Models for crop diseases: Overview of approaches & scales

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Background

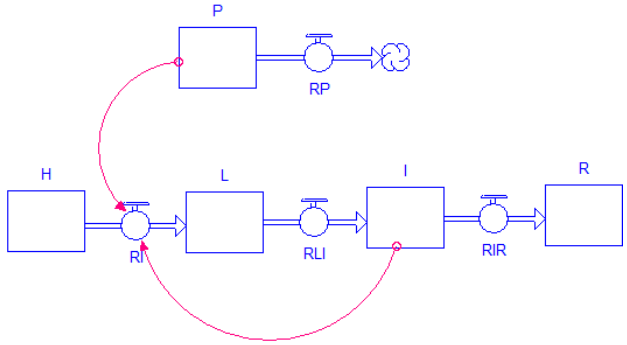
- Modeling plant diseases: many different approaches used, with different objectives
- Two main objectives in modeling plant disease:
  - **Modeling the dynamics of plant disease epidemics**
  - **Modeling crop losses – the effects of plant disease (pest) on crop growth and performance**
- With the ultimate goal of improving disease management, and so:
  - **A very large number of pathosystem (Host + Pathogen) - specific disease management models**

Brief overview of **epidemiological simulation modelling**

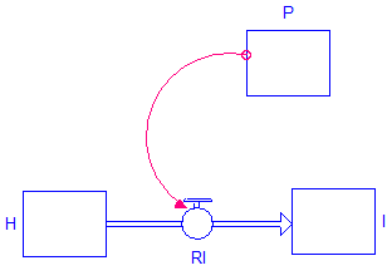
- Types of epidemics and models (monocyclic; polycyclic; mixed monocyclic-polyclic)
- Spatialized models (explicit, implicit spatialization)
- Primary inoculum
- Polyetic processes
- Genetic diversity of the pathogen

Epidemiological structural patterns

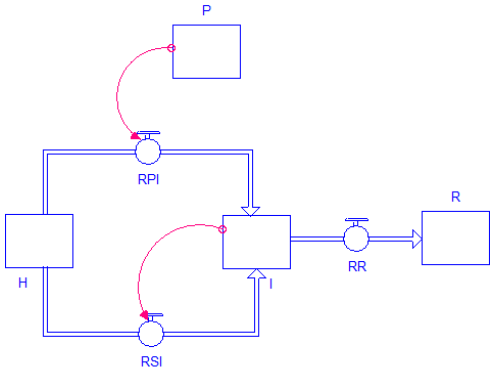
Polycycle – Fraction Host Tissue



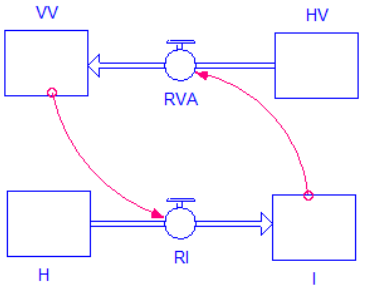
Monocycle
Fruiting Body - Panicle or Head
Seed- or soil-borne diseases



