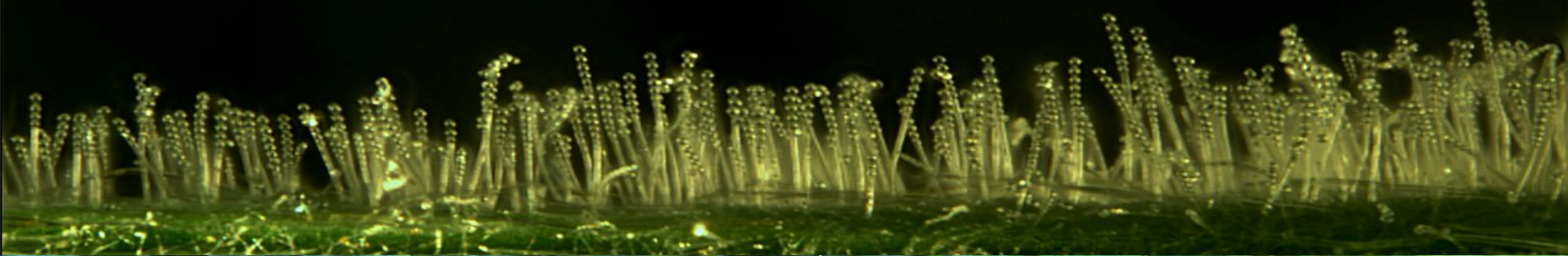
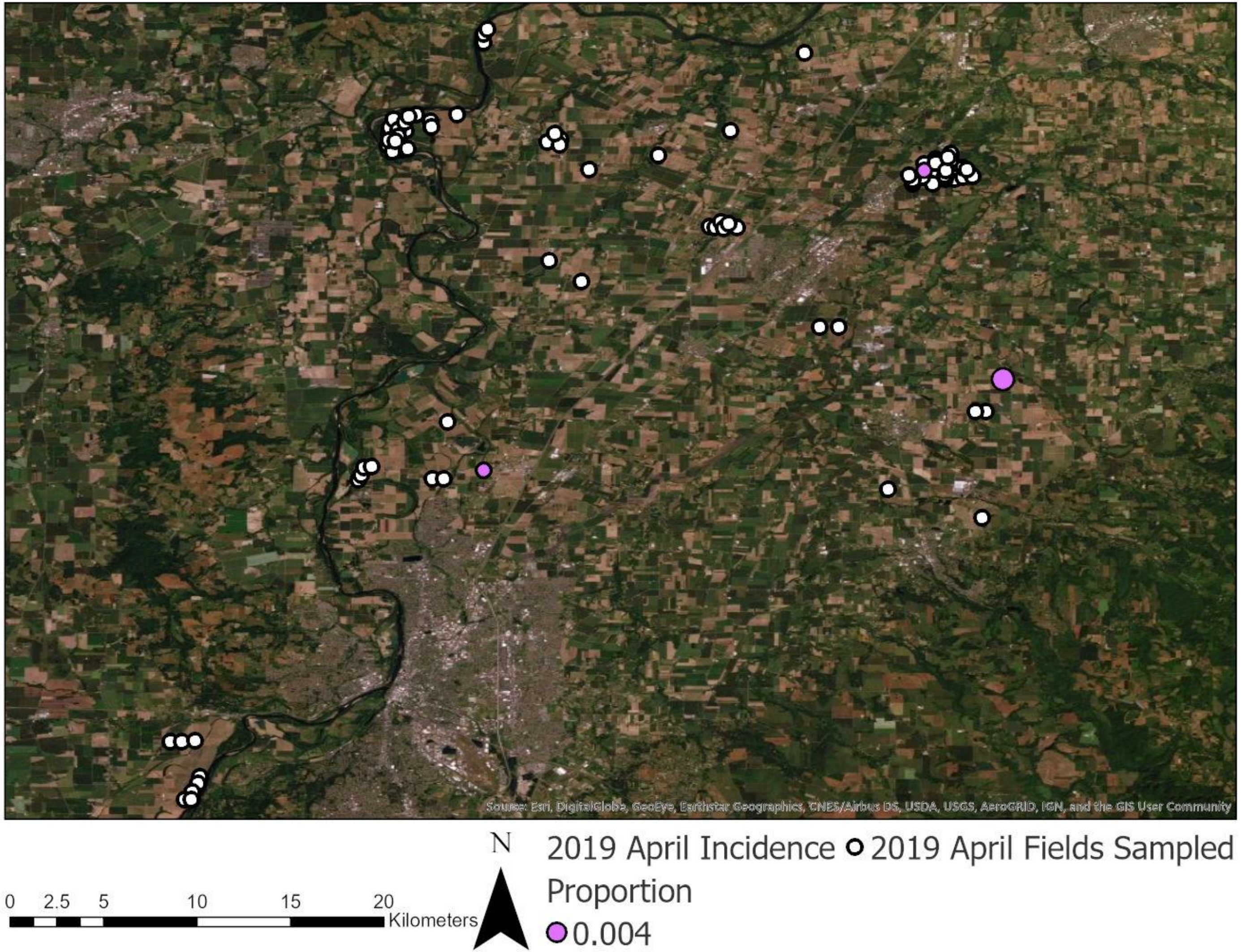
