ModStatSAP – Paris 2018

Using physiologically and spatially structured consumer-resource population models to address current issues in plant pathology

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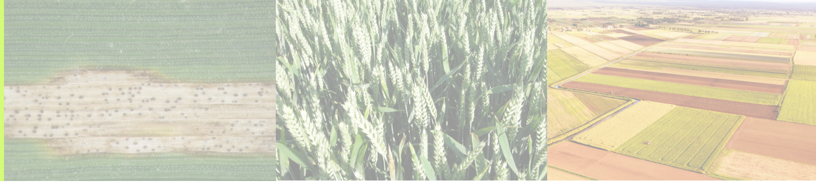
19 mars 2017

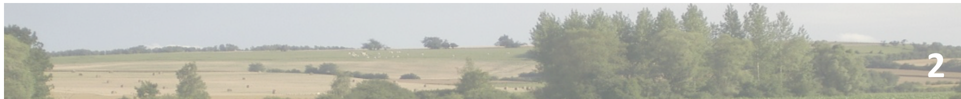


Context

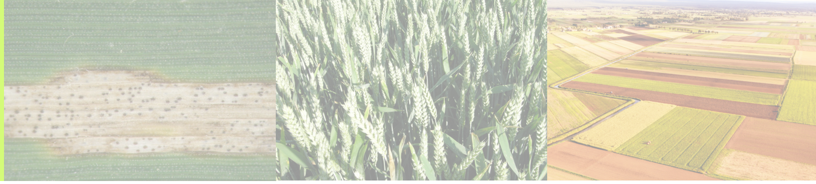
Industrial farming in developed countries: unsustainable in the medium/long run (pathogen evolution, soil depletion, pollution, …).
→ A possible way to explore: agroecology.

Agroecology: Using biodiversity to promote self-regulation of agroecosystems
It seeks to replace external inputs by biotic and abiotic interactions between organisms to reach some level of self-regulation in agrosystems.

Tools & concepts from theoretical ecology to address agronomic questions:
- Systemic & long-term approach;
- Dynamics;
- Interactions and feedbacks between organisms;
- Evolution.



General approach



In this context: Using physiologically and spatially structured consumer-resource population models to address epidemiology and evolution of plant-pathogens systems.

Our question: How to take advantage of available host resource dynamics to mitigate pathogens' impacts in agroecosystems?

Method: Pathosystems viewed as consumer-resource interactions.

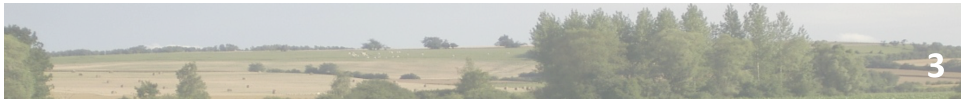
A strong collaboration between
INRA (UMR ÉcoSys, ecophysiology & epidemiology)
and ENS (CERES, ecology & evolution).

