Modeling potential effects of climate change on potato late blight

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Overview

- **Introduction and rationale**
  - Climate change worldwide
  - Collaborative grant with CIP
  - Climate change and potato systems in the Andes
  - Climate change and plant disease
  - Late blight

- **Research objectives**
- **Experimental work**
- **A Late Blight Simulation model**
- **Further Modeling Plans**
- **Conclusions**
Introduction: Predicted climate change

- **Average** expected changes in 21\textsuperscript{st} century
  - Increase in global temperature at least 1.5-2°C
  - Overall *diurnal amplitudes* are expected to decrease
  - Increase in frequency and magnitude of hot weather extremes
  - Occasional cold winter extremes
Introduction: Climate change in the Andes

- Glacier retreat common in Andes, due to increased temp. and El Nino
  - 0.1°C increase per decade since 1939
  - 4-5°C increase predicted
- Reduced cloud cover -> increase in daily temperature range
- Precipitation has slightly increased
  - 0.5-2.5% increase in RH (1950-95)
- Objective: predict the effects of climate change on potato production systems and potato late blight
Introduction: climate change and plant disease

Potential effects of climate change on plant disease epidemics

- Modification of host physiology and resistance
- Shift in geographical distribution of host and pathogen
- Changes in the rate of development and survival
- Increased sporulation and infection
- Evolution of new races of pathogens
## Introduction: microclimate and plant disease

<table>
<thead>
<tr>
<th>Stages in infection cycle</th>
<th>Duration</th>
<th>Temperature</th>
<th>Leaf wetness</th>
<th>Relative humid.</th>
<th>Wind speed, dir.</th>
<th>Solar rad.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spore germination</td>
<td>2-24 hrs</td>
<td>Optim. curve</td>
<td>Duration, positive</td>
<td>Positive</td>
<td>No effect</td>
<td>Negative</td>
</tr>
<tr>
<td>Colonization (latent period)</td>
<td>Several days</td>
<td>Inverse optimum curve</td>
<td>No effect</td>
<td>No effect</td>
<td>No effect</td>
<td>No or indirect effect</td>
</tr>
<tr>
<td>Sporulation</td>
<td>At night, days</td>
<td>Optim. curve</td>
<td>Positive effect</td>
<td>Positive effect</td>
<td>Negative at high wind</td>
<td>Negative</td>
</tr>
<tr>
<td>Spore release</td>
<td>Morning hours</td>
<td>No effect</td>
<td>Negative at drop in RH</td>
<td>Positive</td>
<td>Positive, trigger</td>
<td></td>
</tr>
<tr>
<td>Spore dispersal</td>
<td>Morning days</td>
<td>Negative at high T</td>
<td>Rain positive</td>
<td>Positive survival</td>
<td>Wind, positive</td>
<td>Negative (UV)</td>
</tr>
<tr>
<td>Spore deposition</td>
<td>Seconds</td>
<td>No effect</td>
<td>Rain +/-</td>
<td>Neutral</td>
<td>Wind, pos./neg.</td>
<td>No effect</td>
</tr>
</tbody>
</table>
Introduction: theoretical relations between disease development rate and temperature

- A: constant temp growth curve
- B: simulations with oscillating temps with 0, 5 and 10°C ampl.

Conclusions:
- substantial differences between development at constant and fluctuating temperatures with the same means
- mean temperatures without information about amplitudes may not be sufficient to predict growth or development

Scherm and van Bruggen, 1994
Introduction: Late blight

- Pathogen: *Phytophthora infestans*
- Emergence of new aggressive isolates
- Emergence of fungicide resistant isolates
- Life cycle dependent on weather variables
  - Infection: low temperature and leaf moisture
  - Germination: 10-20°C, leaf wetness
  - Symptom development: 20-22°C
  - Spore production: 12-14°C and high humidity
  - Dispersal: 1-2 m/s wind speed
  - Survival: few hours (temperature, moisture and solar radiation)
Introduction: late blight models

- Current late blight models
  - Forecast model Blitecast, accumulated severity values (Krause, 1975)
  - Simulation model LATEBLIGHT (Bruhn and Fry, 1981) disease severity, daily average weather, fungicide use, host resistance, economic relations

- Current models predicting effects of climate change
  - Based on Blitecast: accumulation of daily heat units
  - Based on LATEBLIGHT: daily average temperature during periods with high relative humidity

- Effects of changing daily amplitudes not possible
- New model with hourly time step needed
Research assumptions and objectives

- **Assumptions**
  - Global climate change associated with changes in diurnal oscillations.
  - Response of pathogen to change in temperature is instantaneous.
  - Current models based on accumulation of heat units do not predict late blight development accurately under climate change.

