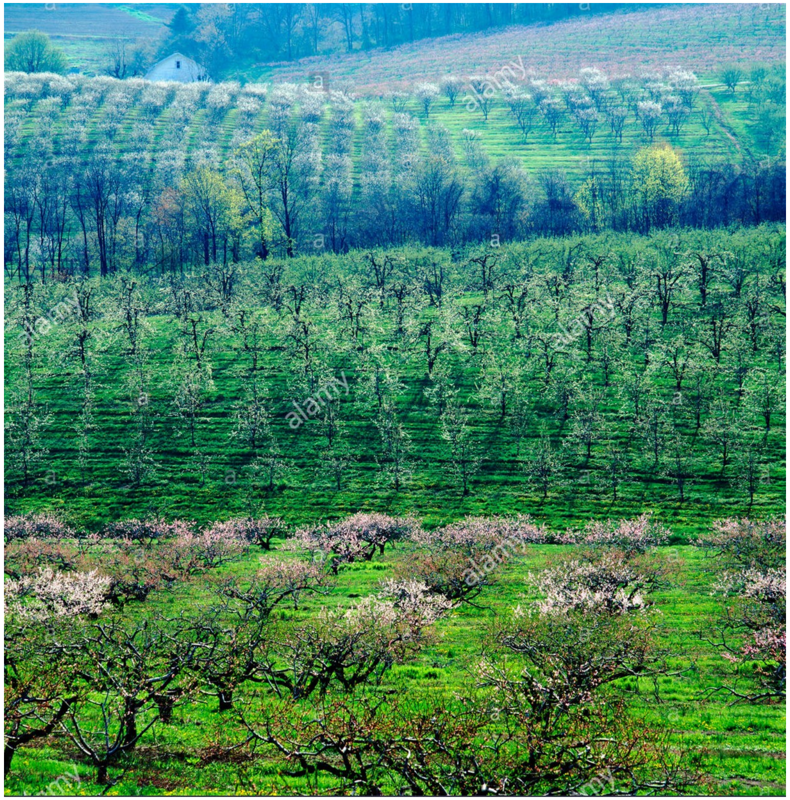
A model for temporal dynamics of brown rot spreading in fruit orchards

BEVACQUA Daniele * QUILOT-TURION Bènèdicte * & BOLZONI Luca §



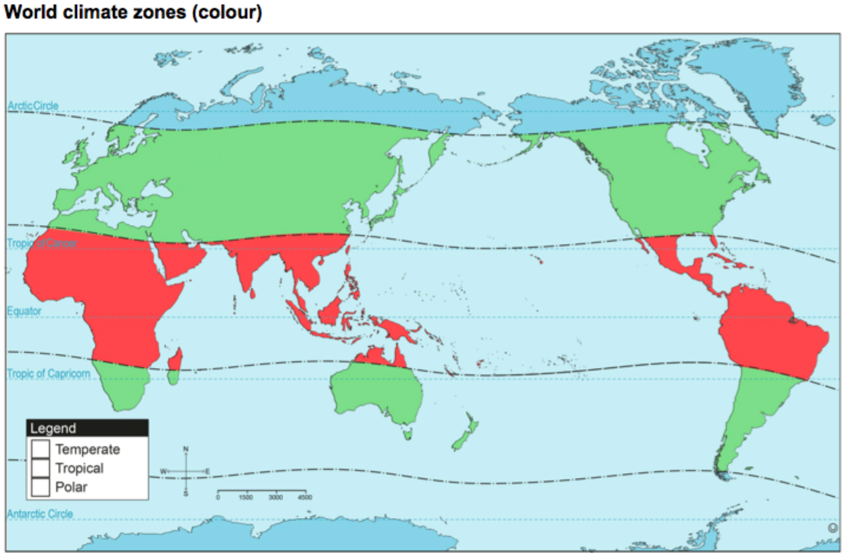
* INRA, Avignon, FRANCE
§ IZSLE, Parma ITALY

INRA SCIENCE & IMPACT

Istituto Zooprofilattico Sperimentale della Lombardia e dell'Emilia-Romagna "B. Ubertini"