INRA SCIENCE & IMPACT

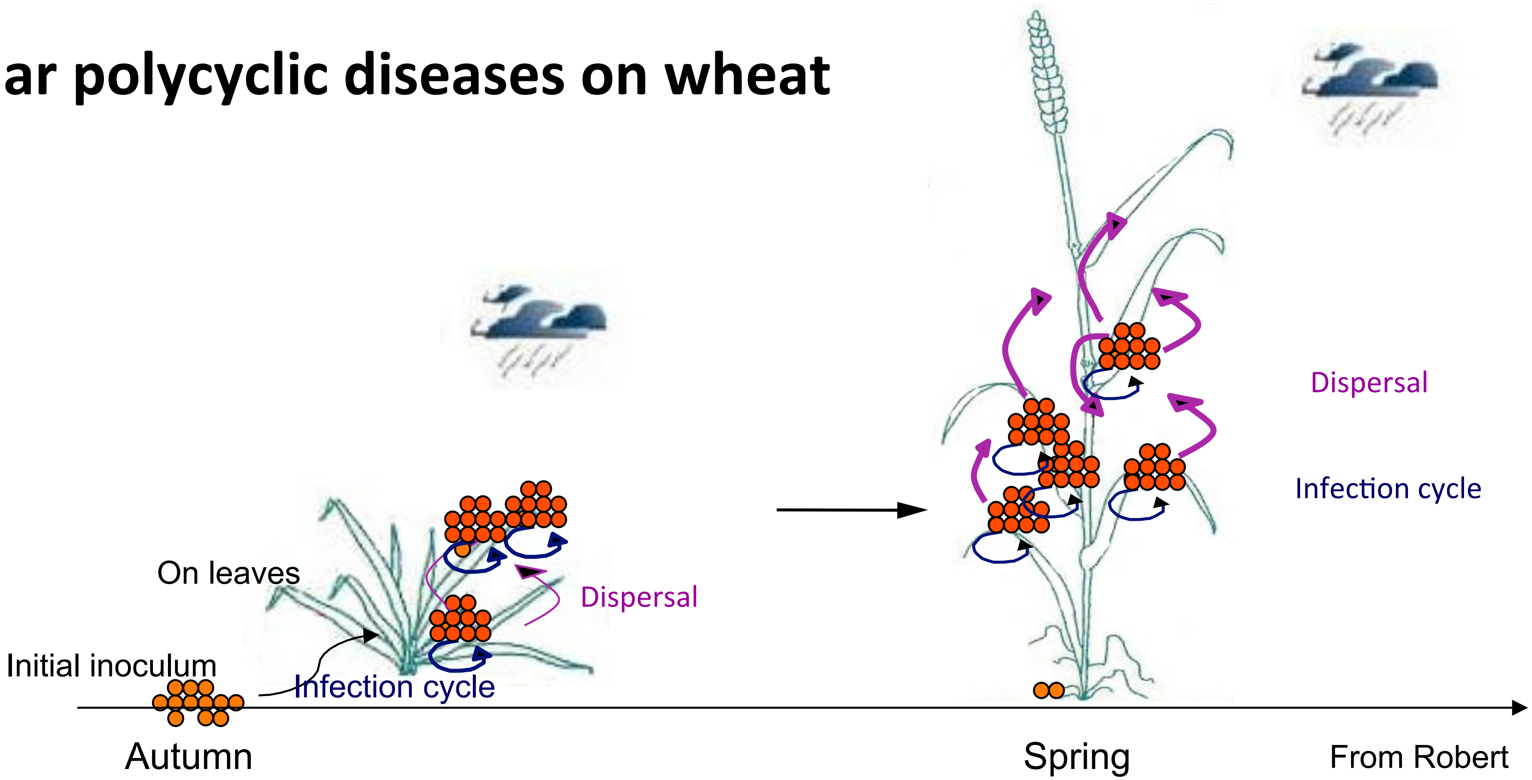
EcoSys

ENS

CERES



Fungal foliar polycyclic diseases on wheat



From Robert et al. (2008)

- Two dynamic interaction scales:
  - → Leaf tissue (infection cycle) = <u>patch</u>.
  - → Canopy (spores dispersal).
- Generic approach applied to brown rust and septoria tritici blotch (STB).

Resources dynamics at 3 scales

Leaf portion (patch, ca. cm^2)

● Resources available for the pathogen (lesions).

● Depend on leaf age (and infection age).

Host canopy

● Vertical and temporal resource distribution for the epidemics (polycyclic).

● Depend on crop growth (and epidemic dynamics).

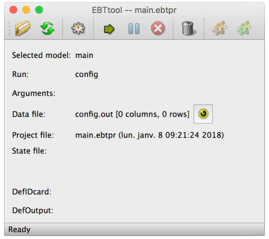
Landscape

● Horizontal resource distribution at a larger scale (pathogen metapopulation).

● Depend on agricultural practices (and long-distance spore dispersal).

Modeling approach #1
Presentation 1

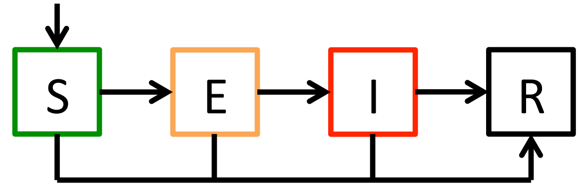
Postdoc C. Gigot (INRA ÉcoSys & ENS IBENS, 2016-2018)



Software:
EBTtool

Objective: Simulate and understand STB polycyclic epidemics using resource-based models at **patch and canopy scales**.

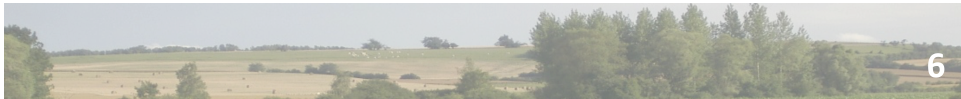
- **Physiologically structured population model** applied to epidemiology.
- **Age-structured SEIR epidemiological model.**



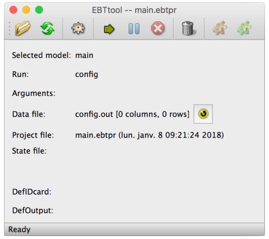
- **Spatial scale:** Patch and canopy.
- **Temporal scale:** (1) Set of ODEs integrated with adaptive time steps (< 1 dd).
  (2) Discretized age classes (10 dd).
  (3) Annual (2500 dd) and pluri-annual.
- **Model variables:**

→ patch scale: patch age & resource, mycelium and spore production & fungal age.

→ canopy scale: population distribution of patches of all types.



