Adaptation and maladaptation of wheat pathogens in managed landscapes. AWHE

Context. The spatial and temporal distribution of crops across landscapes could be key for agricultural climate adaptation and mitigation (Loeuille et al 2013) and a sustainable agroecology (Altieri et al. 2015). Crop disease dynamics depend on this distribution designed by cultural practices (Bargues-Ribéra & Gokhale 2020, Précigout et al. 2023). As part of the EU Green Deal to deliver sustainable agricultural production systems (**APS**) by 2050, pesticide use should be halved by 2030. Changing agricultural practices seems essential to achieve this but will occur within a changing context. Climate change will impact the distribution and abundance of crop pests and pathogens (Chakraborty & Newton 2011, Juroszek & von Tiedemann 2013), posing another challenge to arrive at resilient APS (Rosenzweig & Hillel 2015).
The short generation time of many pests and pathogens allows them to evolve in response to our decisions and potentially escape control (Précigout et al 2017, 2020). To avoid excessive crop loss, eco-evolutionary dynamics of pests and pathogens must be anticipated. Adapation in APS therefore must consist of adaptive management and adaptation policies which control eco-evolutionary dynamics (adaptation) of pests and pathogens (McDonald & Linde 2002, Gilligan 2008, Bousset & Chèvre 2013, Zhan et al 2015, Van Dooren 2022). Integrating all these in predictive models is critical for developing APS strategies (IPCC 2014, Van Bruggen et al 2015).

Objectives
- This PhD project will model the effect of climate change and landscape configuration on crop loss in a crop x pathogen eco-evolutionary model.
- This model will simulate different policy changes and changing agricultural practices next to climate change, producing a socio-ecological model of the agro-ecosystem tailored to the current transition period and providing an in silico environment to evaluate different policies and mitigation strategies.
- Using the complete model, we aim to find adaptive and sustainable policies for landscape organization and crop diversity with the aim to obtain resilient agro-ecosystems. These policies will anticipate and assess evolutionary adaptation by the pathogens and crop loss.

Approach. We will focus on fungal pathogens of wheat. Our approach will extend existing modular models developed by Précigout et al (2020, 2023) with agent-based simulations, adaptive dynamics approximations, branching process modelling of rare genotypes in changing environments, bifurcation analysis and analysis of early warning signals of critical slowing down (Brett el al. 2020).
We will investigate how scenarios with different speeds of climate change will affect the ecological and evolutionary dynamics of the pathogen. This will involve an assessment of adaptational lags in pathogen traits (Van Dooren 2022). We will study the resilience of the agroecosytem during a 20 to 50 year transition period in terms of epidemics and crop production. The pathogen dynamics between years is described by a general discrete-time structured (meta) population model, which is well-studied (e.g., Rueffler et al. 2013, Svardal et al 2015) and where techniques of multi-type branching processes can be used to predict the dynamics of rare pathogen genotypes (Durinx & Metz 2005).
We will use the complete modelling framework to investigate inter alia the trade-off between scenarios where policies aim towards maximization of yield and maximization of robustness against the spread of diseases in different climate change backgrounds.

Innovation and relevance for SU-ITE. This project fits the mission of the Institute very well. It is interdisciplinary by nature. It can serve as a basis for discussing real initiatives and actions with societal stakeholders. We will model the transition period where a sustainable agroecology becomes established. We study the resilience (Dakos & Kefi 2022) of our agroecological system.

Novel in our approach is that we will combine components of previous models (spatial structure, evolution, management, climate change) to arrive at a versatile predictive tool. Novel is that we consider adaptation to climate change in every known sense (1) evolutionary adaptation by gene frequency change (2) the immediate (plastic) adaptive decisions of (rational) agents, (3) adaptation as a policy. The first is a major topic in evolutionary biology, the second a recurring theme in ecology which remains underdeveloped to date (Van Dooren 2022), the third corresponds to conditions set by climate change policies.
The project is challenging. The concept of socioecological systems (SES, Holling, 2001) paves the way to new theory on the dynamics of such coupled systems which are generally recognized to be complex, adaptive systems (Ollson et al 2004). It will develop operational definitions to quantify the resilience and adaptive states of such systems (Folke 2006, Van Dooren 2022).

Time Plan

Year one : Modeling adaptation of the pathogen to environmental change in an existing wheat crop x pathogen eco-evolutionary model and if possible in a new more generic model. Redaction first manuscript.
Year two : Determine statistics which can be used as early warning signals of epidemics (Southall et al. 2012) and determine adaptive and sustainable mitigation strategies. Redaction of second manuscript.
Year three : Predict the consequences of different integral policy scenarios in different climate change contexts. Redaction of third manuscript. Completion and defense of PhD thesis.

Roles of the supervisors. Tom Van Dooren (TVD) and Corinne Robert (CR) will jointly recruit the most suited candidate. TVD will train the student in eco-evolutionary dynamics and CR in crop-pathogen modelling. Both supervisors will assist the student with model development and its implementation in simulations, benefiting from the presence of Pierre-Antoine Précigout in the team of CR and of Vasilis Dakos (CEFE) as a collaborator. TVD will take care of administrative tasks concerning the project, will guarantee the completion of the thesis in due time and will provide a comfortable working environment. He will assure funding for participation in activities of the ED227 and GDR Plasphen and for participation in scientific meetings. The candidate can benefit from research collaborations in the ongoing TRAVERSéES (2010-) project (PI CR) which aims to identify pathways for socio-agricultural systems to arrive at reduced pesticide use. Computer and computing facilities will be provided.

Profile of the candidate

The candidate has a keen interest in the environmental transition and is interested in agroecology and evolution. They has a proven experience in modeling and computing and can work both independently and in a team. They has familiarity with writing in English.

Publications of the supervisors related to the project

Lassalle L (2020) Diversity within: Consequences of individual phenotypic variability on ecological and evolutionary dynamics. PhD Thesis University of Amsterdam, Chapters four and five.
Le Gal A, Robert C et al (2020) Modelling the interactions between landscape structure and spatio-temporal dynamics of pest natural enemies: Implications for conservation biological control. Ecological Modelling 420: 108912.
Précigout PA, Claessen D, Robert C (2017) Crop fertilization impacts epidemics and optimal latent period of biotrophic fungal pathogens. Phytopathology 107: 1256-1267.
Précigout PA, Robert C, Claessen D (2020) Adaptation of biotrophic leaf pathogens to fertilization-mediated changes in plant traits: A comparison of the optimization principle to invasion fitness. Phytopathology.
Précigout PA, Renard D, Sanner J et al (2023) Crop mixtures outperform rotations and landscape mosaics in regulation of two fungal wheat pathogens: a simulation study. Landsc Ecol 38: 77–97.
Rueffler C, Metz JAJ, Van Dooren TJM (2013) What life cycle graphs can tell about the evolution of life histories. J. Math. Biol. 66: 225-279.
Van Dooren TJM (2022) Adaptational lags during periods of environmental change. bioRxiv, 742916v2.