Models for crop diseases:
Overview of approaches & scales

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N Castilla, A Sparks, J Avelino, C Allinne, K Garrett
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-polycyclic)
– 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


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
Brown spot 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.

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

Yield and yield loss modeling
Production levels:

Potential

Yield defining factors:
- radiation
- temperature
- crop phenology
- physiological properties
- crop architecture

Attainable

Yield limiting factors:
- water
- nitrogen
- phosphorus

Actual

Yield reducing factors:
- pests
- diseases
- weeds
- pollutants
- calamities

Yield and yield loss modeling


Simulation modelling of yield losses - examples

<table>
<thead>
<tr>
<th>Crop</th>
<th>Pest</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>Leaf blast</td>
<td>Bastiaans, 1993</td>
</tr>
<tr>
<td>Rice</td>
<td>Multiple diseases</td>
<td>Pinnschmidt et al, 1994</td>
</tr>
<tr>
<td>Rice</td>
<td>Multiple pests</td>
<td>Willocquet et al, 2000; 2002; 2004</td>
</tr>
<tr>
<td>Rice, wheat</td>
<td>Multiple pests</td>
<td>Aggarwal et al, 2006a; 2006b</td>
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<tr>
<td>Wheat</td>
<td>Aphids</td>
<td>Rossing, 1991</td>
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<tr>
<td>Wheat</td>
<td>Leaf rust</td>
<td>Roermund &amp; Spitters, 1990</td>
</tr>
<tr>
<td>Wheat</td>
<td>Multiple pests</td>
<td>Willocquet et al, 2008</td>
</tr>
<tr>
<td>Potato</td>
<td>Multiple pests</td>
<td>Johnson, 1992</td>
</tr>
</tbody>
</table>

Yield and yield loss modeling
# Damage mechanisms of crop pest injuries

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

... 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;
Incorporating different damage mechanisms into a crop growth model: GENEPEST


Yield and yield loss modeling
RICEPEST structure


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


Yield and yield loss modeling
Linking epidemiological and yield loss modeling:

Example: combining EPIRICE and RICEPEST

(Courtesy Adam Sparks, IRRI)
Example: simulated yield gains from host plant resistance to rice bacterial blight
(Courtesy Adam Sparks et al., IRRI)
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.
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

<table>
<thead>
<tr>
<th></th>
<th>Wheat</th>
<th>Rice</th>
<th>Potato</th>
<th>Soybean</th>
<th>Coffee</th>
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<tbody>
<tr>
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<td>X</td>
<td></td>
<td>X</td>
<td>Etc.</td>
<td>Etc.</td>
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<tr>
<td>Tropical humid</td>
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<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropical dry</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tropical mountain</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

To be discussed further:
- perennial crops: grapevine
- other or different annual crops