Mathematical models for agroecoloy

INRAE, UR Plantes et Systèmes de Culture Horticoles (PSH)
Politecnico di Milano (DEIB)

From research to solutions for sustainable agriculture

INRAE: Institut National de Recherche pour l'Agriculture, l'alimentation et l'Environnement

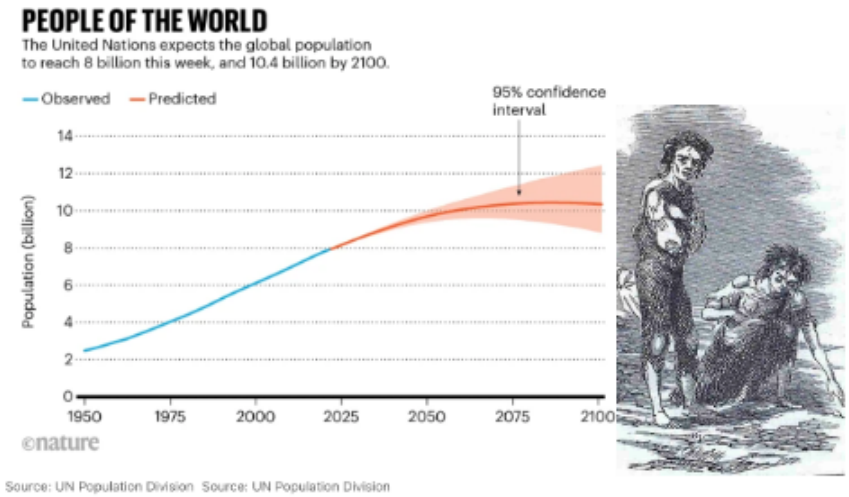
Agricultural land area is $\approx$ **38%** of the **global land surface**. About **1/3** of this is used as **cropland**, while the remaining **2/3** consist of meadows and pastures **for grazing livestock** (FAO statistics, 2020).

Agricultural lands from satellite

Food security and agroecology

The challenges

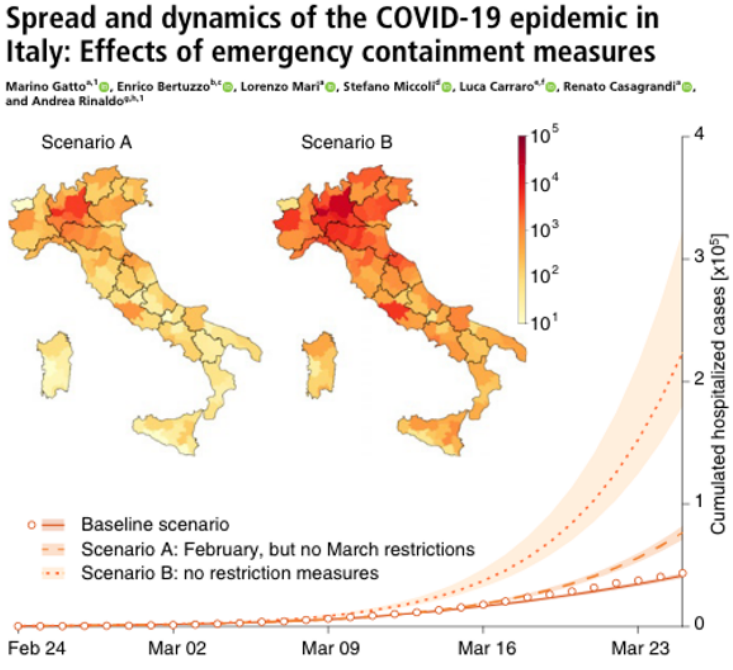
- Increasing demand of food production $\rightarrow$ management of natural resources.
- Reducing use of phytosanitary products $\rightarrow$ parasitism, herbivory
- Climate change $\rightarrow$ Ecological niches



Mathematical models

An invaluable tool

- Hypothesis Testing
- **Prediction Making**
- Mechanistic Understanding
- Designing Experiments
- **Scenario Evaluation**
- Resource Optimization
- **Policy Development**
- Understanding Evolution and Adaptation



