Post-Harvest Diseases of Apples: From Spore Dispersal to Epidemiology

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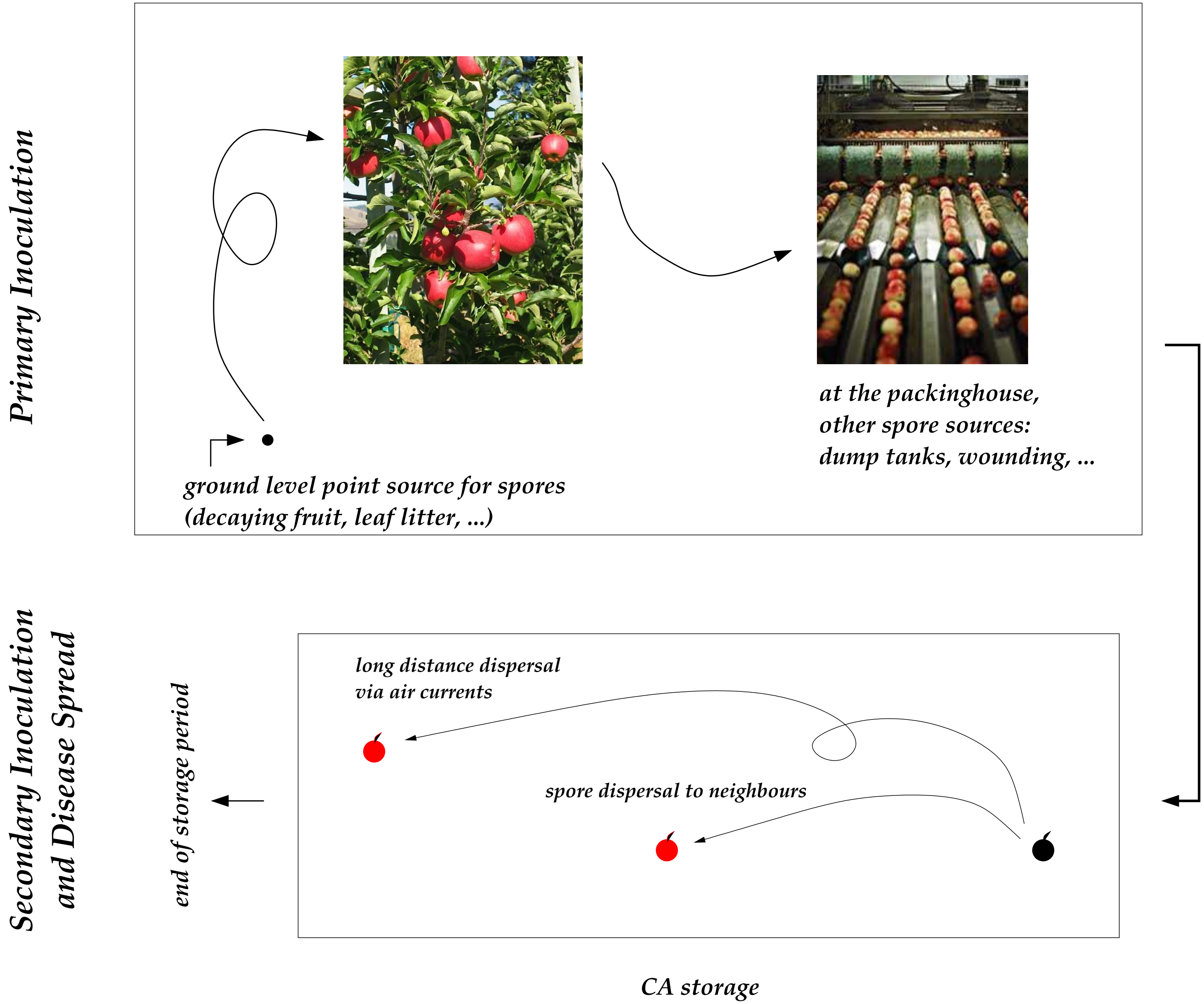
Post-Harvest Diseases

- Fungal infection causes severe decay of apples during storage

Spore Dispersal to Epidemiology



Disease Incidence and Orchard Management

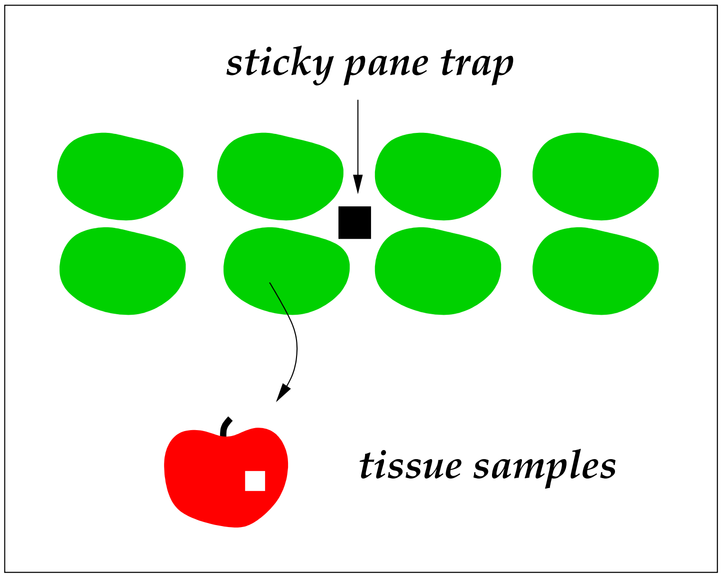
Assumption : There is a direct causal relationship between orchard management practices and disease incidence on stored fruit.

Evidence :

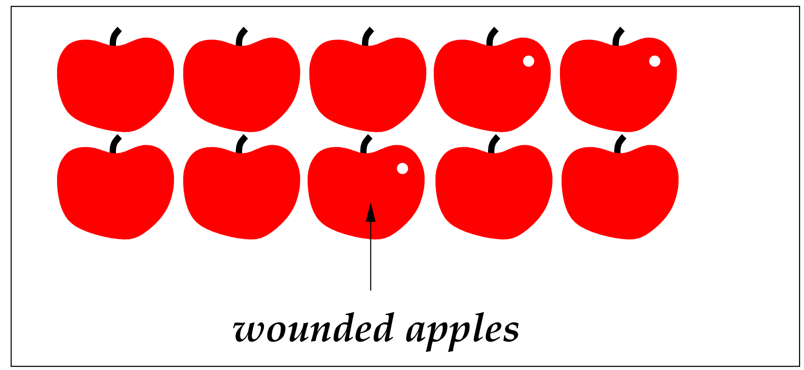
- Spotts et. al. (2009) At-harvest prediction of grey mould risk in pear fruit in long-term cold storage. *Crop Protection* 28(5):414–420.
- Spotts, R.A., Sanderson, P.G., Lennox, C.L., Sugar, D., and Cervantes, L.A. 1998. Wounding, wound healing and staining of mature pear fruit. *Postharvest Biology and Technology* 13:27-36.

