Plant tolerance is explained by resource-based plant–nematode interactions

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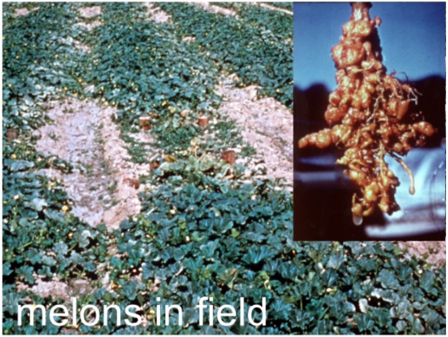
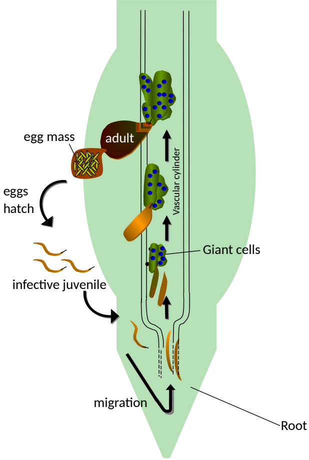
Root-knot nematodes (RKN)

Meloidogyne spp.

- Obligate, sedentary endoparasite
- Clonal reproduction
- Males are rare and play no role in life cycle or infection
- 2 main phases (in the soil and in the roots)

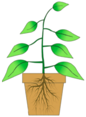




Castagnone et al, 2006; Snyder et al, 2006; Bird et al, 2009; Moens et al, 2009

Plant responses to nematode parasitism

Strong variations within and among plant species

		Plant growth	
		yes	no
Nematode reproduction	yes	 tolerant	 susceptible
	no	 resistant *quali.*	—

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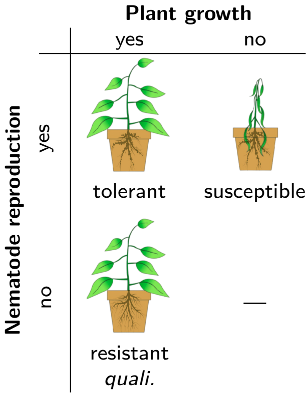

Qualitative resistance

- monogenic
- few resistant genes identified
- emergence of virulent nematodes

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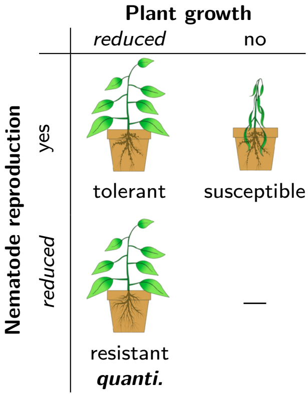

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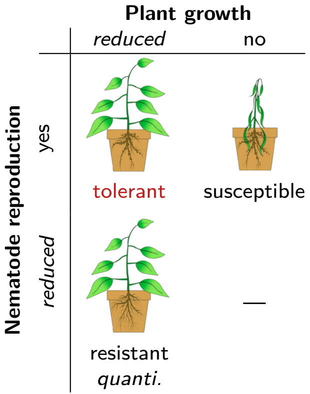

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Tolerance = plant ability to grow with pathogen

- **"normal"** nematode development
- **no/limited** plant symptoms
- soil infestation by RKN

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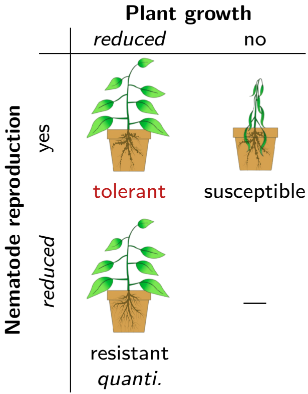

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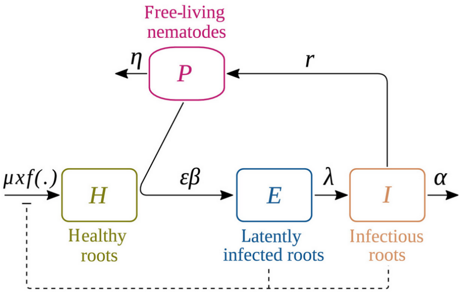
Which mechanisms underlie plant tolerance?

