a model to highlight the tions between plant growth, powdery crop management and climate; a ity analysis

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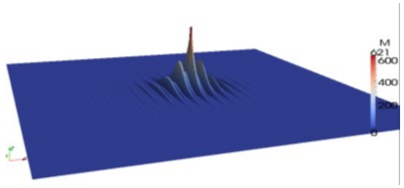
Models for grapevine powdery mildew

3D mechanistic process based model

- **Plant scale**
- **Model of vinestock development**
- **Model of powdery mildew**
- **Dispersion process** inside the plant (wind)
- **Cultural management**

calibration

SEIR model



PDE-ODE continuous model

- **Plot scale**
- **Model of leaf area evolution**
- **Model of spores dispersion in the plot**
  Plot heterogeneities
- **Cultural management**

Calonnec A, et al. (2008). *Plant Pathology*, 57, 493-508.

Burie JB, Langlais M, Calonnec A, (2011). *Annals of Botany* 107, 885-95.

Mammeri Y, Burie JB, Langlais M, Calonnec A. (2014). *Ecological Modelling,* 290, 178-191

Vignoïd: A discrete mechanistic process based simulation model coupling grapevine and powdery mildew

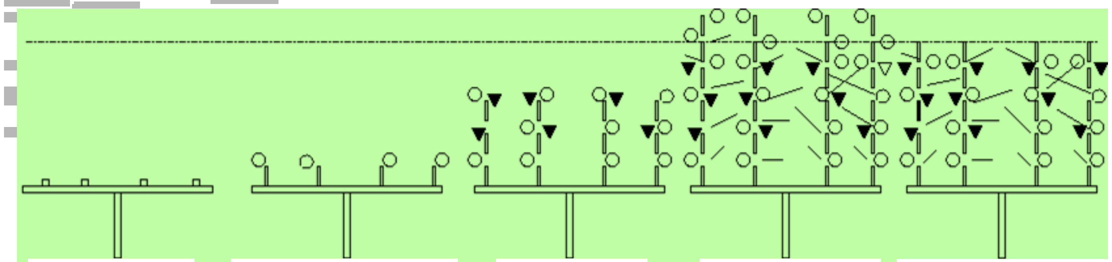
- Understand and assess the dynamical interactions between the Host / Pathogen / Environment (plant growth, phenology, spore dispersion…)

- Simulate spatio-temporal dynamics from various scenarii (climate, training system, isolates, treatments…) and explore through the modelisation the capacity of host development to modify the disease progress

- Define plant conducts the most unfavorable to the pathogen development

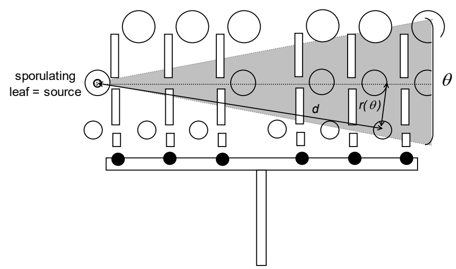
An architectural model able to explore the host and pathogen processes involved

Host development



Initial conditions | Leaves appearance, and development | Primary shoots development | Secondary shoots development | Shoot topping : modification of the ramifications

Dispersal process



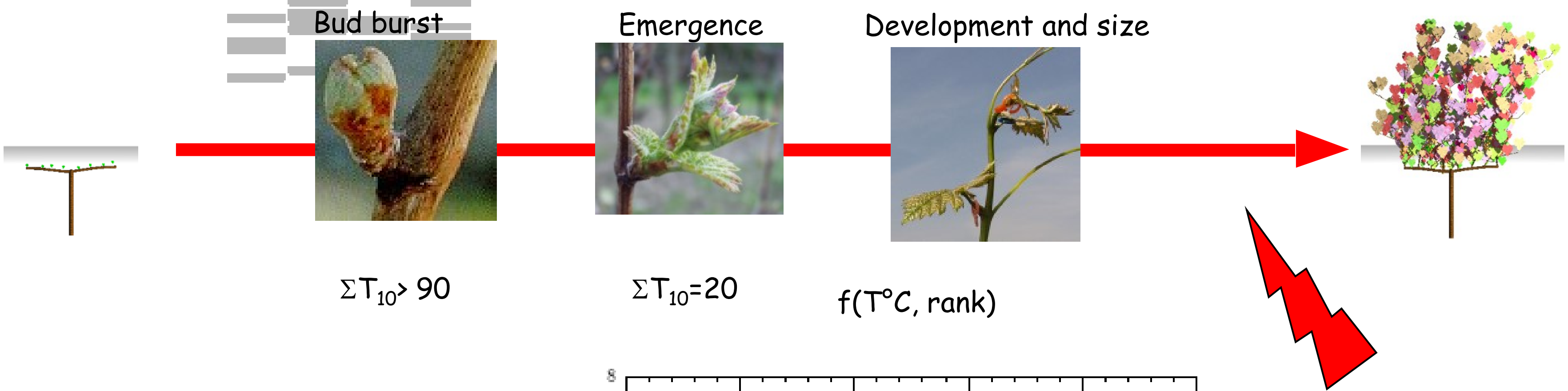
Pathogen development

Infection → colony growth → sporulation

Function of leaves age

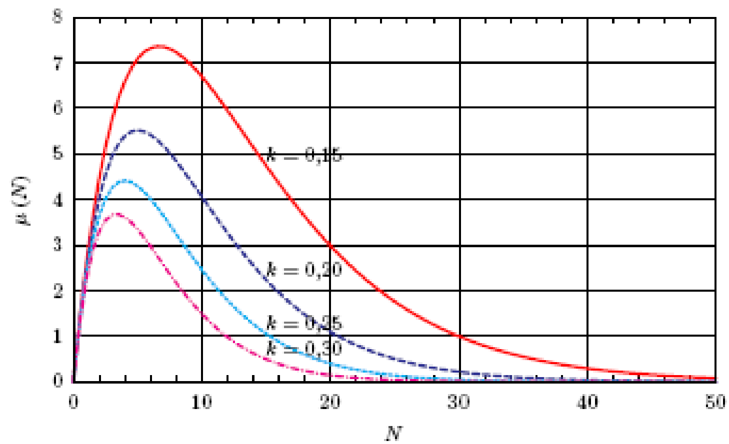
Calonnec A, et al. (2008). *Plant Pathology*, 57, 493-508.