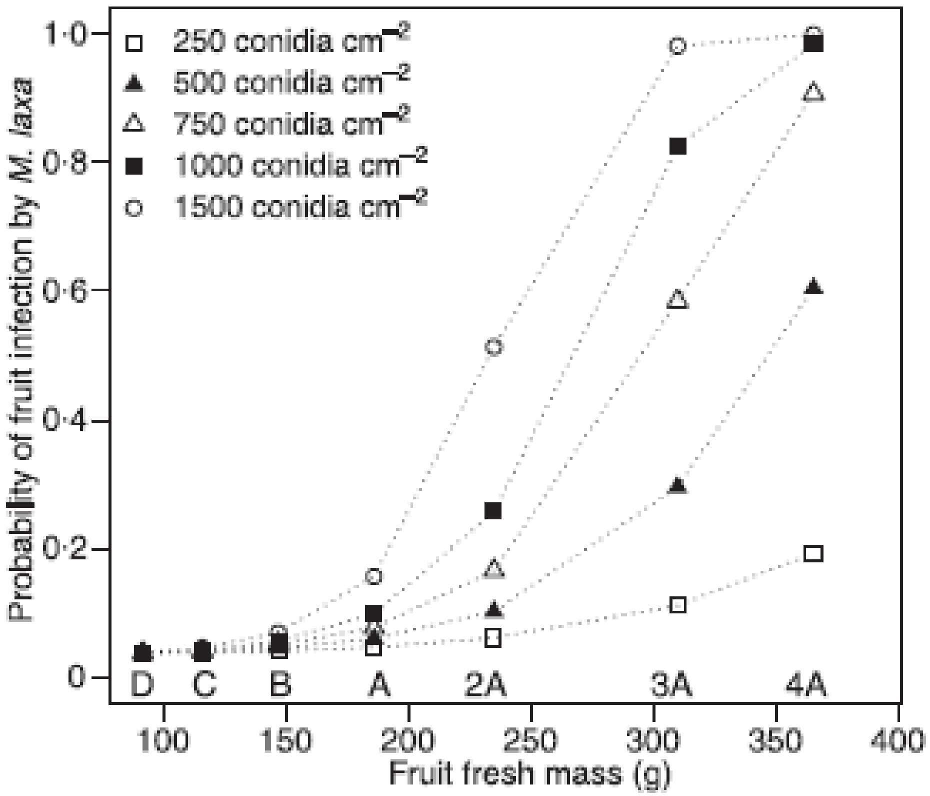
Introduction

- Brown rot, caused by *monilinia* spp., is one of the main fruits disease (peach, cherry, apricot,…)
- Present in all temperate regions and responsible for important economic losses
- Control mostly done by chemicals (fungicides)