Plant-pathosystem modelling

Traditionally,

- **Epidemiological models**: focus on pathogen population dynamics
  (Tankam et al, 2020; Nilusmas et al, 2020)

Nilusmas et al, 2020



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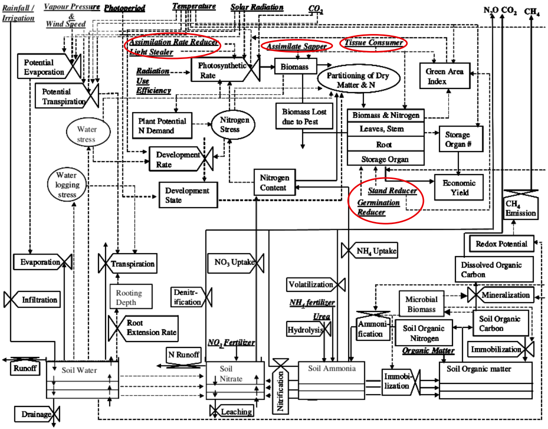

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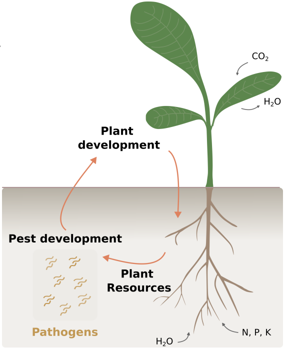
My approach: coupled modelling of plant physiology and pest population dynamics

$\Rightarrow$ notable attempt: *Zaffaroni et al, 2020*



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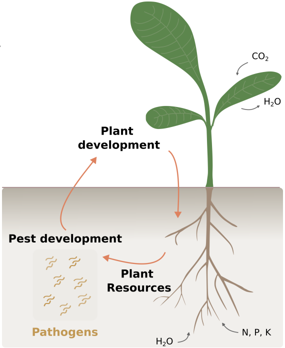
My objectives

- Classify plant responses to RKN parasitism
- Identify plant tolerance mechanisms
- Influence of combination of plant traits on tolerance
- Robustness of tolerance traits across RKN virulence scenarios



Plant–nematode model

B: healthy biomass
C: resource

$$\frac{dB}{dt} =$$

$$\frac{dC}{dt} =$$

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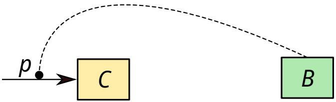

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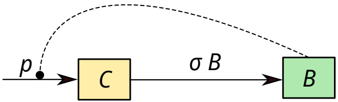

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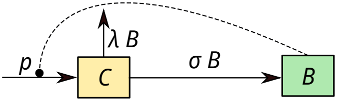

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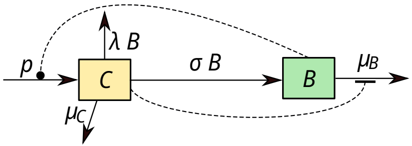

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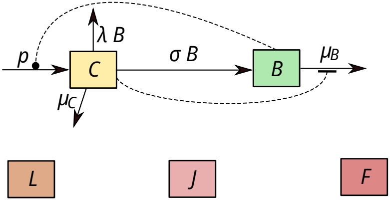

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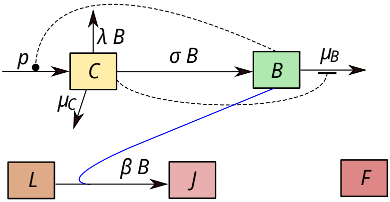

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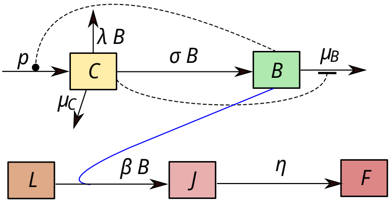

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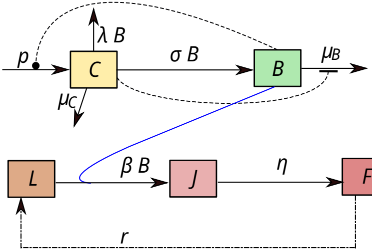

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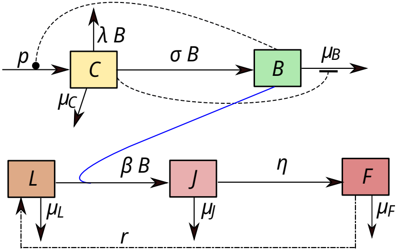

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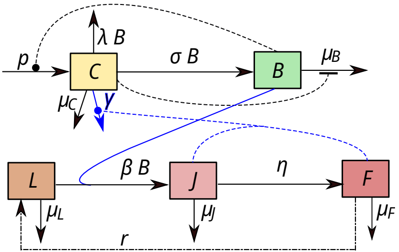

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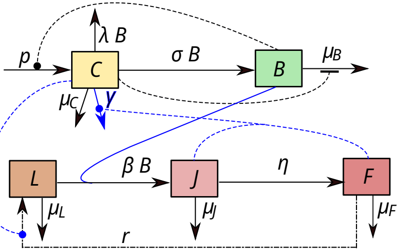