Peach leaf curl: control and adaptation to climate change

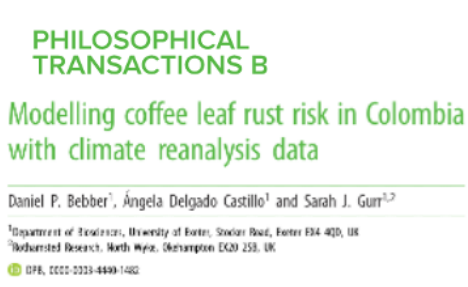
Master thesis 1 - start before September 2025

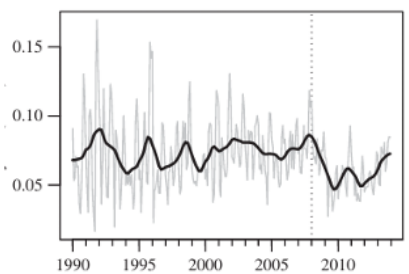
Leaf curl disease - fungus *Taphrina deformans*

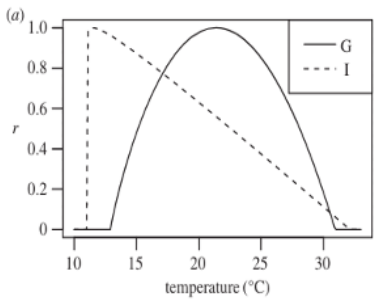
Peach leaf curl: control and adaptation to climate change

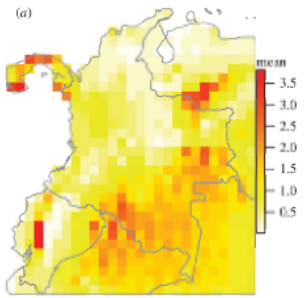
Master thesis 1 - start before September 2025

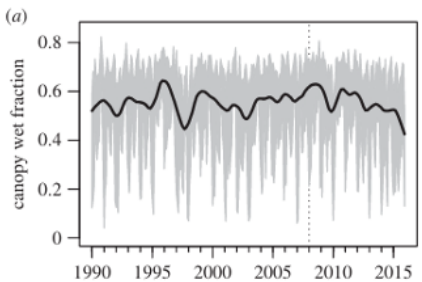
- **Objective**: optimize leaf curl control and predict climate change impact
- **Data available**: time series of disease severity and meteorological variables in different French locations
- **Methods**: Risk model - Niche models - Deep Learning