Field Study

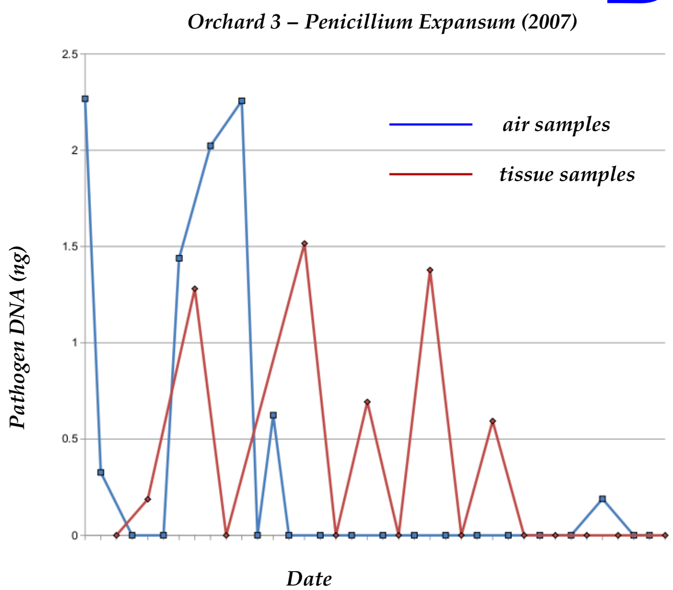
In the Orchard: Spore presence

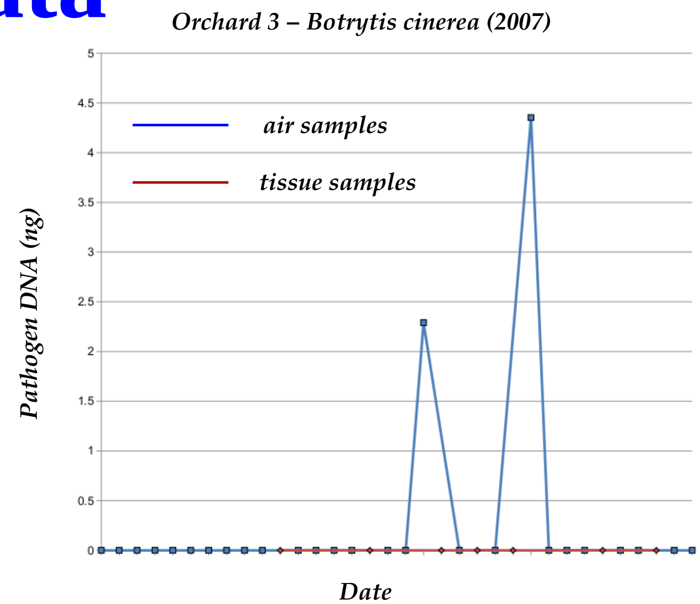


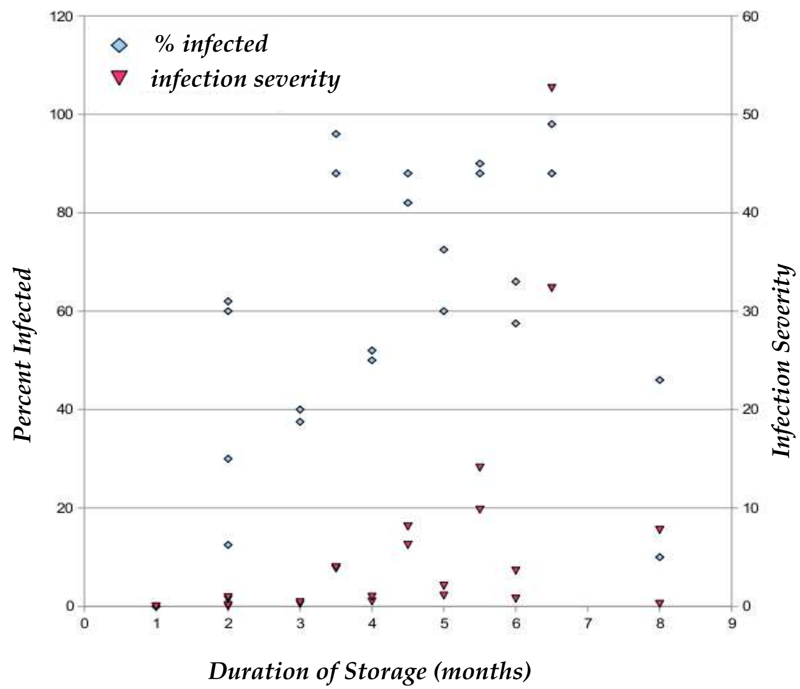
In CA storage: Disease incidence



Data

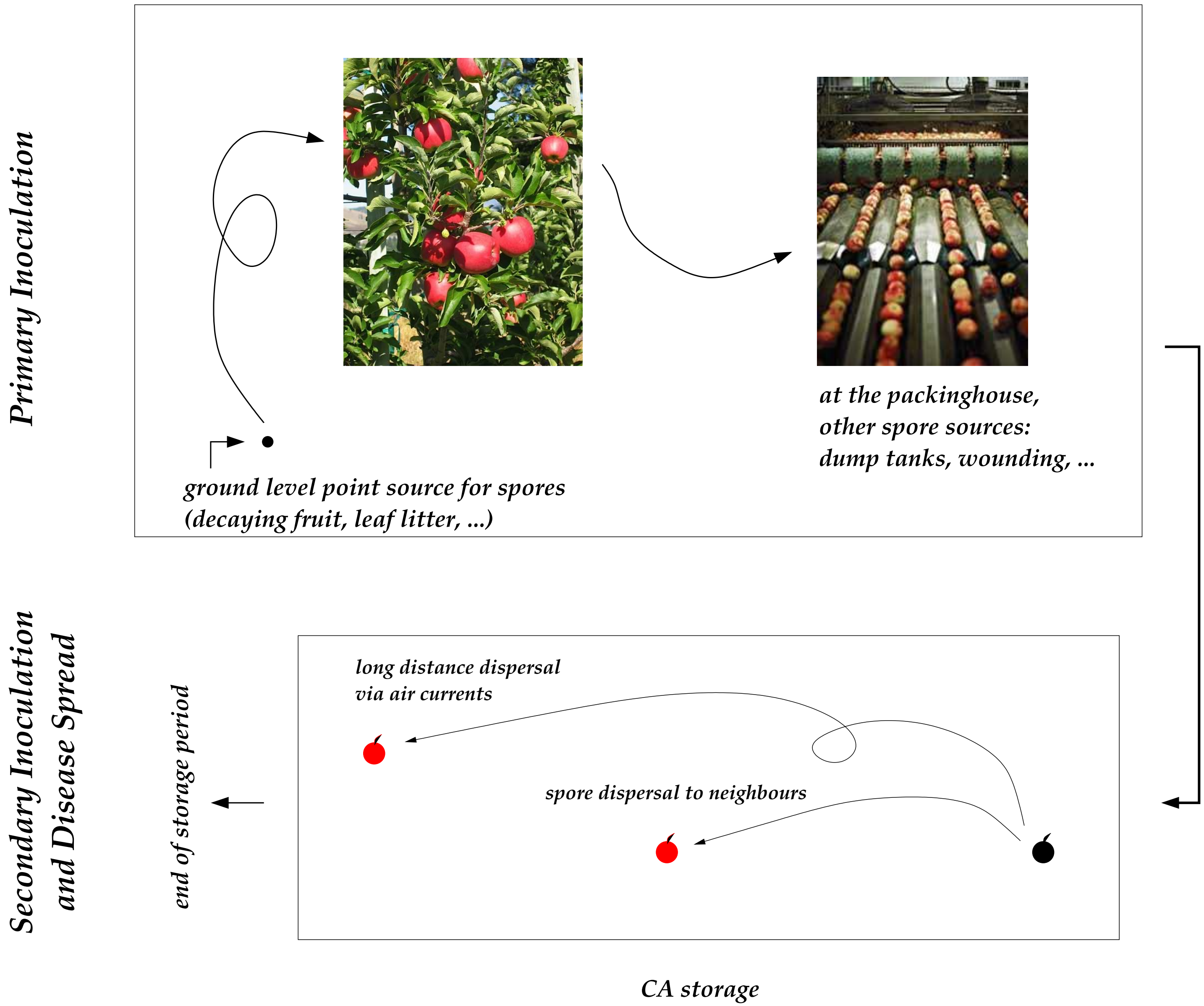




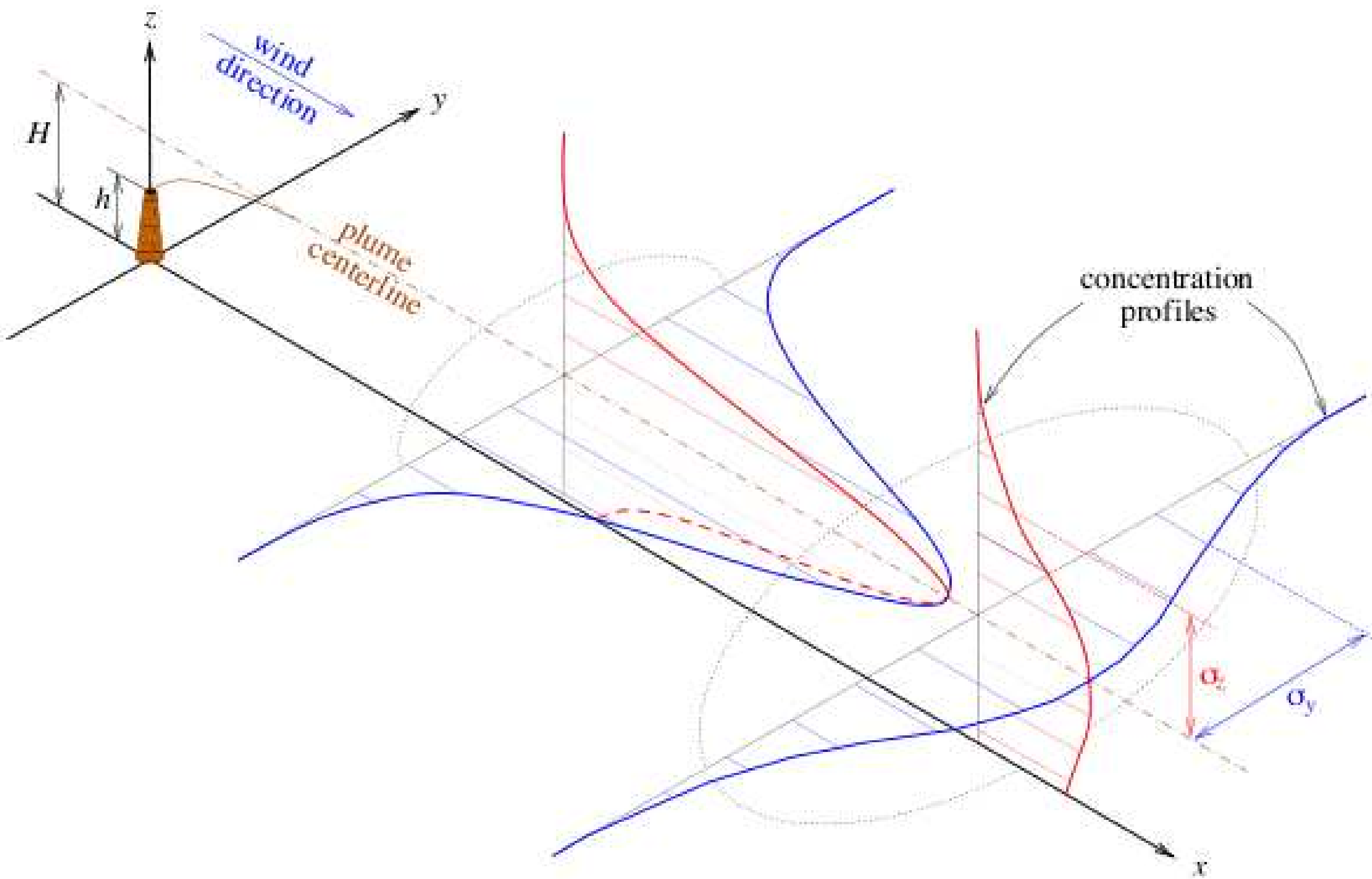


Spore presence data predicted very little.

Spore Dispersal to Epidemiology



Model #1: Spore Dispersal



Source: Stockie, J.M. (2010) The mathmatics of atmopheric dispersion modelling. *Atmopheric Environment* **44**:1097-1107

Gaussian Plume Model for a Point Source

Steady-State solution:

$$C(r, y, z) = \frac{Q}{4\pi u r} \exp\left(-\frac{y^2}{4r}\right) \left[\exp\left(-\frac{(z-H)^2}{4r}\right) + \exp\left(-\frac{(z+H)^2}{4r}\right)\right]$$

where

$$r = \frac{1}{u} \int_0^x K(\xi) d(\xi)$$

and where