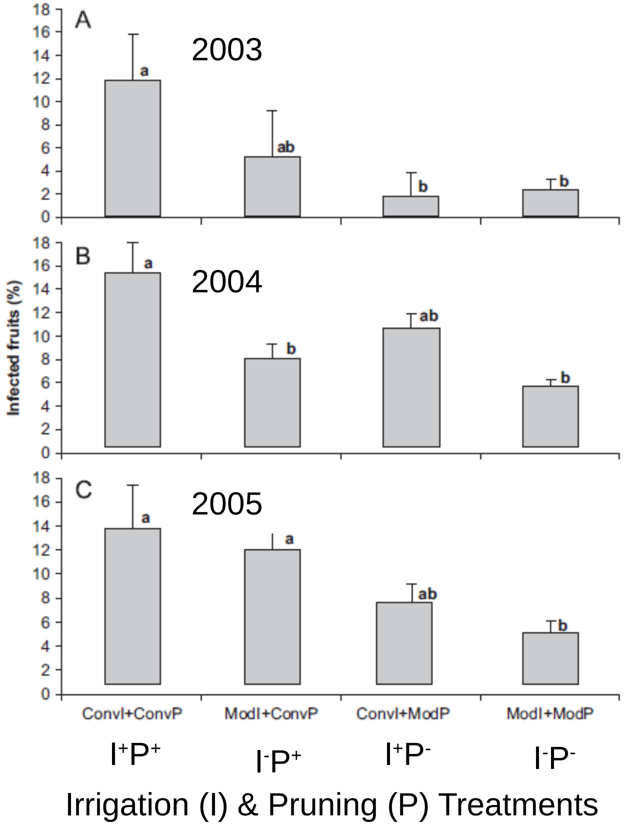


Introduction

Past works: experimental evidence and steady state models



Gibert *et al*. 2007 *J.Am.Soc. Hort.Sc*



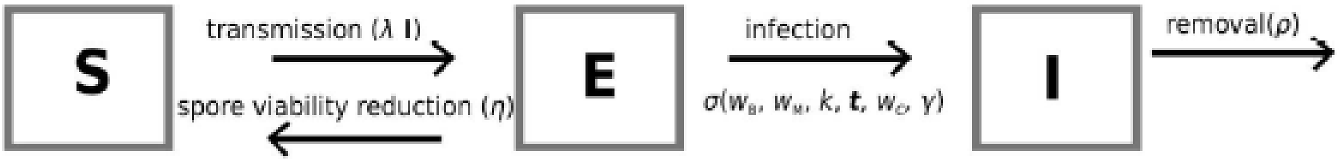
Mercier *et al*. 2008 *Crop Prot*.

Aims of present work:

- Develop and analyze a model for the temporal progression of brown rot that captures interactions among fruit exposure to the pathogen, fruit growth and infection
- Evaluate the consequences of “green” agricultural practices on the yield

The model

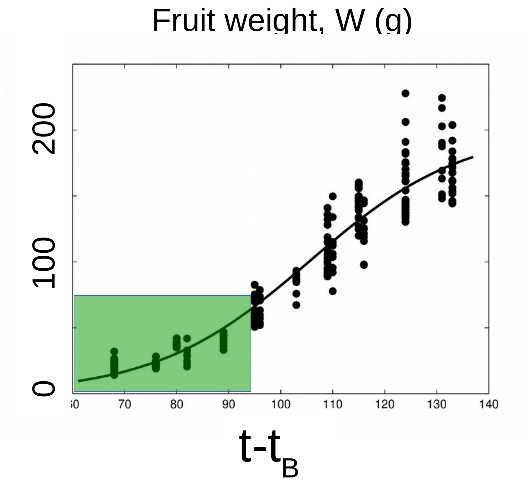
The model describes the dynamics of the fruit/host abundance in relation to the brown rot infection with fruit/host that can be susceptible (S), exposed (E) or infected (I).



$$\begin{cases} \dfrac{dS}{dt} = \eta E - \lambda I \cdot S \\ \dfrac{dE}{dt} = \lambda I \cdot S - \eta E - \sigma(t) \cdot E \\ \dfrac{dI}{dt} = \sigma(t) \cdot E - \rho I \end{cases}$$

where: $$\sigma(t) = \begin{cases} 0 & \text{if} \quad W(t) < w_C \\ \gamma \cdot W(t) & \text{if} \quad W(t) > w_C \end{cases}$$

and $$W(t) = \frac{w_B \cdot w_M}{w_B + (w_M - w_B) e^{-k \cdot (t - t_B)}}$$



w_B	Fruit weight at bloom time
w_M	Maximum fruit fresh weight
k	Conversion rate of resources into fruit mass
w_C	Fruit fresh weight threshold for cuticle cracking
η^{-1}	Average duration of spores viability on the fruit surface
λ	Transmission rate per infectious unit
γ	Infection constant
ρ	Removal rate

Case study: peach-brown rot system

- **Available data**:
  - Experimental orchard of 43 peach *Prunus persica*
  - Abundance of symptomless (S+E) and infected fruits during the growing season
  - Weight and age of 633 fruits during the growing season