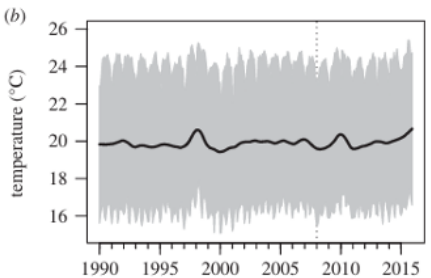


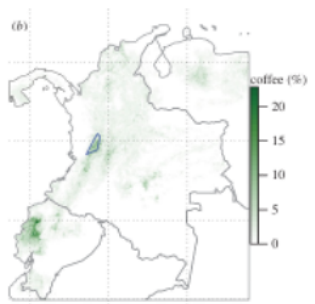


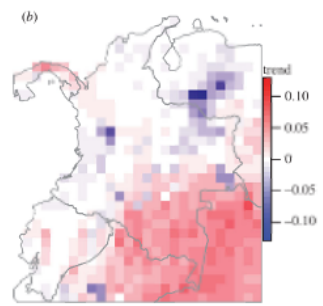












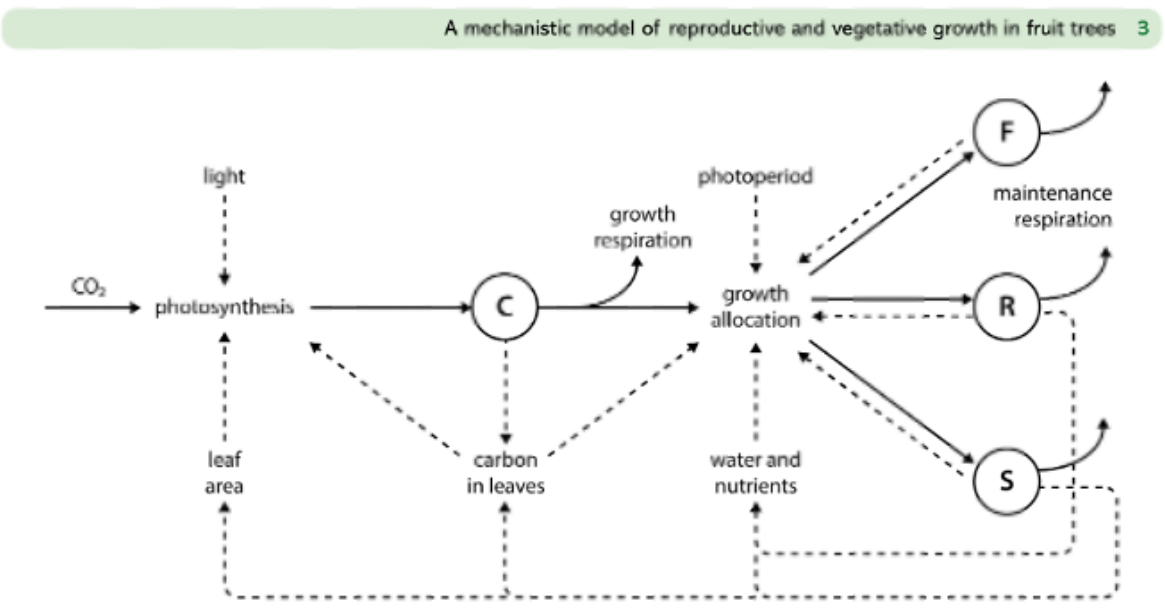
Models for Asparagus cultivar

Master thesis 2 - start before September 2026

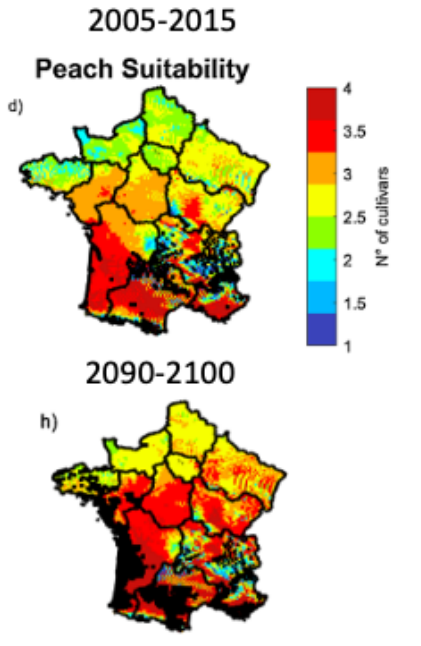
Models for Asparagus cultivar

Master thesis 2 - start before September 2026

- Objective: optimizing management and/or facing climate change and/or controlling pests
- Data available: database from Asperges de France
- Methods: Plant growth models - Niche models - Optimal control theory ,Resource-consumer models



Source: master thesis of Cividini & Mattioli



Source: master thesis of Vanalli

Practial informations

- Visiting period at Avignon INRA (3-6 months)
- Salary ca. 650 euros per month
- Language: English-French-Italian
- Before you: M. Cividini & F.Mattioli (2014), **E. Casagrande** (2017), **C. Vanalli** (2018), P. Salvagno (2019), **A. Coppola** (2022), **D. Stucchi** (2022). **L. Erbetta** (2023)
- contact: daniele.bevacqua@inrae.fr

Palace of the Popes, Avignon

Internship Offer
INRAE, Avignon, France

New modeling frameworks for the asparagus cultivar to optimally control agronomic practices, facing climate changes and controlling pests