- **Objectives**
  - Study the effect of oscillating temperatures on late blight epidemic components.
  - Develop a simulation model that takes daily temperature oscillations into account.
Growth Chamber Experiment - Methods

- Effects of temperature oscillation on epidemic components
  - Two clonal lineages of *Phytophthora infestans*
  - Susceptible potato cultivar
  - Drop inoculation (20,000 spores/ml)
  - Pre-incubation: 14 hours
  - Treatments: 7 mean temperatures, constant and oscillating with two daily amplitudes

- Components assessed
  - Incubation and latent periods
  - Number of lesions – infection efficiency
  - Lesion growth rate
  - Sporulation intensity
Effect of constant and oscillating temperatures on latency progression rate, (h⁻¹) of late blight. Curves were obtained by fitting the data to a 4-parameter thermodynamic model.
Effect of constant and oscillating temperatures on the late blight lesion growth rate in cm day\(^{-1}\). Curves were obtained by fitting the data to a 4-parameter thermodynamic model.

Shakya et al., 2015
Effect of constant and oscillating temperatures on number of late blight lesions mm$^{-2}$ zoospore$^{-1}$. Curves were obtained by fitting the data to a 4-parameter thermodynamic model.

Shakya et al., 2015
Effect of constant and oscillating temperatures on the *P. infestans* sporulation intensity as sporangia cm$^{-2}$. Curves were obtained by fitting the data to a 4-parameter thermodynamic model.
Conclusions from growth chamber experiment

- Growth and development of *P. infestans* differed significantly under oscillating temperatures compared to constant temperatures.
- Faster incubation and latency development under oscillating temps at relatively low average temperatures.
- Small oscillation in temperature (±5°C) increased infection efficiency, lesion growth rate and sporulation intensity.
- Lesions continue to grow even at high mean temperature with ±10°C amplitude.
- Need to incorporate temperature oscillations when simulating plant disease development under climate change.

Shakya et al. 2015
BLIGHTSIM model development

- **Model structure and assumptions**
  - BLIGHTSIM is a mechanistic simulation model
  - Total potentially susceptible sites are distributed over healthy, latently infected, infectious and removed sites.
  - A site is $1\text{mm}^2$
  - Max. number of sites per leaflet= 2000
  - Minimum latent period= 57 hours
  - Lesion grows for 3-5 days at decreasing relative rates
  - Infectious period= 24 hours

- **Input variables:** Hourly temperature and relative humidity

- **Programming language:** R
BLIGHTSIM model structure
Methodology: Model description

- Latent sites originate from two sources: infectious sites and day-old latent sites
- Model starts with fixed number of initial latent sites
- f1-f4 are reducing functions for temps (and RH) below and above the optimum, derived from growth chamber experiments
- Relative lesion growth rate was estimated by dividing the area increase by the observed area that day.
Methodology: Model fitting for calibration of growth chamber data

- Disease progress curves (US-23 isolate) for all temperature*amplitude combinations
- Initial number of infectious sites=0
- Variable number of initial latent sites (optimization, taking infection efficiency into account)
- Hourly multiplication factor HMF=0 (one cycle in growth chamber experiment); for field validation HMF=0.15 -0.45
- Model was run for 154 hours; for field validation 6000 hrs
Methodology: adjustment functions

- Temperature functions as obtained from growth chamber data
- Spor.*InfEff vs. temp. and Spor. vs. RH for HMF adjustments

Shakya, unpubl.
Harrison and Lowe, 1989
Results: calibration at constant temperatures in the growth chamber

- Observed ( . . . ) and simulated (___) disease progress in the growth chamber under constant temperatures
Results: calibration at oscillating temperatures in the growth chamber

- Observed (…) and simulated (___) disease progress in the growth chamber under oscillating temperatures (± 5°C)
Methodology: Model fitting for calibration and validation of field data

- Hourly temperature and relative humidity data from Ecuador
- Approx. weekly late blight severity data (Jorge Andrade)
- Initial number of infectious sites=0
- Initial number of latent sites=0.00000001 (50 sites/ha)
- Hourly multiplication factor optimization: 0.15 - 0.45
- Model was run for 1680 hours (10 weeks)
Calibration of field data of potato late blight

- Latola, Ecuador, 1997
- Initialization:
  - $I_{1a} = 10^{-8}$ sites
  - $H = 0.99999999$
- Parameter:
  - HMF = 0.21

Narouei Khandan et al., unpubl.
Validation of field data of potato late blight

- Cataglahua, Ecuador, 1997
- Initialization:
  - $I_{1a} = 10^{-8}$ sites
  - $H = 0.99999999$
- Parameter:
  - $HMF = 0.21$
Further modeling plans

- Comparison of BLIGHTSIM and LATEBLIGHT
- Sensitivity analysis of all parameters in BLIGHTSIM
- Scenario analysis: changes in average daily temperatures versus changes in daily temperature ranges
- Link BLIGHTSIM to a potato growth and yield model
- Predict effects of climate change on yield and economics in Andes
Conclusions

- BLIGHTSIM is a simple model (< 1 page of code in R)
- BLIGHTSIM simulates late blight development accurately in the growth chamber and in the field
- The model provides a good fit to the disease progress data: Plots of predicted versus observed values: $R^2 = 0.77-0.98$ and slope close to 1.
- Additional sensitivity analysis and field validation of BLIGHTSIM are still required.
- Integration of BLIGHTSIM with a potato growth model will help in understanding the effect of climate change in the Andes region where the DTR is expected to increase.
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