A model for vine stock growth

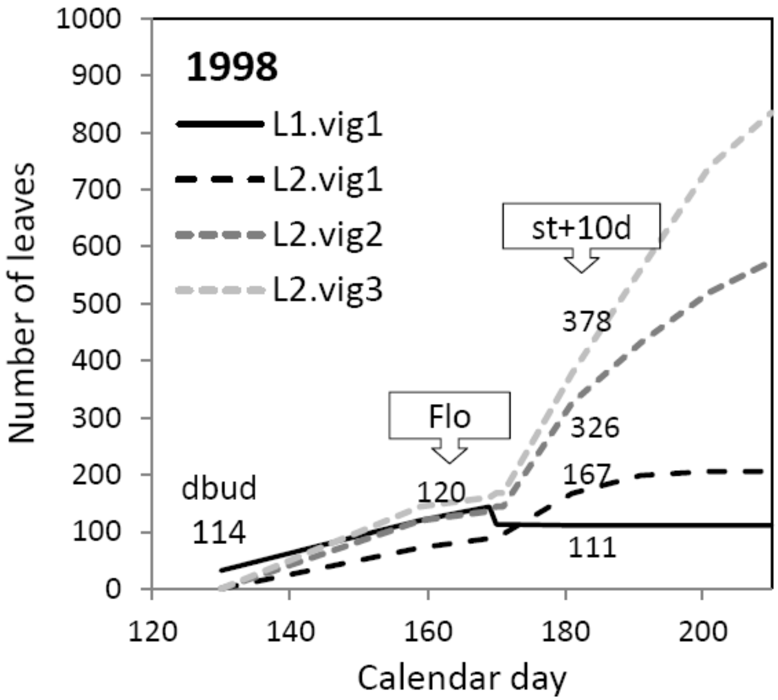


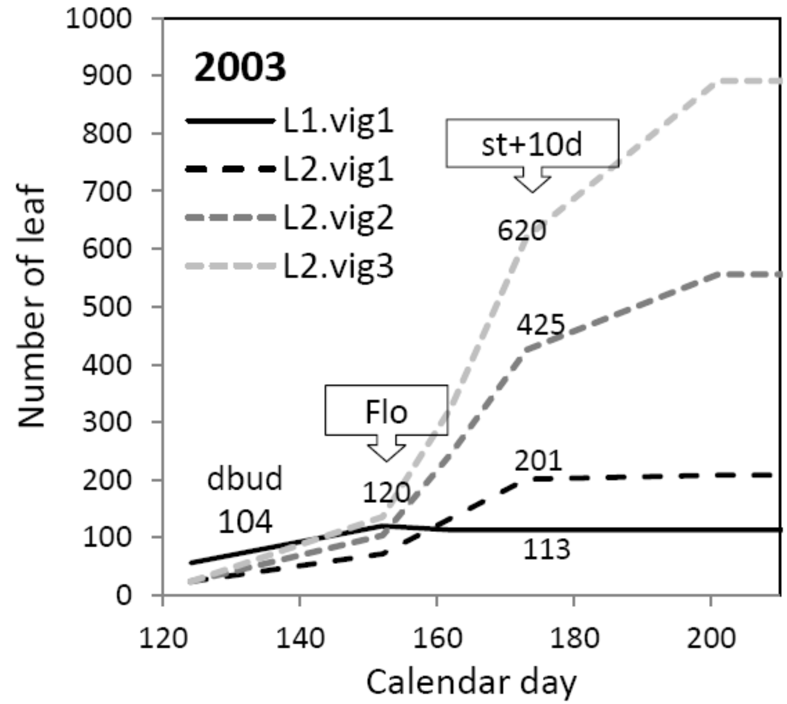
Secondary shoots development
(shoot topping, Vigour)

- structure and dynamics of the canopy
- organs susceptibility
- the host variability



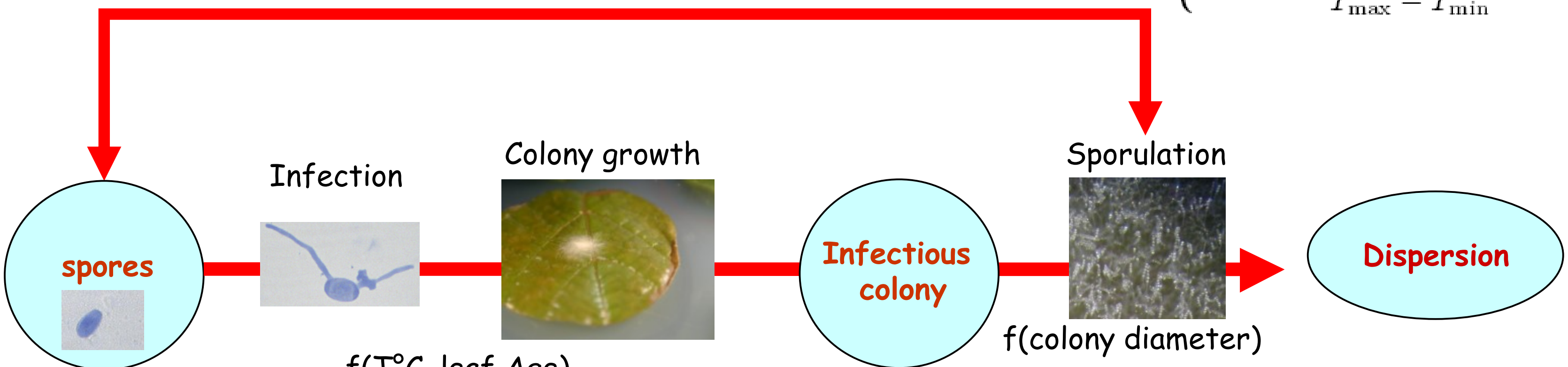
Variation of Host development: vigour effect





A model for powdery mildew development

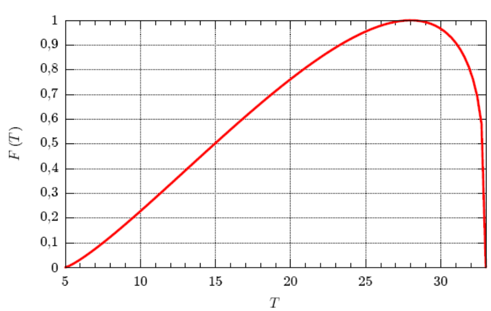
Latence period = f(T°C) $F(T) = RT_n(T)^n(1 - T_n(T))^m, \quad \begin{cases} R = \dfrac{(m+n)^{m+n}}{m^m n^n} \\ T_n(T) = \dfrac{T - T_{min}}{T_{max} - T_{min}} \end{cases}.$



f(T°C, leaf Age)