Mixed – Shoot or Tiller

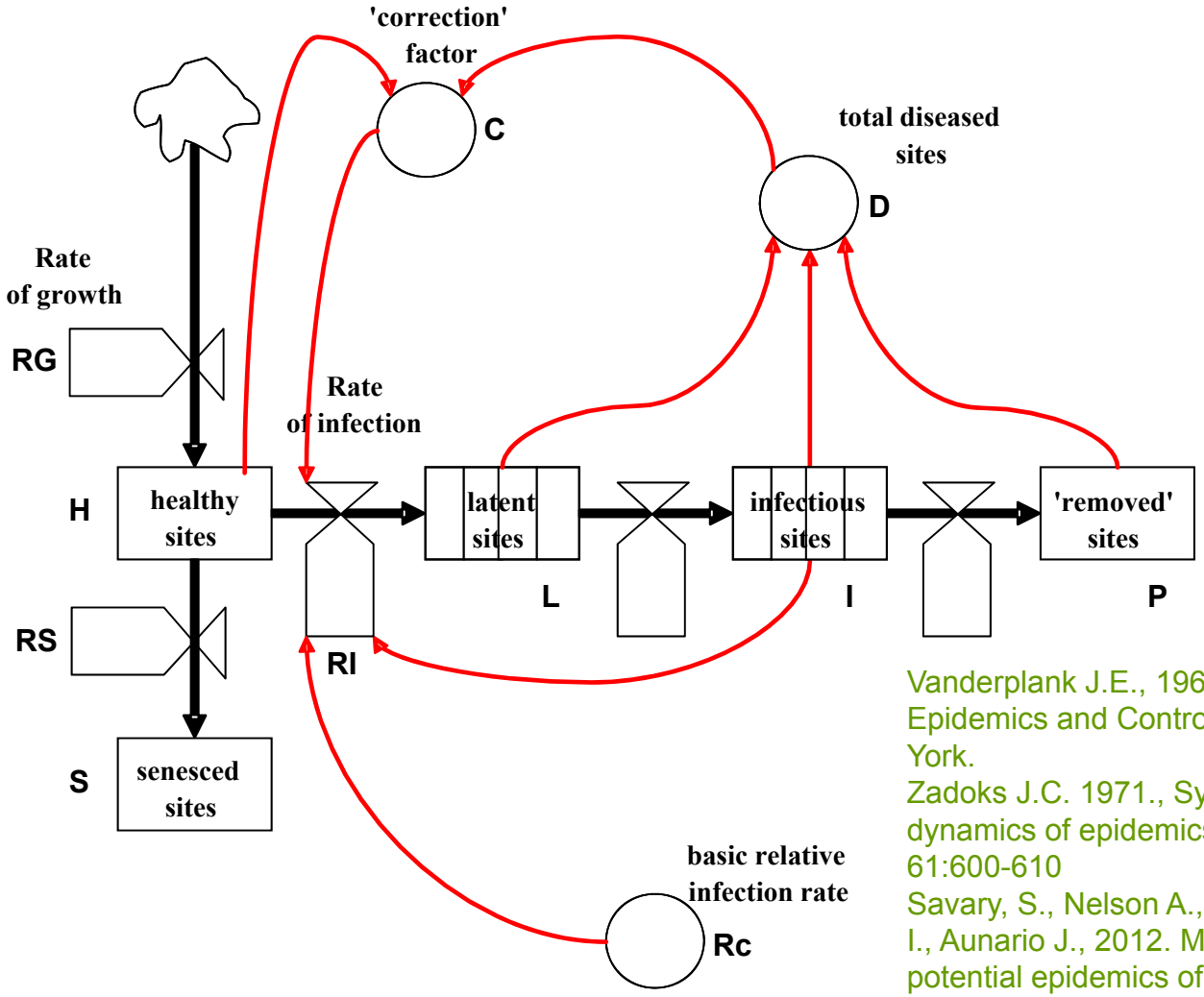


Vector-borne



epidemiological modeling

An epidemiological example: EPIRICE



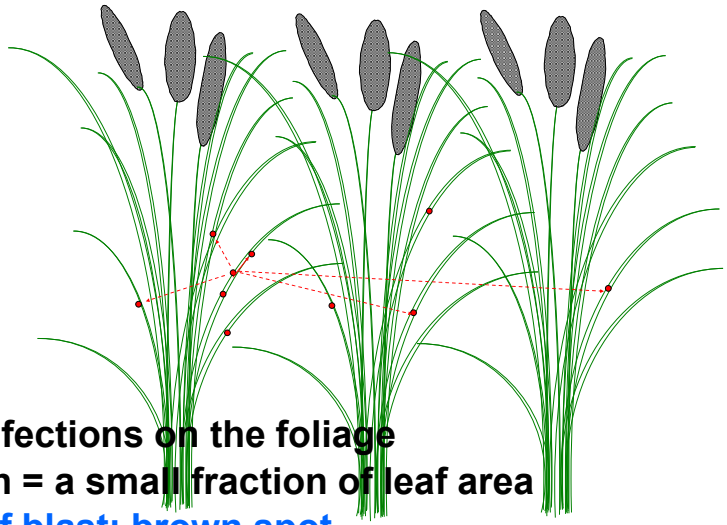
Vanderplank J.E., 1963. Plant Diseases. Epidemics and Control. Academic Press, New York.

Zadoks J.C. 1971., Systems analysis and the dynamics of epidemics. Phytopathology 61:600-610

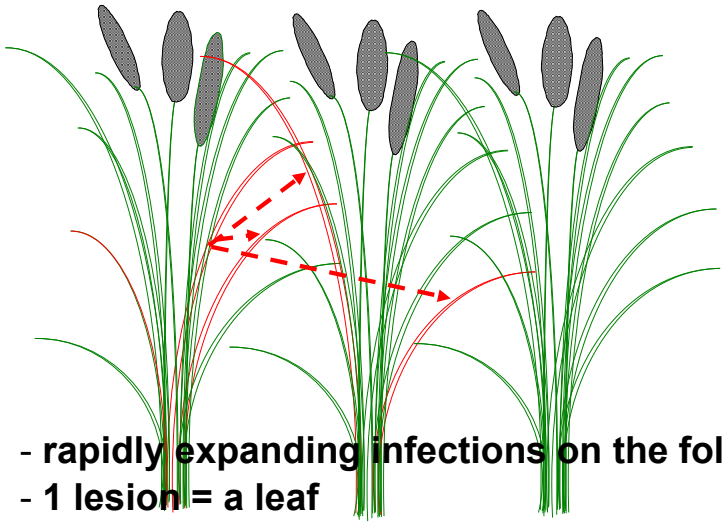
Savary, S., Nelson A., Willocquet L., Pangga I., Aunario J., 2012. Modelling and mapping potential epidemics of rice diseases globally. Crop Protection, In Press.

epidemiological modeling

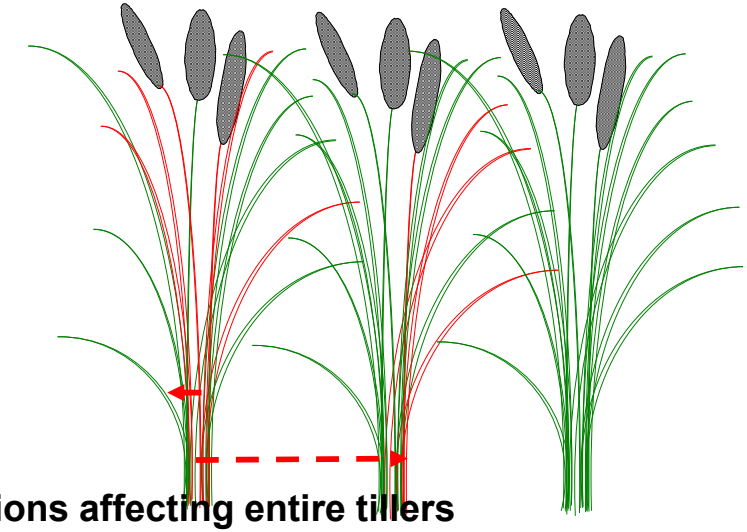
spatial scales of plant disease epidemics in EPIRICE



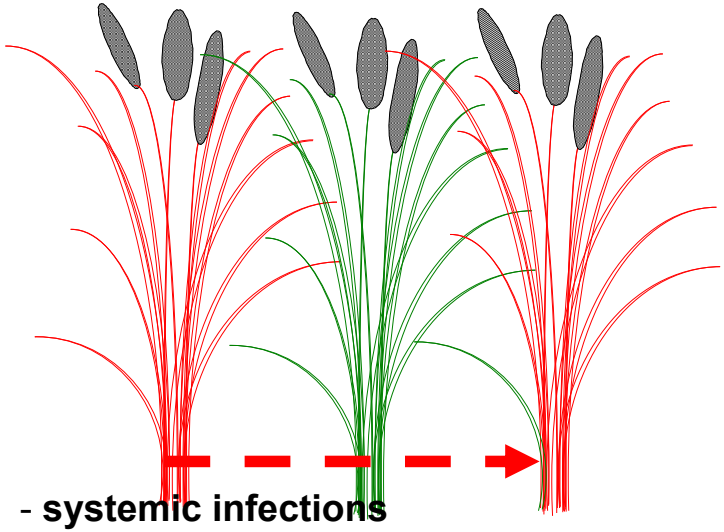
- local infections on the foliage
- 1 lesion = a small fraction of leaf area
- ex.: leaf blast; brown spot



- rapidly expanding infections on the foliage
- 1 lesion = a leaf
- ex.: bacterial blight