- **Parameter estimation**
  - 3 fruit growth parameters from weight & age data (w_B, w_M, k) from optimization
  - 2 epidemiological parameters (η, w_C) from literature
  - 3 epidemiological parameters (λ, γ, ρ) from optimization

- **Model analysis and simulations**
  - Basic reproduction number
  - Yield sensitivity to parameter estimate uncertainty
  - Yield sensitivity to agricultural practices (winter field cleaning & fruit load control)

Results & Discussion

The basic reproduction number

The basic reproduction number $\Re_0(t_I, t_H)$: average number of secondary infectious cases generated by a single primary infection introduced at time t_I in completely susceptible population that will be removed at harvest time t_H

$$\Re_0(t_I, t_H) = \int_{t_I}^{t_H} e^{-\rho(t-t_I)} \lambda S(t_I) \left(\int_{t_I}^{t_H} \sigma(\tau) e^{-(\eta+\sigma(\tau))(\tau-t)} d\tau \right) dt$$

$$\begin{cases} \frac{dS}{dt} = \eta E - \lambda I \cdot S \\ \frac{dE}{dt} = \lambda I \cdot S - \eta E - \sigma(t) \cdot E \\ \frac{dI}{dt} = \sigma(t) \cdot E - \rho I \end{cases}$$

Probability that a primary infectious fruit introduced at time t_I is still infectious at time t

Number of new expositions generated by a primary infectious fruit in the instant dt in a completely susceptible host population

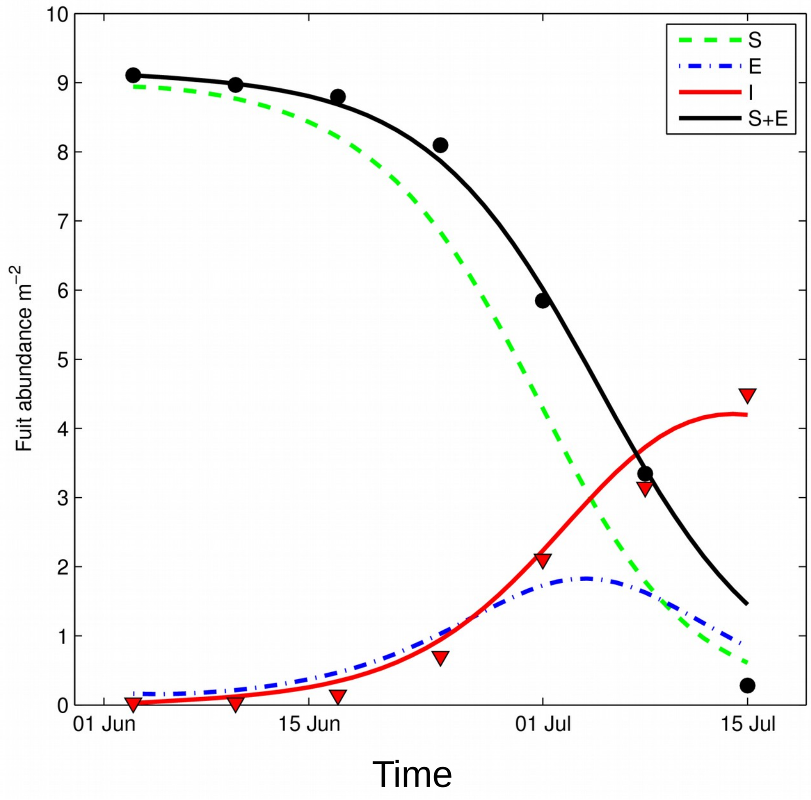
Probability that an exposed fruit at time t is still in the exposed class at time τ (> t)