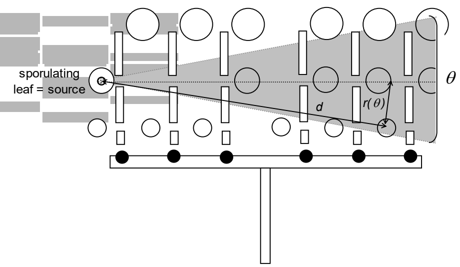
$Q_r = Ae^{P_5 Diam}$

I= $I_{max}F_g(T)\, e^{P_4 AgeF}$



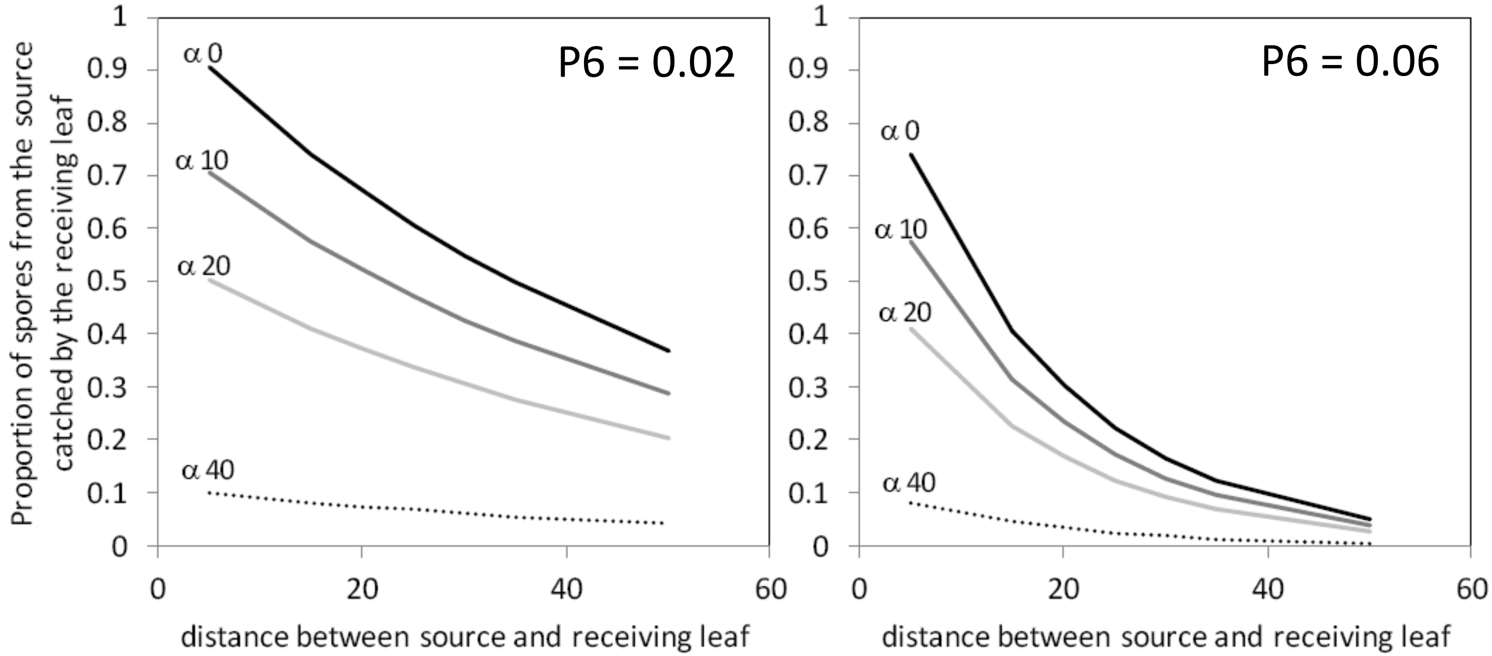
- The pathogen variability (isolate +- aggressiveness , fctT°C, ontogenic resistance)