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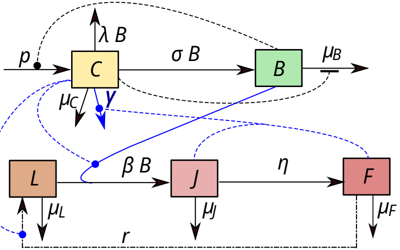

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Plant–nematode model: equilibria

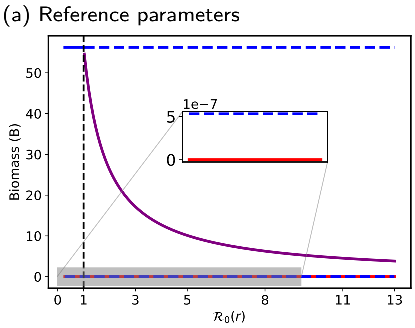
Simplifying hypothesis on plant quantitative resistances: $K_\rho = K_f = K_e$

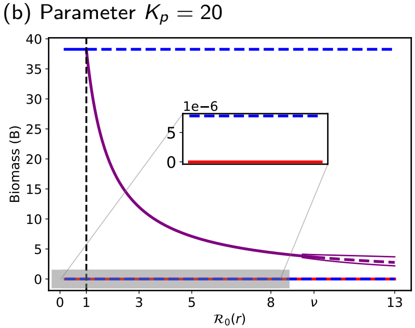
- **Extinction equilibrium**: $(0,0,0,0,0)$ always locally asymptotically stable (LAS)
- **Pest-free equilibria** when $p > p_{\min}$:
  - $(0,0,0,B_h^1,C_h)$ unstable
  - $(0,0,0,B_h^2,C_h)$ LAS iff

$$\mathcal{R}_0 = \underbrace{\left(\frac{\eta}{\eta+\mu_J}\right)}_{J\to F} \underbrace{\frac{r}{\mu_F}\left(\frac{C_h}{K_e+C_h}\right)}_{F\to L} \underbrace{\left(\frac{\beta B_h}{\beta B_h+\mu_L}\right)\left(\frac{C_h}{K_e+C_h}\right)}_{L\to J} < 1$$

- **Coexistence equilibria**: $(L_i, J_i, F_i, B_i, C_i)$
  - Existence: C_i solution of a 6th-order polynomial and such that $C_i > C_h$ (plant-dependent threshold) and $C_i > \hat{\pi}$ (nematode-dependent threshold)
  - Stability (numerical): for $\mathcal{R}_0 > 1$, unique equilibrium LAS

Plant-nematode model: bifurcation





(a,b) **Extinction equilibrium** always LAS

(a,b) Transcritical bifurcation at $\mathcal{R}_0 = 1$: stability exchange between **high pest-free equilibrium** and **coexistence equilibrium**

(b) Hopf bifurcation at $\mathcal{R}_0 = \nu$: **coexistence equilibrium** becomes unstable

Solid curves: stable – Dashed curves: unstable

***Conclusion**: for $\mathcal{R}_0 > 1$, plant and nematode can coexist*

Plant tolerance

Indicators

- **Seasonal nematode reproduction factor**:

$$\rho = \frac{L(T)}{L(0)}$$

  over a cropping season T and **threshold** $\boldsymbol{\rho = 2^5 = 32}$

- **Relative yield index**:

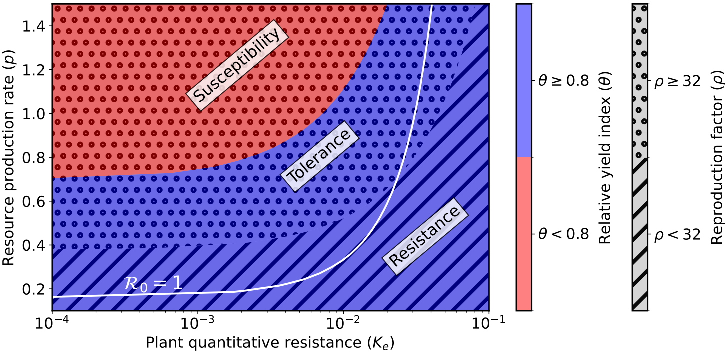
$$\theta = \frac{\widehat{B_I}}{\widehat{B_H}}$$

  with $\widehat{B_X} = \int_0^T B(t)\,dt$ a plant yield proxy with $(X = I)$ or without $(X = H)$ nematodes and **threshold** $\boldsymbol{\theta = 0.8}$

Plant response	θ	ρ
Susceptibility	Low	High
Tolerance	**High**	**High**
Resistance	High	Low

Influential parameters: plant quantitative resistance (K_e) and resource production rate (p)