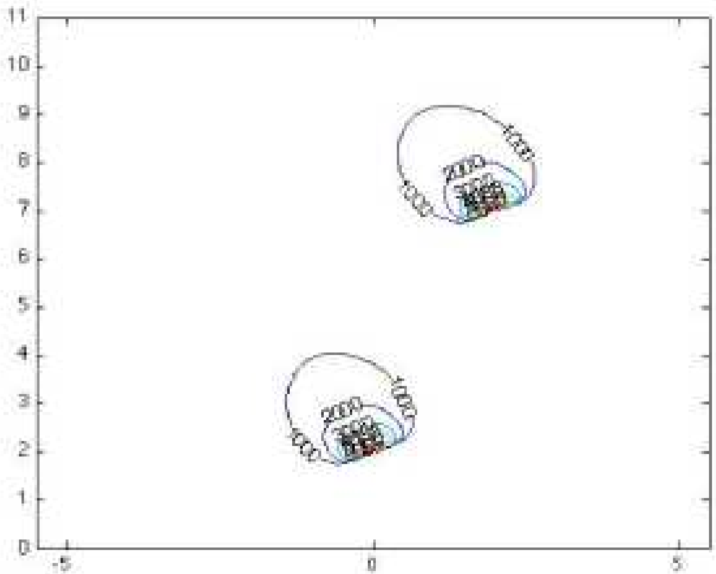
C	$=$	concentration of contaminant
(x, y, z)	$=$	cartesian coordinates centred at the source
u	$=$	wind velocity
H	$=$	height of the source
Q	$=$	emission rate

Source: Stockie (2010) The mathematics of atmospheric dispersion modelling *Atmospheric Environment* **44**(8):1097-1107

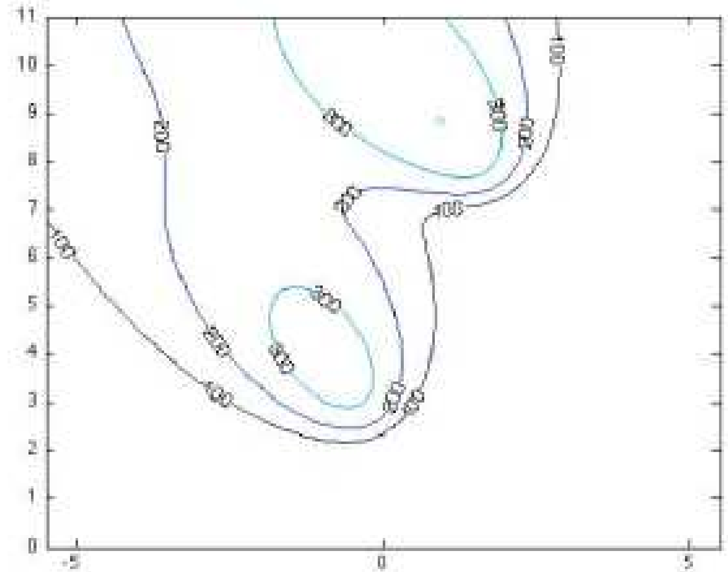
Assumptions

1. contaminant emitted at a constant rate and constant height
2. constant wind velocity aligned with positive x-axis
3. parameters are time-independant & the time scale is long
4. eddy diffusivities, K, functions of x only & diffusion is isotropic
5. wind velocity is sufficiently large so that diffusion in the x-direction is negligible
6. variations in topography are negligible
7. the contaminant does not penetrate the ground