A dispersion process

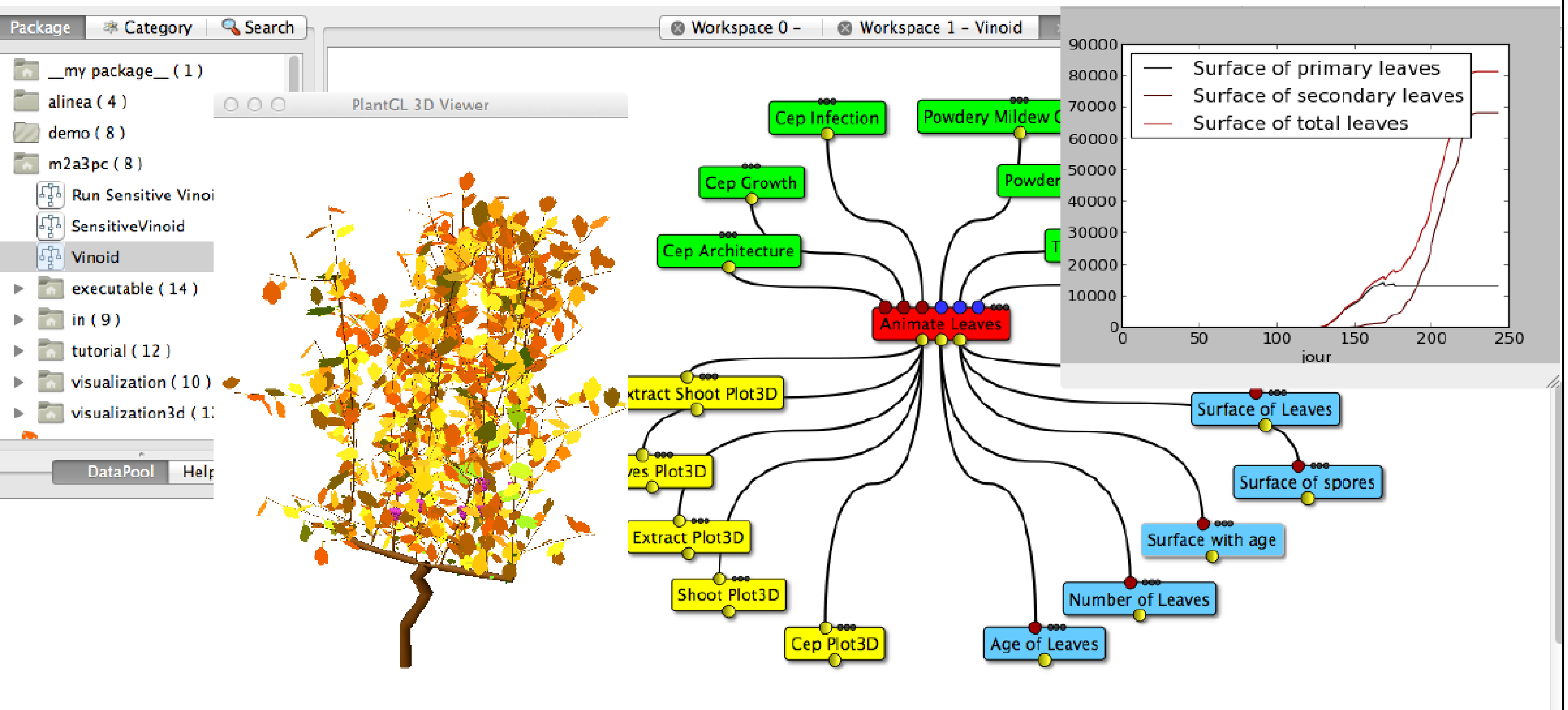


$$Q_c = Q_r.S.e^{-P6.d}$$

Qc = spores captured by the canopy
Qr= spores released by the source
S= leaf surface
d= distance to the source



Platform Open Alea in Python langage

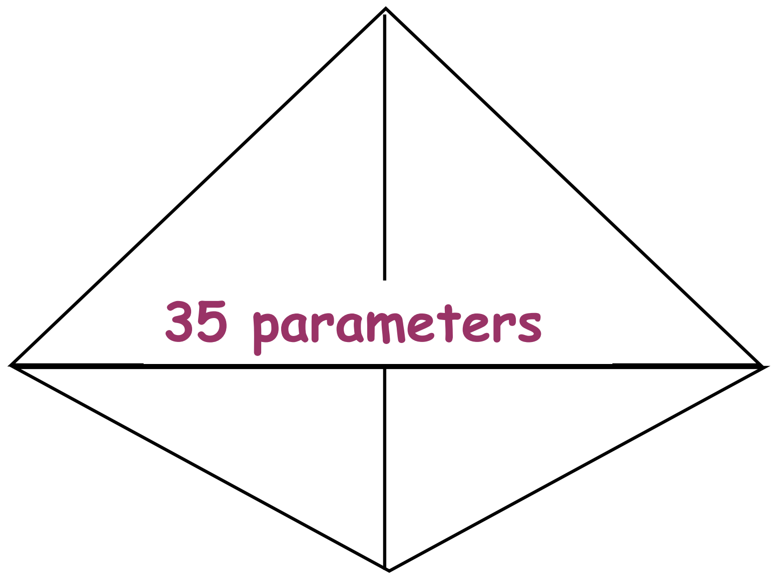


Human

Vine conduct (shoot topping : date and height, pruning: number and density of buds)

Host

(max leaves size, rate of shoot and leaves development, leaves susceptibility, structure and rate of development of secondary shoots, vigor)



Pathogen

Inoculation
(date, localization)

Isolates
(infection, colony development, sporulation…)

Climate

Temperature
(development of host and pathogen)

Wind
(spores release)

Sensitivity analysis

Identify the plant-pathogen parameters that have the highest effect on the output (number and surface of diseased leaves)

Can we define optimal conditions of plant management depending on the disease pressure or initiation or climatic conditions?

What will be the effect on disease development with a variety showing different pattern of ontogenic resistance?

Can we decrease the disease level by delaying the shoot topping or by increasing the distance between buds?

Are these effects dependant on initial and climatic conditions?

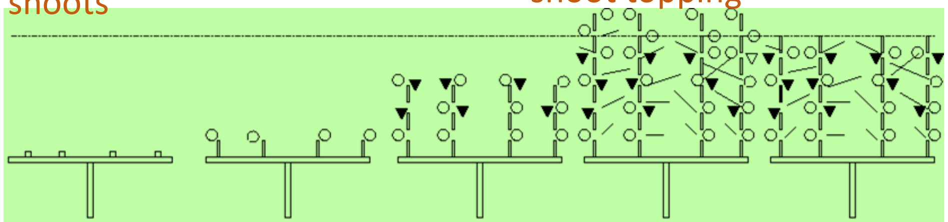
Sensitivity analysis

Distance between shoots

Height of shoot topping

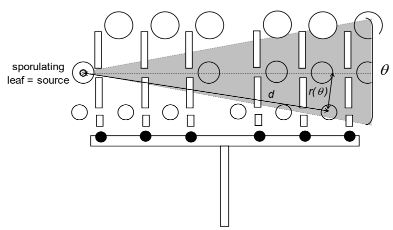
Vigour

Host development



4 Parameters from plant growth or plant management

Dispersal process



Dispersion

$$Q_c = Q_r.S.e^{-P6.d}$$

2 Parameters from pathogen

Early inoculation (stage 1L) or Late inoculation (3L)