- infections affecting entire tillers
- 1 lesion = a tiller
- ex.: sheath blight

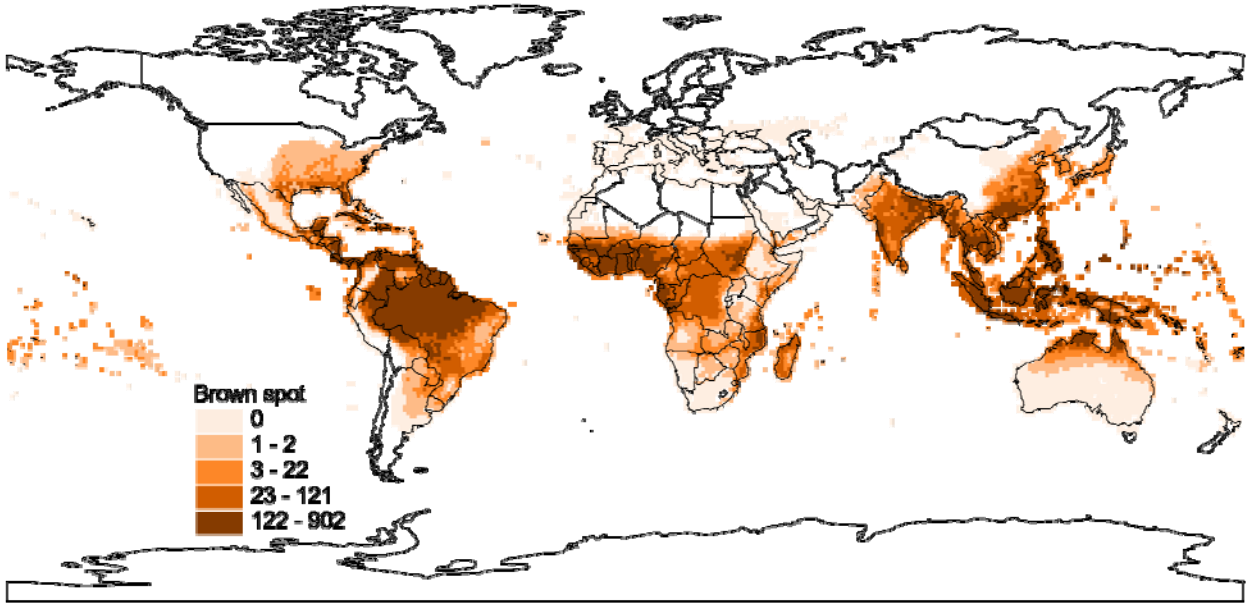


- systemic infections
- 1 lesion = a plant
- ex.: tungro

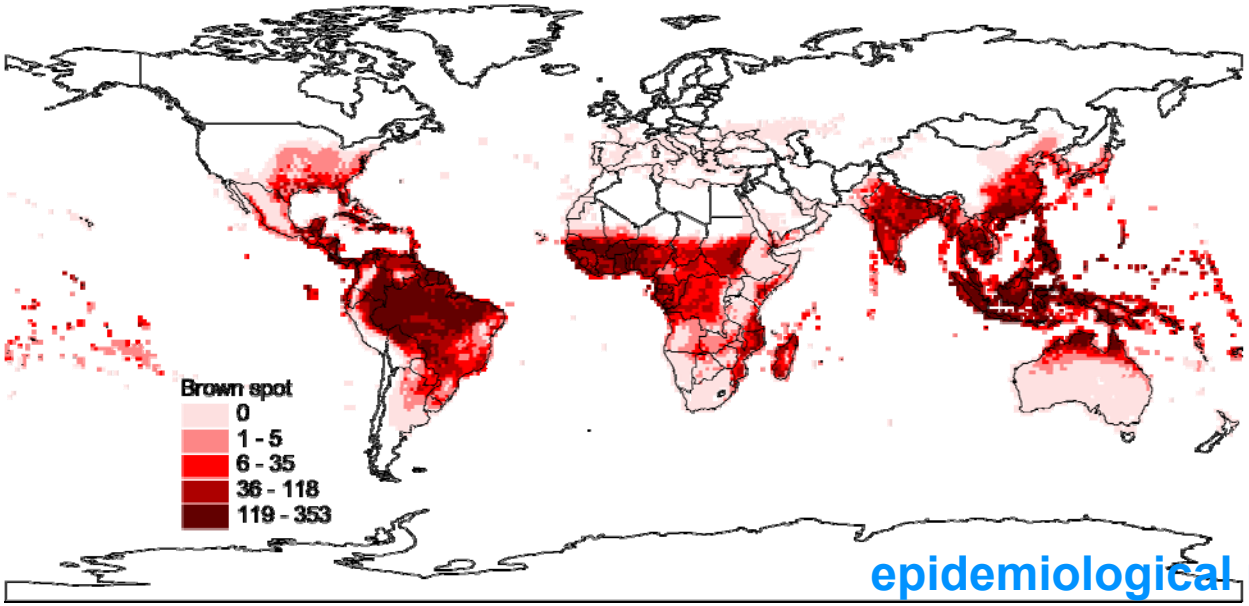
epidemiological modeling

Avg
1997-2008

Brown spot



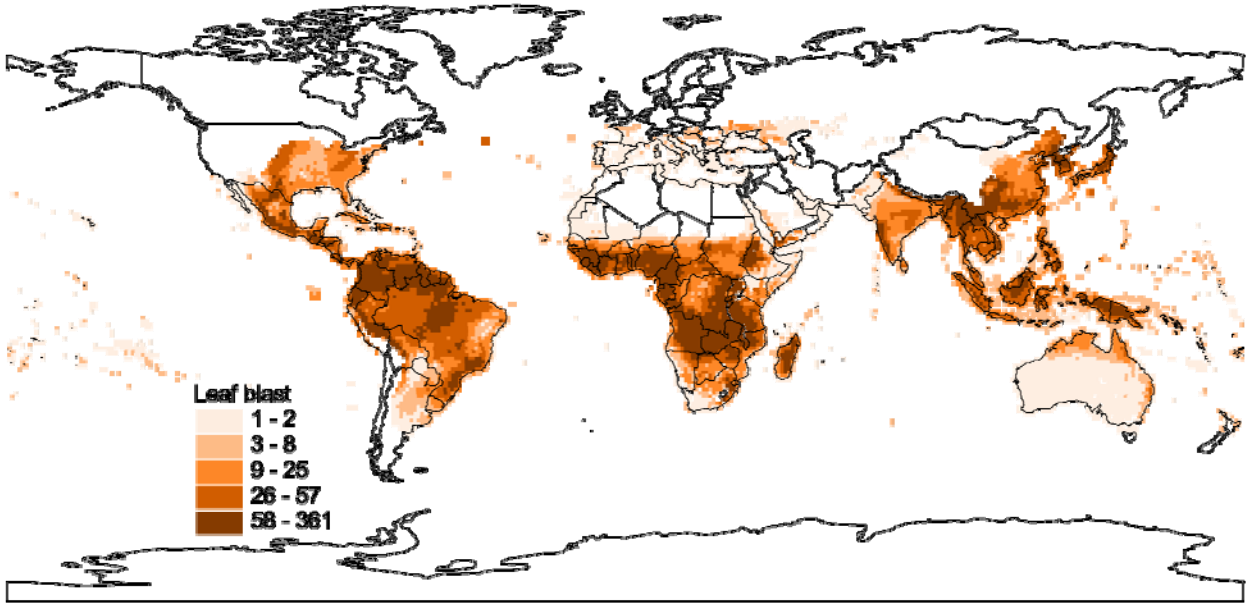
Std
1997-2008



epidemiological modeling

Avg
1997-2008

Leaf blast



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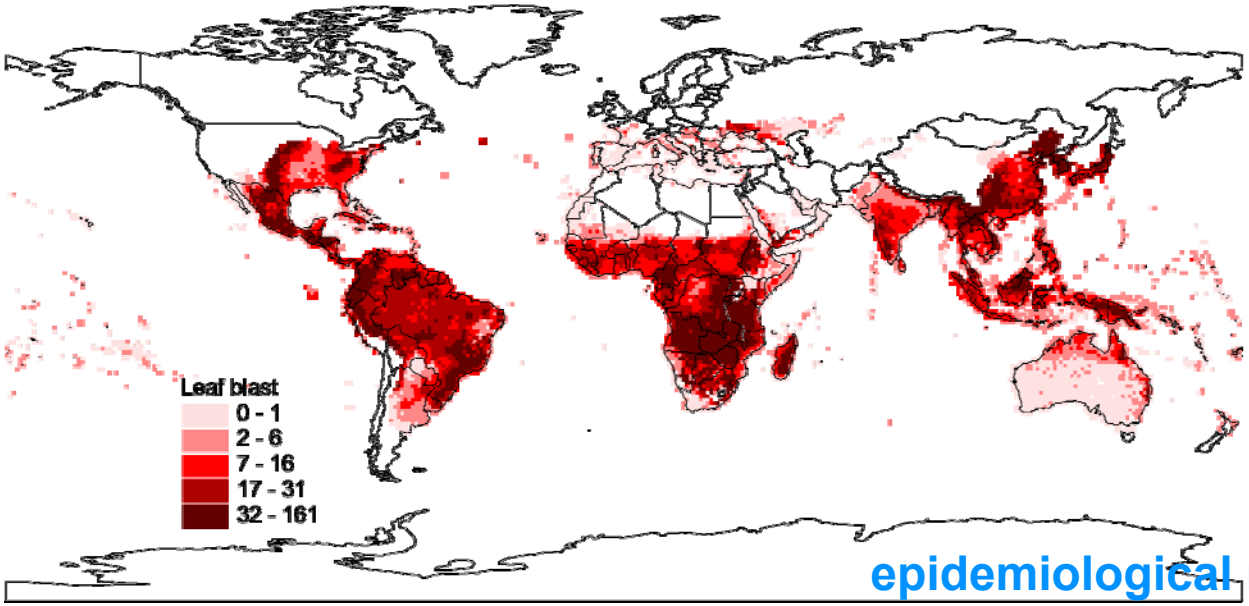
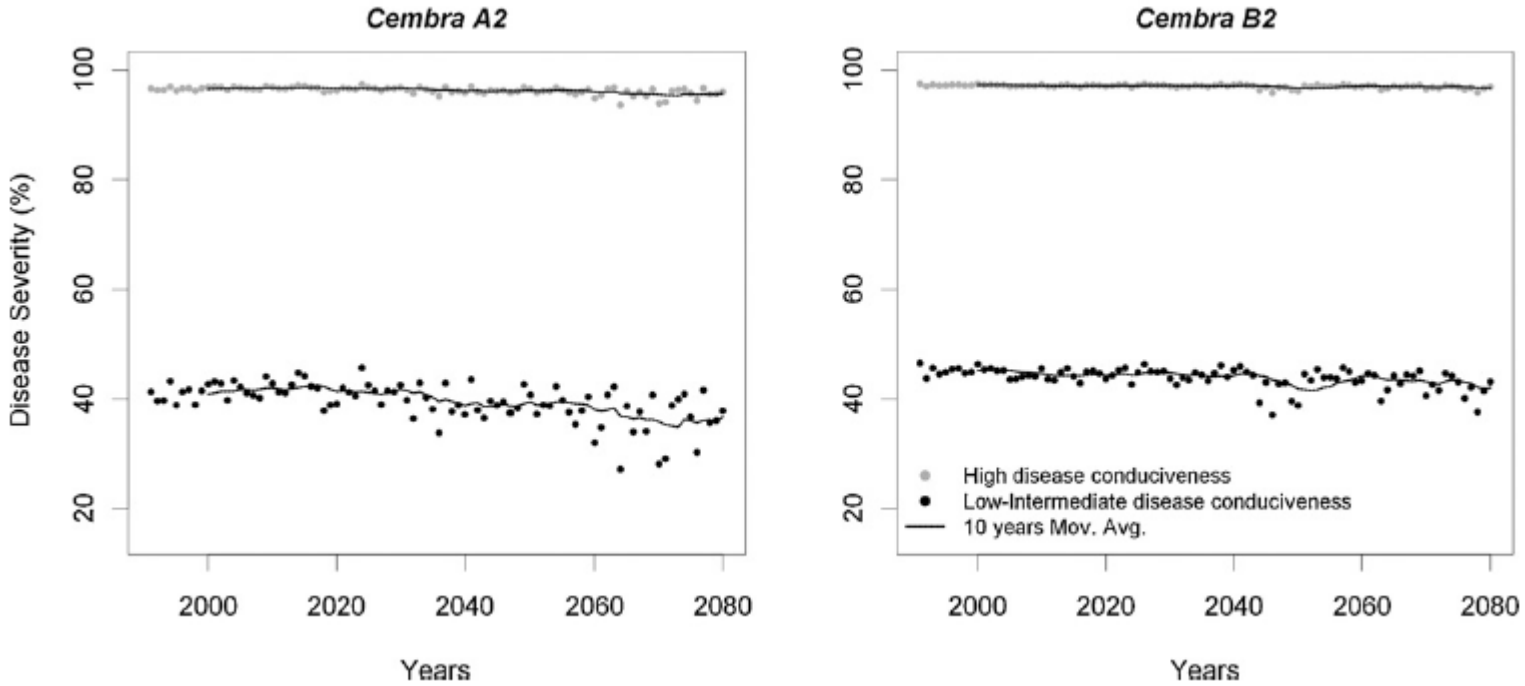


epidemiological modeling

Another epidemiological example: Modelling grapevine powdery mildew epidemics under different CC scenarios



Model simulations of powdery mildew severity (%) in a scenario of low-intermediate conduciveness (black symbols) and high conduciveness (grey symbols) for the disease according to scenarios A2 and B2 for Cembra (higher elevation). 10-year moving average lines are superimposed on the series.

Caffarra, A., Rinaldi, M., Eccel, E., Rossi, V., & Pertot, I. (2012). Modelling the impact of climate change on the interaction between grapevine and its pests and pathogens: European grapevine moth and powdery mildew. *Agriculture, Ecosystems & Environment*, *148*, 89-101.

Challenges (J. Yuen, pers. comm.)

time scale (epidemiological processes studied)

<<

time scale (processes in crop models)

