Crop Modelling CoP Webinar:
Disease crop modeling advances and challenges for large scale simulation studies

From the evaluation of the environmental suitability of plant pathogens to the integration of disease and crop models: data needs, use cases and challenges

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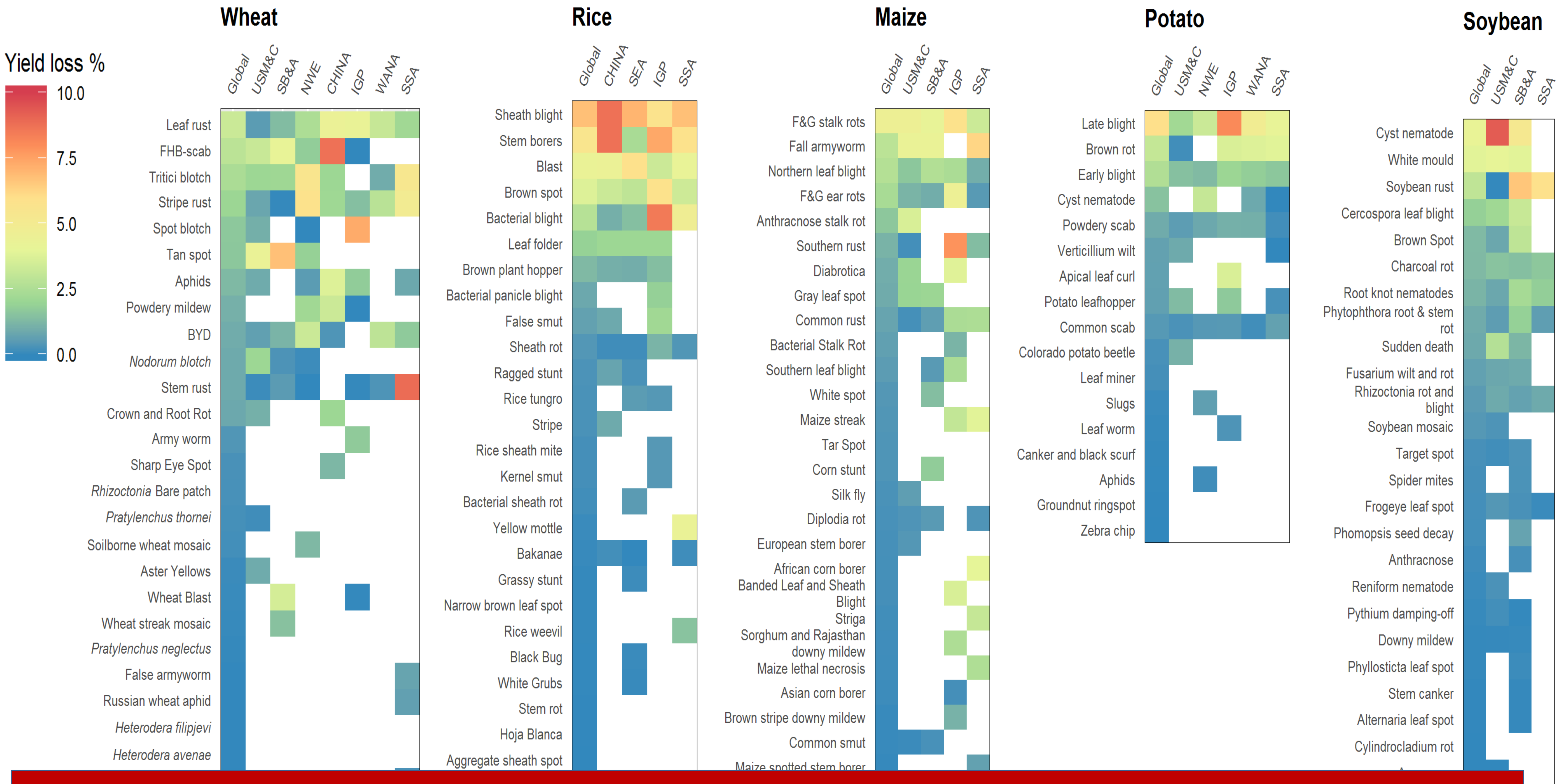
The relevance of modelling the impact of plant pests and diseases on crop

- Plant diseases are a **major cause for yield losses** worldwide and an important, yet poorly documented, **source of uncertainty in modelling outputs**.
- Disease yield loss quantification is critical to inform **tactical to strategic decisions for disease management**, for priority setting and to support public policies.
- **Yield losses can be simulated** using agrophysiological models in which **damage mechanisms** have been incorporated.
- **Simulations** that do not account for crop pathogens and pests **are bound to lead to overestimates**, in some cases, very large ones.

Estimates of crop losses by pathogens and pests



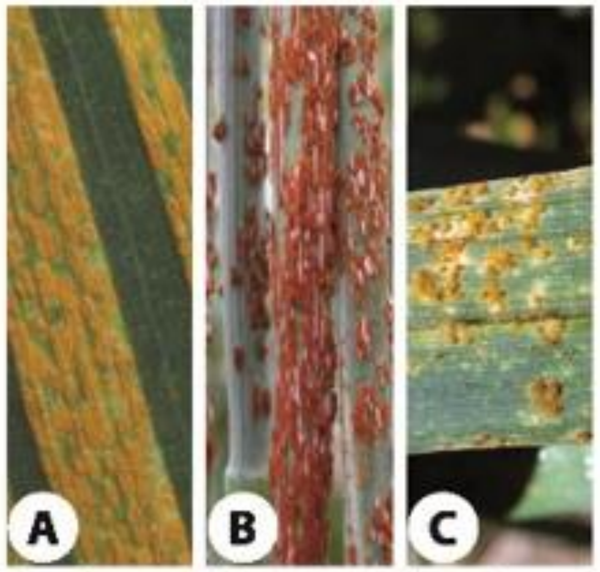
137 P&Ps were reported with a large variation in crop losses caused by specific P&Ps. The relative importance of P&Ps varied across food security hotspots

Savary S, Willocquet L, Pethybridge SJ, Esker P, McRoberts N, Nelson A. 2019. The global burden of pathogens and pests on major food crops. Nature Ecology & Evolution 3, 430–439

The impacts of plant disease epidemics on food security can be examined

WHEAT RUSTS | FUSARIUM HEAD BLIGHT | POTATO LATE BLIGHT | RICE BROWN SPOT

WHEAT RUSTS



Source: stripeust.wsu.edu, theconversation.com, blog.extension.uga.edu

A) P. striiformis, B) P. graminis, C) P. triticina

Where: N. America, Europe, Africa, Asia

When: 20th and 21st century

Chronic, acute and emerging

Type B, C

COMPONENT	EFFECT
Production	Large
Stocks	Impacted
Physical access	*Not affected*
Economic access	Impacted
Stability	Impacted
Nutritive value	Large

FUSARIUM HEAD BLIGHT

Source: news.ca.uky.edu

Fusarium spp.

Where: N. America, China, Europe

When: Today

Acute

Type G

COMPONENT	EFFECT
Production	Strongly impacted
Stocks	Strongly impacted
Physical access	Impacted
Economic access	Impacted
Stability	Impacted
Nutritive value	Very large

POTATO LATE BLIGHT
RICE BROWN SPOT
WHEAT RUSTS

Source: freepik.com

Physical access	Impacted
Economic access	Large
Stability	*Not affected*
Nutritive value	*Not affected*