Pathogen development

Infection → colony growth → sporulation

Leaves susceptibility/ ontogenic resistance

$$I = I_{max}F_g(T)\ e^{P_4 AgeF}$$

Sporulation

$$Q_r = Ae^{P_5 Diam}$$

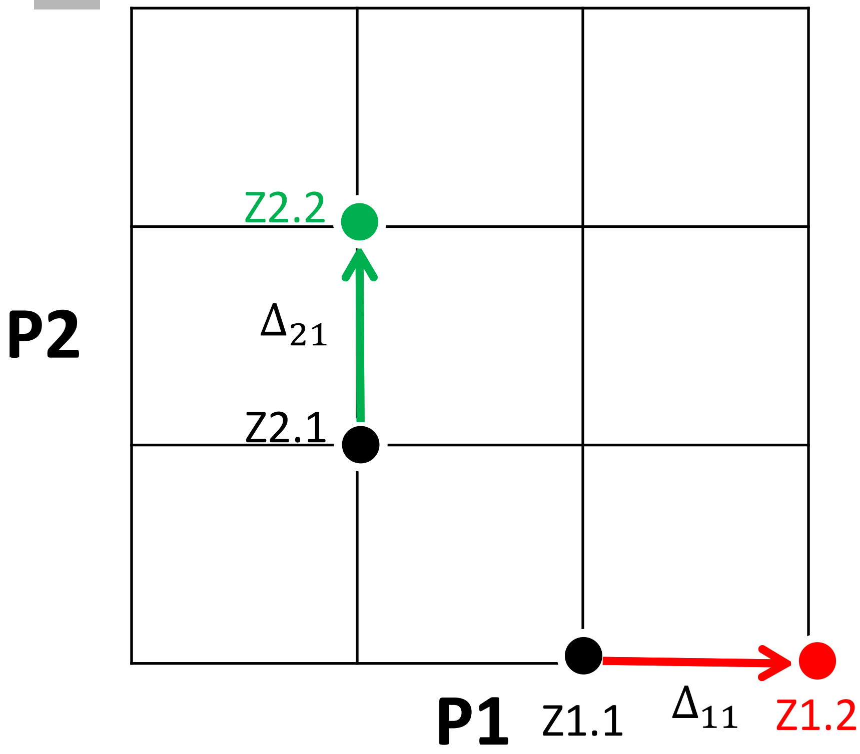
Five climatic scenarii

Method : Morris ‘one at a time’

- Define a design by combining *k* values (10) of the *p* parameters (6)
- Add a « jump » Δ_{ij} to the i^{th} parameter

Method : Morris ‘one at a time’

Example of path (*p*=2 parameters, *k*=2 levels, *r*=1 path)



Z1.1	Z2.1
Z1.1	Z2.2
Z1.2	Z2.2

Method : Morris 'one at a time'

Example of path (*p*=6 parameters, *k*=2 levels, *r*=1 path= 7 simulations)

Z1.1	Z2.1	Z3.1	Z4.1	Z5.1	Z6.1
Z1.1	Z2.1	Z3.1	Z4.2	Z5.1	Z6.1
Z1.1	Z2.1	Z3.1	Z4.2	Z5.1	Z6.2
Z1.1	Z2.2	Z3.1	Z4.2	Z5.1	Z6.2
Z1.1	Z2.2	Z3.2	Z4.2	Z5.1	Z6.2
Z1.1	Z2.2	Z3.2	Z4.2	Z5.2	Z6.2
Z1.2	Z2.2	Z3.2	Z4.2	Z5.2	Z6.2

Method : Morris 'one at a time'

- Define a design by combining *k* values (10) of the *p* parameters (6)
- Add a « jump » Δ_{ij} to the i^{th} parameter
- Compute an « elementary effect »

$$d_{ij} = \frac{\left[y(z_1, \dots, z_i + \Delta_{ij}, \dots, z_p) - y(z_1, \dots z_i, \dots z_p)\right]}{\Delta_{ij}}$$

- Repeat the procedure for all parameters (*i*=1, …, *p*)
- Replicate *r* times (*j*=1, …, *r*) (1000)
- Compute **absolute mean** and **variance of elementary effects** from *r* replicates

$$\mu^*_j = \sum_{i=1}^{r} \left|d_{ij}\right| / r \qquad \sigma_i = \sqrt{\sum_{j=1}^{r} \left(d_{ij} - \mu_i\right)^2 / r}$$

7 000 simulations for 1 condition

70 000 simulations for 10 conditions (2 dates of contaminations, 5 climatic scenario)