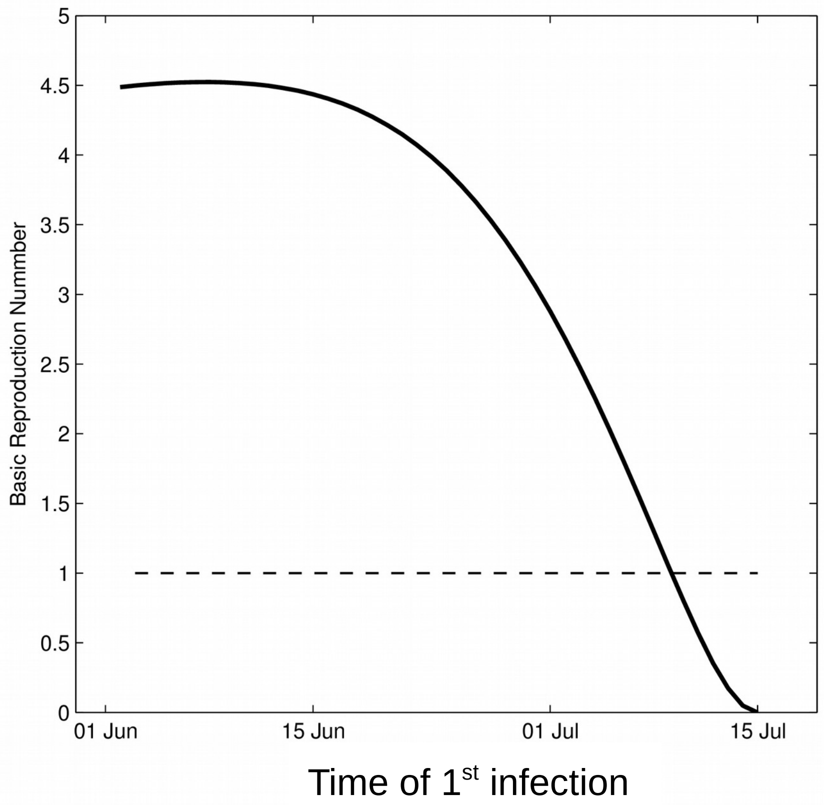
Probability to become infectious in the instant $d\tau$

Note: the well known Basic Reproduction Number $\Re_0 = \frac{\sigma}{\eta+\sigma} \frac{\lambda S(t_0)}{\rho}$ is a particular case ($t_H \rightarrow +\infty$ and $\sigma(\tau) = \sigma$) of our expression