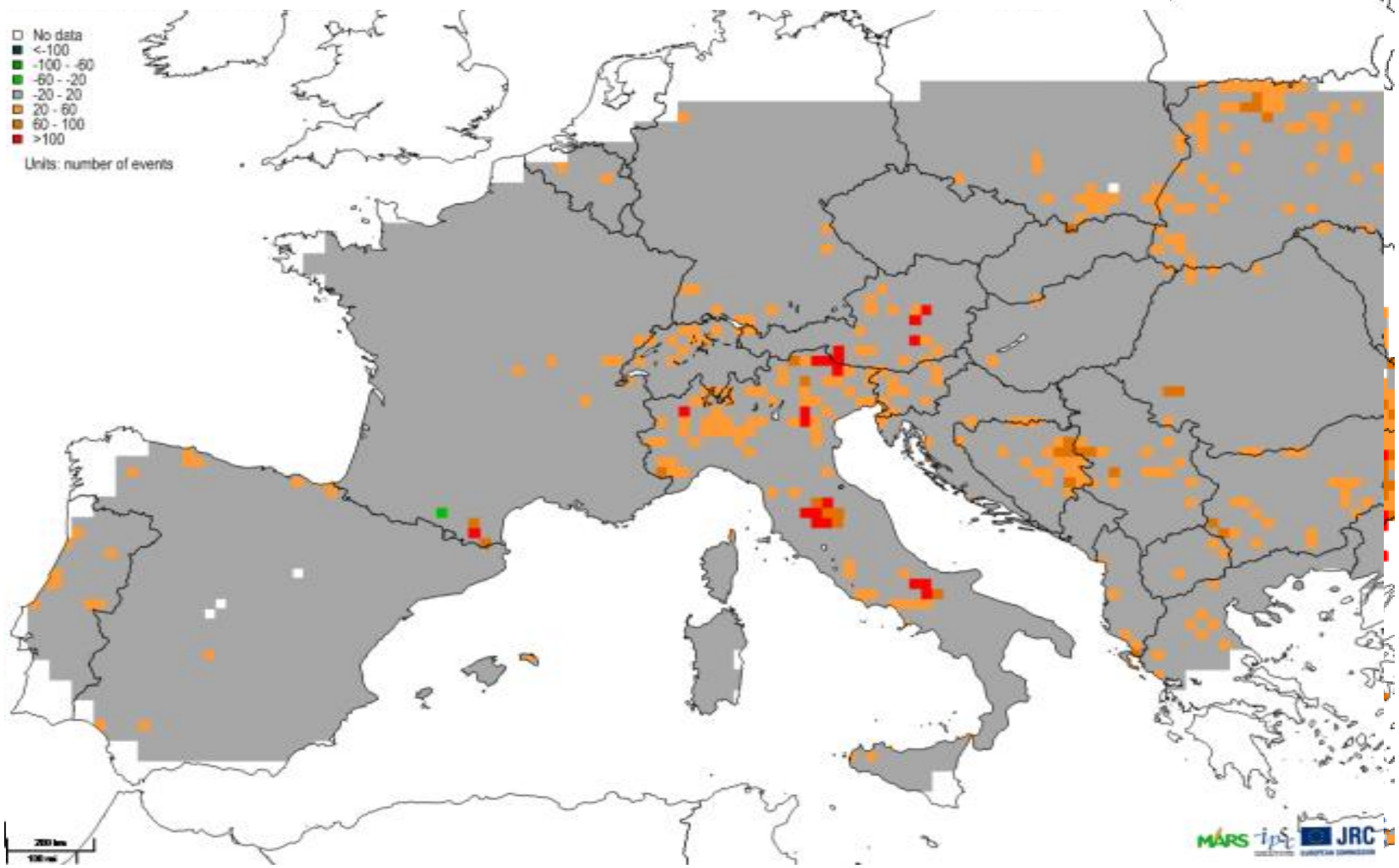
Savary et al., 2017, Food Security

Climate change leads to high uncertainty in plant disease spread and intensity

- The effect of **changing atmospheric composition and climate** on individual **pathosystems** can be ***positive, negative or neutral*** (Garrett et al., 2006; Chakraborty et al., 2008)

Sclerotinia sclerotium **- Sunflower - B1 2050 vs baseline**

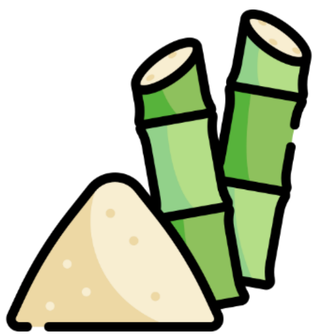
- infections
no variation
+ infections



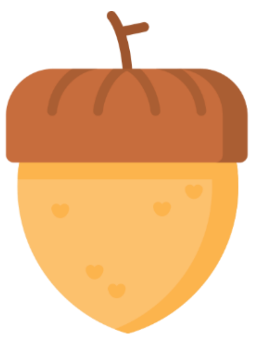
Bregaglio et al., 2012, Agron. Sust. Dev.

Why modelling pests and diseases impact on crop is needed?

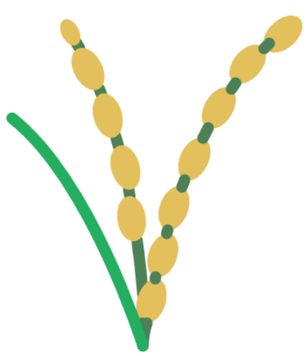
- A possible clasiffication of plant disease models:
  - **Epidemiological models**, the target is the **dynamic** of plant disease epidemics
  - **Yield loss models**, the target is the reproduction of the **impact** of the pest/disease on crop yield.



- A model to predict the suitability of weather conditions to the orange rust disease of sugarcane.



- An informative model-based system for early forecast of hazelnut quality.

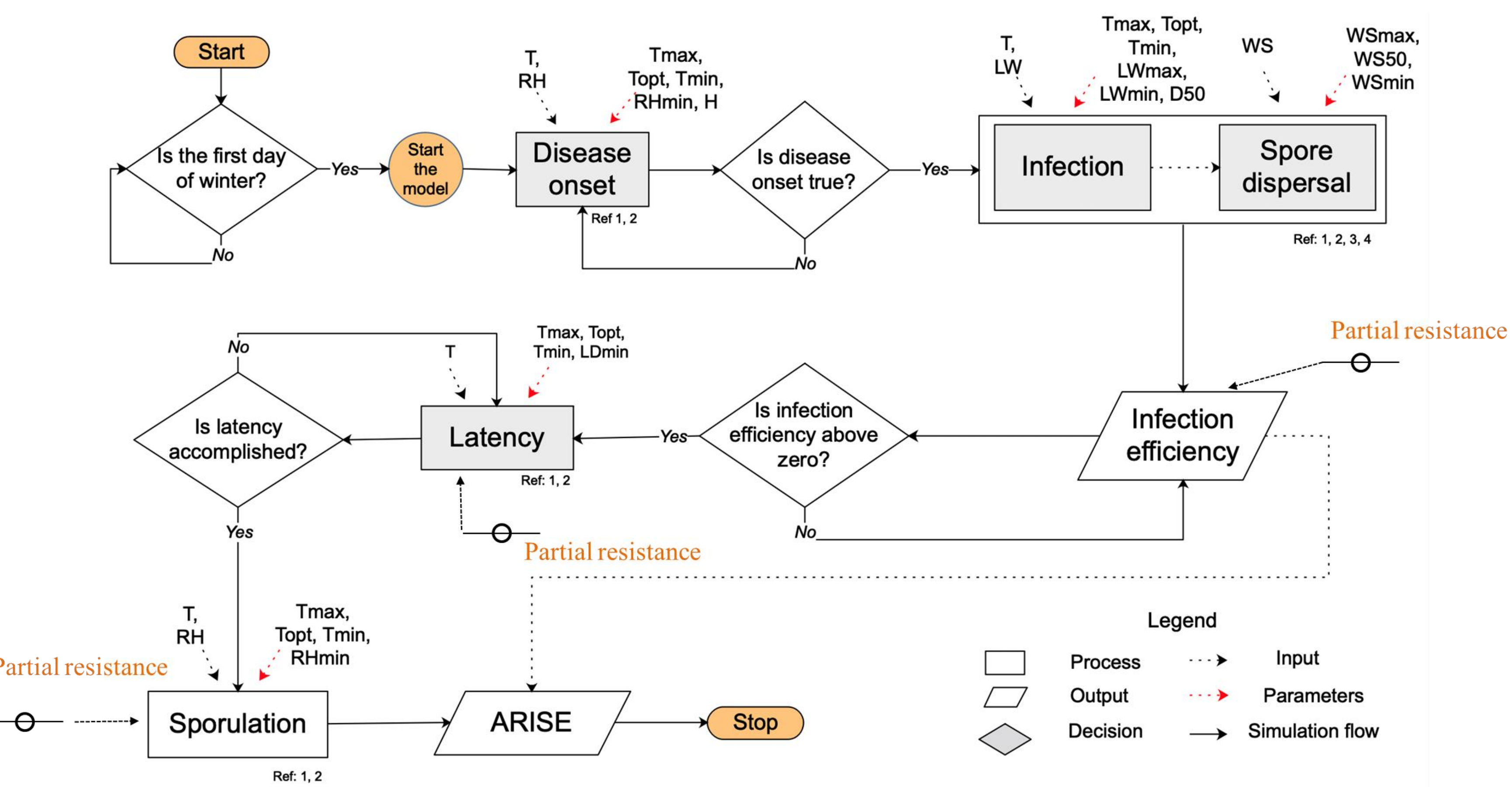


- A model to predict the impact of rice blast epidemics in current and future scenarios.