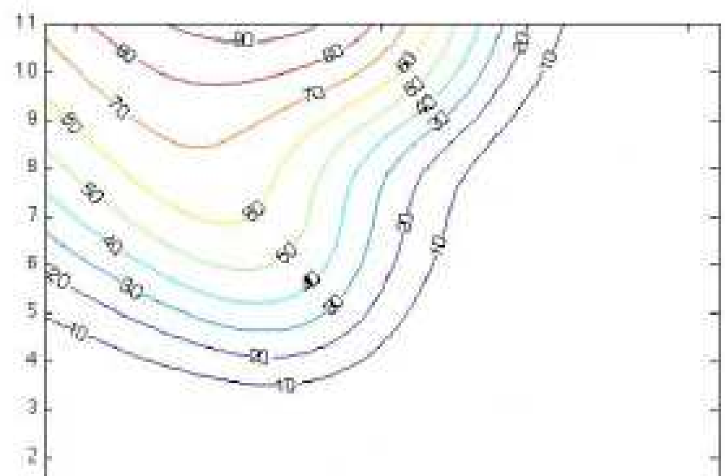
Concentration Profiles



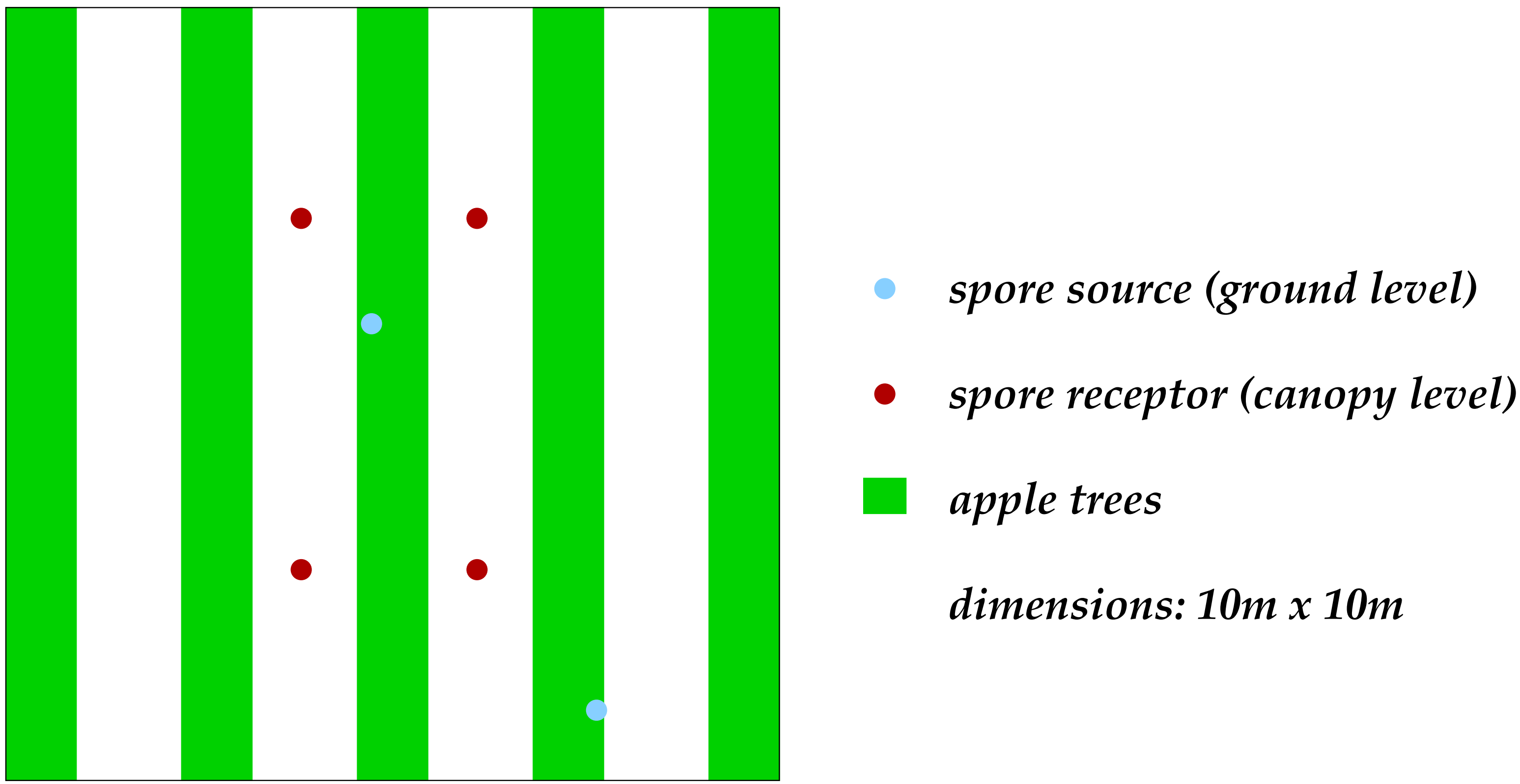
(a) Ground-level



(b) Mid-plume



Orchard & Receptor Layout



How many spore receptors does it take to get an accurate measure of spore presence?

Simulation Experiments

Consider

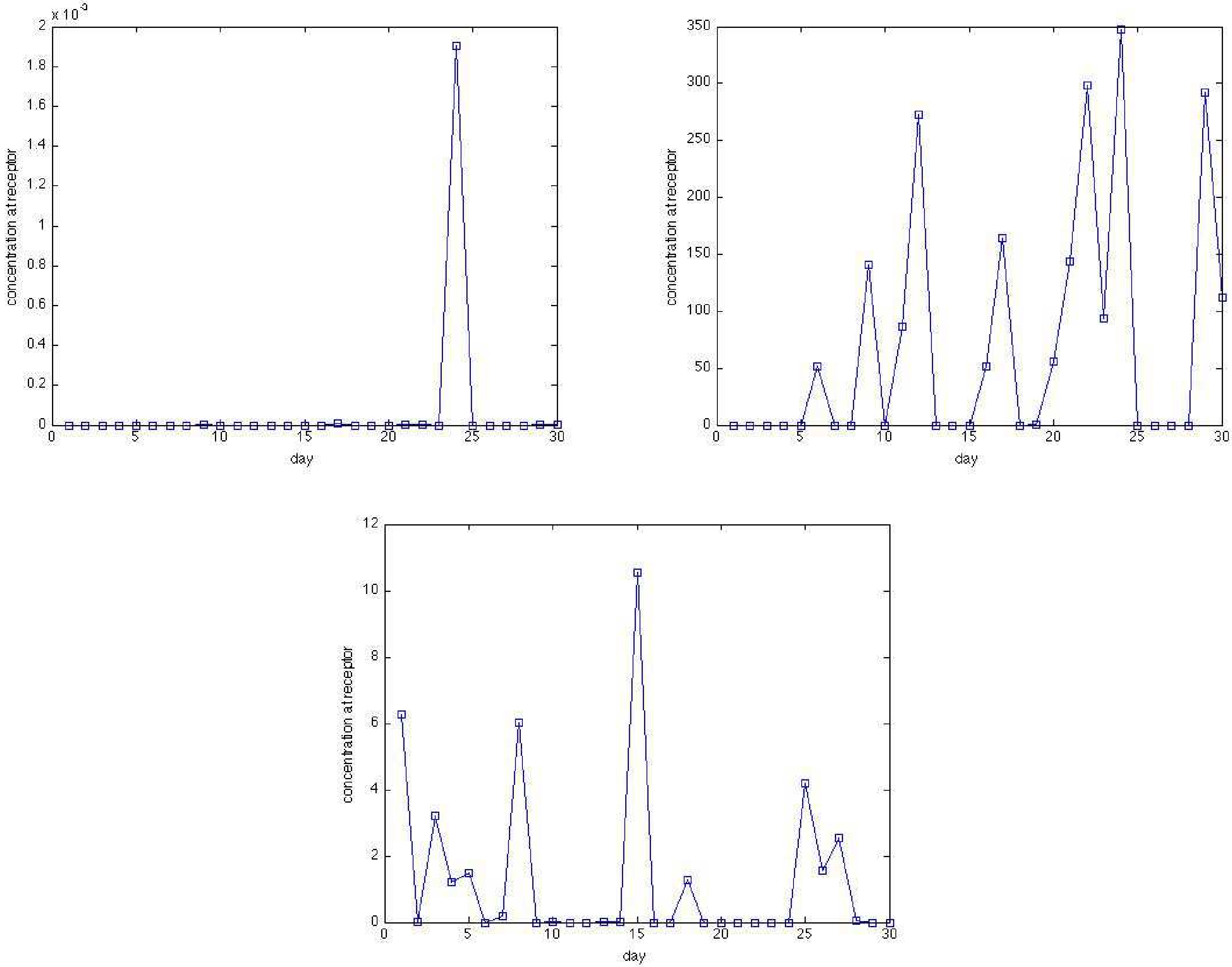
$$\begin{aligned} S &= \text{measure of total spore presence detected by } t = T \\ &= S(C(\vec{X}_s), n_r,\ T, \vec{W}, n_s), \end{aligned}$$