<<

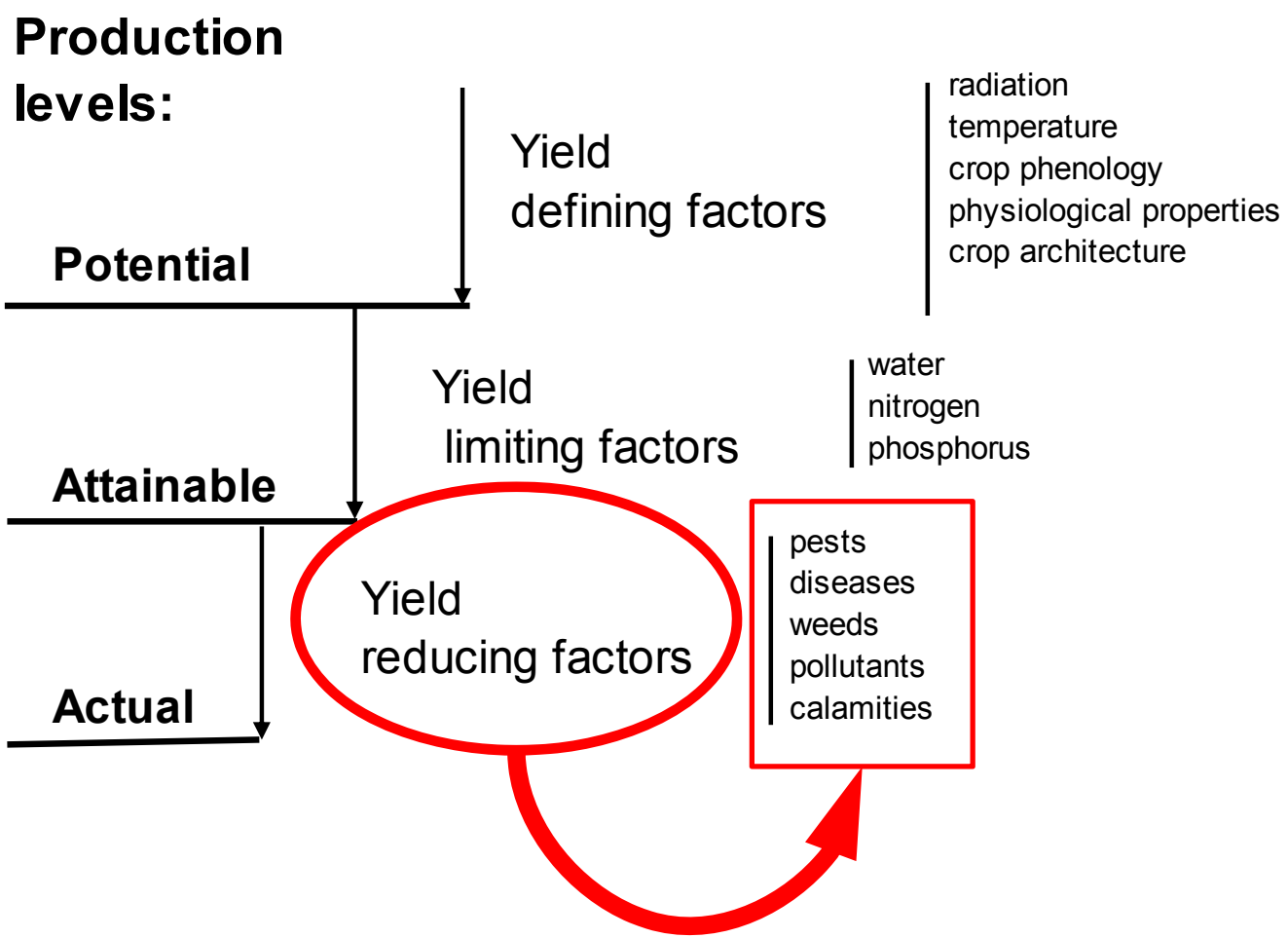
time scale (climate change scenarios)

epidemiological modeling

Brief overview of crop loss simulation modelling

- Crop (agrophysiological) growth models with damage mechanisms
- Damage mechanisms
- RI – RUE models
- multiple diseases (pests) models

Production levels



Rabbinge, R. 1993. The ecological background of food production. In: Crop protection and sustainable agriculture. Ciba Foundation 77. Chadwick DJ, Marsh J, Eds. John Wiley & Sons, Chichester, UK.

Van Ittersum, M. K., and Rabbinge, R. 1997. Ecology for analysis and quantification of agricultural input-output combinations. Field Crops Res. 52:197-208.

Yield and yield loss modeling

Simulation modelling of yield losses - examples

Crop	Pest	Reference
Rice	Leaf blast	Bastiaans, 1993
Rice	Multiple diseases	Pinnschmidt et al, 1994
Rice	Multiple pests	Willocquet et al, 2000; 2002; 2004
Rice, wheat	Multiple pests	Aggarwal et al, 2006a; 2006b
Wheat	Aphids	Rossing, 1991
Wheat	Leaf rust	Roermund & Spitters, 1990
Wheat	Multiple pests	Willocquet et al, 2008
Potato	Multiple pests	Johnson, 1992

Damage mechanisms of crop pest injuries

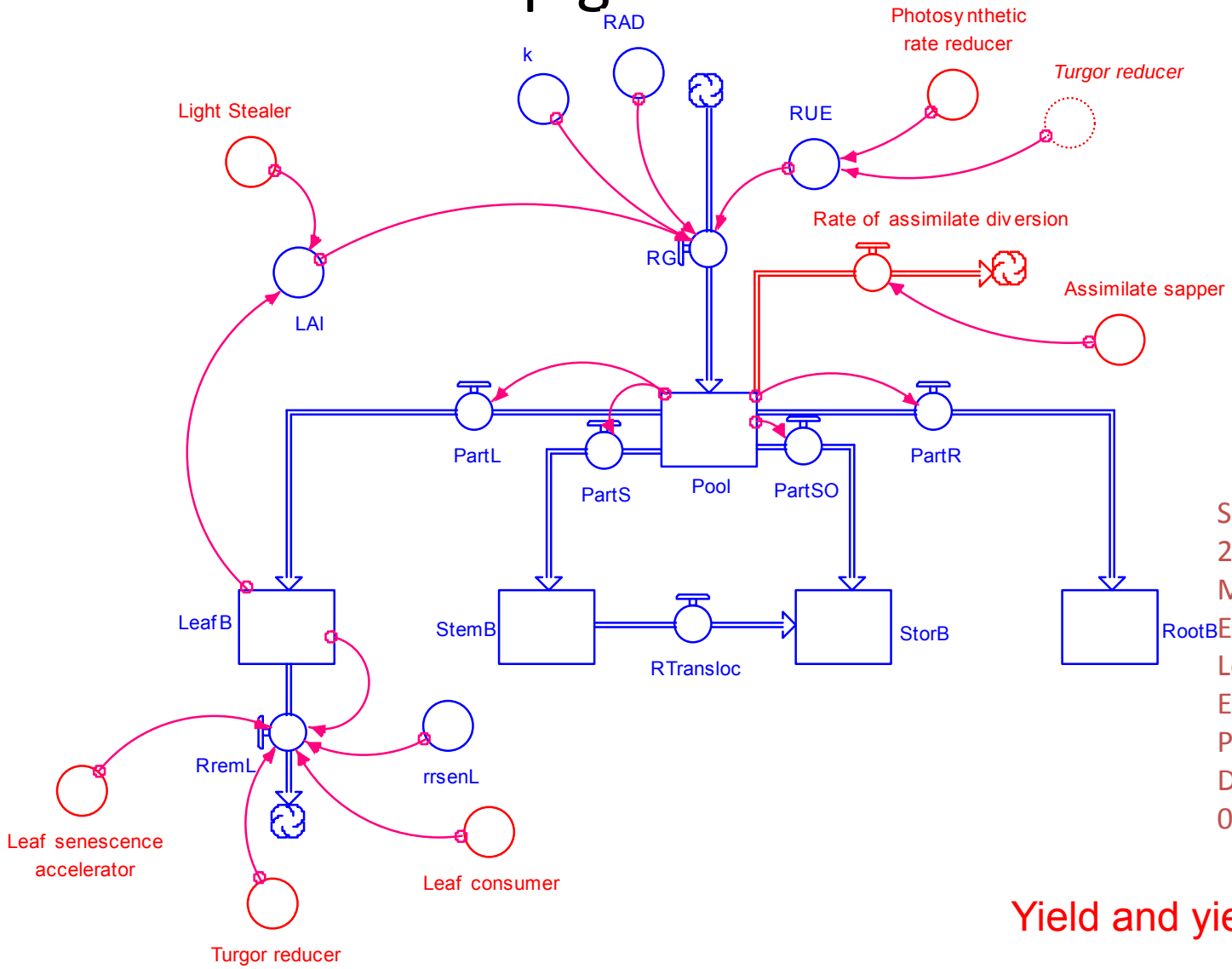
Damage mechanism	Physiological effect	Effect in a crop growth model	Examples of pests
Light stealer	Reduces the intercepted radiation	Reduces the green LAI	Pathogens producing lesions on leaves
Leaf senescence accelerator	Increases leaf senescence, causes defoliation	Reduces leaf biomass by increasing the rate of leaf senescence	Foliar pathogens such as leaf spotting pathogens, downy mildews
Tissue consumer	Reduces the tissue biomass	Outflows from biomasses of the injured organs	Defoliating insects
Stand reducer	Reduces the number and biomass of plants	Reduces biomass of all organs	Damping-off fungi
Photosynthetic Rate reducer	Reduces the rate of carbon uptake	Reduces the RUE	Viruses, root-infecting pests, stem infecting pests, some foliar pathogens
Turgor reducer	Disrupts xylem and phloem transport	Reduces the RUE, accelerates leaf senescence	Vascular, wilt pathogens
Assimilate sapper	Removes soluble assimilates from host	Outflows assimilates from the pool of assimilates	Sucking insects, e.g. aphids, some planthoppers, biotrophic fungi exporting assimilates from host cells