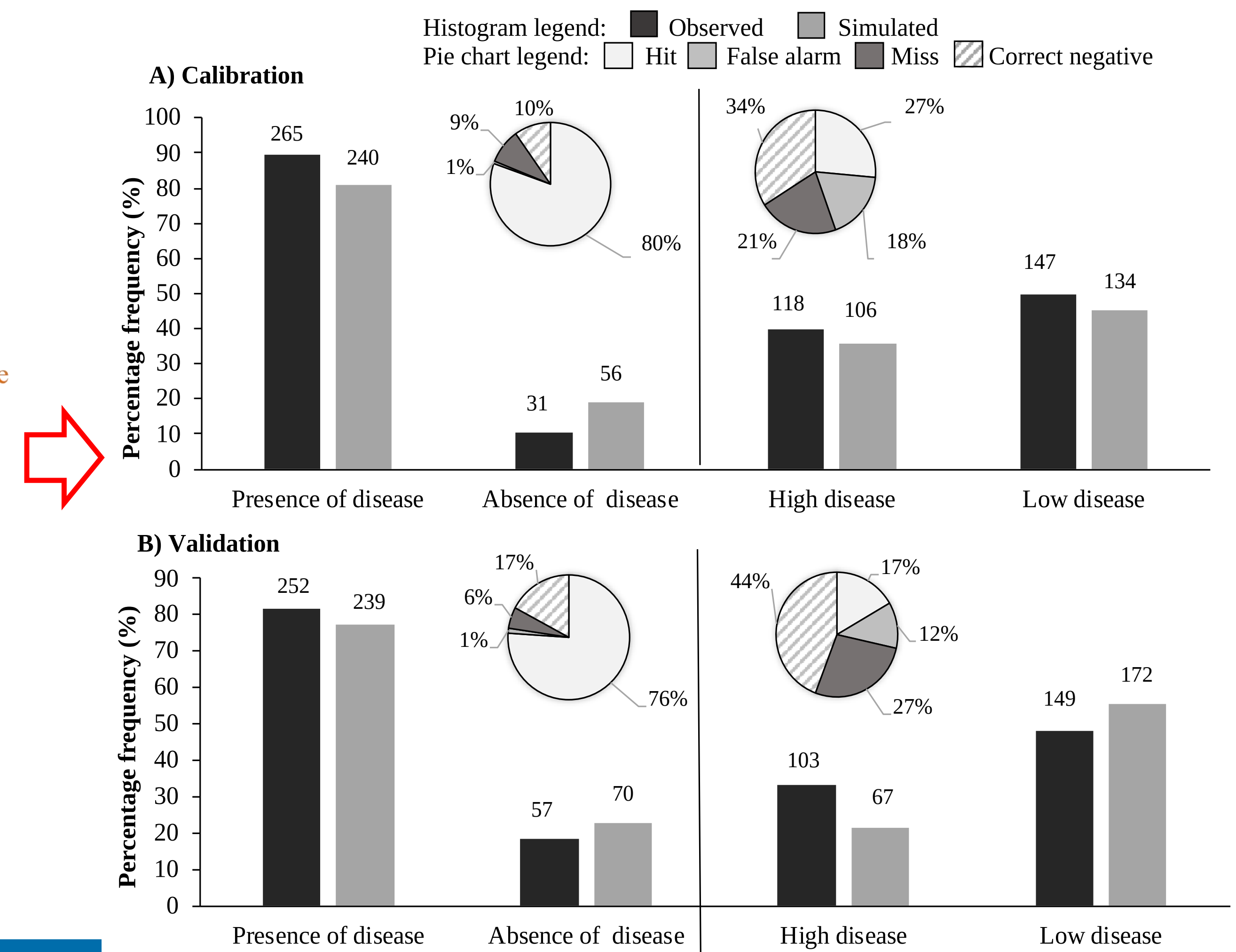
Use cases: orange rust on sugarcame

- Orange rust caused by the polycyclic fungus *Puccinia kuehnii* is an emerging disease of sugarcane.
- Yield losses in susceptible and intermediate resistant varieties can reach 40%.
- Need of forecasting systems for in-season support and scenario analyses.

Existing modelling approaches calibrated with literature data

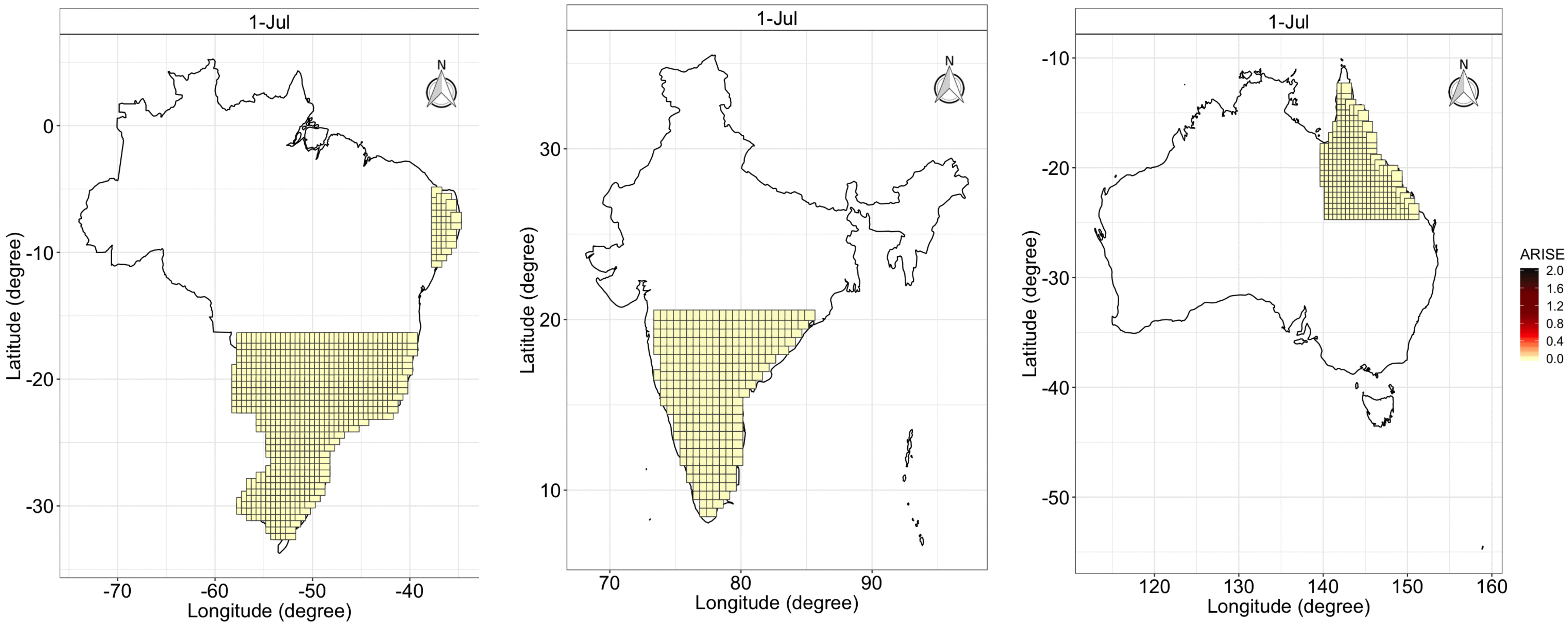


Model performances in reproducing disease severity



Use cases: orange rust on sugarcame

- A total of 605 field samplings were taken on 70 sugarcane farms in the Pradópolis region, state of São Paulo → need of upscaling according to weather database.
- After the evaluation with field data, the model was projected on main sugarcane producing country to test its behavior on large area simulations.



