Multi scale modeling of infection pressure from *Phytophthora infestans.*

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Summary
Aerial dispersal of inoculum is the primary means of movement for many plant diseases, but as influx of inoculum depends on a complex interplay of population biological, atmospheric and spore survival processes, it is difficult to predict. This research aims at building tools for such prediction. BLIGHTSPACE is a spatio-temporal model (parameterized for potato late blight) that has been developed and utilized to study the progress of epidemics in individual fields and networks of fields. Simulations were recently made and compared to independent data, collected in field trials on the spread of two genotypes of *Phytophthora infestans* in five potato cultivars in the Netherlands. In addition, two different atmospheric dispersion models were developed to provide long-range transport of spores within BLIGHTSPACE. Numerical results compared favorably with experimental data. A further sub-model for the survival of spores during long-range transportation has been added. Integration of these sub-models has produced an aerobiological 'add-on' for decision support systems and a multi-scale epidemic model for investigating various (spatial) strategies for the deployment of host resistance.

Keywords
Phytophthora infestans, spores, dispersal, survival.

Presentations

Introduction
The spread of pathogen inoculum to uninfected hosts is critical to the spatio-temporal development of plant disease epidemics. Improved computer simulation of spore transport in heterogeneous landscapes could lead to an increased understanding of the epidemiology of many aerially transmitted

diseases. An increased understanding could in turn lead to new plant disease management strategies that rely more on information and less on insurance sprays. It is the long term aim of our research to develop and use a multiple scale epidemiological model for potato late blight to investigate (in a spatial context) operational and strategic issues pertaining to disease management. An enhanced understanding of the spatial aspects of epidemic development at the field and regional scales could lead to the identification of new strategies for the regional management of potato late blight.

Simulating potato late blight on plants and in fields

BLIGHTSPACE is a spatially explicit, age-structured, integro-difference equation model that was developed to simulate general (blanket) and focal (developing from a point source) epidemics of *P. infestans*, and to explore the effect of heterogeneous genotype mixtures on the development of disease. The model simulates the life cycle of the pathogen, the growth of the potato host plant, environmentally dependent host-pathogen interactions, fungicide applications and the temporal and spatial development of general and focal late blight epidemics for various scales and patterns of host genotypes and with various different dispersal kernels (within field transport). Thus, the novel contribution of BLIGHTSPACE is its ability to model spatial relationships in the potato late blight pathosystem and it has already been used to investigate the effects of different scales and patterns of host genotypes on the development of focal and general epidemics (Skelsey *et al*., 2004). Observed data for validation of this model came from field trials with five potato cultivars in the Dutch location of Wageningen in 2002 and 2004. Epidemics were initiated using two different isolates. The number of replications was three. These data had not been previously used for estimating model parameters. Predefined performance criteria were met in 80 % of the epidemics, demonstrating that the model is able to translate measured resistance components, weather data and initial conditions into realistic disease progress curves. Two examples of observed and predicted epidemics are given in Fig. 1.

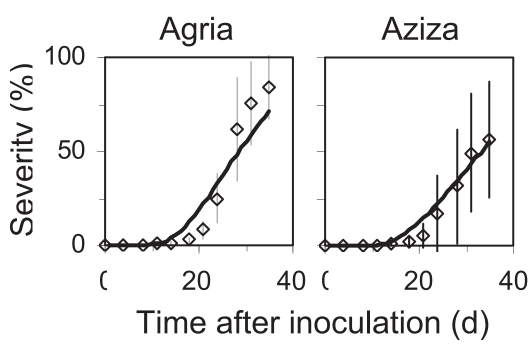

Figure. 1. Observed (diamonds) and predicted (continuous line) disease progress curves of potato late blight epidemics under field conditions in Wageningen (NL) in 2002. The simluated disease progress curves were obtained with the model BLIGHTSPACE. Vertical lines represent the standard deviation of the observed mean blight severity.

Simulating potato late blight in heterogeneous landscapes

BLIGHTSPACE can also be used to generate larger landscapes that contain networks of host fields, where each field undergoes local epidemic and host development as described in the previous section. In such a virtual environment, connection of fields through the dispersal of spores necessitates the use of a long distance spore transport model as the simple, probabilistic dispersal kernels used for within field transport are no longer suitable at the larger, regional scale. Development of such a model requires an amalgamation of knowledge on the life-cycle of the disease, atmospheric physics, and the interaction of the spore with the environment. Before model construction could begin, a very fundamental question had to be addressed – how many spores are a threat to a potato crop? 'Folk wisdom' maintains that a single spore is all that is required for an epidemic to take place and as no dispersal model is accurate to the level of single particles, it became important to find out the range of spore inputs of importance to the pathosystem. BLIGHTSPACE was used to determine the sensitivity of the late blight pathosystem to spore inputs; the yield (t(DM)/ha) response of potato crops to spore inputs was investigated under the influence of variety properties and various fungicide management regimes and with 10 different years of meteorological data as input. Approximately 5,000 epidemics were simulated; the results indicating that contrary to folk wisdom, some resistant scenarios were able to tolerate fairly high levels of spore influx, suggesting that there was scope for simulating long distance dispersal of spores with resistant cultivars but not for some of the highly susceptible varieties which were extremely sensitive to spore input. Fig. 2 shows the yield response for a resistant cultivar under four different fungicide management regimes:

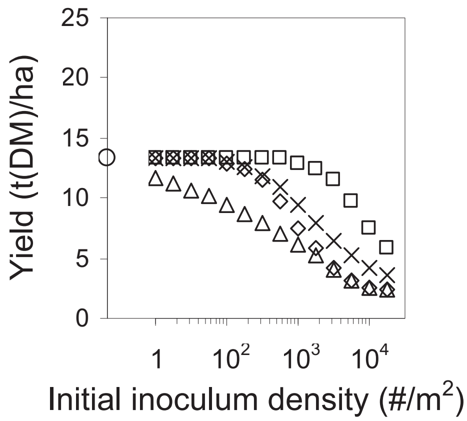

Figure. 2. Relationship between final yield and initial inoculum density in simulated potato late blight epidemics in a late/susceptible cultivar. Four fungicide regimes are compared: □ = adaptive, × = 7 day fixed schedule, ◊= adaptive with the first application missed, and Δ = no applications. ○ = final yield in a crop with no disease. Each data point represents an average over 10 years of meteorological input data.

Two different models for the dispersal of spores from a low-level release were developed. The first was a numerical 'quasi-Gaussian' plume dispersal and deposition model. It offers advantages over other Gaussian plume models for spore dispersal as it offers a more physically realistic representation of vertical diffusion. The second was a fully analytical Gaussian plume dispersal and deposition model which has the advantage of modest computing requirements. Both models were tested by calculating expected spore concentrations and assessing the goodness-of-fit with experimental data, where spore concentrations were measured above a potato crop at up to 100 m from a point source of *Lycopodium clavatum* spores during 10 minute release sessions (Spijkerboer *et al.*, 2002). Fig. 3 shows that numerical results compared very favorably with experimental data for the quasi-Gaussian model, and to a lesser degree for the fully analytical plume model:

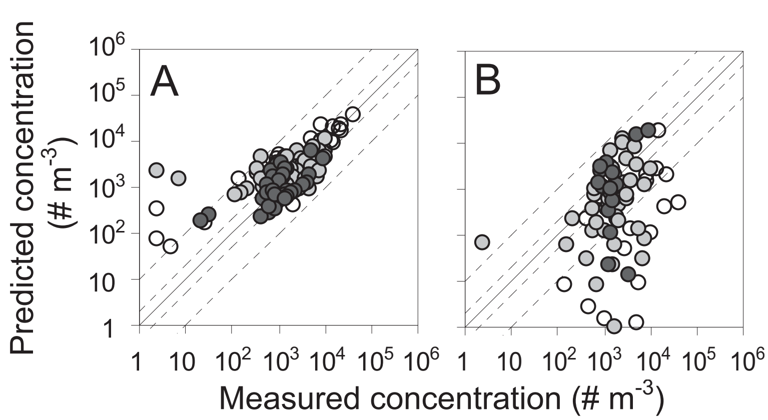

Figure. 3. Predicted versus measured spore concentrations. The outer dashed lines mark the limits of a prediction error of factor 10, the inner dashed lines a prediction error of factor 2, and the solid line is a 1 to 1 line. Data points are color-coded on a grey scale representing increasing distance from the point of spore release. Panel A shows results for the quasi-Gaussian plume model and panel B the analytical Gaussian plume model.

Spore survival

Solar irradiance, temperature and relative humidity are the key weather variables that influence the survival of *P. infestans*. In a recent study, solar irradiance was highlighted as the major factor responsible for reductions in sporangia viability (Mizubuti *et al.*, 1999). The results of this study were used to create a simple model for spore survival during transportation.

Integration

Two different integrated versions of the aforementioned submodels were created. In the first, the numerical quasi-Gaussian plume model is used in conjunction with the spore survival model and various elements of BLIGHTSPACE to produce a simulation model that modifies the spray recommendations of standard decision support systems according to aerobiological aspects of the pathosystem. Field experiments are currently underway to test the efficacy of this model in increasing spray intervals. In the second, more computer intensive version, the analytical dispersion and spore survival models are fully integrated within BLIGHTSPACE to produce a multi-scale epidemic model for potato late blight in heterogeneous landscapes. This model is currently being used to develop new spatiotemporal strategies for the deployment of host resistance at field and landscape scales. This is becoming a particularly important area of research given recent advances in plant breeding.

Conclusions

The minimal modeling approach adopted in the development of these models means that they can be used to generate and test hypotheses about the epidemiology of plant diseases. Translation of new scientific knowledge into practical management strategies for the regional management of potato late blight is currently underway.

References

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