… and an eighth mechanism: reproductive tissue transformation (smuts and gall midges) – A. Djurle, Pers. Comm.

Rabbinge, R., and Vereyken, P. H. 1980. The effects of diseases or pests upon host. Z. Pflanzenk. Pflanzensch. 87:409-422;
Rabbinge, R., and Rijsdijk, P. H. 1981. Disease and crop physiology: a modeler's point of view. Pages 201-220 in: Effects of Disease on the Physiology of the Growing Plants. P. G. Ayres, ed. Cambridge Univ. Press, Cambridge, UK;
Boote, K. J., Jones, J. W., Mishoe, J. W., and Berger, R. D. 1983. Coupling pests to crop growth simulators to predict yield reductions. Phytopathology 73:1581-1587;
Savary S, Willocquet L. 2014. Simulation Modeling in Botanical Epidemiology and Crop Loss analysis. APSnet Education Center. The Plant Health Instructor. DOI: 10.1094/PHI-A-2014-0314-01.

Yield and yield loss modeling

Incorporating different damage mechanisms into a crop growth model: GENEPEST



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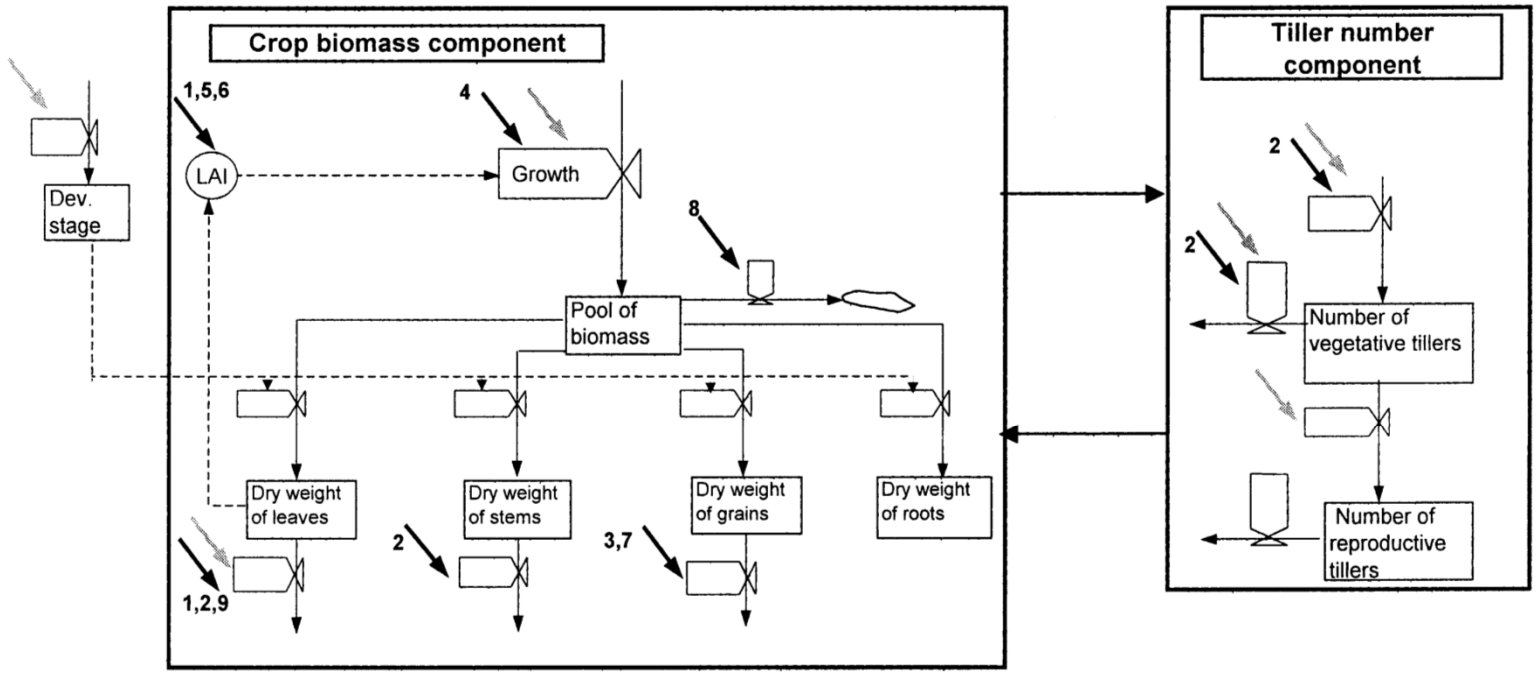
Yield and yield loss modeling

RICEPEST structure



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Yield and yield loss modeling