Valeriano et al. (2020). International Journal of Biometeorology, major revision

Use cases: rotten hazelnuts

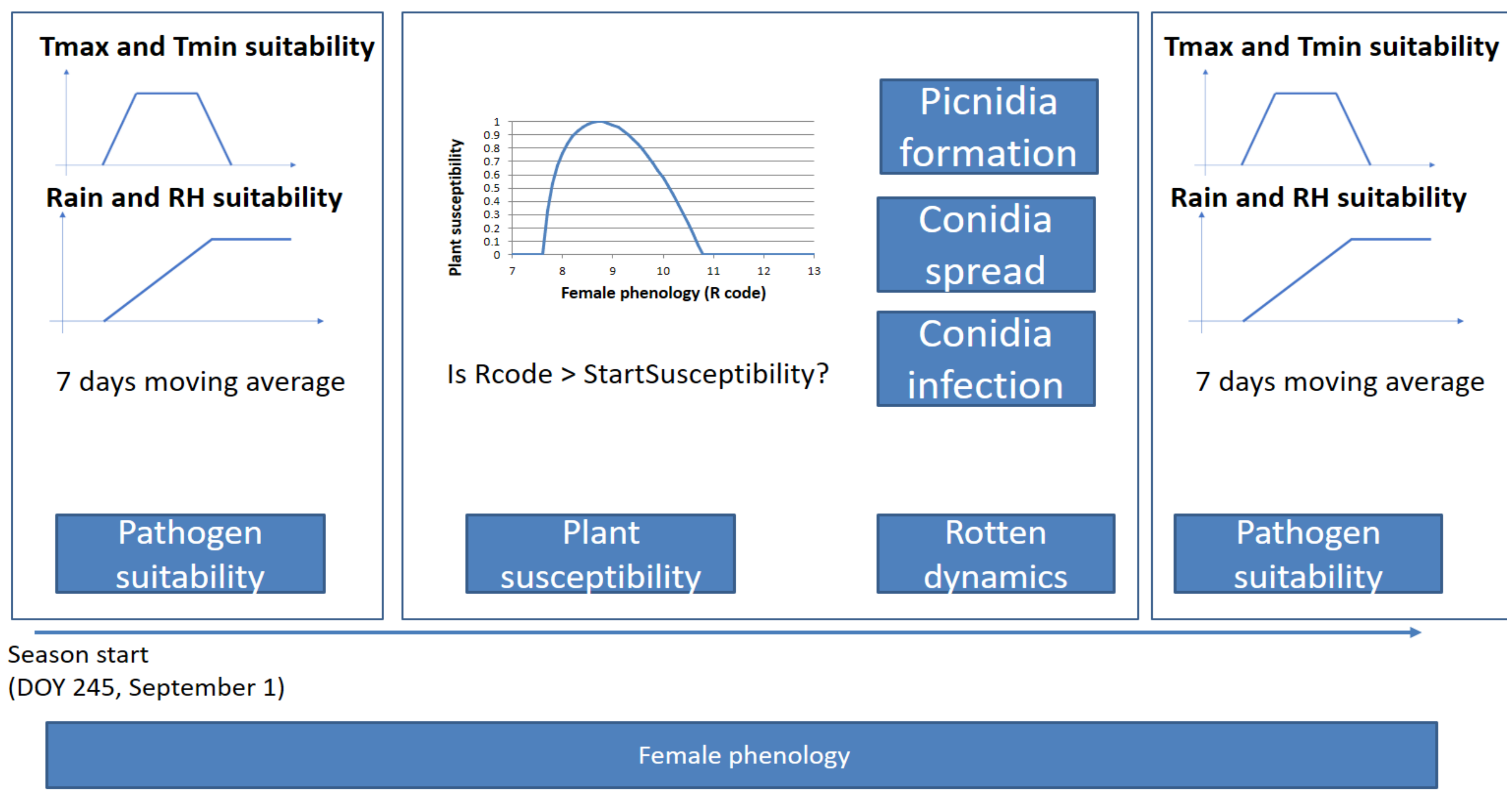
- Insect pests and diseases affect the quantitative and qualitative aspects of hazelnut yield, MatHiLDE project.
- Demand for decision support systems to optimize chemical control and forecasting activities to provide early yield predictions.

All kinds of defects, including brown spotted or moldy nut kernels.

Uncertain causal agent

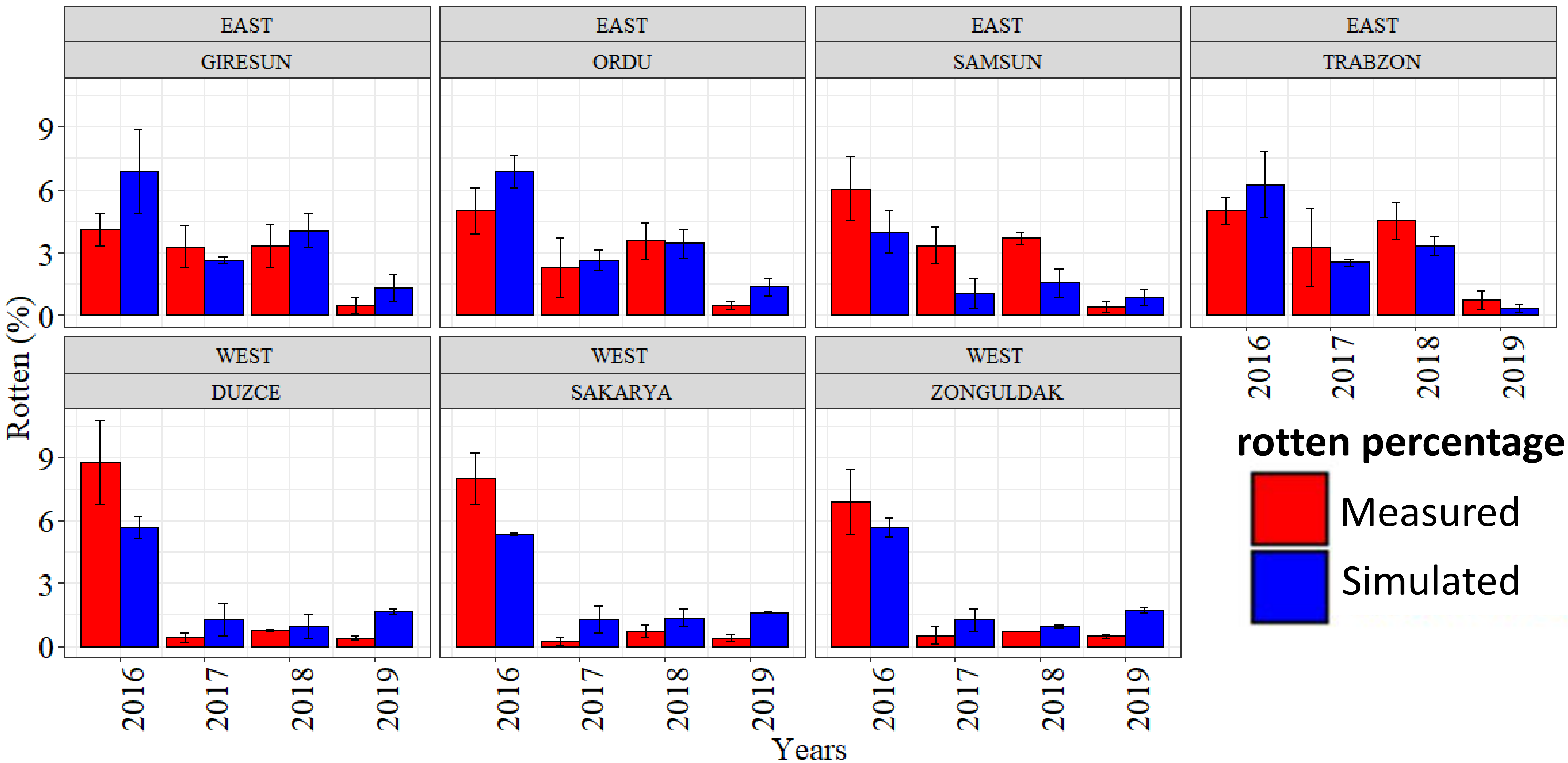
Diaporthe spp (dominant)

Model worklow



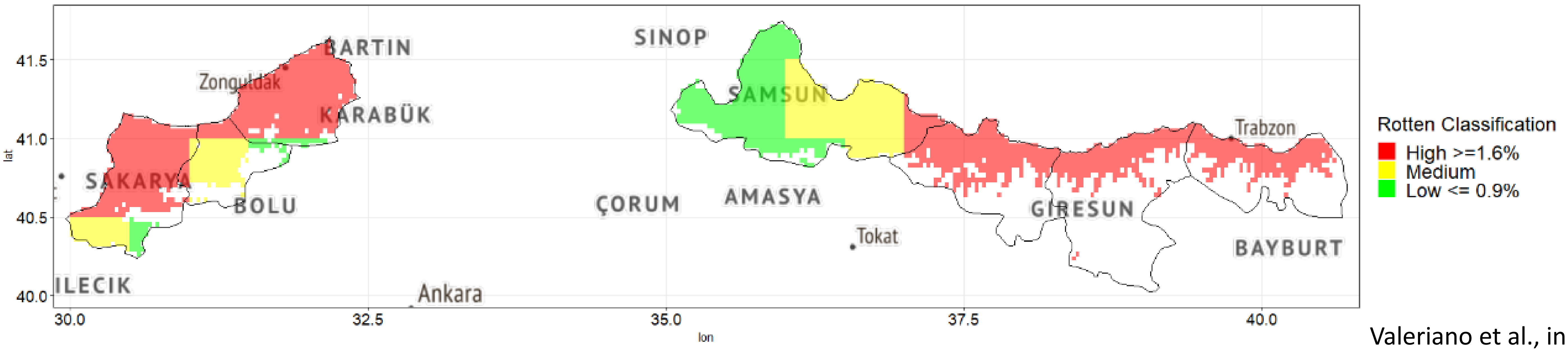
Use cases: rotten hazelnuts

- Four years of data (2016-2019) with around 100 sampling points per year on the main Turkish hazelnut producing areas (smartapp under development).
- Automatic calibration on 22 locations moving parameters within literature ranges.
- Model evaluation with independent subsets of observations.