where

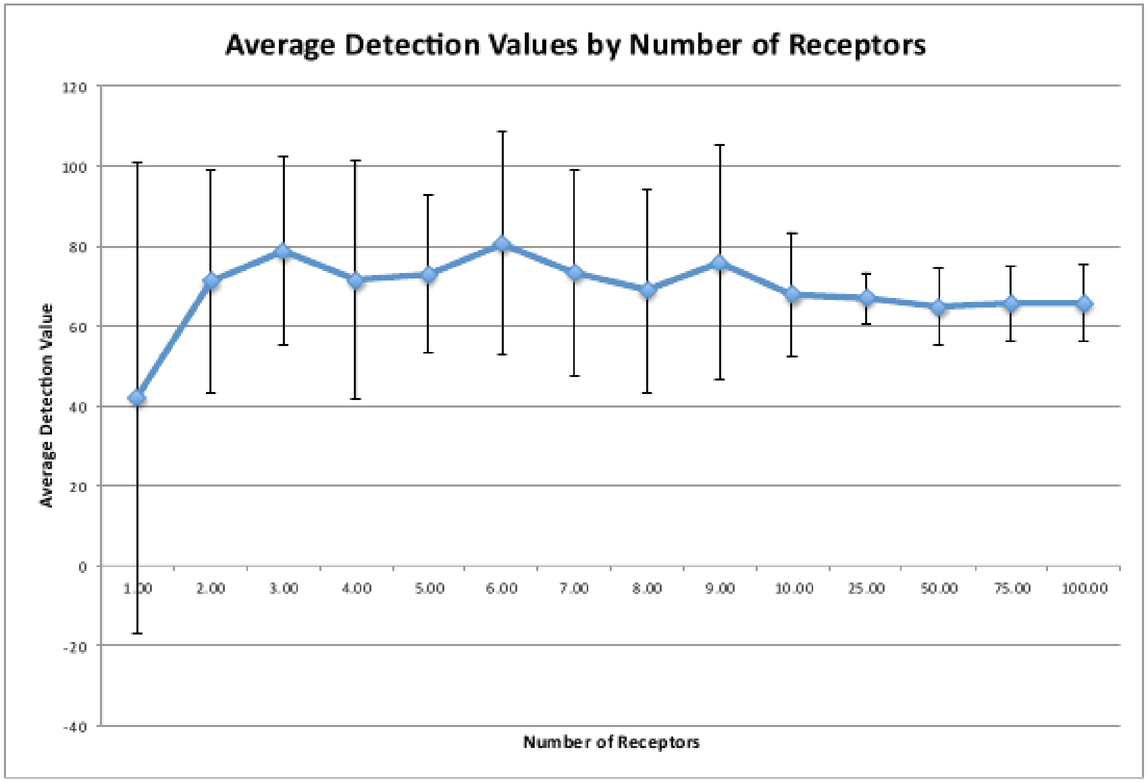
$$\begin{aligned} n_r &= \text{**number of spore receptors} \quad (0 \leq n \leq 100), \\ T &= \text{simulation time}, \\ \vec{W} &= \text{vector of wind data for} \quad (0 \leq t \leq T), \\ n_s &= \text{number of spore sources}, \\ \vec{X}_s &= \text{position of spore sources}. \end{aligned}$$

- Test: optimal n_r
- Experiment: fix all parameters, Replicates (20): vary $\vec{X}_s$.

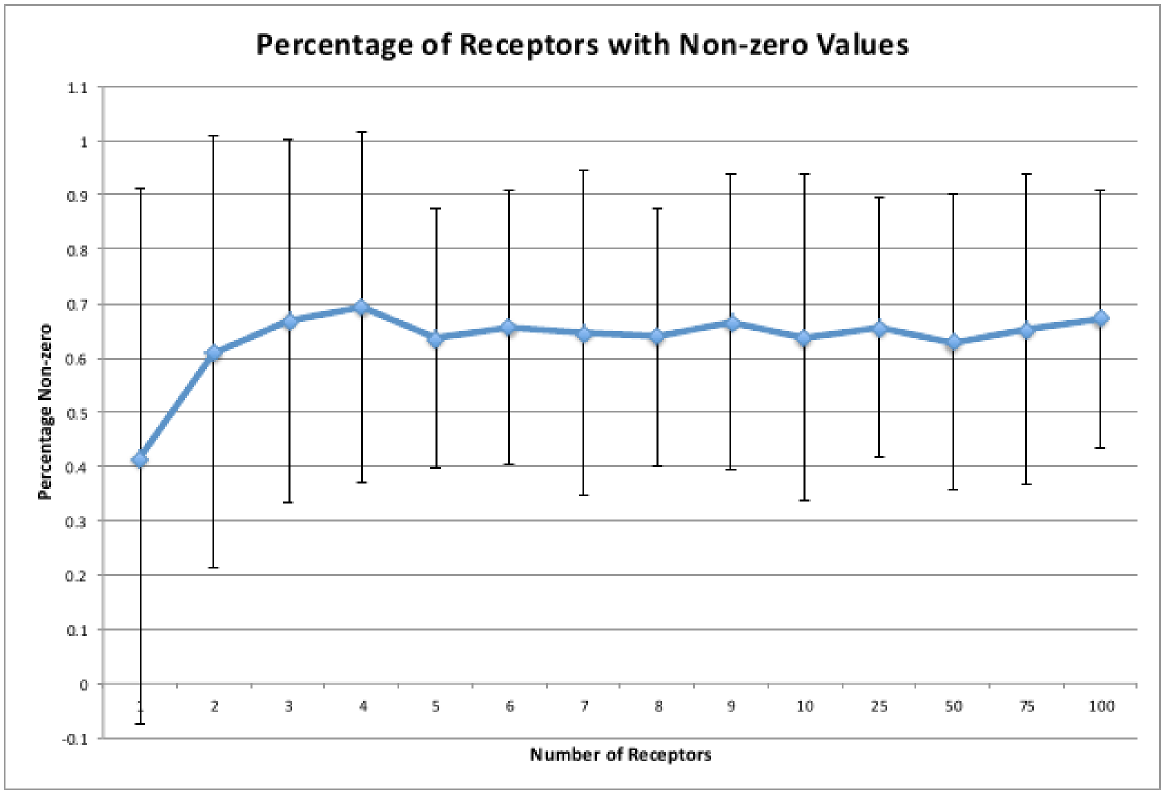
Simulation Results - Spore Detection



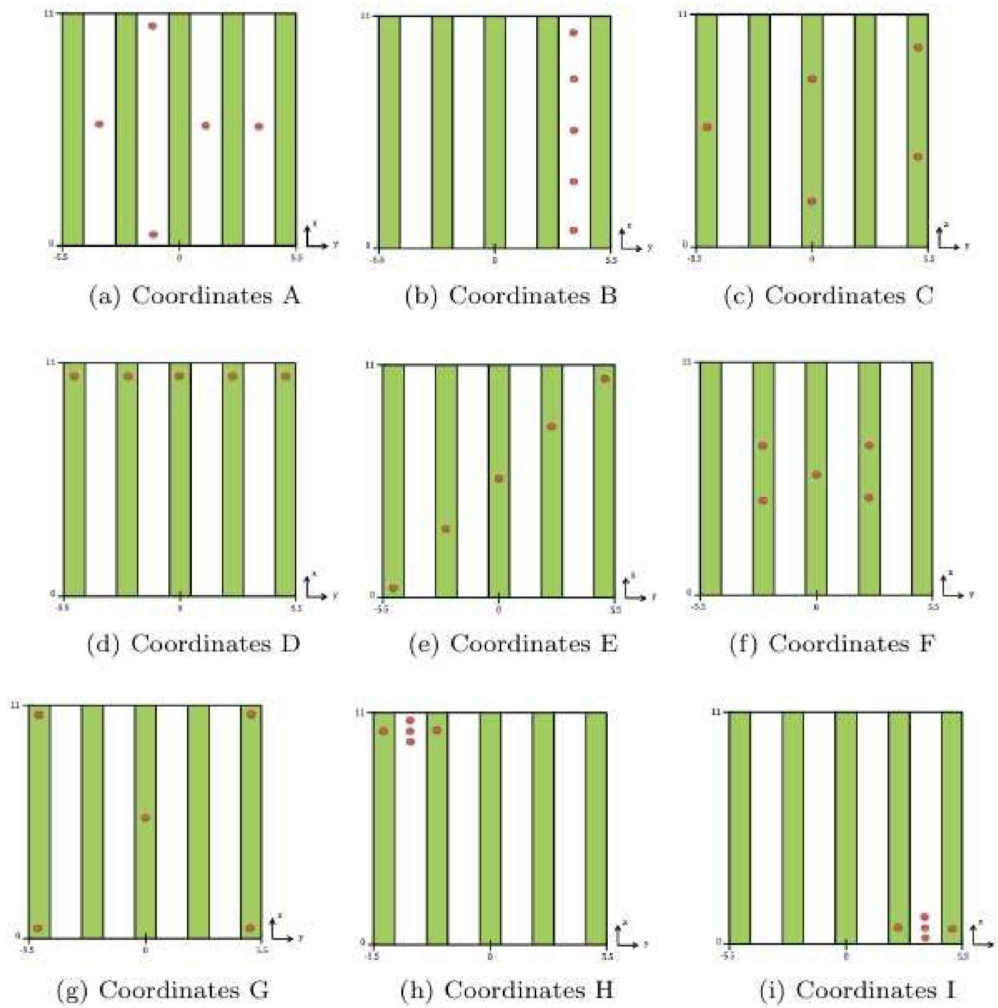
Simulation Results - Monthly Averages



Simulation Results - Percent Nonzero Detection

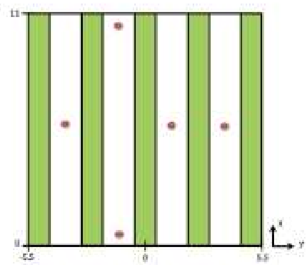


Simulation Results - Receptor Arrangement

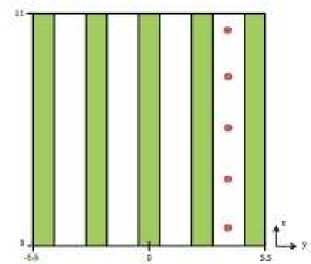


(a) Coordinates A
(b) Coordinates B
(c) Coordinates C
(d) Coordinates D
(e) Coordinates E
(f) Coordinates F
(g) Coordinates G
(h) Coordinates H
(i) Coordinates I