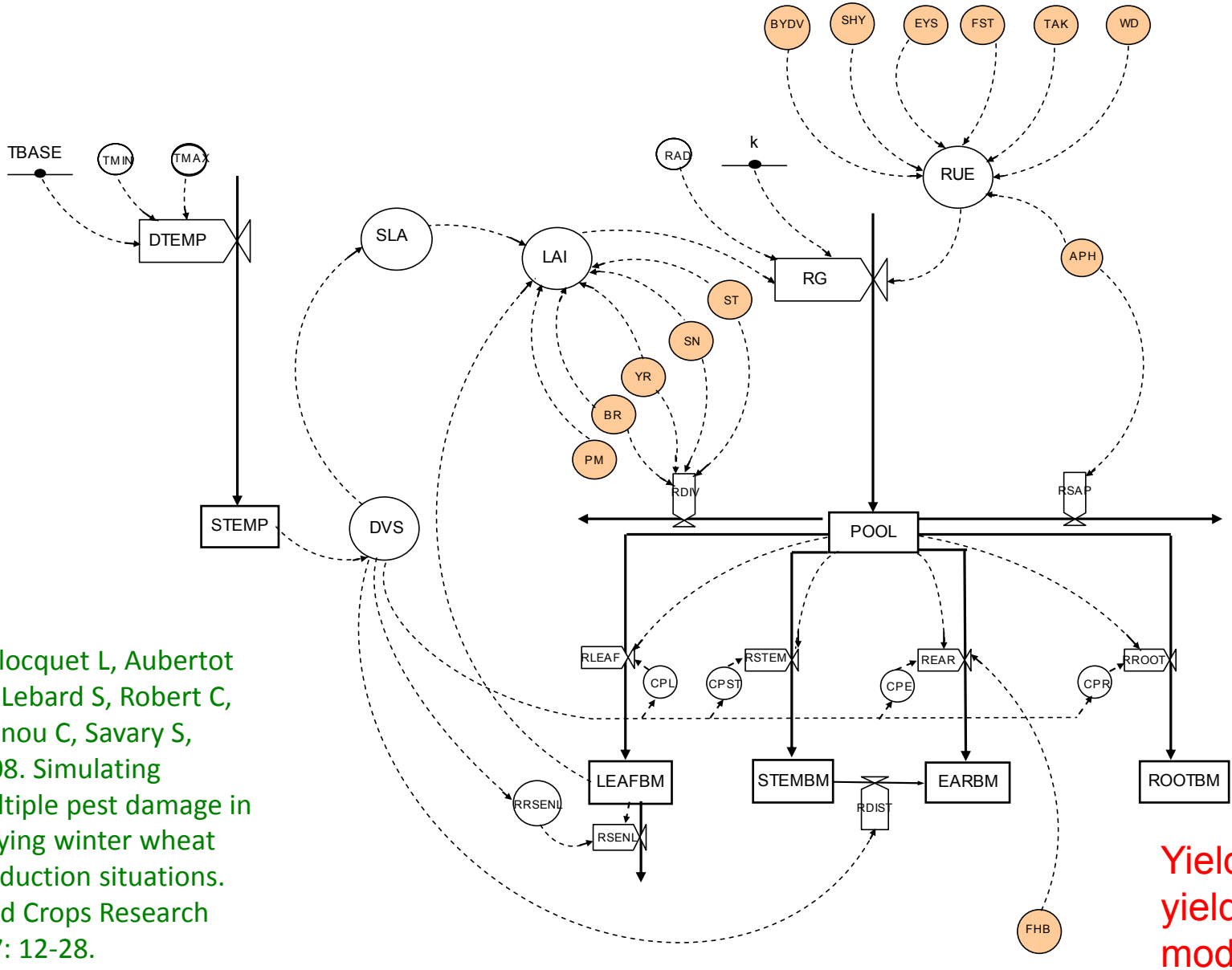
Pests included in WHEATPEST

- Diseases
  - brown rust, yellow rust, powdery mildew, Septoria tritici blotch, Stagonospora nodorum blotch
  - eyespot, sharp eyespot
  - Fusarium stem rot
  - Fusarium head blight
  - take-all
  - BYDV
- Insects
  - aphids
- Weeds

Willocquet L, Aubertot JN, Lebard S, Robert C, Lannou C, Savary S, 2008. Simulating multiple pest damage in varying winter wheat production situations. Field Crops Research 107: 12-28.

Yield and yield loss modeling

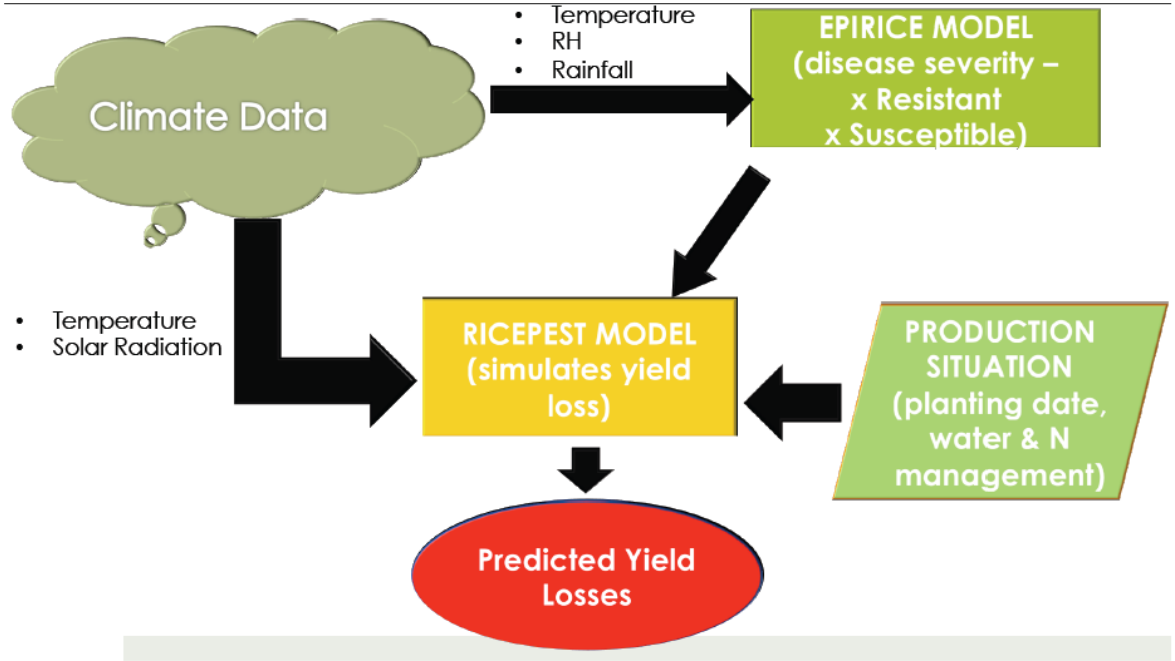
WHEATPEST structure



Willocquet L, Aubertot JN, Lebard S, Robert C, Lannou C, Savary S, 2008. Simulating multiple pest damage in varying winter wheat production situations. Field Crops Research 107: 12-28.