Results & Discussion

The temporal dynamics

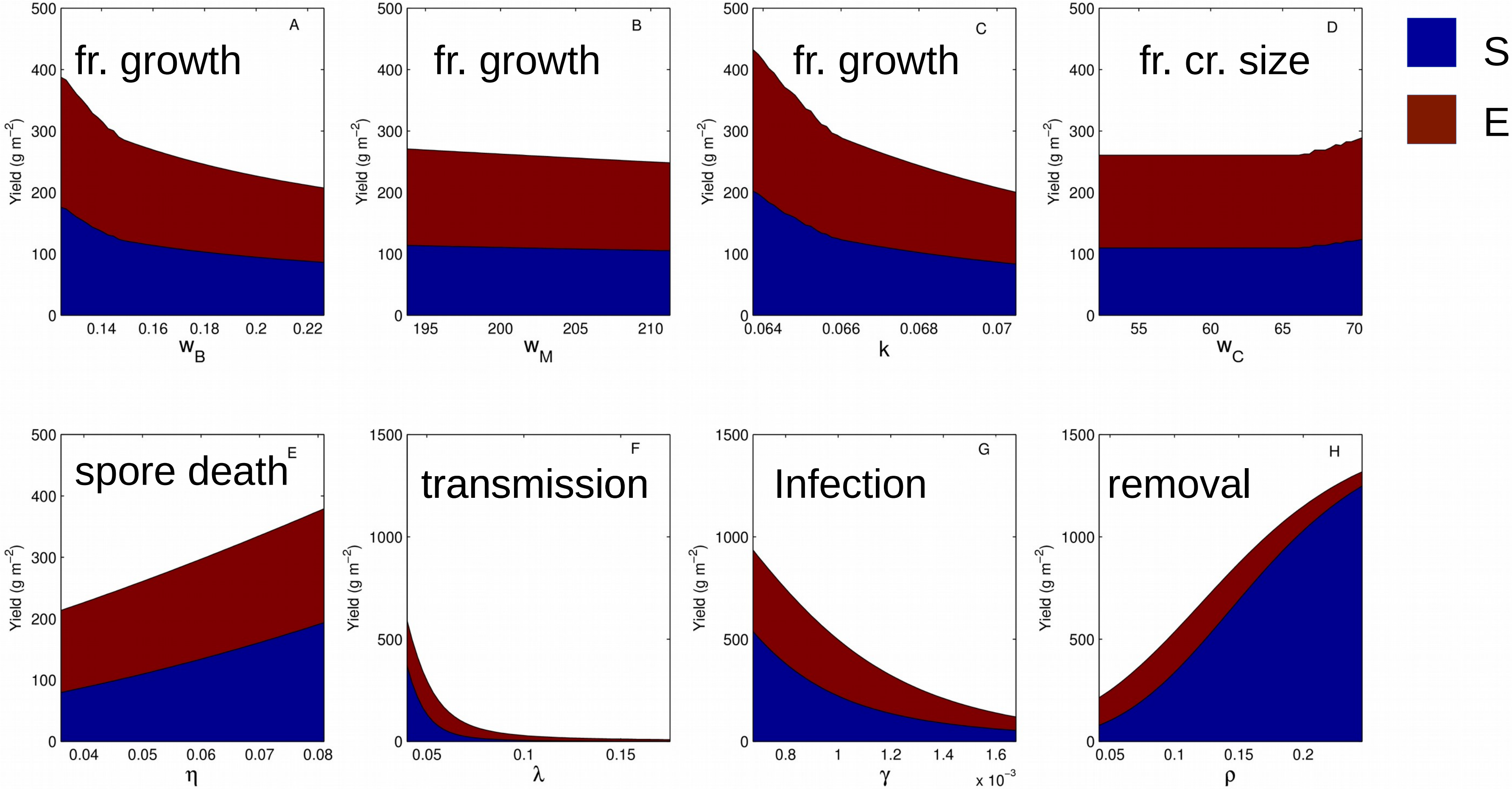




- Good reconstruction of observed patterns
- At harvest time almost all fruits were infectious
- The threshold for epidemic development $\Re_0(t_I, t_H) = 1$ was widely overtaken at any time of first infection t_I for t_H = 15th July.