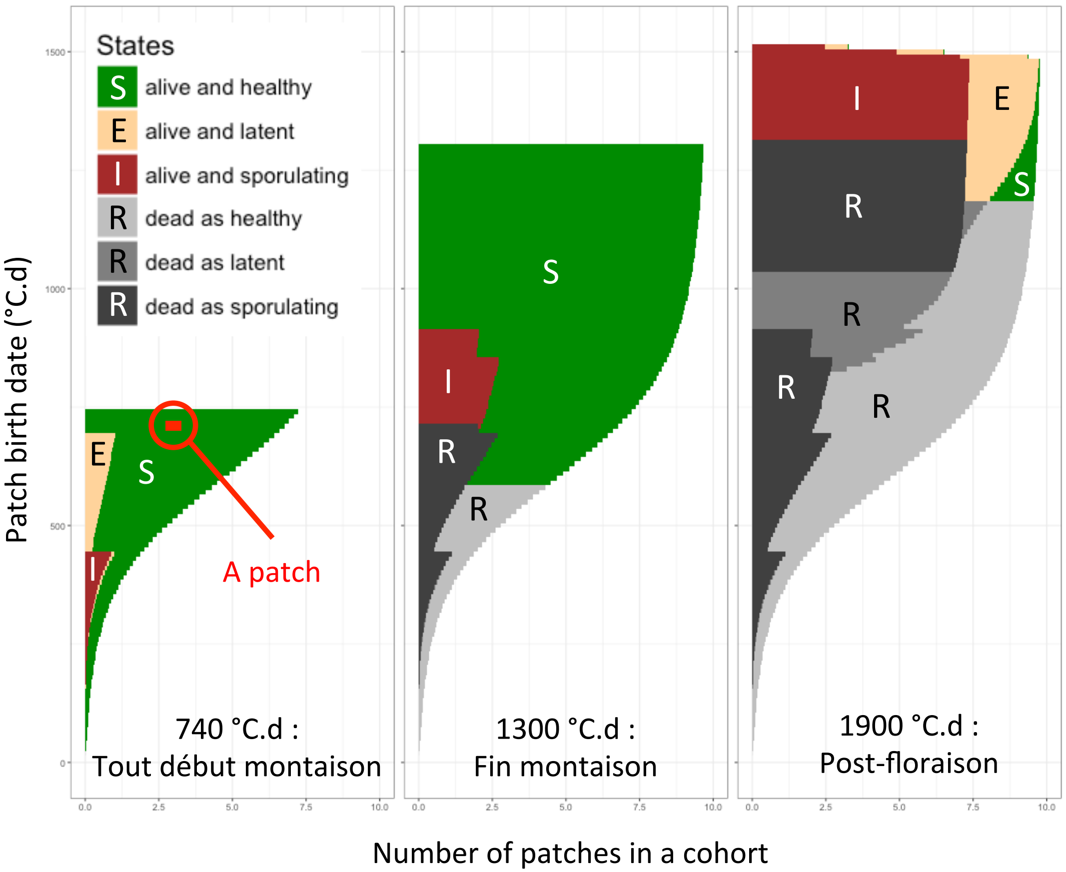
Modeling approach #1
Presentation 2



Canopy

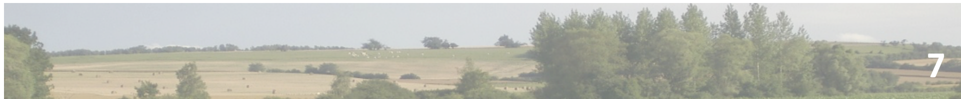
- A set of dynamic age-structured patches.
- Assumption: birth date proportional to patch height within the canopy.

Software: **EBTtool**

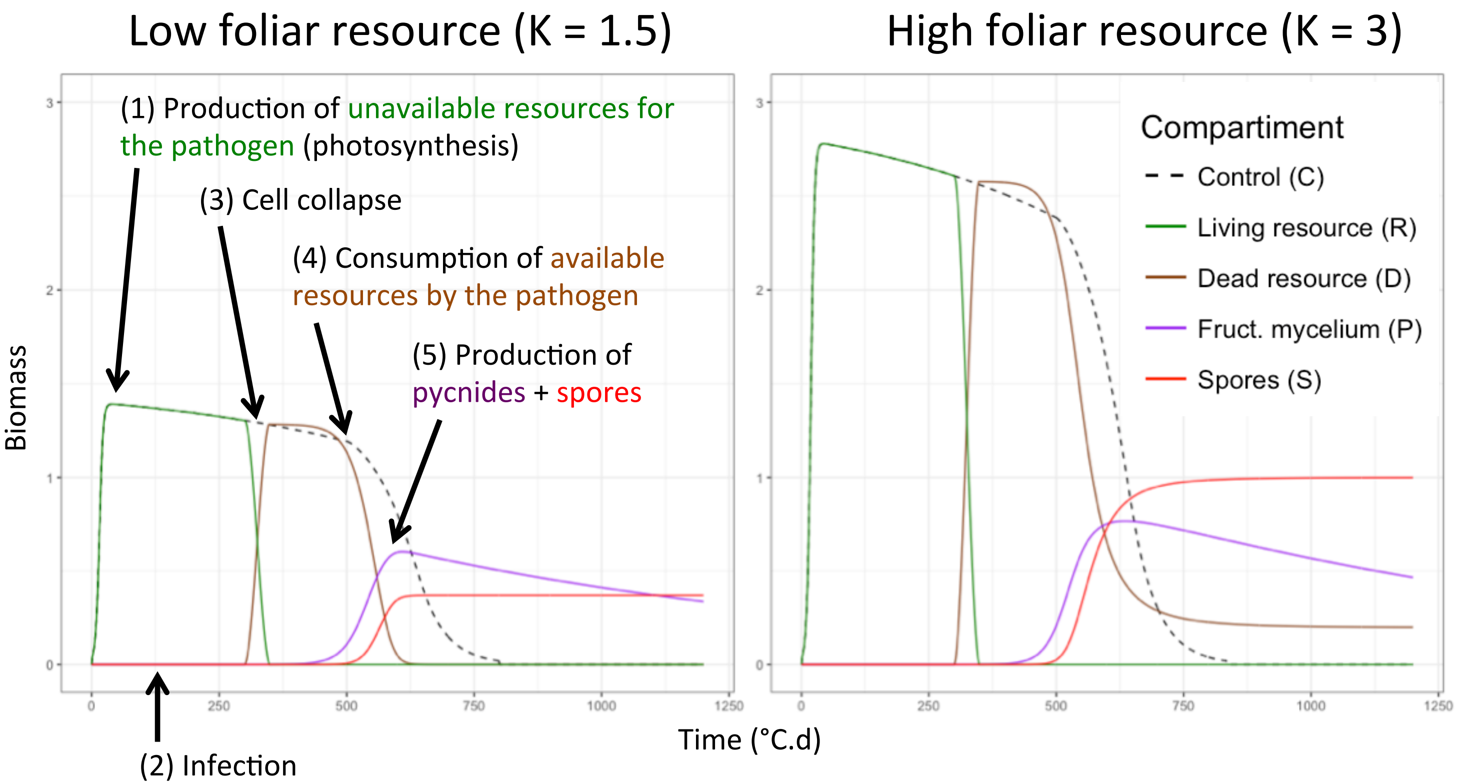


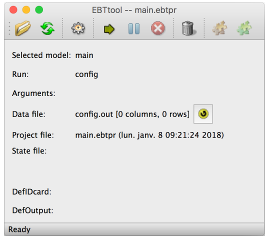
Post-earing wheat plant (Gate, 1995)

Simulation of STB epidemics on wheat canopy with multiple dispersal & infection events.