Use cases: rotten hazelnuts

- Monthly bulletins since February 2020 using past weather data as "possible futures".
- Model executed on NASA Power grids and on *in-situ* weather stations.
- Post-processing of model outputs with machine learning algorithms.
- Clear overestimation of field data in 2020 → problems to solve, back to model formalization.
- Sensitivity analysis under development to inspect model behaviour

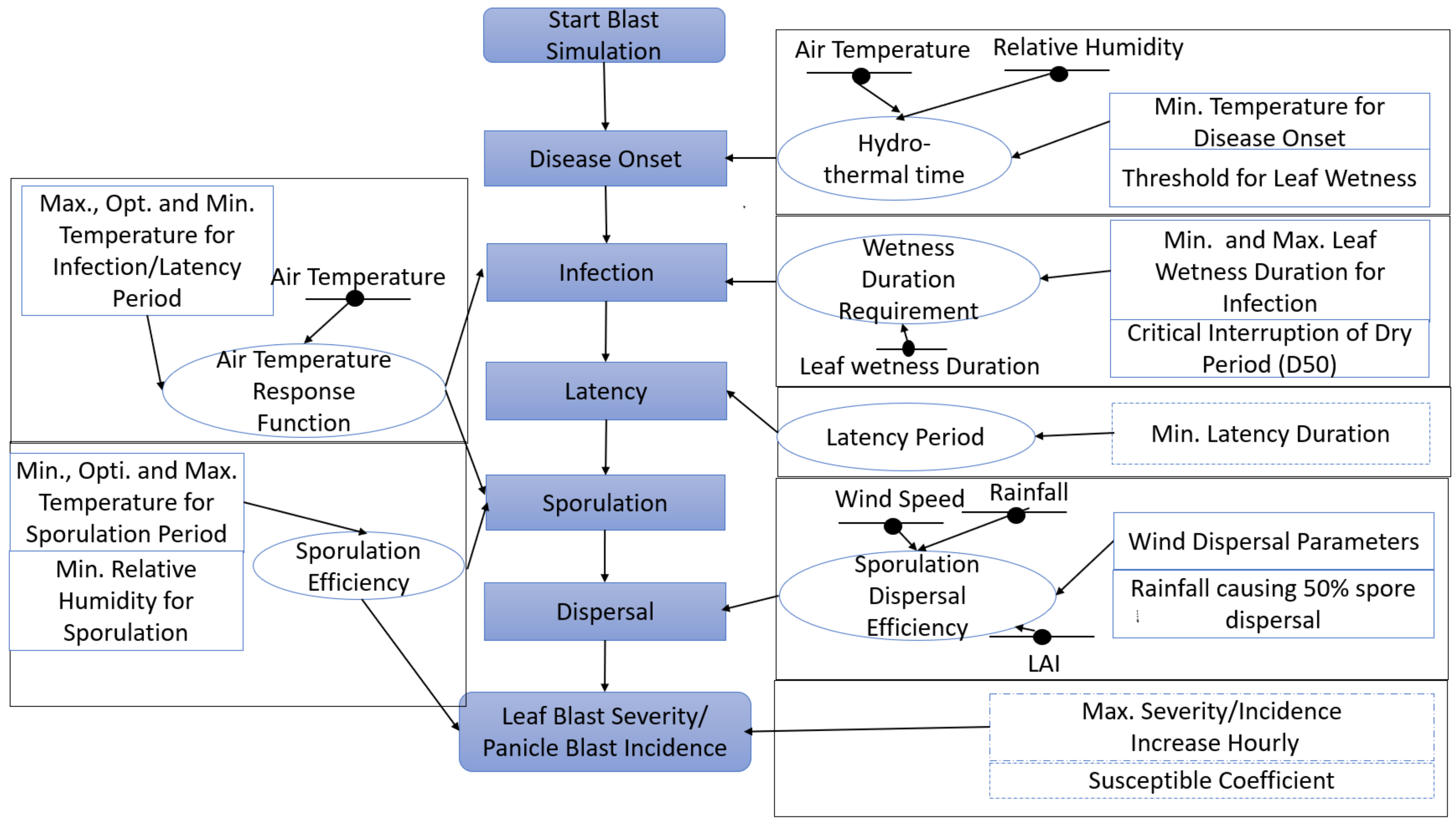


Valeriano et al., in preparation

Use cases: rice blast in Italy

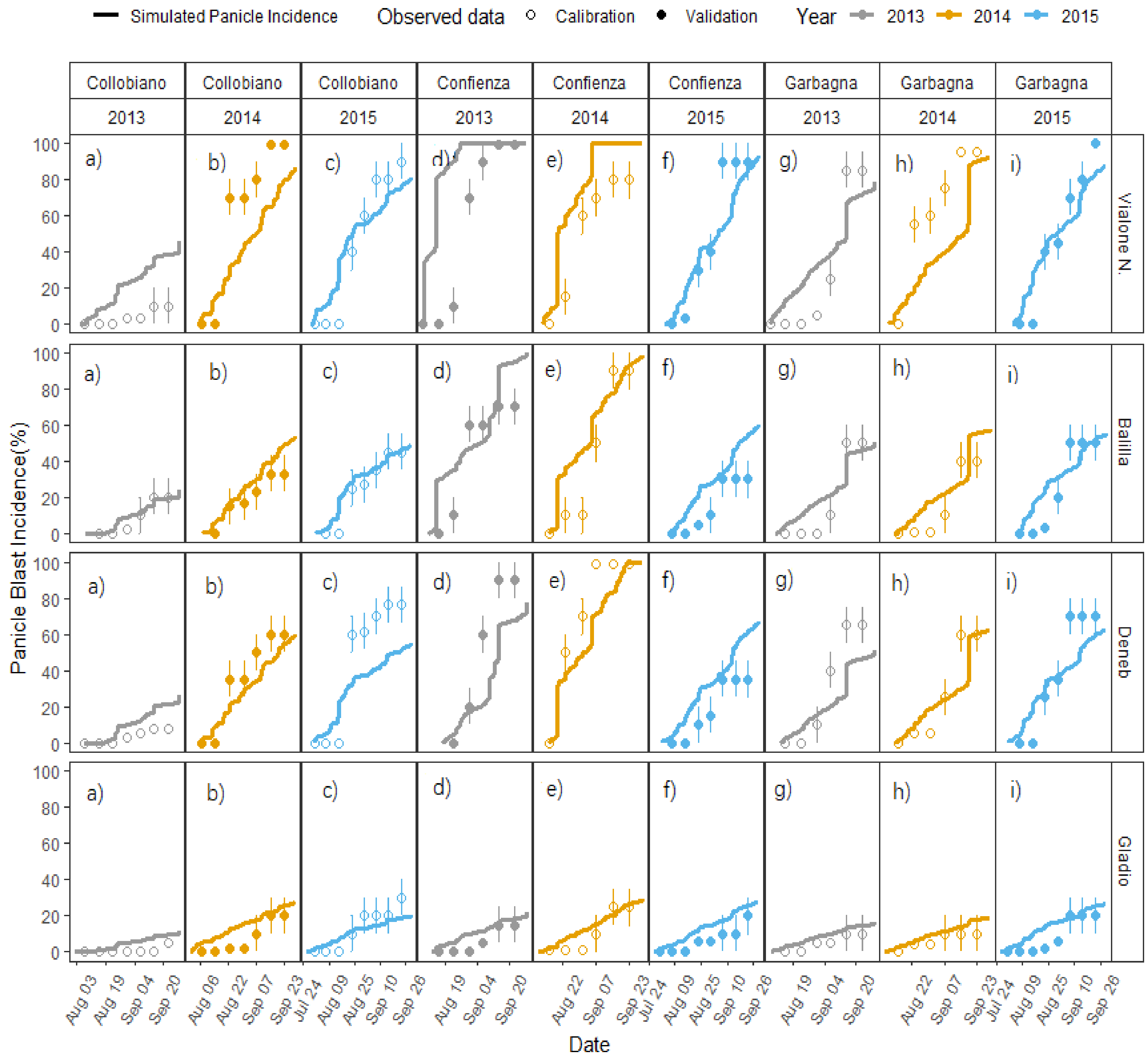
- Italian rice production, contributing to more than half of the European production is seriously threatened by blast disease (causal agent *Magnaporthe oryzae*).
- Farmers to annually spray fungicides once or twice on over 75% of the rice area
- The majority of the Italian rice varieties are moderate to highly susceptible to the pathogen.