Yield and yield loss modeling

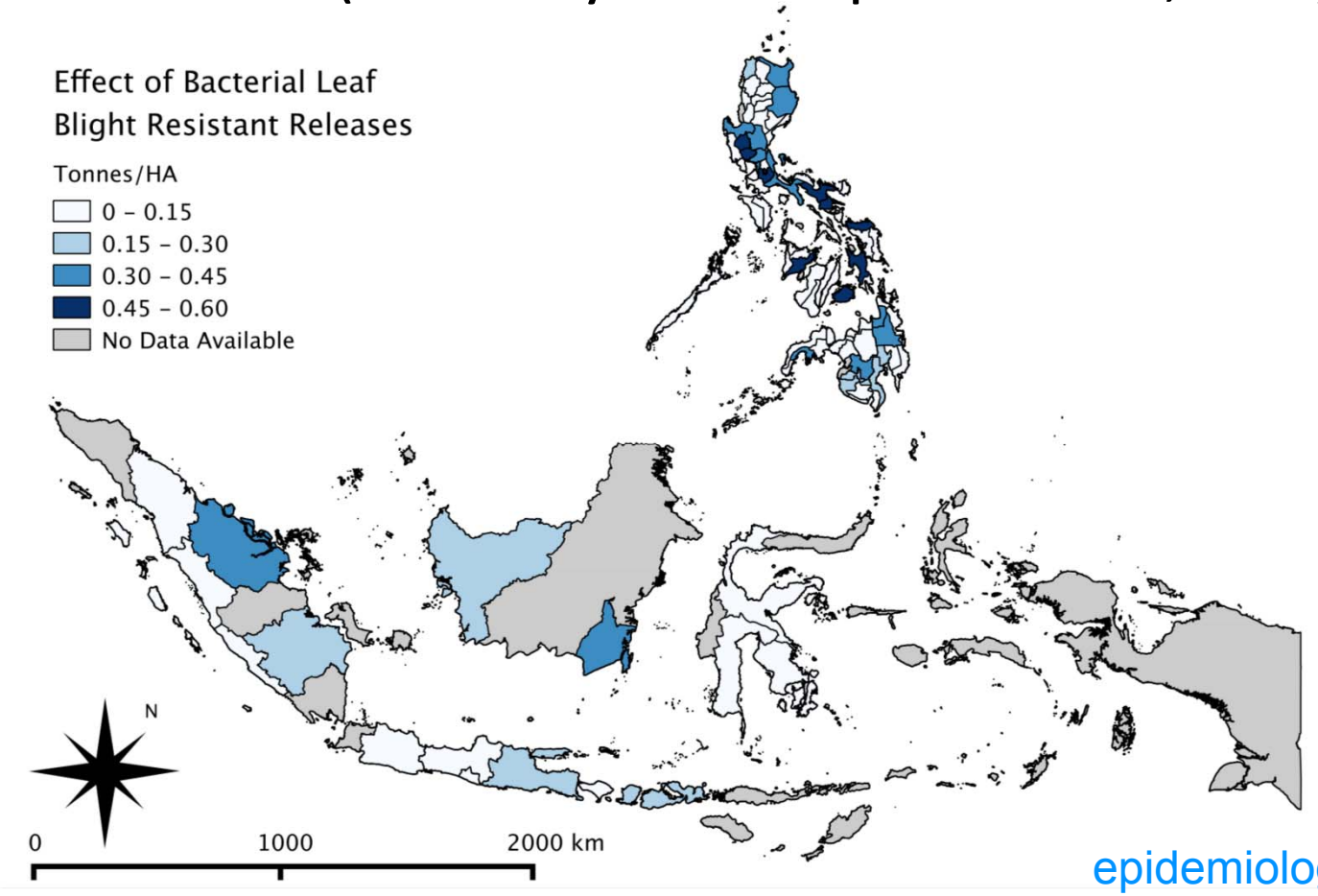
Linking epidemiological and yield loss modeling:
Example: combining EPIRICE and RICEPEST
(Courtesy Adam Sparks, IRRI)



epidemiological &
yield and yield loss modeling

Example: simulated yield gains from host plant resistance to rice bacterial blight

(Courtesy Adam Sparks et al., IRRI)



epidemiological &
yield and yield loss modeling

Assessment of achievements and needs

Progress: damage mechanisms & models

- Much progress has been made on the modeling of the effects of harmful organisms on crops (damage mechanisms)
- As a result, it is possible to model crop losses caused by one or multiple injuries (diseases, pests) in a generic manner (i.e., any crop, any disease/pest)

Assessment of achievements and needs

Progress: losses to multiple injuries

- Disease management often has to account for the existence of **multiple diseases and pests** in order to be relevant and efficient
- From a **crop loss** – crop performance – perspective: addressing multiple diseases (and pests) is desirable
- Yield loss models (e.g., RICEPEST, WHEATPEST) incorporating multiple injuries (diseases, insects, weeds) have been developed

Assessment of achievements and needs

Obstacle: actual field injury data

- **But the availability of injury functions – the time course of diseases/pests under actual field conditions – is a major obstacle**

Assessment of achievements and needs

Challenges

- Even for the main food crops worldwide (rice, wheat, maize, soybean, potato), there is a **critical shortage of field data on observed (multiple) injuries**
- The shortage of field data – not the limitation of process-knowledge – is the main obstacle in modeling crop pests and diseases and their relations to crops

Assessment of achievements and needs

Steps forward

- A critical step forward would be to develop a **generic modeling framework** for **injury functions** (ideotypes of injury time courses)
- representing the dynamics of injury over time in reference, key, conditions
- along with other dynamics (i.e., other disease/pest)
- These collective dynamics of injury functions representing **multiple injury = Crop Health scenarios**
- which, in turn, could be used as drivers for crop loss models

Concepts for a new AgMIP Group

Our emphasis within AgMiP is on generic epidemiological and generic crop loss modelling structures

Concepts for a new AgMIP Group

- Crop growth models: exist
  → potential yield (T, rad, plant genotype)
  → attainable yield (same, + yield limiting factors)
- New step: add yield-reducing factors to existing models: implies
  → driving functions for diseases (pests)
  → couplers = damage mechanisms
- Missing: driving functions for diseases
  → develop a framework to model potential (if necessary, multiple) epidemics

Framework of activities for a proposed AgMiP Research Group

- Focusing on **crop health** (multiple diseases, pests)
- **Generic** simulation models for **disease epidemics**
- Enabling to develop **crop health scenarios**
- A crop health scenario = a set of injury levels caused by different diseases, pests
- Crop health scenario: used as **driver** to model crop growth and **crop loss**
- Allows addressing (1) **potential** and **actual** crop health risks and (2) **crop losses** and (3) **yield gains** (from management) in a generic manner

Target patho-systems

Crops and Ecologies
Table to fill
Check « ecologies »
NOT too many crosses

	Wheat	Rice	Potato	Soybean	Coffee	
Temperate	X		X	Etc.	Etc.	
Tropical humid		X				
Tropical dry	X	X	X			
Tropical mountain			X			

To be discussed further:

- perennial crops: grapevine
- other or different annual crops