Modeling approach #1
Results: Effect of resource quantity on infection cycle



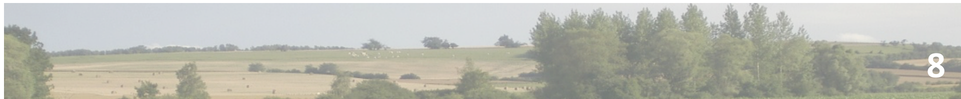


Software:
EBTtool

➚ foliar resources:

→ ➚ pycnidia + spores.

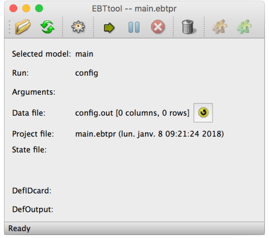
→ Similar to observations from experiments in controlled conditions.



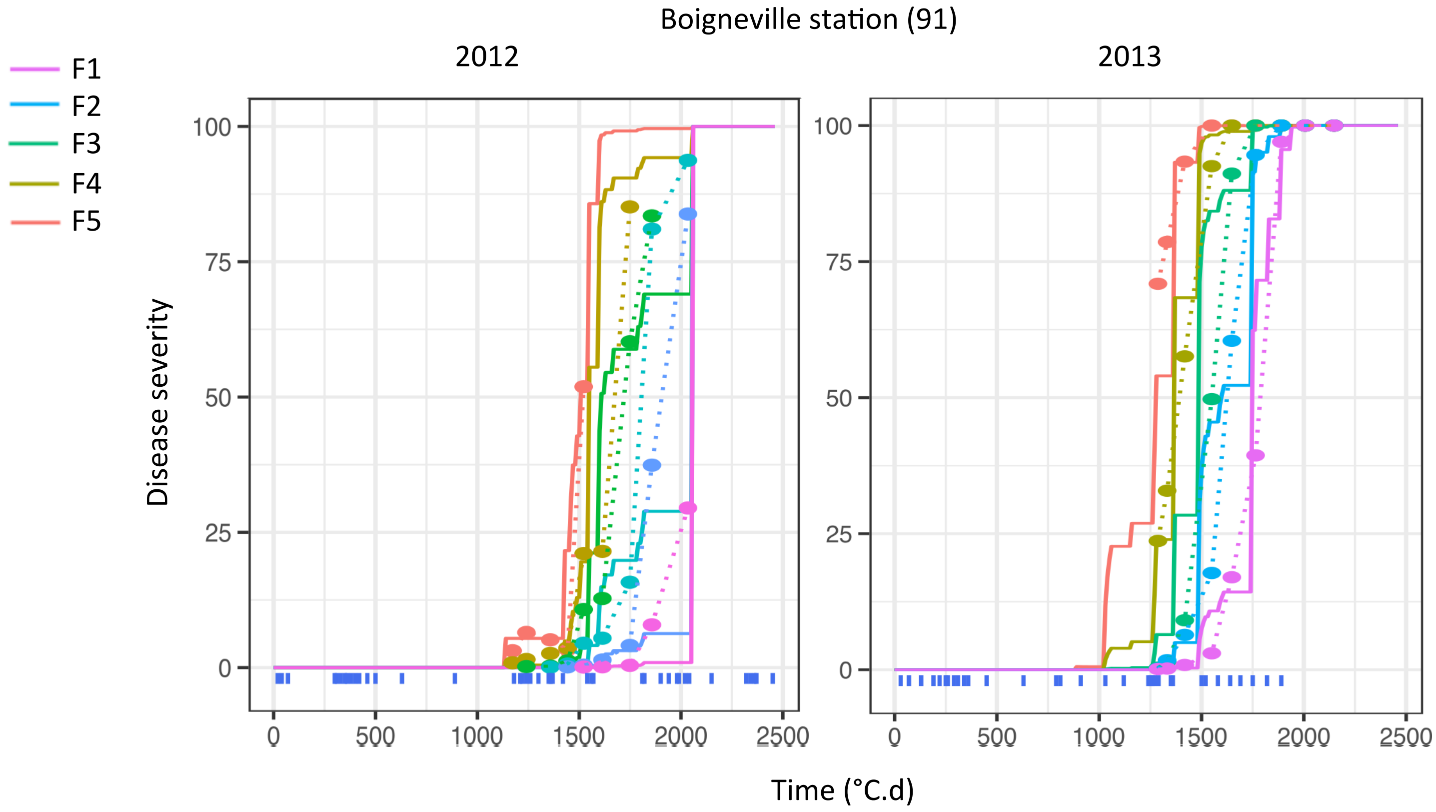
Modeling approach #1
Results: Consistency checks

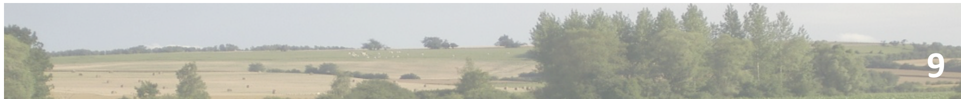
Different meteorological data

- Temperature and rain.
- Compare model outputs to recorded disease severity data.