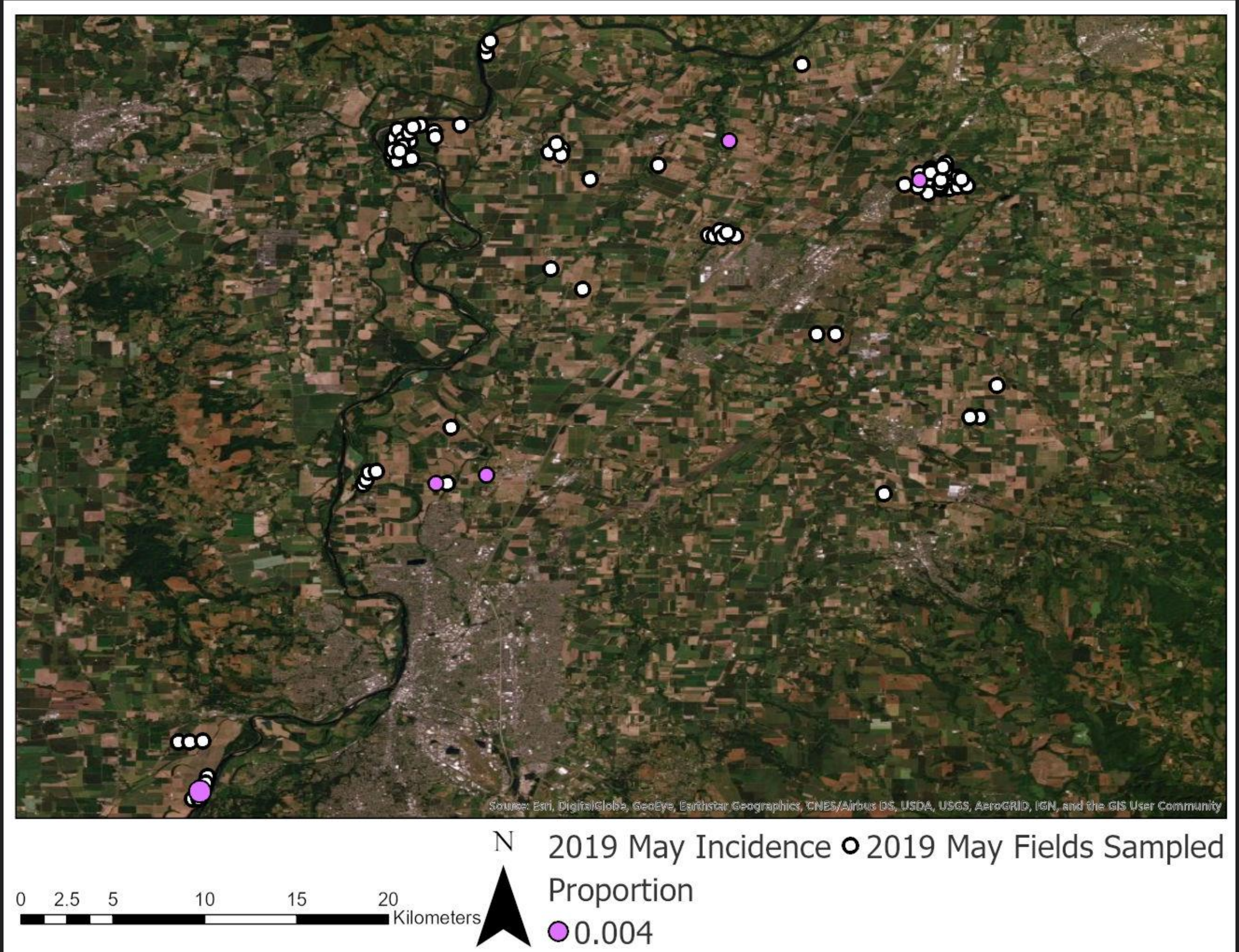
Optimizing Disease Management in Crop Production