‘Number of diseased leaves’: 1998, early inoculation

flowering

Height of shoot topping

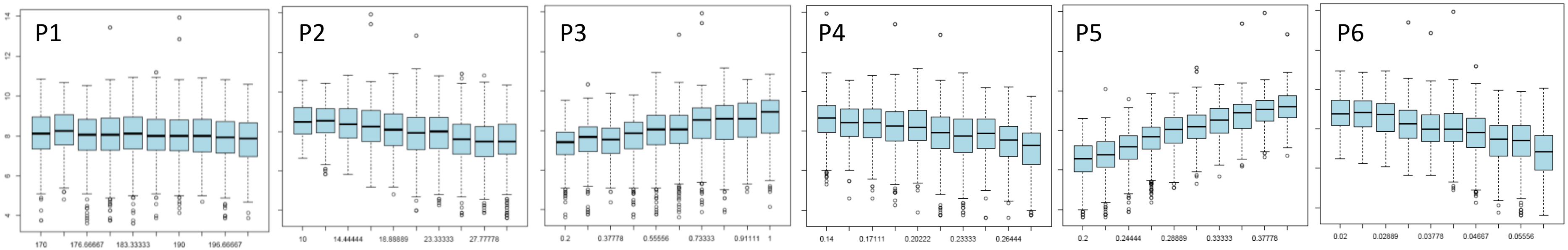
distance between shoots

Vigour

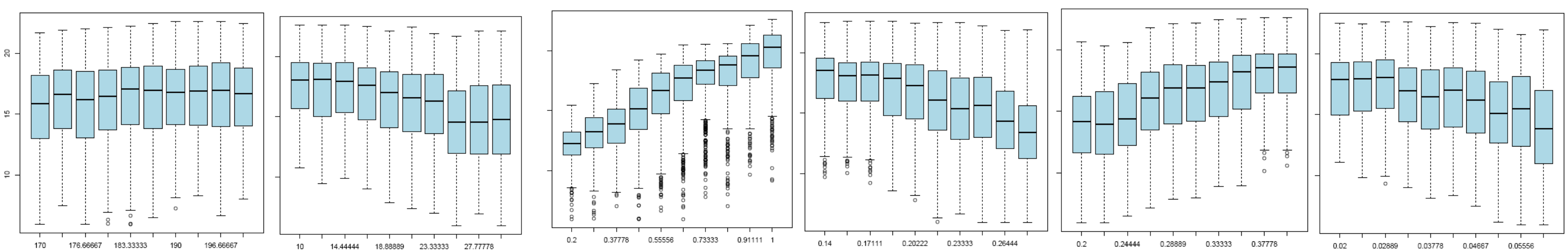
Decrease of ontogenic resistance

Sporulation level

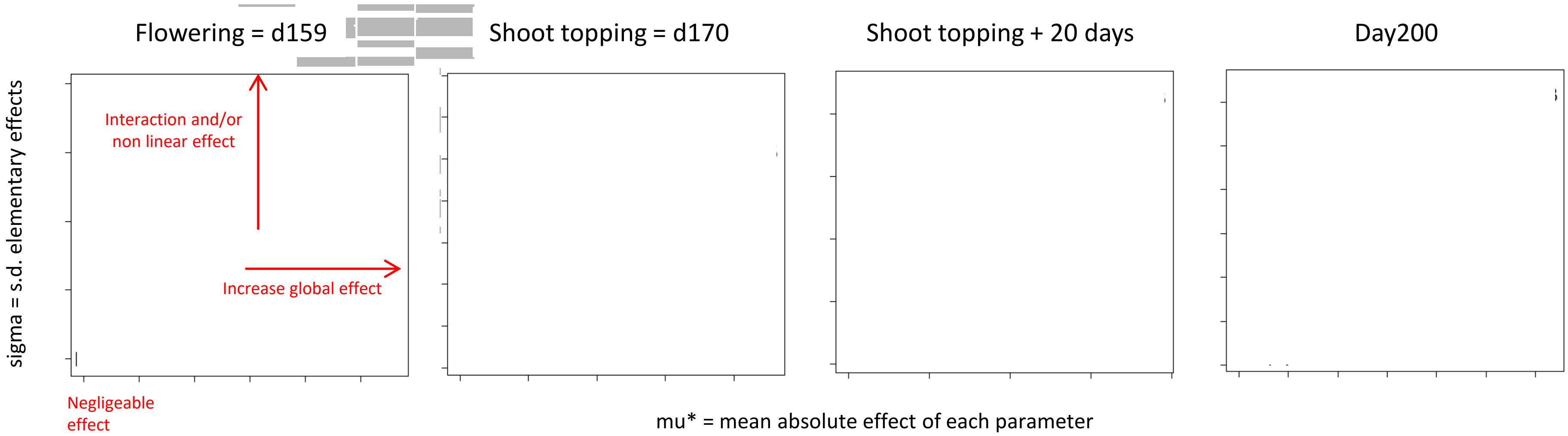
Dispersion



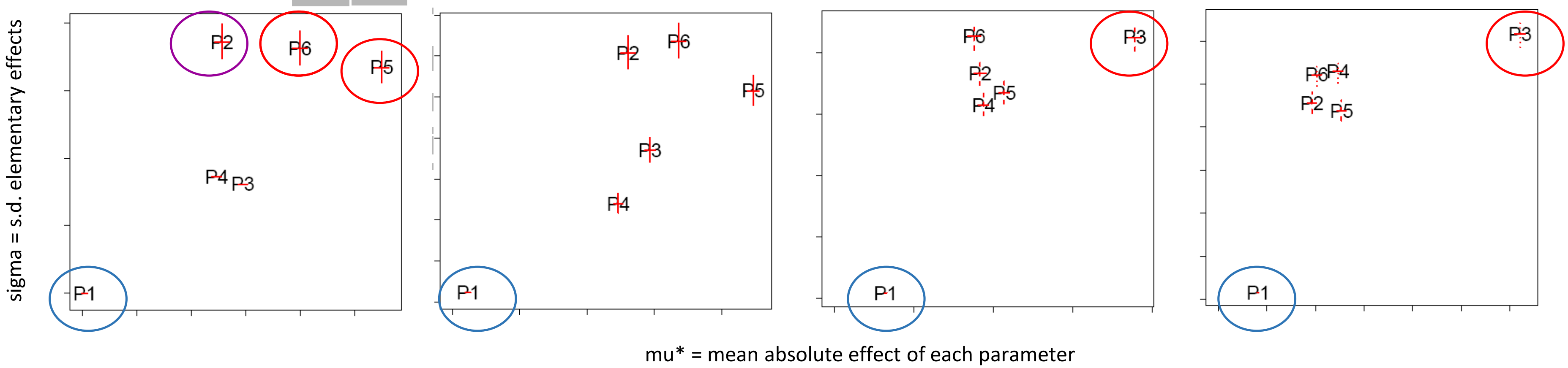
20 days after shoot topping

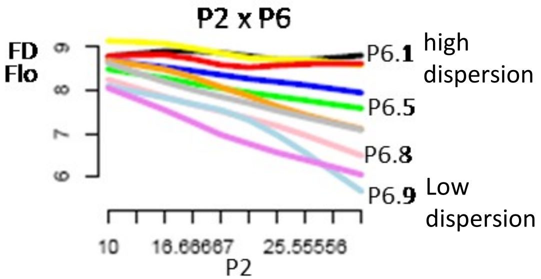


‘Number of diseased leaves’: 1998, early inoculation



'Number of diseased leaves': 1998, early inoculation





Early in the epidemic, P5 (sporulation) and P6 (dispersion) have strong effects

During plant growth, after shoot topping, P3 (vigour) become the parameter with the highest sensitivity

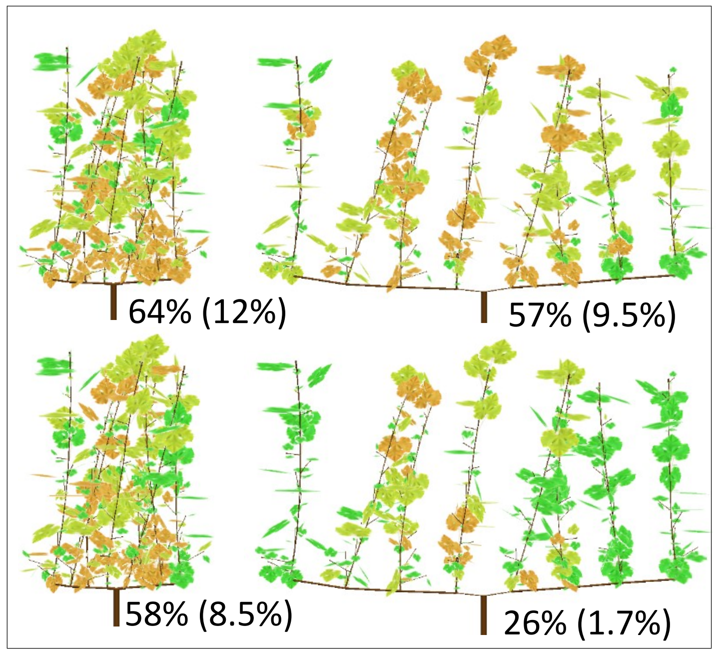
P1 (heigth of shoot topping) always has a negligeable effect