Software: **EBTtool**

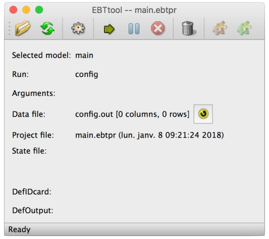




Modeling approach #1
Results: Sensitivity analysis of plant traits on epidemics

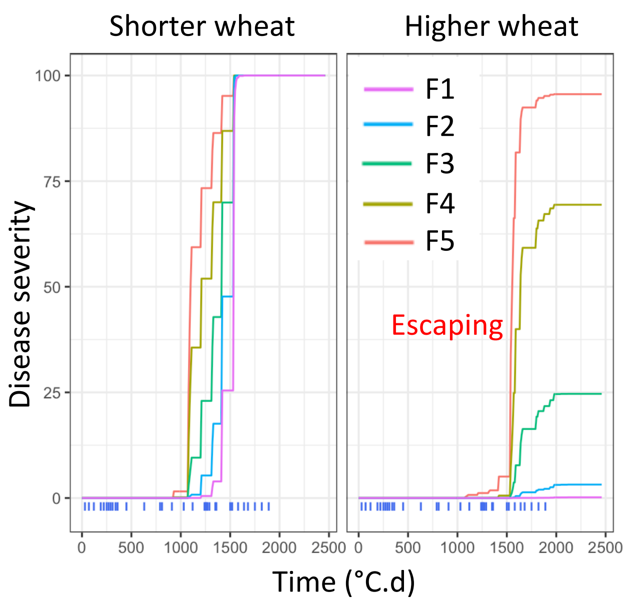
Different simulations

- Plant height: modern dwarf varieties, old 2-m-height varieties, …
- Infection coefficient: quantitative resistance
- Fertilization level (in progress)

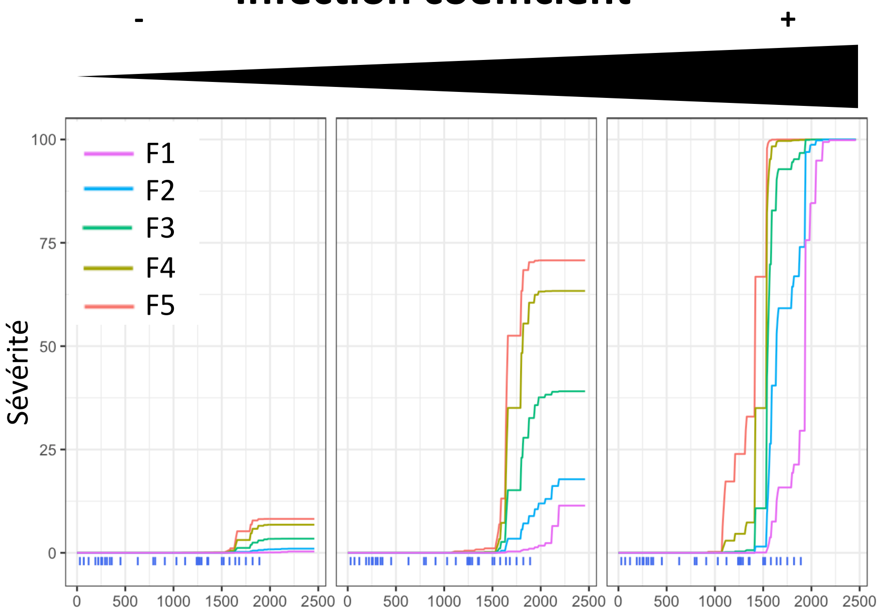


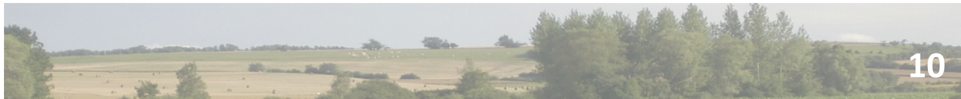
Software: **EBTtool**

Plant height



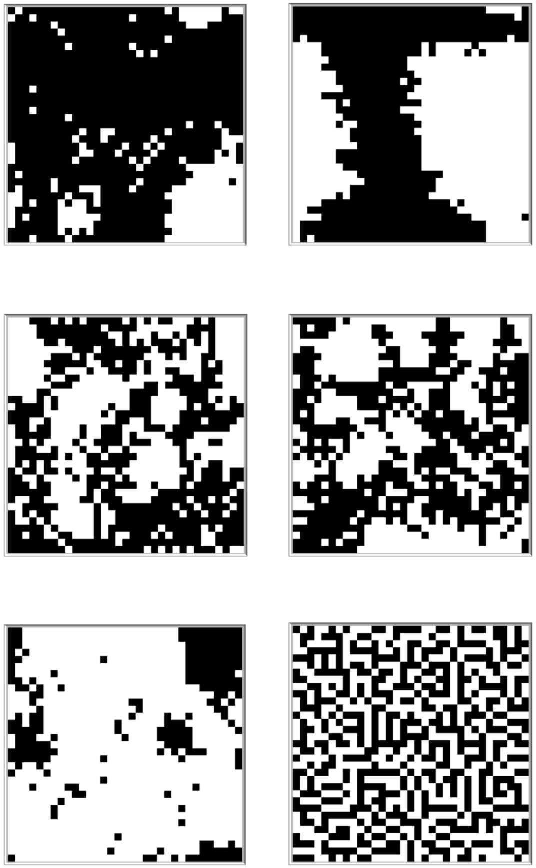
Infection coefficient





PhD thesis P.-A. Précigout (INRA ÉcoSys & ENS IBENS, 2014-2018)

Objective: Quantify the effects of mosaic of agricultural practices on brown rust epidemics at the **landscape scale.**

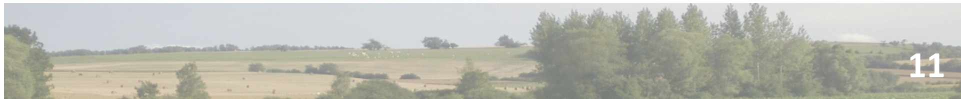


Landscape scale:

- Spatially explicit model → landscape heterogeneity.
- Simplification of spatial complexity → geometry of ecological interaction (Dieckmann et al., 2000).