Host Laboratory, supervision and conditions

- **Host lab.**: INRAE, Plants and cropping Systems in Horticutlture (PSH), Avignon (France)
- **Host supervisor(s)**: Daniele Bevacqua,
- **Start date, duration and compensation**: between September 2025 and February 2027; 6 months; ca. 650 euro/month

Context

Crop production faces numerous challenges in the near future. The global population is growing, driving increased food demand, while climate change and the pressure to reduce chemical pesticides call for new approaches to agricultural practices. Ecological principles, when applied to agronomy, give rise to agroecology—a rapidly growing field with significant potential for sustainable agricultural solutions. Mathematical models that describe crop growth and ecological interactions can play a key role in addressing these challenges. This Master's thesis aims to develop original modeling approaches to tackle various issues related to the cultivation of asparagus. Asparagus is a perennial plant, and its management must consider the entire lifecycle, taking into account its interactions with climate and pest pressures over time

Objectives and Expected Results

In 2023, INRAE initiated a collaboration with "Asperges de France" and in the fall of 2024 a Ph.D. thesis was launched focusing on asparagus agroecology. This Master's thesis is part of this ongoing collaboration and aims to investigate specific issues related to optimal control of agronomic practices, climate change, and pest pressure.

The key challenges for asparagus producers include: *i*) controlling soil temperature using plastic covers to decide the peak production time and *ii*) determining the optimal time to stop harvest in a given season, to maximize yield over several seasons. These decisions significantly impact plant growth, particularly the development of a canopy that

Figure 1: Asparagus spears growing and Asparagus beetle (*Crioceris asparagi*)

assimilates atmospheric carbon and stores reserves for spear production in the following season. Optimal control theory offers a framework for optimizing these decisions. Recent advances in this area with applications to agroecological issues have been made by colleagues from another INRAE unit (see, e.g., Tankam-Chedjou et al. (2021, 2020)).

Climate change, by altering the phenology and growth of plants, will redefine suitable areas for asparagus cultivation. Studies in our lab have explored these impacts on peach cultivars (see Vanalli et al. (2021)) and we plan to use a similar approach to evaluate the effect of predicted climate change on asparagus.

Another critical issue is the asparagus beetle (*Crioceris asparagi*), a pest responsible for significant losses. Currently, it is managed using broad-spectrum insecticides, which pose environmental risks and face increasing regulatory restrictions. Identifying alternative pest control methods is essential. Modeling plant-pest interactions can guide the development of sustainable control practices. We plan to develop an approach similar to what has been done in a previous master thesis and then published in Bevacqua et al. (2024),

The candidate student will work with supervisors to select a specific area for investigation, focusing on developing new models to address one or more of these challenges

Intern's Main Activities

1. Literature review on crop growth and ecological models
2. Conception and calibration of a process based model
3. Discussion of results, report writing, and presentation of findings to internaitonsl scieintifics and socio-economic partners.

Collaboration Opportunities

The intern will have the opportunity to collaborate with experts from INRAE's units and panel of international colleagues

Required Profile

- Master's degree in final year.
- Required Knowledge: Mathematical modeling and statistics
- Appreciated knowledge: Epidemiology, Management of natural resources, Plant Science
- Skills: Proficiency in programming languages (R, Python or Matlab) and ability to manage datasets.

Contact Information

- **Email**: daniele.bevacqua@inrae.fr, including your CV.

References

Bevacqua, D., A. Coppola, and R. Casagrandi (2024, May). An ecological model to analyze and control the dynamics of the leafminer pest Tuta absoluta on tomato (Solanum lycopersicum). *Entomologia Generalis 44*(2), 451–458.

Tankam-Chedjou, I., F. Grognard, J. J. Tewa, and S. Touzeau (2021, May). Optimal and sustainable management of a soilborne banana pest. *Applied Mathematics and Computation 397*, 125883.

Tankam-Chedjou, I., S. Touzeau, L. Mailleret, J. J. Tewa, and F. Grognard (2020, April). Modelling and control of a banana soilborne pest in a multi-seasonal framework. *Mathematical Biosciences 322*, 108324.