Results & Discussion

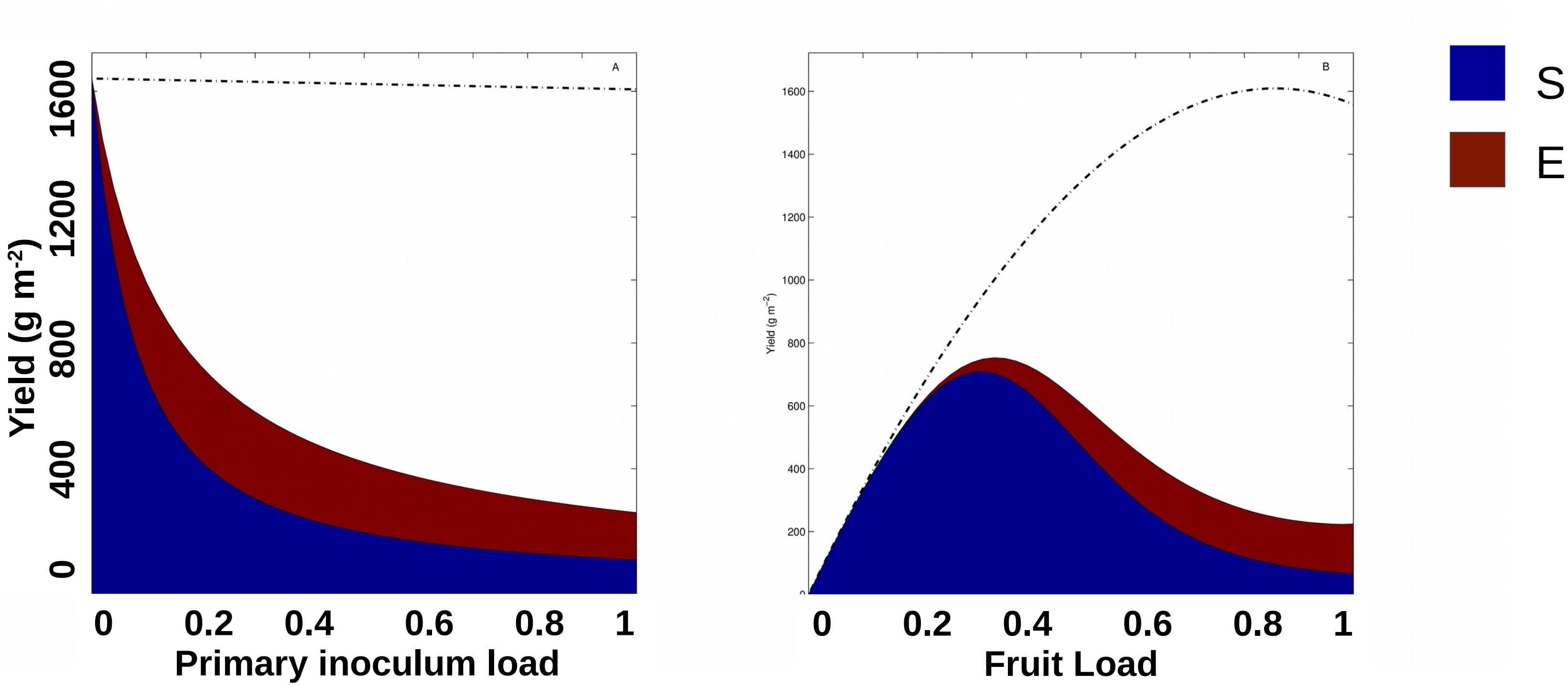
Yield sensitivity to uncertainty in parameter estimates



- The importance of the tested parameter space
- An increase in the fruit growth (w_B, w_M, k) is undesirable
- The infection rate γ, which is highly dependent on meteorological conditions, plays a key role
- The removal rate ρ , which can be controlled by agric. practices , plays a key role

Results & Discussion

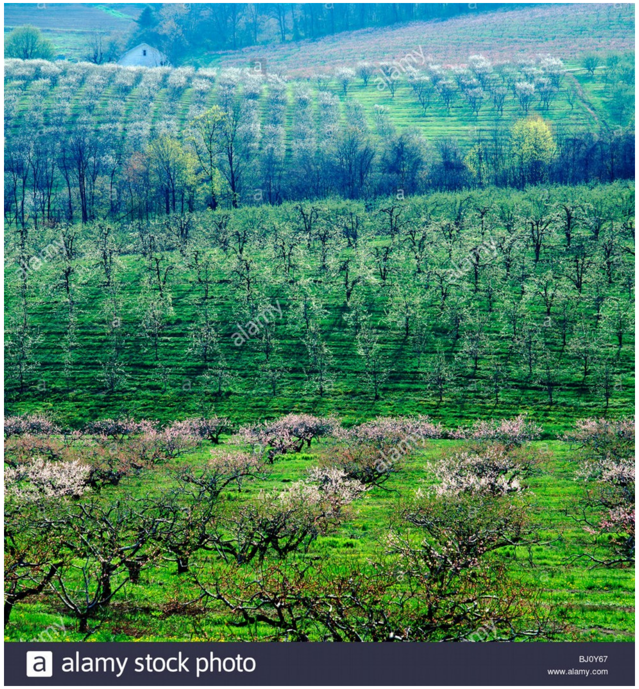
Yield sensitivity to agricultural practices



Winter sanitation → Primary inoculum load → Initial fraction of *S*, *E* and *I*
Fruit thinning → Fruit load → Initial fruit ab.(*S*+*E*+I) & maximum fruit size (w_M)

- Winter sanitation is efficient only if capable to severely reduce primary inoculum load
- Optimal fruit load in presence of the brown rot is 35%, 90% otherwise
- Apparent contrast with previous works

Acknowledgments



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