Assumptions:

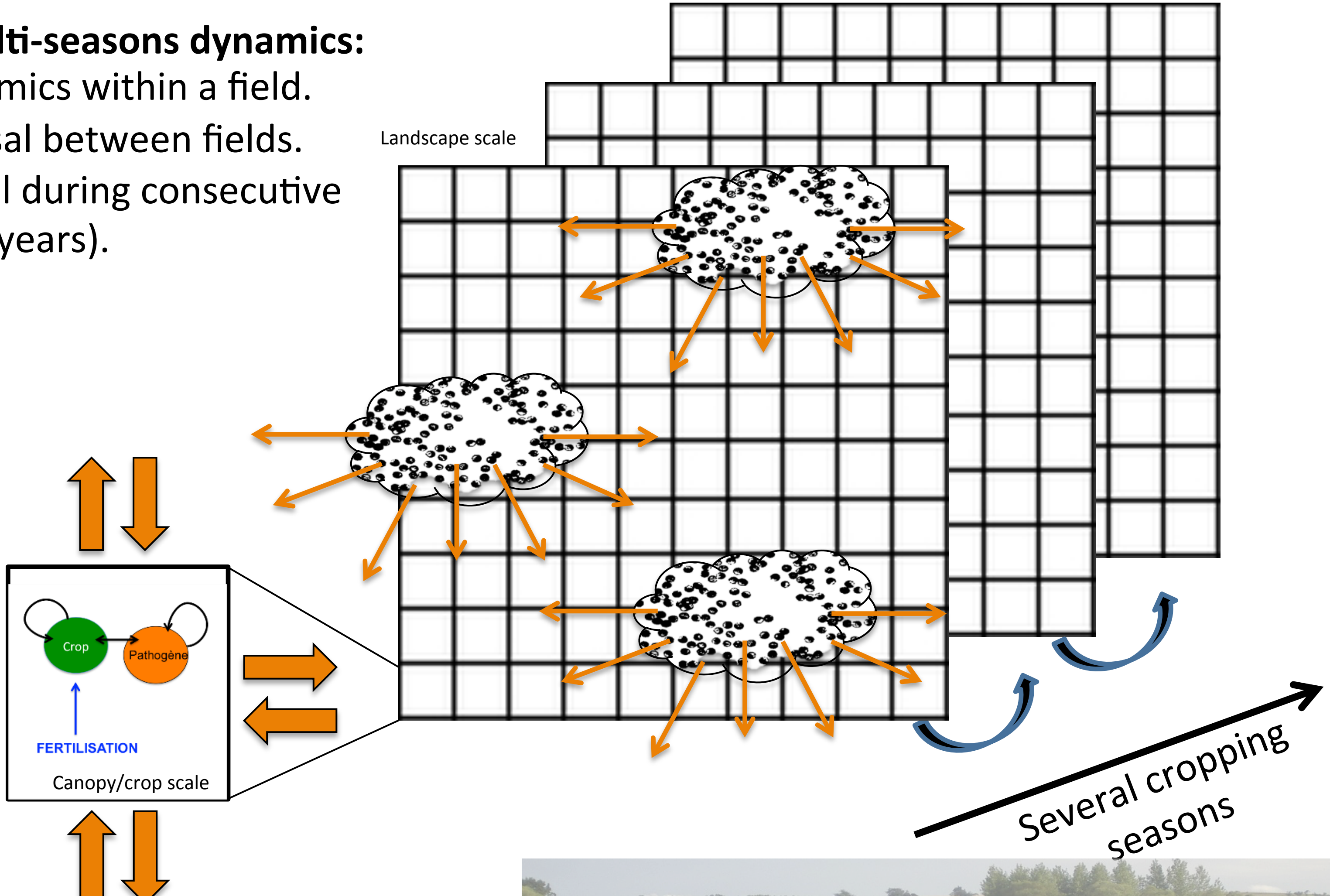
- Resource dynamics at the landscape scale impact pathogen dynamics.
- Fertilization determines the quantity of available resources for the pathogen.
- The only spatial heterogeneity in the landscape is the fertilization level of the fields.

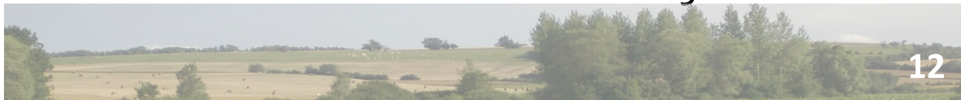


Application of this framework to study interactions between fertilization and wheat brown rust (in progress)

Mono- and multi-seasons dynamics:

- Disease dynamics within a field.
- Spore dispersal between fields.
- Spore survival during consecutive seasons (multi-years).