Conditions for tolerance



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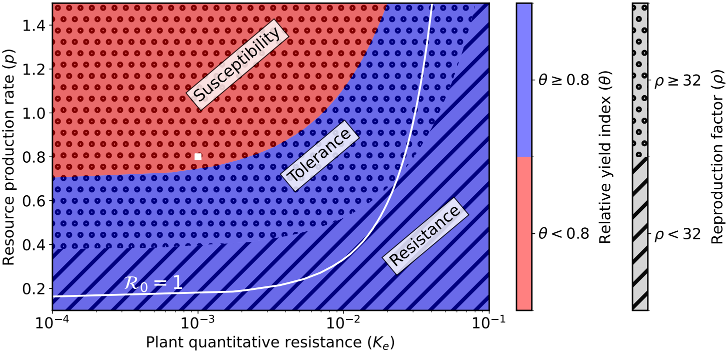
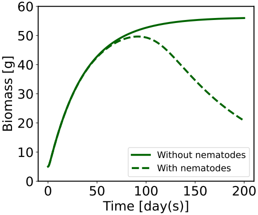


☐ susceptible ($\theta = 0.78$)

☐ Reference plant



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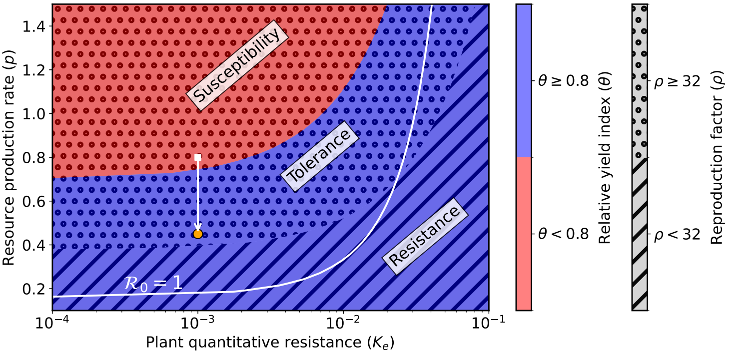
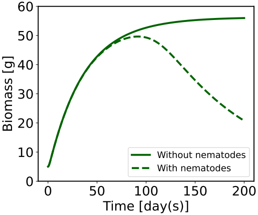
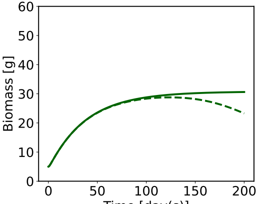


□ susceptible ($\theta = 0.78$) $\rightarrow$ tolerant ($\theta = 0.95$) ●

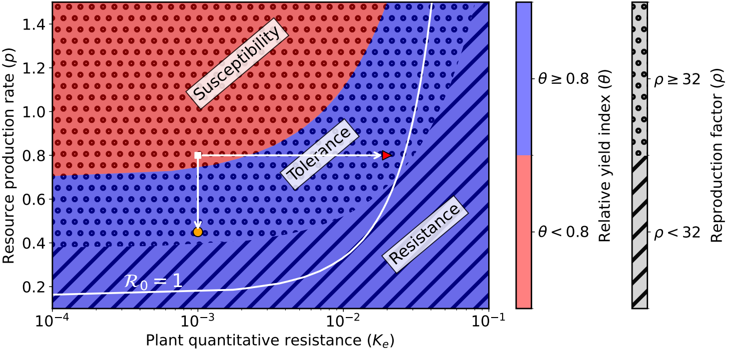
□ Reference plant



● Lower resource production

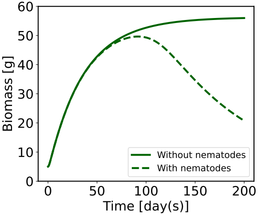


Conditions for tolerance

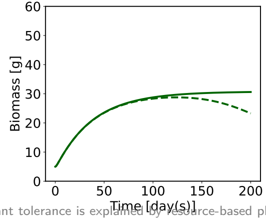


☐ susceptible ($\theta = 0.78$) $\rightarrow$ tolerant ($\theta = 0.95$) ● ▲, but different yields:

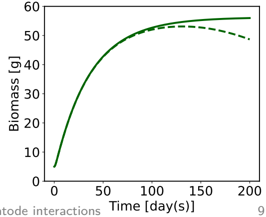
☐ Reference plant



● Lower resource production



▲ Higher quantitative resistance



Conclusion

Tolerance

- **Conditions for coexistence**: $C_i > C_h$ and $C_i > \hat{\pi}$
- **Conditions for tolerance**:
  - Higher quantitative resistance *if available*
  - Lower resource production *but trade-off between tolerance and absolute yield*

SCAN ME


{thank you}