Vanalli, C., R. Casagrandi, M. Gatto, and D. Bevacqua (2021). Shifts in the thermal niche of fruit trees under climate change: The case of peach cultivation in France. *Agricultural and Forest Meteorology 300*(108327).

Internship Offer
INRAE, Avignon, France

Peach leaf curl: control and adaptation to climate change

Host Laboratory, supervision and conditions

- **Host lab.**: INRAE, Plants and cropping Systems in Horticutlture (PSH), Avignon (France)
- **Host supervisor(s)**: Daniele Bevacqua, Bénédicte Quilot-Turion
- **Start date, duration and compensation**: before October 2025; 6 months; ca. 650 euro/month

Context

The future of fruit production depends on producing high-quality fruits with low environmental impact. Peach trees are highly susceptible to pathogens and pests. Current chemical control practices pose environmental and health risks and may promote the development of resistant strains. One significant disease affecting peach trees is leaf curl, caused by the fungus *Taphrina deformans*. Symptoms include leaf thickening and deformation, leading to defoliation (finally impacting fruit yield) and, in severe cases, tree death. Developing predictive models for disease risk under various climatic scenarios, as well as identifying resistant varieties, is crucial for sustainable production (see e.g. Chaloner et al. (2019)).

Objectives and Expected Results

Previous works have led to models estimating leaf curl disease intensity based on climate conditions (Giosuè et al., 2000; Thomidis et al., 2010). This internship will ameliorate existing modeling approaches explicitly considering plant phenology, using new techniques (possibly including deep learning see e.g. Lee and Yun (2023)) and an original dataset providing disease symptoms in different years in different French locations, characterized by different climates.

The new modeling framework will be used, in combination with estimates of climate change in the 21th century, to assess wich area will be suitable peach cultivation in France (see Vanalli et al. (2021)) and which will be the expected impact of leaf curl under expected climates and places of cultivation.

Figure 1: Symptoms caused by *Taphrina deformans* on peach trees.

Intern's Main Activities

1. Literature review on risk diseases models
2. Conception and calibration of a risk model for peach leaf curl
3. Discussion of results, report writing, and presentation of findings to the team and external partners.

Collaboration Opportunities

The intern will have the opportunity to collaborate with experts from INRAE's units and University of Avignon (e.g. Davide Martinetti, Marie Launay, Florent Bonneu) and from a panel of international colleagues (Chiara Vanalli, Nik Cunniffe and Renato Casagrandi respecively from École Polytechnique Fédérale de Lausanne, University of Cambridge, and Politecnico di Milano)

Required Profile

- Master's degree in final year.
- Required Knowledge: Mathematical modeling and statistics
- Appreciated knowledge: Epidemiology, Management of natural resources, Plant Science
- Skills: Proficiency in programming languages (R, Python or Matlab) and ability to manage datasets.

Contact Information

- **Email**: daniele.bevacqua@inrae.fr, including your CV.

References

Chaloner, T. M., H. N. Fones, V. Varma, D. P. Bebber, and S. J. Gurr (2019). A new mechanistic model of weather-dependent Septoria tritici blotch disease risk. *Philosophical Transactions of the Royal Society B: Biological Sciences 374*(1775).

Giosuè, S., G. Spada, V. Rossi, G. Carli, and I. Ponti (2000). Forecasting Infections of the Leaf Curl Disease on Peaches Caused by Taphrina deformans. *European Journal of Plant Pathology* (106), 563–571.

Lee, S. and C. M. Yun (2023). A deep learning model for predicting risks of crop pests and diseases from sequential environmental data. *Plant Methods 19*(1), 145.

Thomidis, T., V. Rossi, and E. Exadaktylou (2010, December). Evaluation of a disease forecast model for peach leaf curl in the Prefecture of Imathia, Greece. *Crop Protection 29*(12), 1460–1465.

Vanalli, C., R. Casagrandi, M. Gatto, and D. Bevacqua (2021). Shifts in the thermal niche of fruit trees under climate change: The case of peach cultivation in France. *Agricultural and Forest Meteorology 300*(108327).