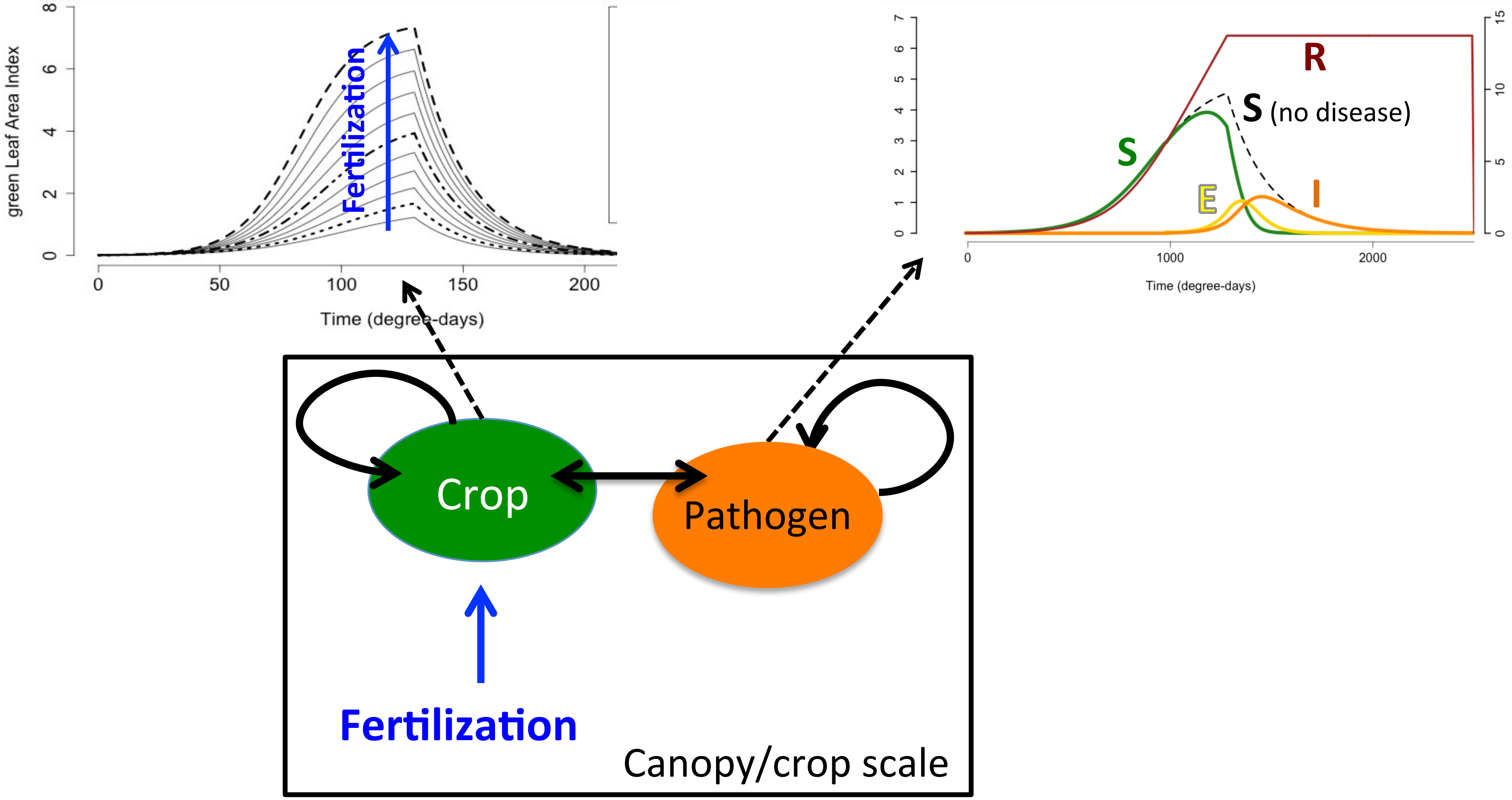


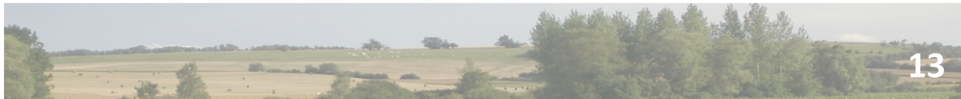


Application of this framework to study interactions between fertilization and wheat brown rust (in progress)

Growing canopy

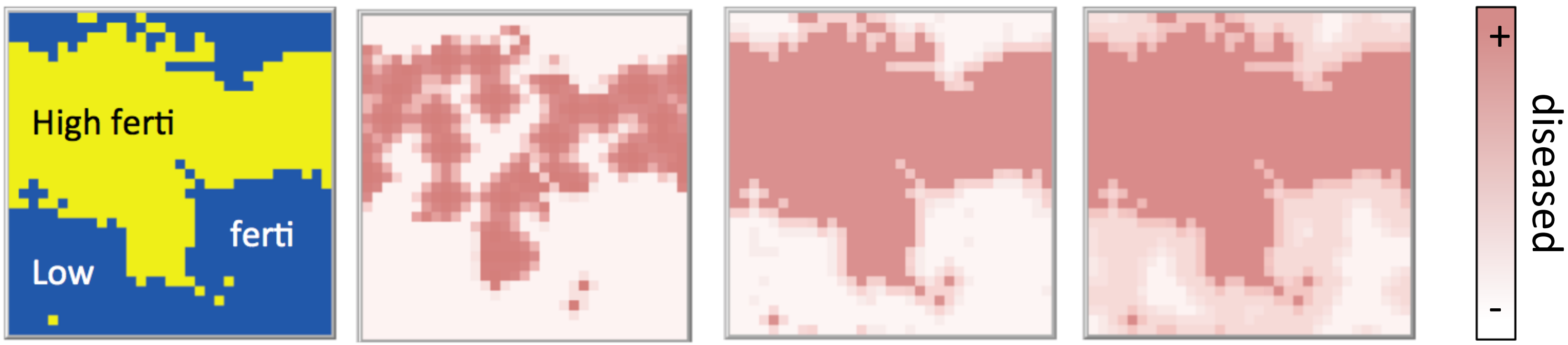
Pathogen dynamics





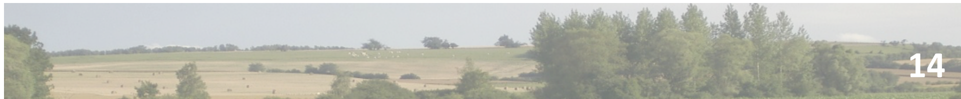
Fertilization heterogeneity slows down pathogen colonization of the landscape

Software: **NetLogo**



Landscape structure | Season 5 | Season 10 | Season 20

- Areas with low fertilization → Low spore production and "block" pathogen dispersal.
  → Decreasing epidemics at the landscape scale.
- Pathogen maladaptation.