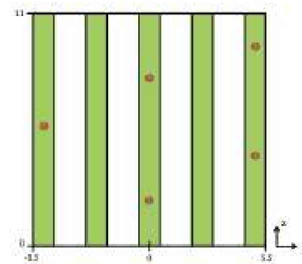
Simulation Results - Receptor Arrangement



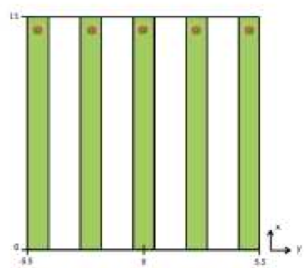
(a) Coordinates A



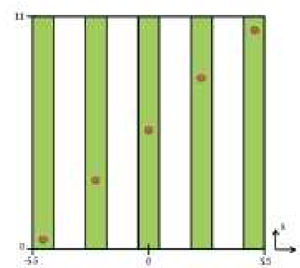
(b) Coordinates B



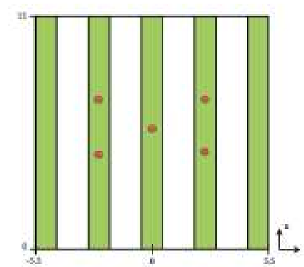
(c) Coordinates C



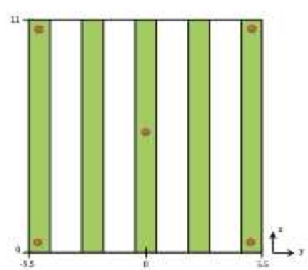
(d) Coordinates D



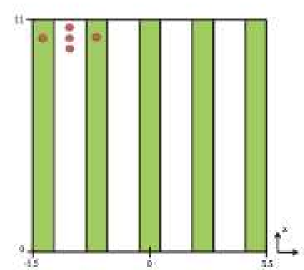
(e) Coordinates E