Leaf and panicle blast symptoms



Use cases: rice blast in Italy

- Field experimental data on four Italian varieties at variable resistance
- Same model parameterized for leaf and panicle blast



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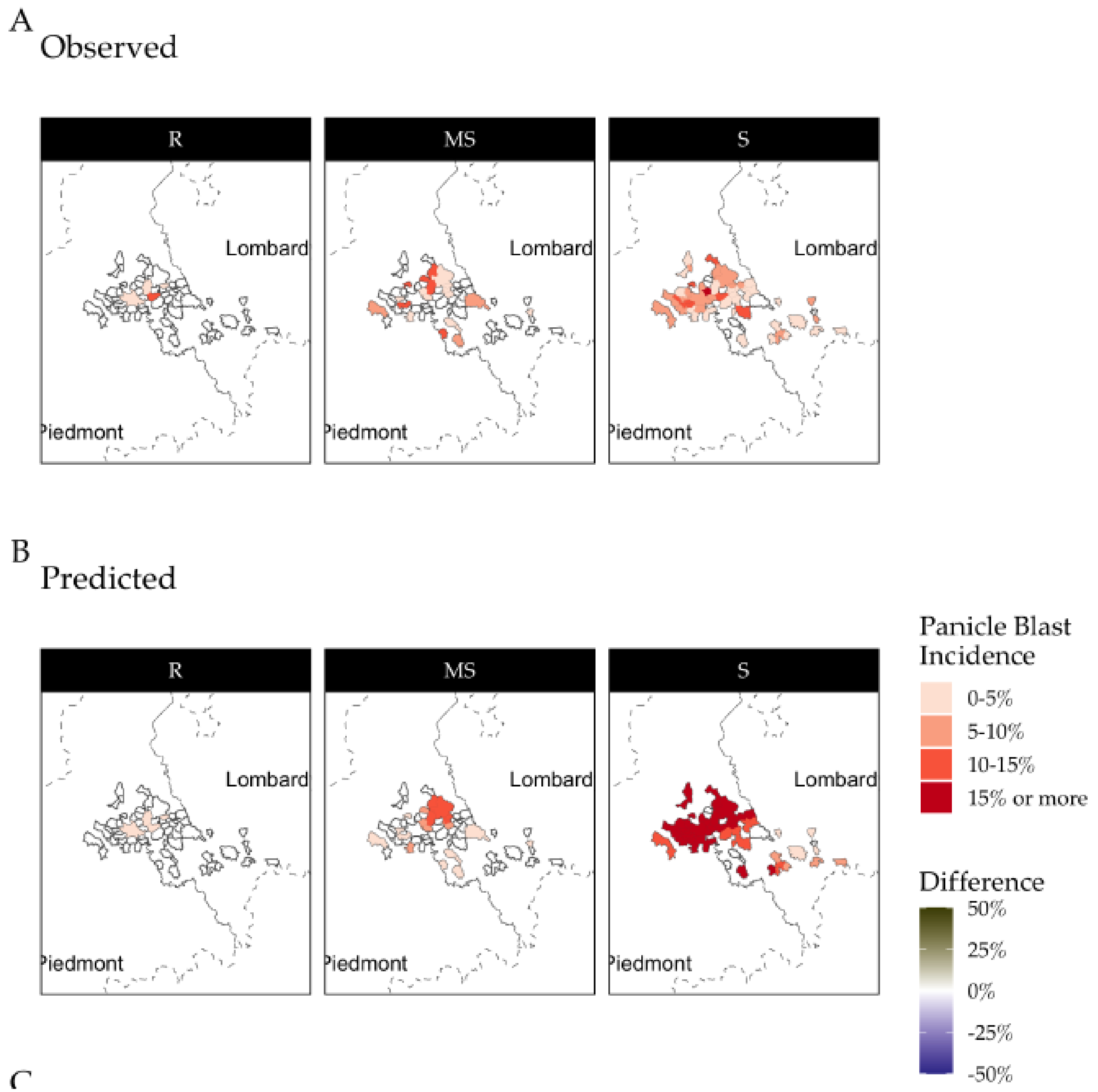