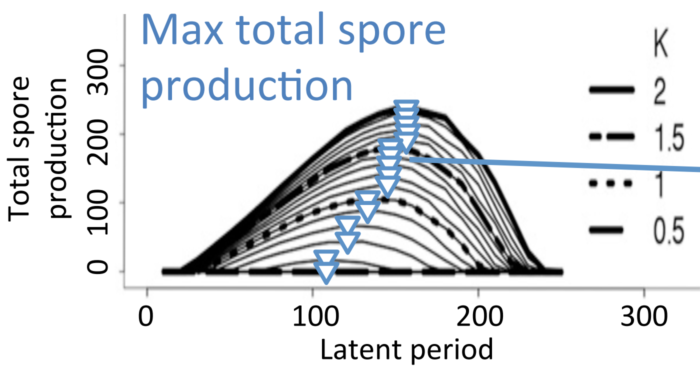


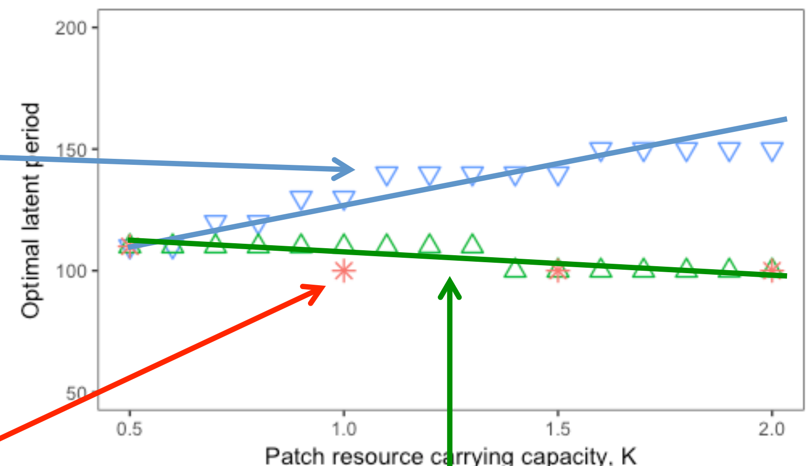
Overview of other key results

Pathogen evolution: example of the latent and incubation periods

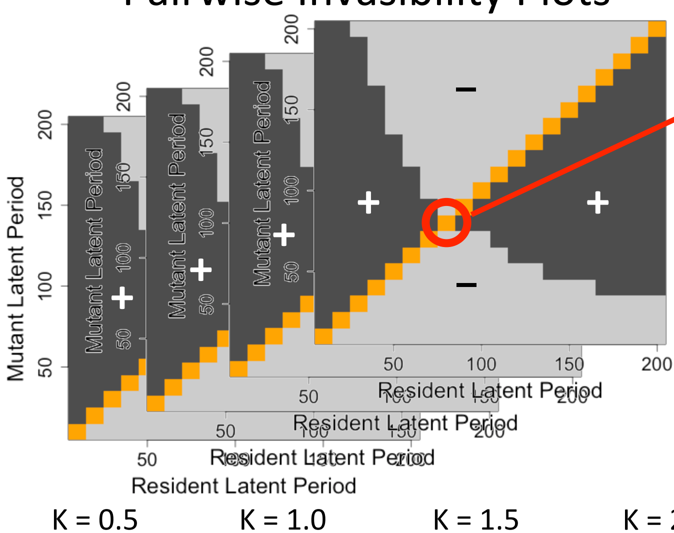
→ Based on *ad hoc* fitness measures or invasion fitness (adaptive dynamics)

- Fertilization level and brown rust (see below)
- Virulence and STB (in progress)





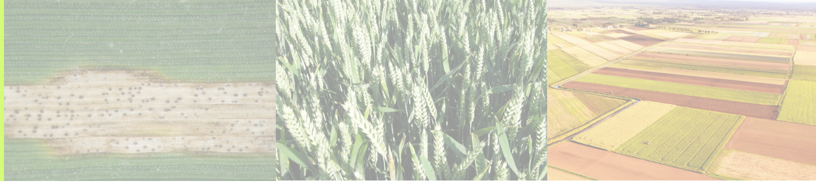
Pairwise Invasibility Plots



Evolutionary stable strategy

AUDPC (Area Under Disease Progress Curve):
Quantity of healthy host tissue = critical resource

Conclusion

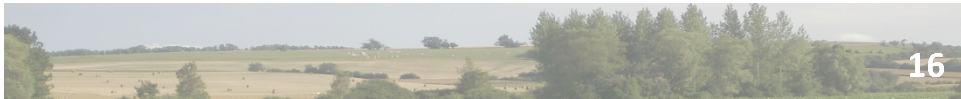


These modeling approaches offer the opportunity to:

● **Predict** (qualitatively) **short and long term epidemiological dynamics** based on assumptions on the consumer-resource interactions at the lesion, canopy and landscape scales.
● **Reveal pathogen trade-offs** (transmission, virulence, aggressiveness) **that emerge from the interactions** between the pathogen and ecophysiological and morphological dynamics of the crop canopy.
● Study the effect of **spatial resource heterogeneity on pathogen dynamics, adaptation and maladaptation**.

Some references:

● Metz JAJ, Nisbet RM, Geritz SAH. 1992. How should we define ‘fitness’ for general ecological scenarios? *Trends in Ecology & Evolution*, 7, 198–202.
● Précigout P-A, Claessen D, Robert C. 2017. Crop fertilization impacts epidemics and optimal latent period of biotrophic fungal pathogens. *Phytopathology*, 107(10), 1256-1267.
● de Roos AM, Leonardsson K, Persson L, Mittelbach GG .2002. Ontogenetic niche shifts and flexible behavior in size-structured populations. *Ecological Monographs*, 72(2), 271-292.



Thank you