Twomey et al. (2015)


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
N
2019 April Incidence Proportion
0.004
2019 April Fields Sampled
0 2.5 5 10 15 20
Kilometers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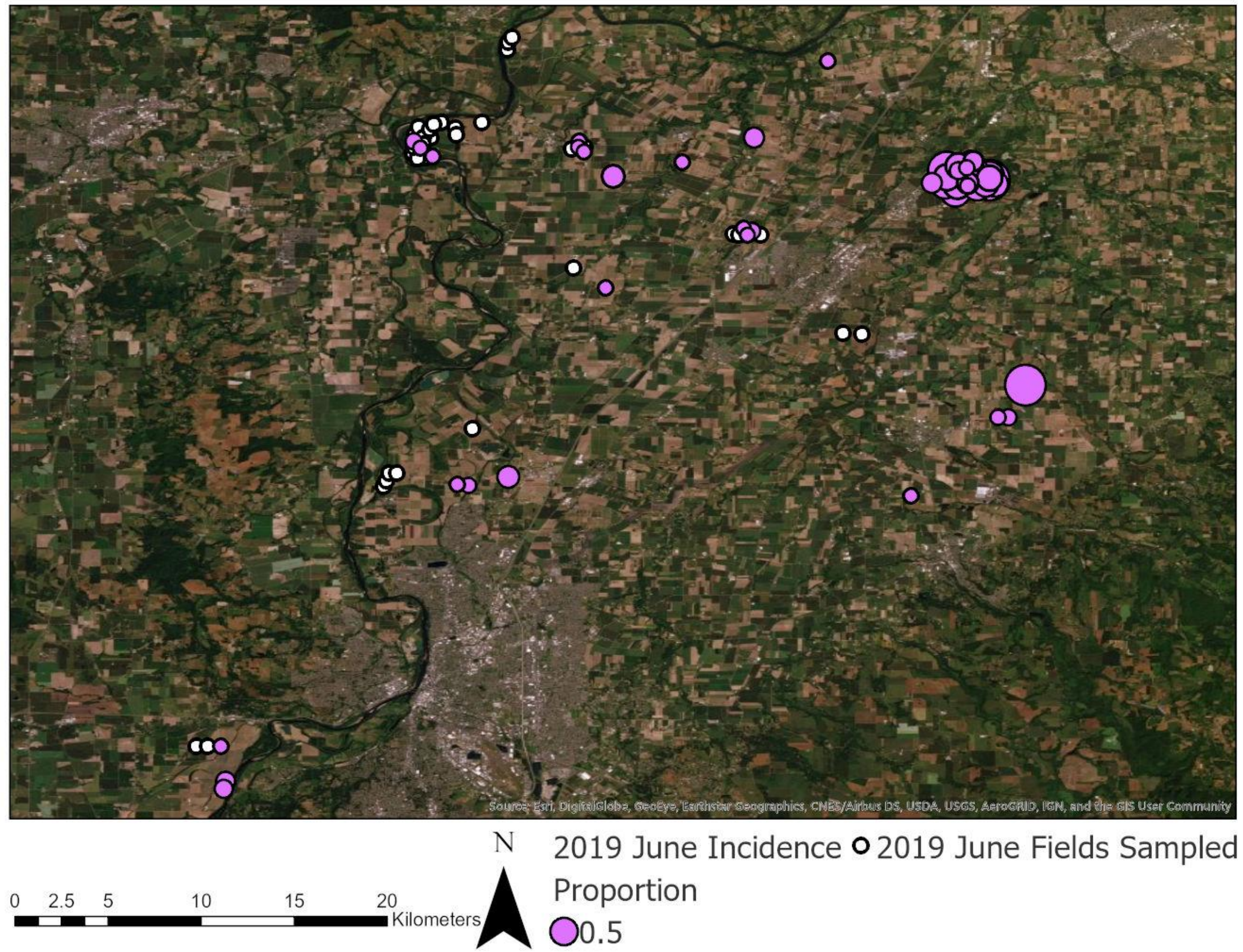
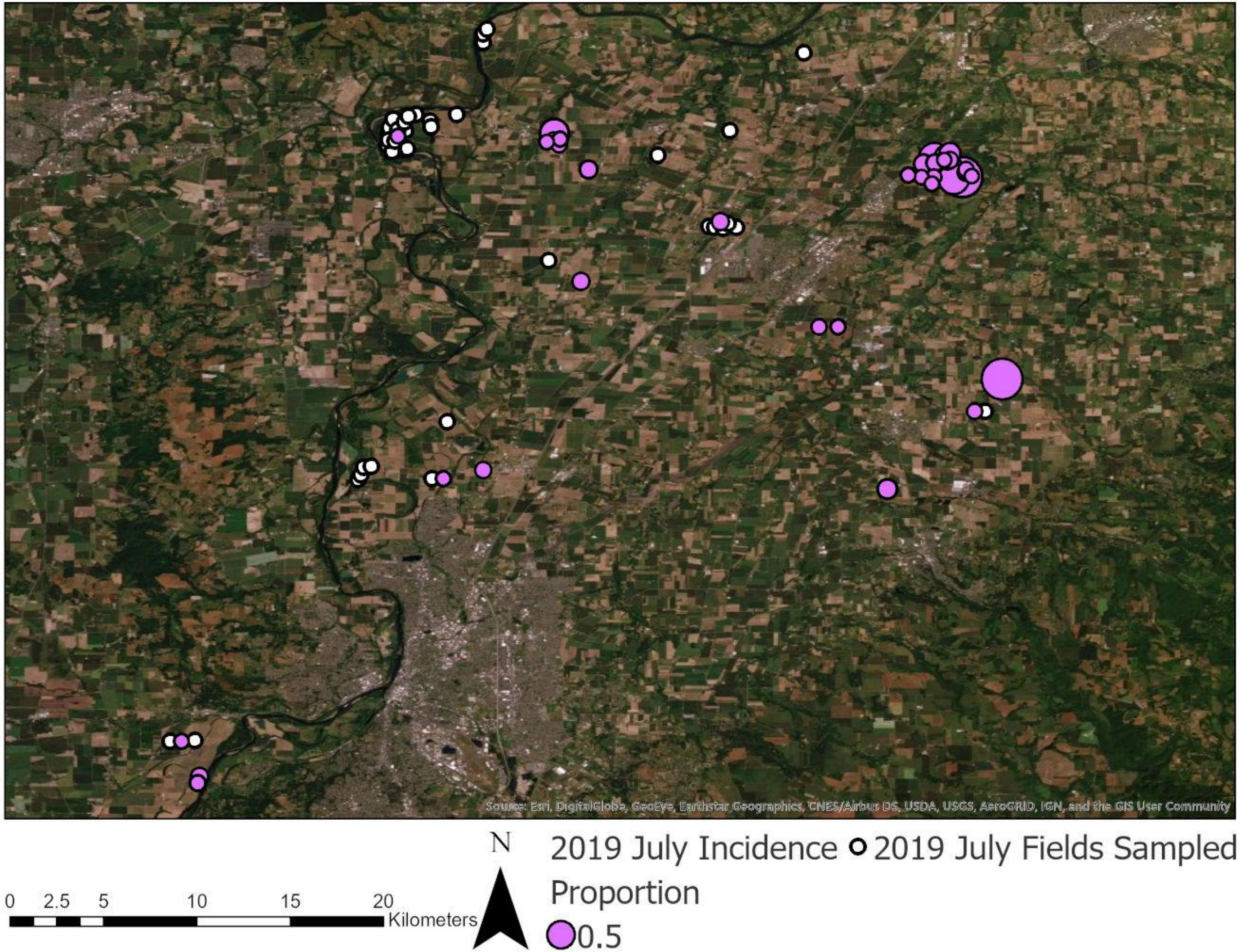
N
0 2.5 5 10 15 20
Kilometers
2019 May Incidence
Proportion
0.004
2019 May Fields Sampled


