities for **plant susceptibility**

**89% rows**  
**70% patches**  
at day 220

disease  
spread



disease  
spread



# Conclusion

- We developed a model able to simulate the dispersal of an airborne pathogen (powdery mildew) and the disease on a highly anthropized crop (vine) at a **plot scale**.
- A promising tool to explore the **efficiency of innovative disease control strategies** based on plant and/or crop structure management under **low pesticide use**.
- The efficiencies of decreasing disease spread differs at shoot topping and at the end of the season, to consider for bunch damages !
- R/S varietal mixture in rows (89% disease reduction)  
R/S varietal mixture in patches (70% )  
Heterogeneities in plot phenology (64%) (late bud break)  
Heterogeneities for growth in rows (47%) (alternate cover-cropping?)  
Heterogeneities for growth in patches (31%)
- Sensitivity analysis for parameters link to dispersion has still to be done, and combination of innovative strategies