Use cases: rice blast in Italy

- Field experimental data on four Italian varieties at variable resistance
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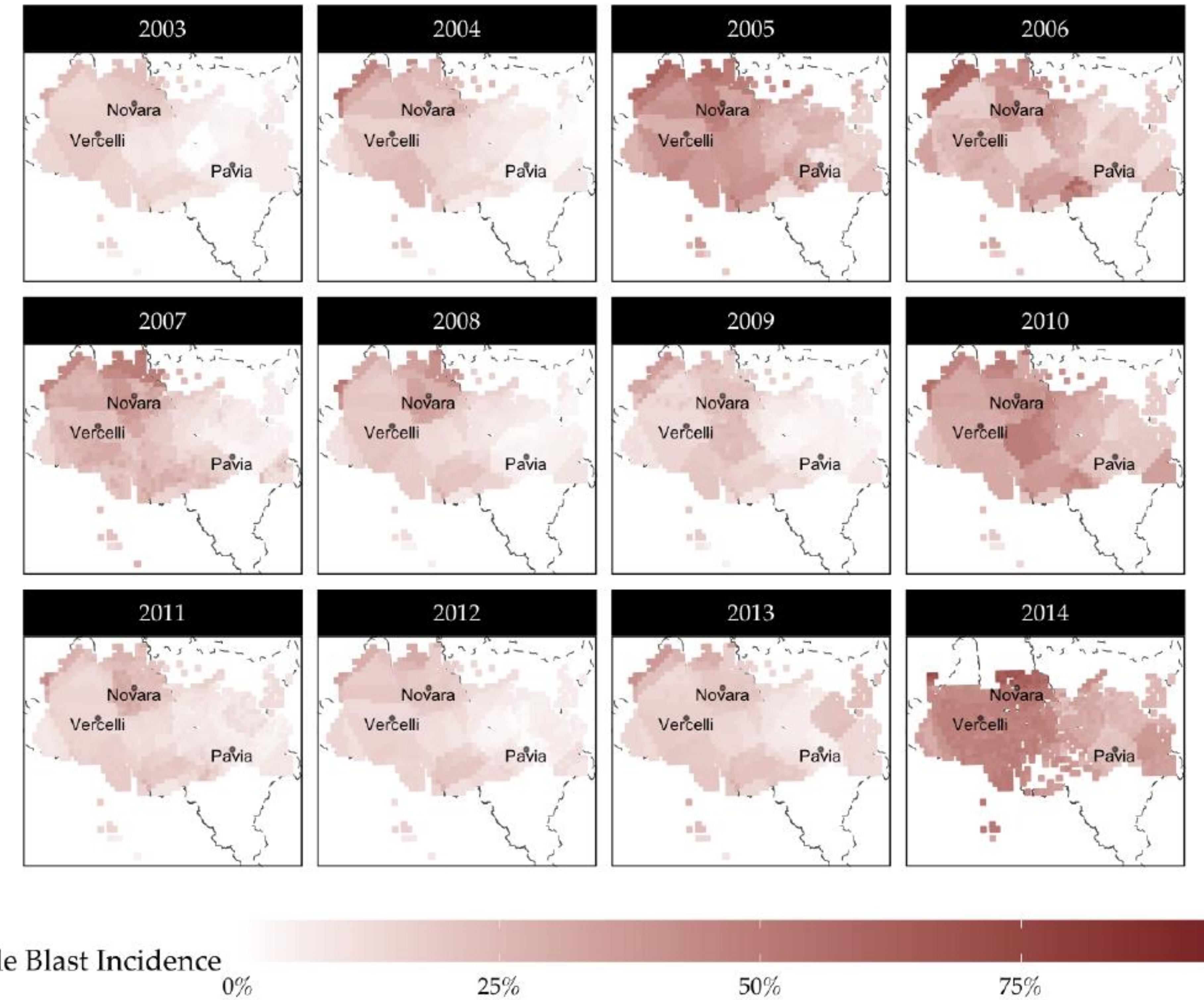
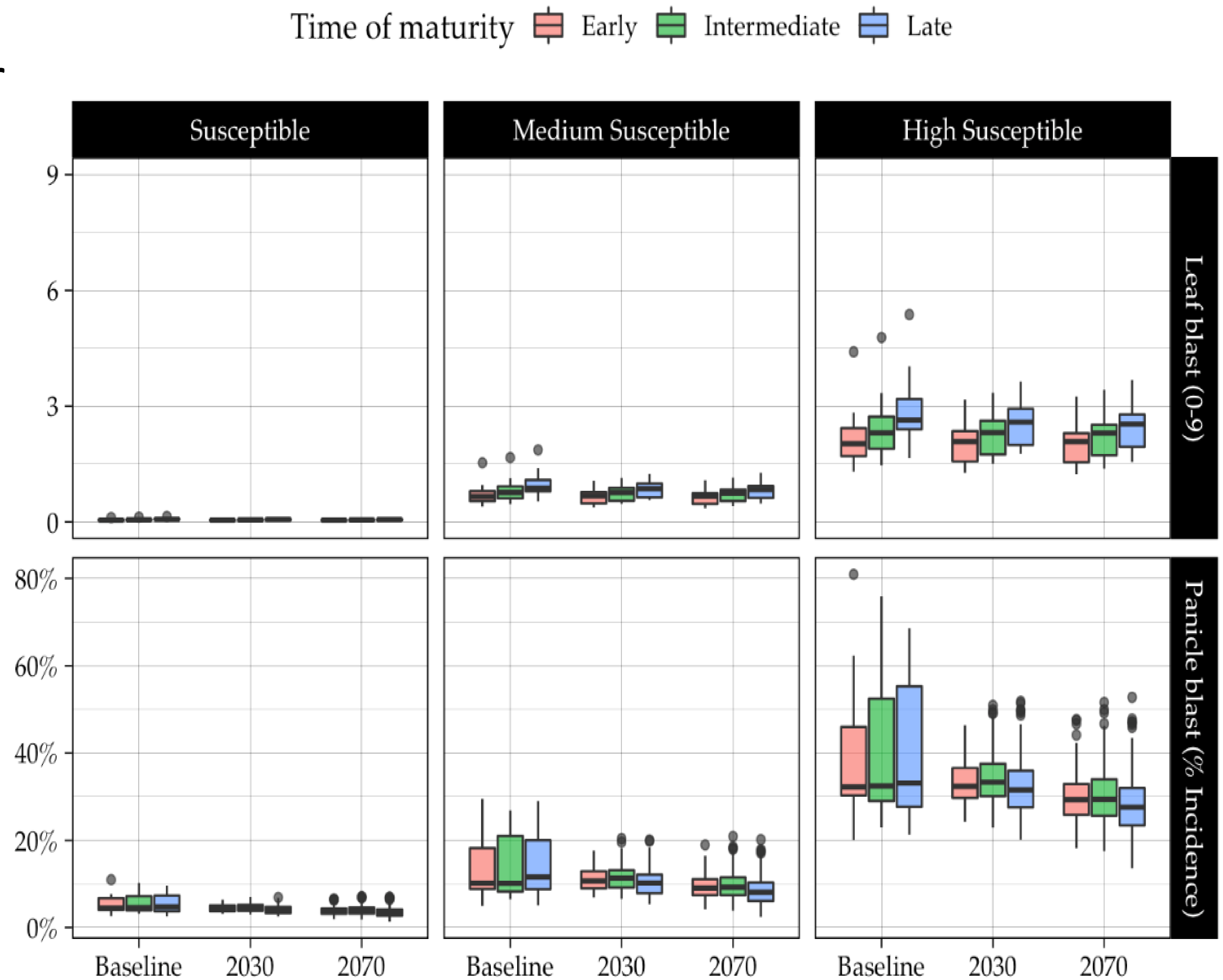
- Further model evaluation with data at municipality level
- Model application in the main Italian rice district



Use cases: rice blast in Italy

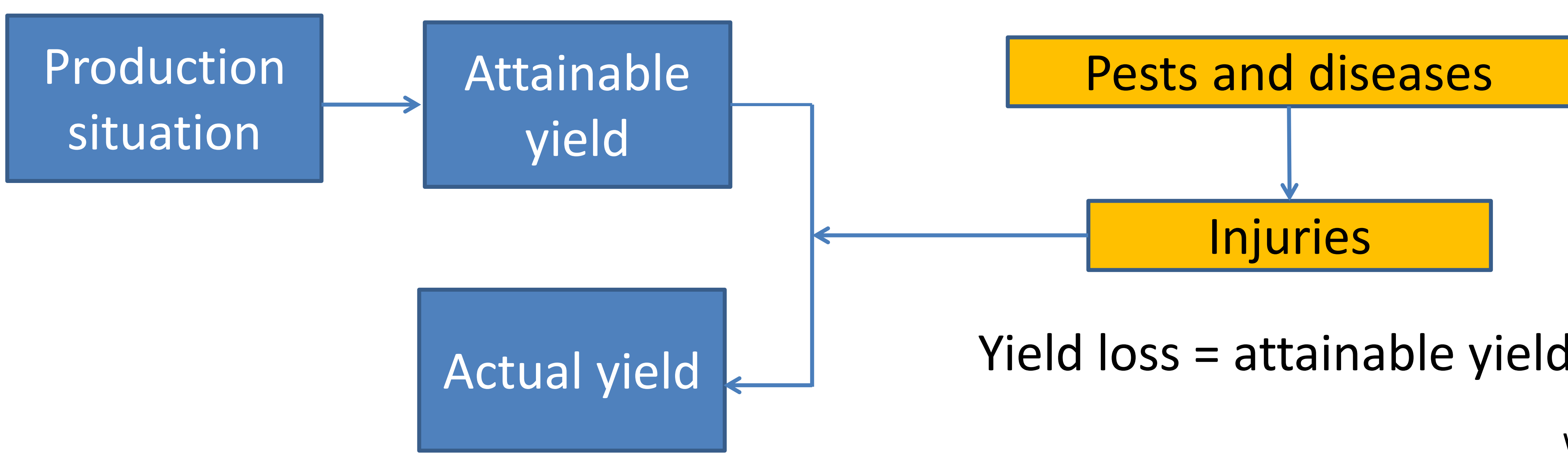
- Field experimental data on four Italian varieties at variable resistance.
- Same model parameterized for leaf and panicle blast.
- Further model evaluation with data at municipality level.
- Model application in the main Italian rice district.
- Simulations under climate change scenarios.



Wu et al., submitted to Agricultural Systems

Incorporating damage mechanisms into crop models

- The **dynamic linkage** between **disease and pest injuries** and the **host crop** is realized through **coupling points** between **pest/disease and crop models**.
- **Seven pest and disease damage mechanisms** were identified (Boote et al., 1983, i.e., light stealer, leaf senescence accelerator, tissue consumer, stand reducer, photosynthetic rate reducer, turgor reducer and assimilate sappers).