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
N
0 2.5 5 10 15 20
Kilometers
2019 June Incidence
2019 June Fields Sampled
Proportion
0.5



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
N
0 2.5 5 10 15 20
Kilometers
2019 July Incidence
Proportion
0.5
2019 July Fields Sampled

Modeling Components

Economic control model

Epidemiological network model

Epidemiological network model

- Time transition model that estimates the probability of disease between periods (May-June and June-July).

- Auto-infection:
    - Measures the spread of disease within a yard.

- Dispersal component:
    - Measures the spread of disease between yards.
    - Considers pathogen strain and host plant variety

Epidemiological network model

$$\log\left(\frac{p_i}{1-p_i}\right) = \sum_{k=1}^{K} I_k^{(t)}(i)\left[\beta_k + \delta_k\left(\frac{\tilde{y}_i}{n_{\tilde{y}_i}}\exp\left(-\eta_{1k}s_i\right)\right) + \gamma_k\sum_{j=1}^{M_i}\left(\frac{a_j z_j}{n_{z_j}}\exp\left(-\eta_{2k}s_j\right)w_{ij}\exp\left(-\alpha_k d_{ij}\right)I_k^{(s)}(j)\right)\right]$$

Variable	Description
$\tilde{y}_i$	number of diseased plants at yard i in the prior month
$n_{\tilde{y}_i}$	number of plants sampled at yard i in the prior month
a_i	area (hectares) of yard i
s_i	number of fungicide applications made in yard i in the prior month
z_j	number of diseased plants at yard j in the prior month
n_{z_j}	number of plants sampled at yard j in the prior month
a_j	area (hectares) of yard j
s_j	number of fungicide applications made in yard j in the prior month
d_{ij}	distance (km) from centroids of yard i to yard j
w_{ij}	wind vector on $i-j$ direction in the prior month

Source pathogen strain and target variety susceptibility

$$\log\left(\frac{p_i}{1-p_i}\right) = \sum_{k=1}^{K} I_k^{(t)}(i)\left[\beta_k + \delta_k\left(\frac{\tilde{y}_i}{n_{\tilde{y}_i}}\exp\left(-\eta_{1k}s_i\right)\right) + \gamma_k \sum_{j=1}^{M_i}\left(\frac{a_j z_j}{n_{z_j}}\exp\left(-\eta_{2k}s_j\right)w_{ij}\exp\left(-\alpha_k d_{ij}\right)I_k^{(s)}(j)\right)\right]$$

V6 Mildew	Non-V6 Mildew
R6 Variety DISEASE	Nugget (R6) NO DISEASE
non-R6 Variety DISEASE	non-R6 Variety DISEASE

- V6 pathogen strain can infect plants with R6 and non-R6 variety
- non-V6 pathogen strain can only infect plants with non-R6 variety

Modeling Components

Economic model

Epidemiological model

Economic model

- Profit function which is affected by disease levels.

- Revenue component:
  - Yield loss - affects quantity.
  - Quality loss - affects price.
  - Price affected by market demand scenarios.

- Cost component:
  - Fixed and variable costs.
  - Cost of fungicide sprays.

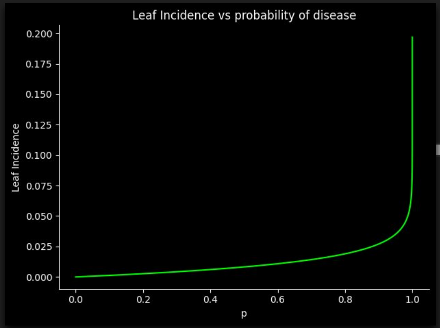
Economic model

$$\pi = \sum_{i=1}^{N} \left(R\left(p_i\right) - C\left(\bar{x}_i\right) - C\left(s_i\right) \right)$$