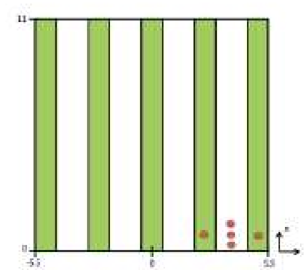
(f) Coordinates F



(g) Coordinates G

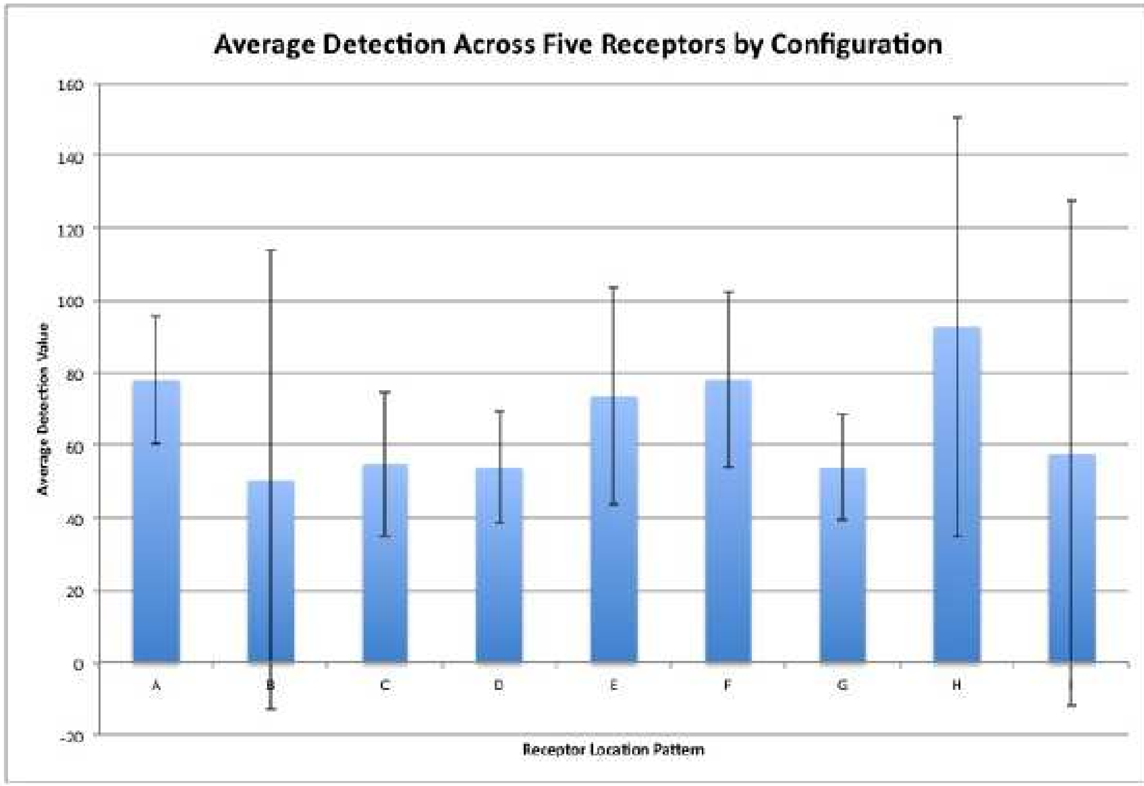


(h) Coordinates H

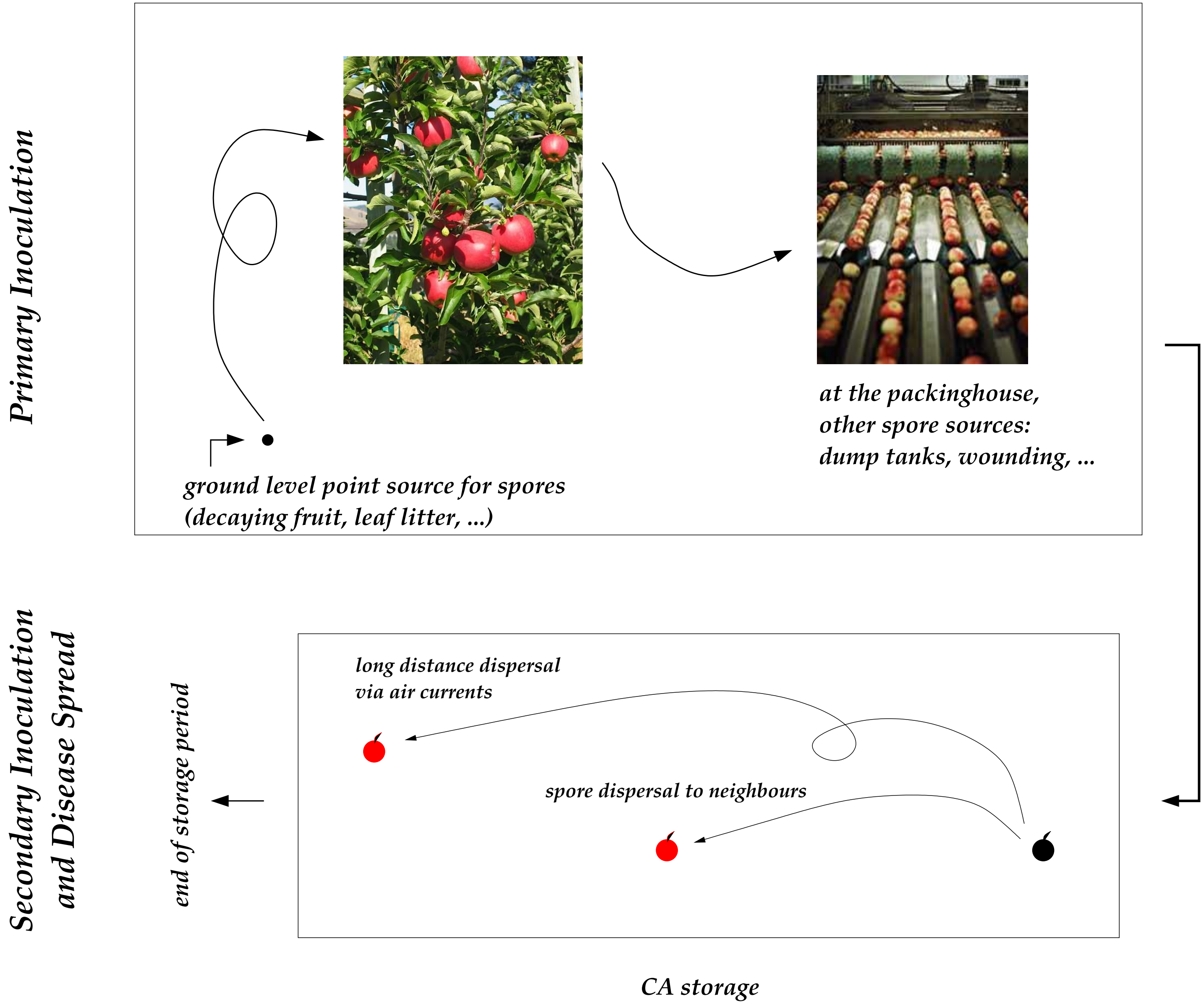


(i) Coordinates I

Simulation Results - Receptor Arrangement



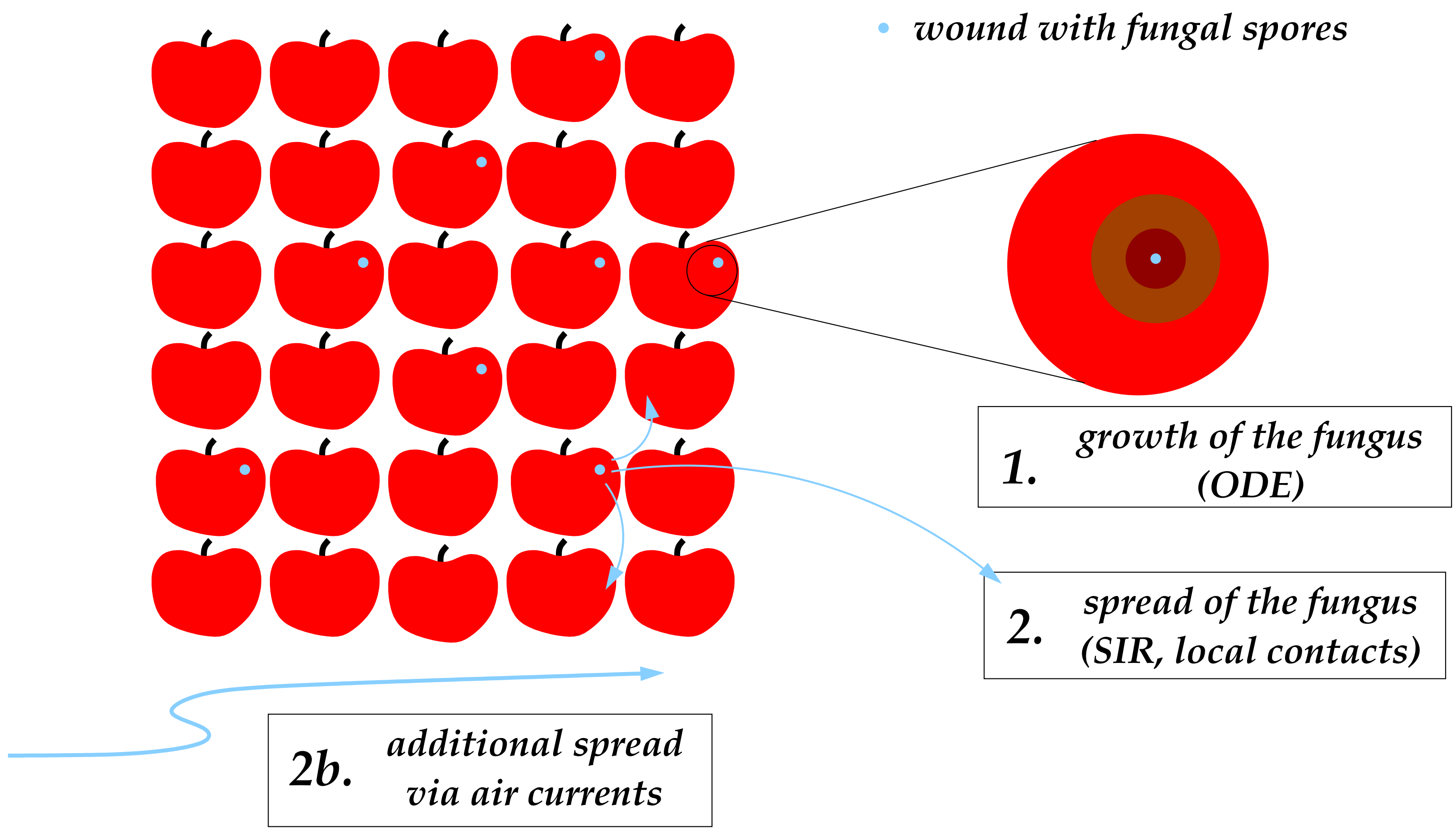
Spore Dispersal to Epidemiology



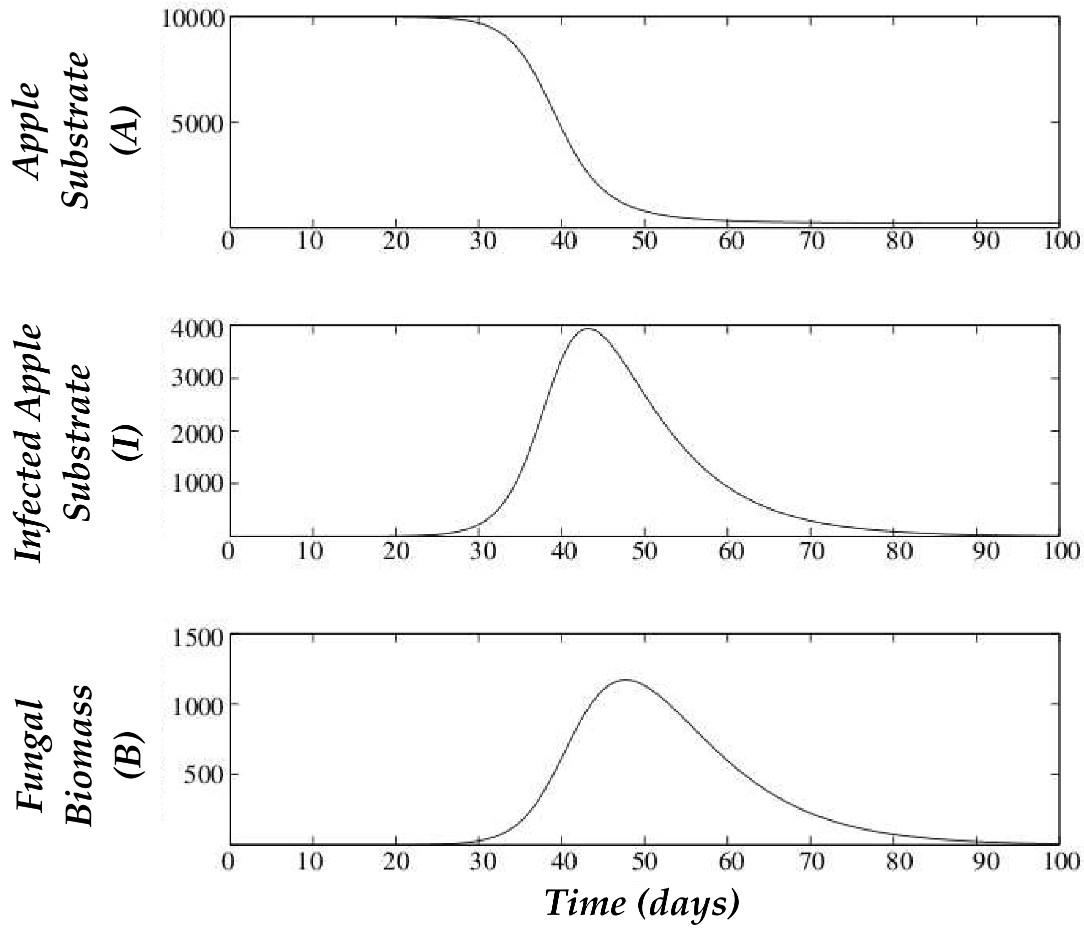
Model #2: Epidemiology - Why?