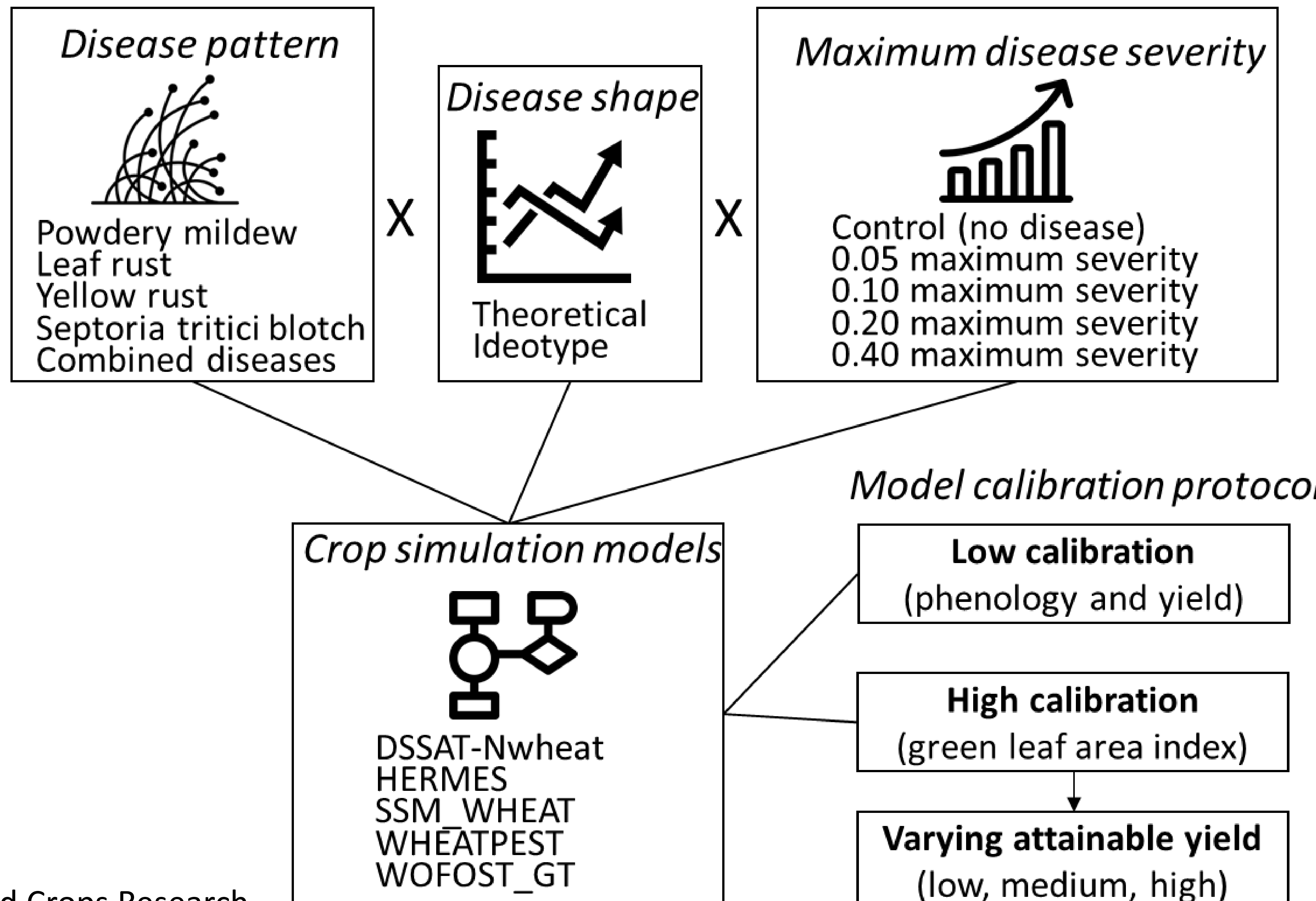


Yield loss = attainable yield – actual yield

Willocquet et al., 1998

Incorporating damage mechanisms into crop models

- The simulation experiment design: WHEATPEST (Willocquet et al., 2008) reference model to incorporate damage mechanisms into several wheat models.
- Simulation protocol to identify the main sources of uncertainty in yield loss modelling.
- Simulations performed at two calibration levels (i.e., with and without leaf area index data).



major revision on Field Crops Research

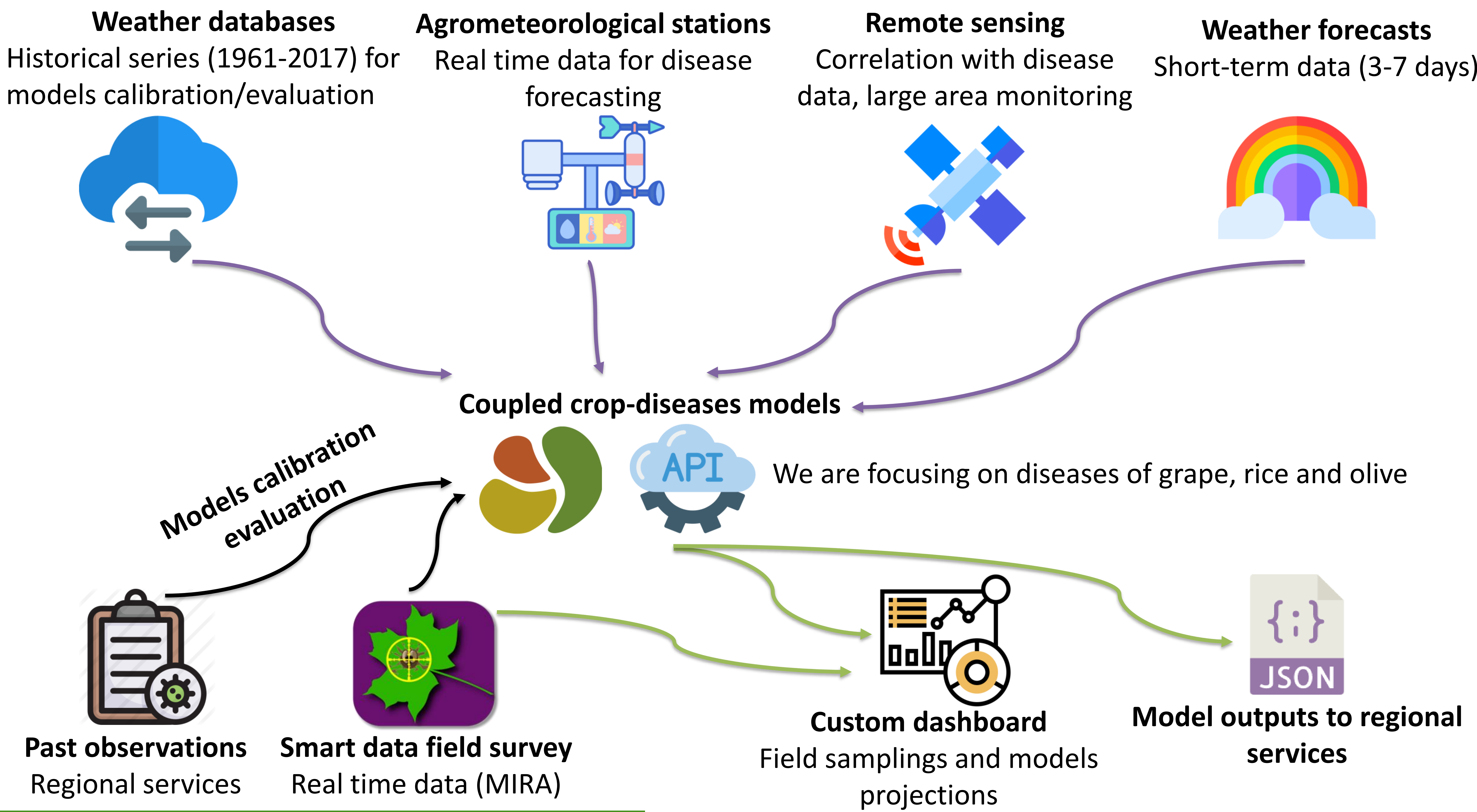
Main outcomes

- 3-way ANOVAs were performed to investigate the effect of the models, diseases, and disease severity levels, separately for each combination of calibration level and injury driver.
- F values are highest for "disease level" factor, which has the highest effect on yield loss, intermediate for “model” and smallest for “disease”. F values are reduced when model calibration is higher.

	High calibration		Low calibration	
	Ideotype injury	Theoretical injury	Ideotype injury	theoretical injury
Model	30^{***}	27^{***}	41^{***}	45^{***}
Disease	4^{***}	2^{ns}	4^{***}	2^{ns}
Disease level	154^{***}	296^{***}	120^{***}	228^{***}

Perspectives

Focus group with 8 Italian regions



A common workflow for the three case studies

Need	Action	Data and skills
Identify the priorities in pests/disease modelling	Stakeholders involvement to characterize urgent needs	Surveys, meetings, literature search, working group, research projects.
Acquire knowledge on the target pathosystem	Literature search on the pathogen biological cycle and on the factors influencing epidemics	Laboratory studies where the components of the pathogens cycle are studied as a function of climate
Formalize the models to simulate the key epidemiological processes	Parameterization (existing models) or development of models for specific processes, and their coupling	Programming skills to implement models, adequate software frameworks, sensitivity analyses to test models behaviour
Calibration and evaluation of models with ground thruth	Test of the models accuracy in reproducing reference data for the target pathosystems	Agro-meteorological data, reference disease data, automatic calibration tools to optimize models performances
Large area model application for monitoring or forecasting	Link with georeferenced databases, execute simulations and extract information	Public/private databases, GIS, IT skills to automatize models execution, data analysis to elaborate model outputs.

THANK YOU FOR YOUR ATTENTION

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