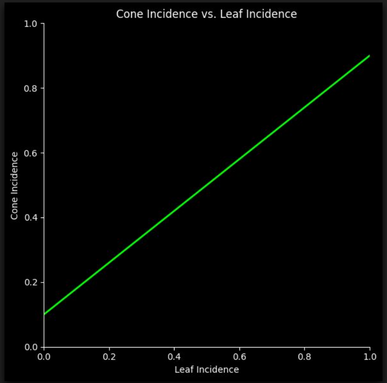
Variable	Description
π	total profit
N	number of yards
$R(p_i)$	revenue of a given yard i adjusted by the damage caused by disease incidence p_i
$C(\overline{x}_i)$	fixed and variable costs of yard i
$C(s_i)$	average cost of fungicide sprays of yard i

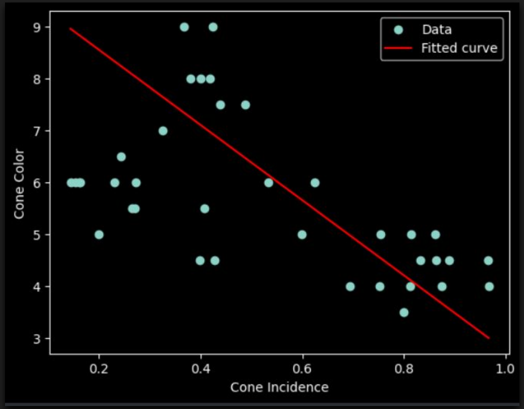
Damage Functions

Plant incidence -> leaf incidence

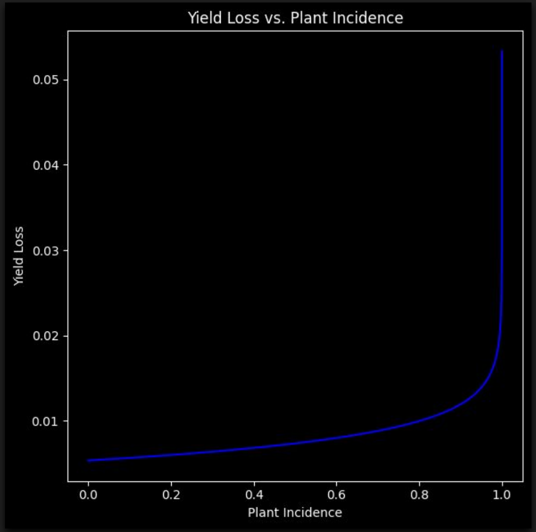


Leaf incidence -> cone incidence



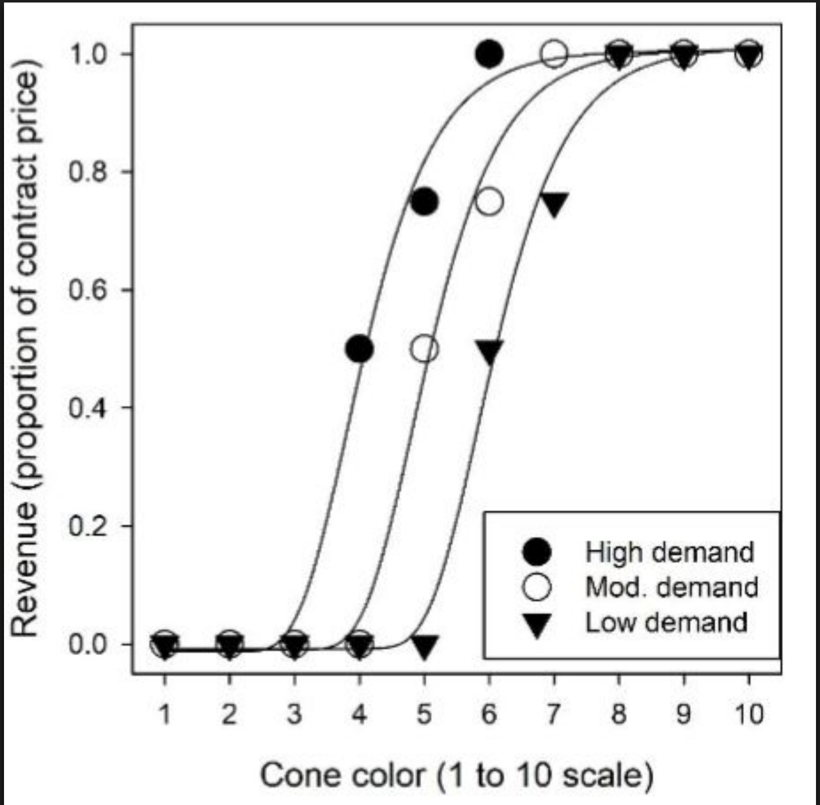


Loss in quality



Loss in yield

Effect of market demand conditions on price



Modeling Components

Economic model

Epidemiological model

Linking the two components

Goal: Find optimal number of fungicide sprays to maximize profit over all yards in the landscape:

$$\max_{s_1,...,s_N} \pi = \max_{s_1,...,s_N} \sum_{i=1}^{N} \left(R(p_i) - C(\bar{x}_i) - C(s_i) \right)$$

which is subject to probability of disease in a given yard:

$$\log\left(\frac{p_i}{1-p_i}\right) = \sum_{k=1}^{K} I_k^{(t)}(i) \left[\beta_k + \delta_k \left(\frac{\tilde{y}_i}{n_{\tilde{y}_i}} \exp(-\eta_{1k} s_i) \right) + \gamma_k \sum_{j=1}^{M_i} \left(\frac{a_j z_j}{n_{z_j}} \exp(-\eta_{2k} s_j) w_{ij} \exp(-\alpha_k d_{ij}) I_k^{(s)}(j) \right) \right]$$

Preliminary results

Example Scenario

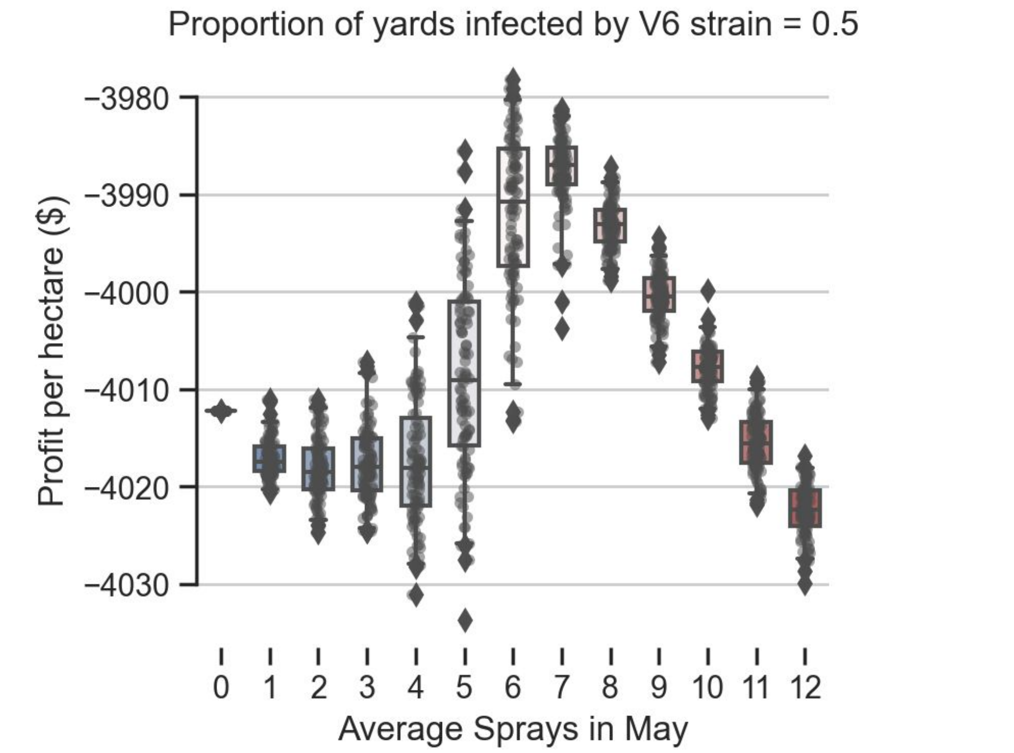


Figure: Profit per hectare in 2014 with initial probability of disease of 0.1. (Based on 100 simulations)

- Set 50% of yards affected by V6 strain
- Probability of initial infections in May fixed at 0.1
- Average sprays in May varied
- Negative profit because disease was high in 2014
- All yards in landscape can be infected in May.