P2 (distance between shoot) is in interaction with P6 (dispersion)

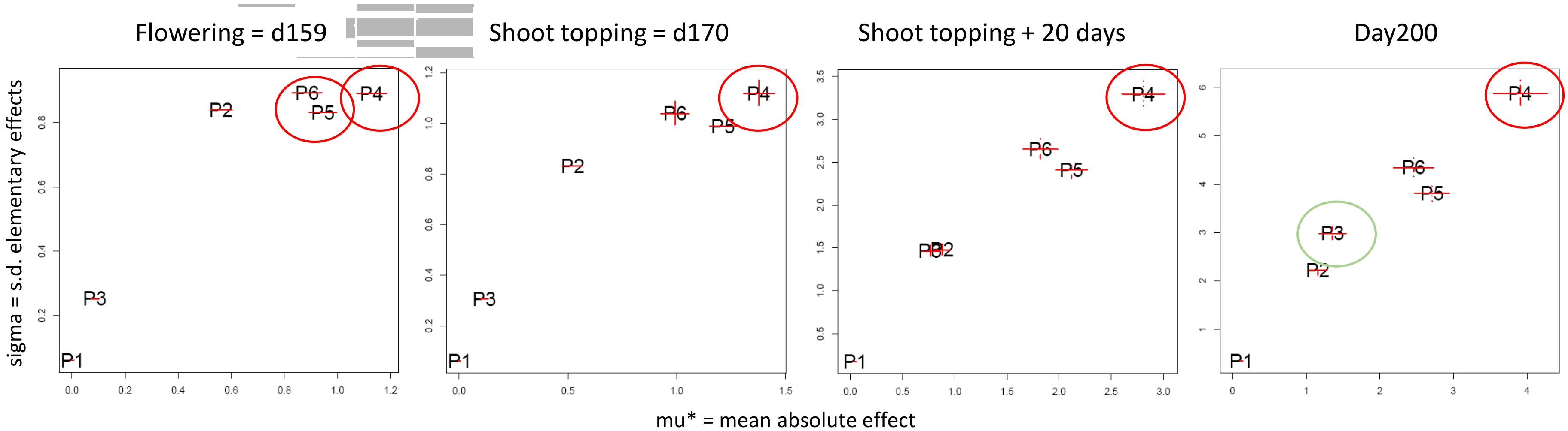
Interactions between parameters
distance between shoots (P2) and dispersion (P6)

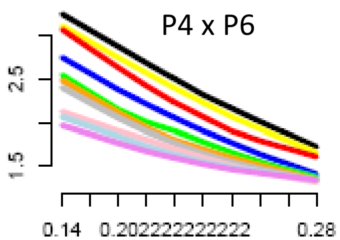
Shoot topping + 20 days

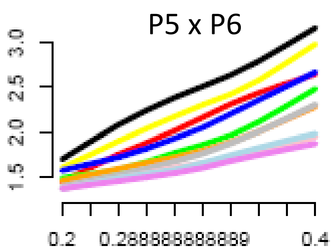
		Low Distance	high Distance
	P2	10	30
	P6		
high dispersion	0.02		
Low dispersion	0.06		



‘Number of diseased leaves’: 1998, late inoculation







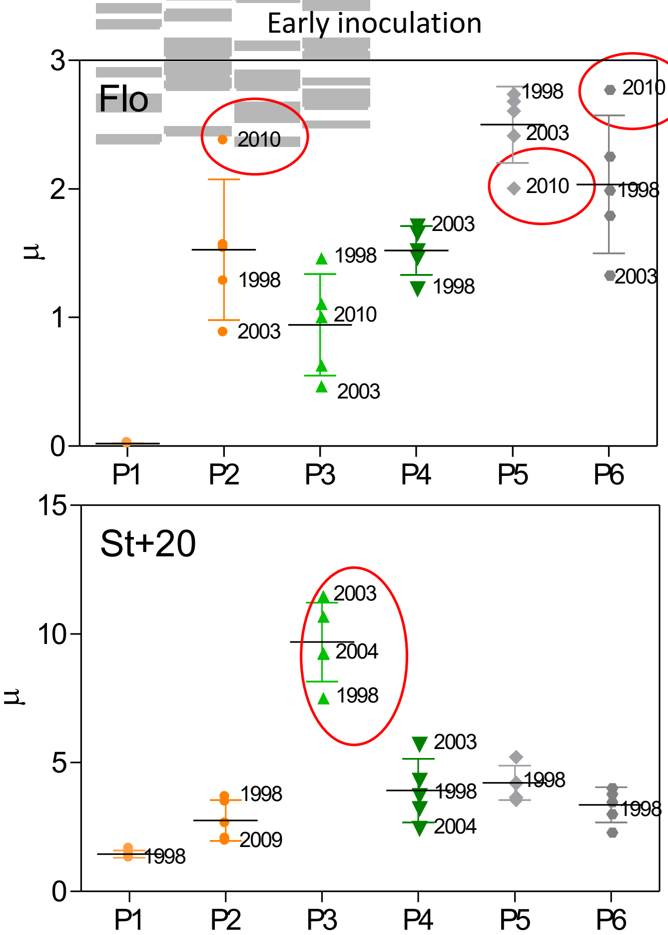
P4 (ontogenic resistance), P5, P6 become the most sensitive parameters

Vigour is a secondary except at the end of the growing season

There is a high level of interactions between parameters

Sensitivity of parameters function of climatic scenario

Mean effect

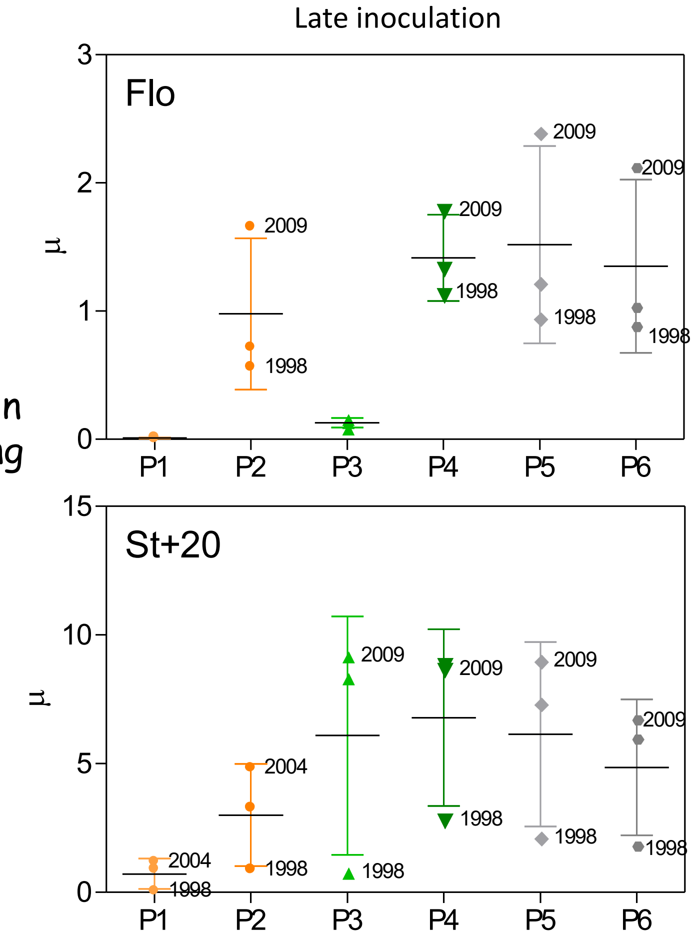


Some scénarii (like 2010) distinct at flowering : distance between shoot and dispersion are more important but sporulation less

Vigour is the most important factor as soon as shoot topping +20 days for all climatic scenario

Sensitivity of parameters function of climatic scenario

For late inoculation, we observe a lot of variation between the most influent parameters depending on climatic scenario

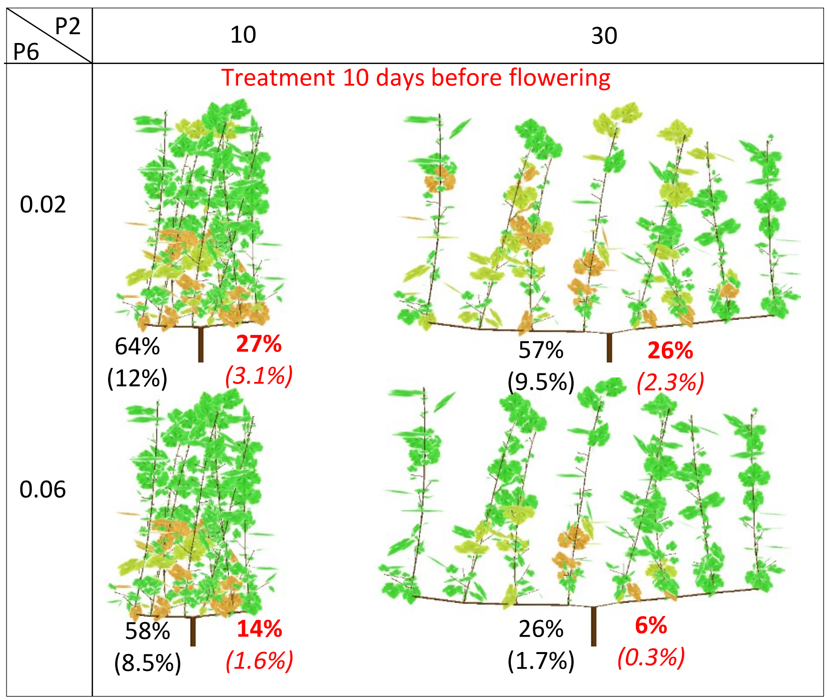


Consequences for disease control

The control of the disease is crucial at early time

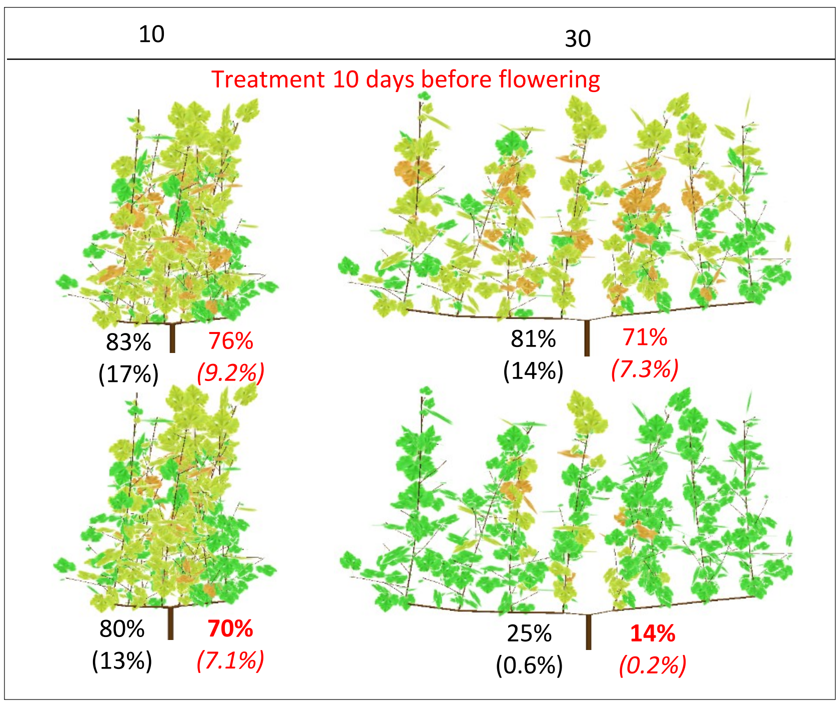
Depending on our understanding of the dispersion process, factors such as distance between shoots, fungicide treatments will have an effect on the disease or not!

1998



High fungicide effect even at high dispersion
Increased fungicide effect for low dispersion and high distance between buds

2010



Fungicide effect only if the dispersion is low and the distance between shoot is high

To conclude

The model is consistent with experimental results *(importance of the initial conditions and the vigour effect for early inoculation)*

The sensitivity analysis reveals that:

1. the initial condition of sporulation and dispersion are of main importance for disease severity

2. The plant vigour is of main importance for increasing disease severity after shoot topping

3. For late inoculation, Ontogenic resistance become the most sensitive parameter, whereas Vigour is a secondary factor

4. The potential effect of the distance between shoots (canopy density) is function of the spore dispersion