- It is expensive to open the storage rooms to assess the extent of disease.
- Accurate prediction of disease-free storage periods would prevent major crop losses.

Model #2: Epidemiology



Fungal Growth Model



$$\frac{dA}{dt} = -\alpha G I A$$

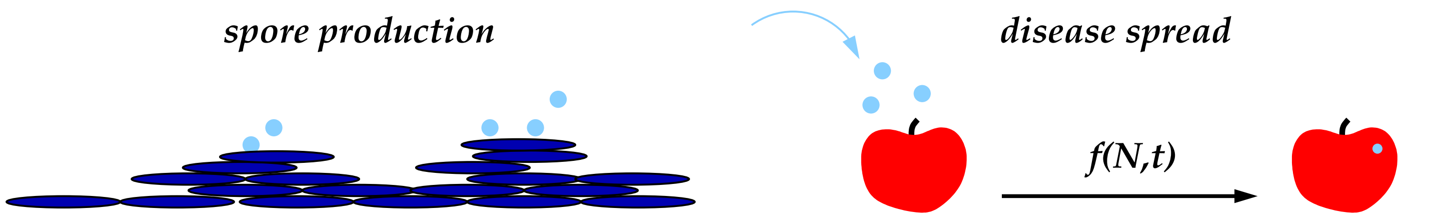
$$\frac{dI}{dt} = \alpha G I A - \beta I$$

$$\frac{dB}{dt} = G I - \mu B$$

Adapted From: Lamour et.al. (2002) Quasi-steady state approximation to a fungal growth model *Journal of Mathematics Applied in Medicine and Biology* **19**:163–183

Disease Spread

Disease Spread - SIR



Infection spread from one apple to another is given by

$$f(N,t) = \mathbf{1}(N)\, p\, \gamma(t),$$

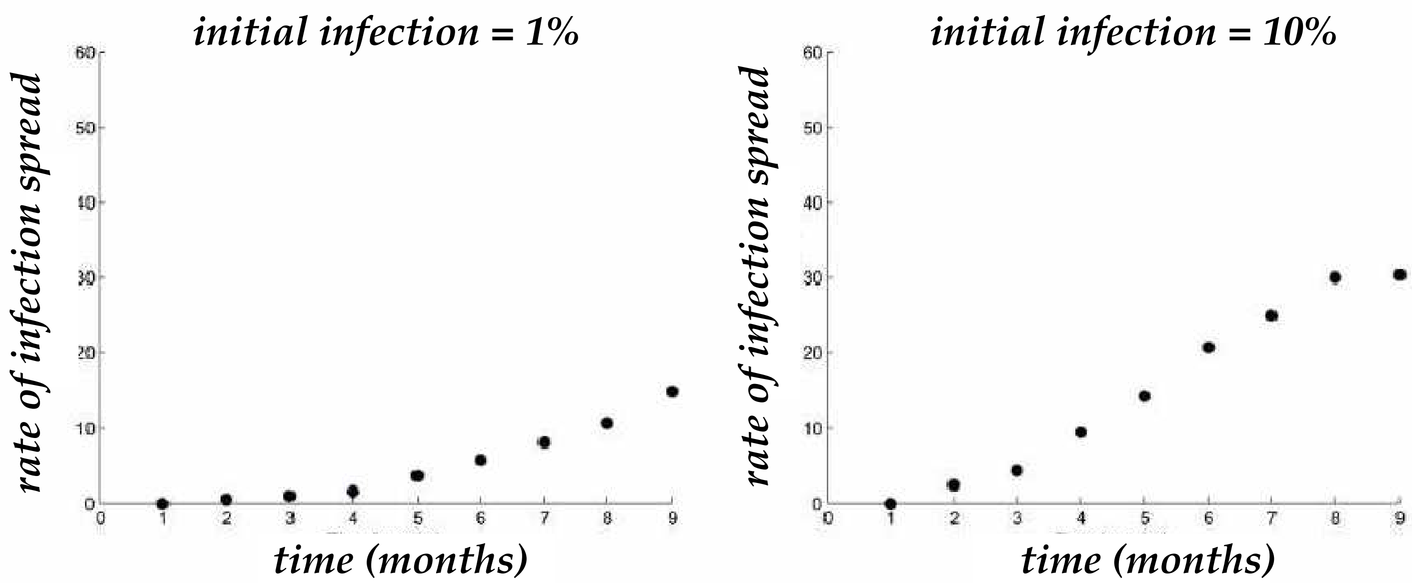
where

N = number of nearest neighbours that have $B(t) > B_{min}$

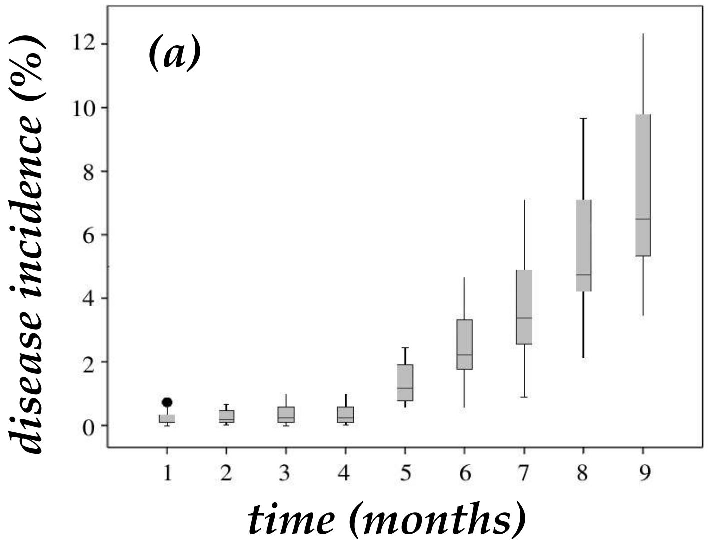
p = baseline infection rate

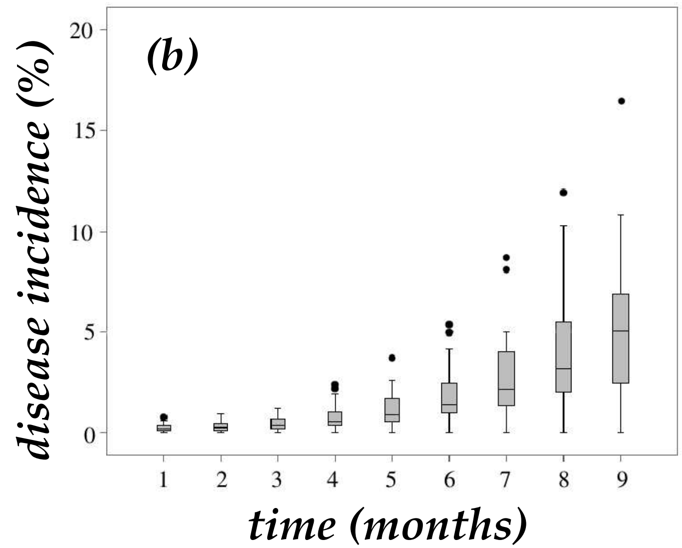
$\gamma(t)$ = susceptibility function, $\gamma'(t) > 0$

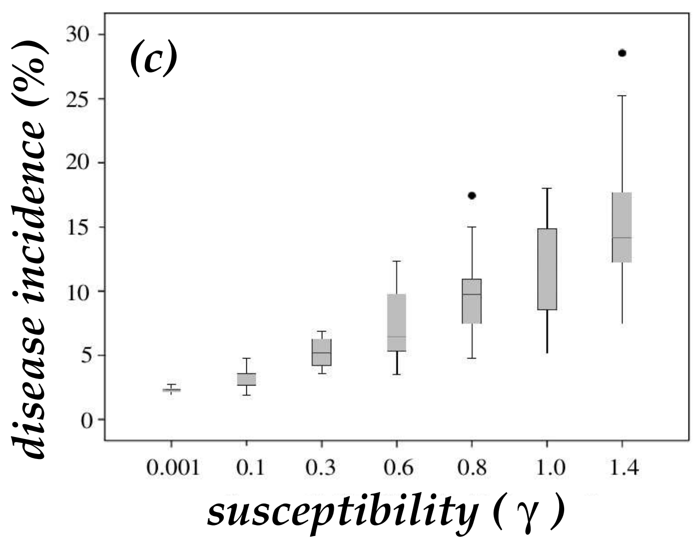
Results - Initial Infection



Results - Spread & Susceptibility

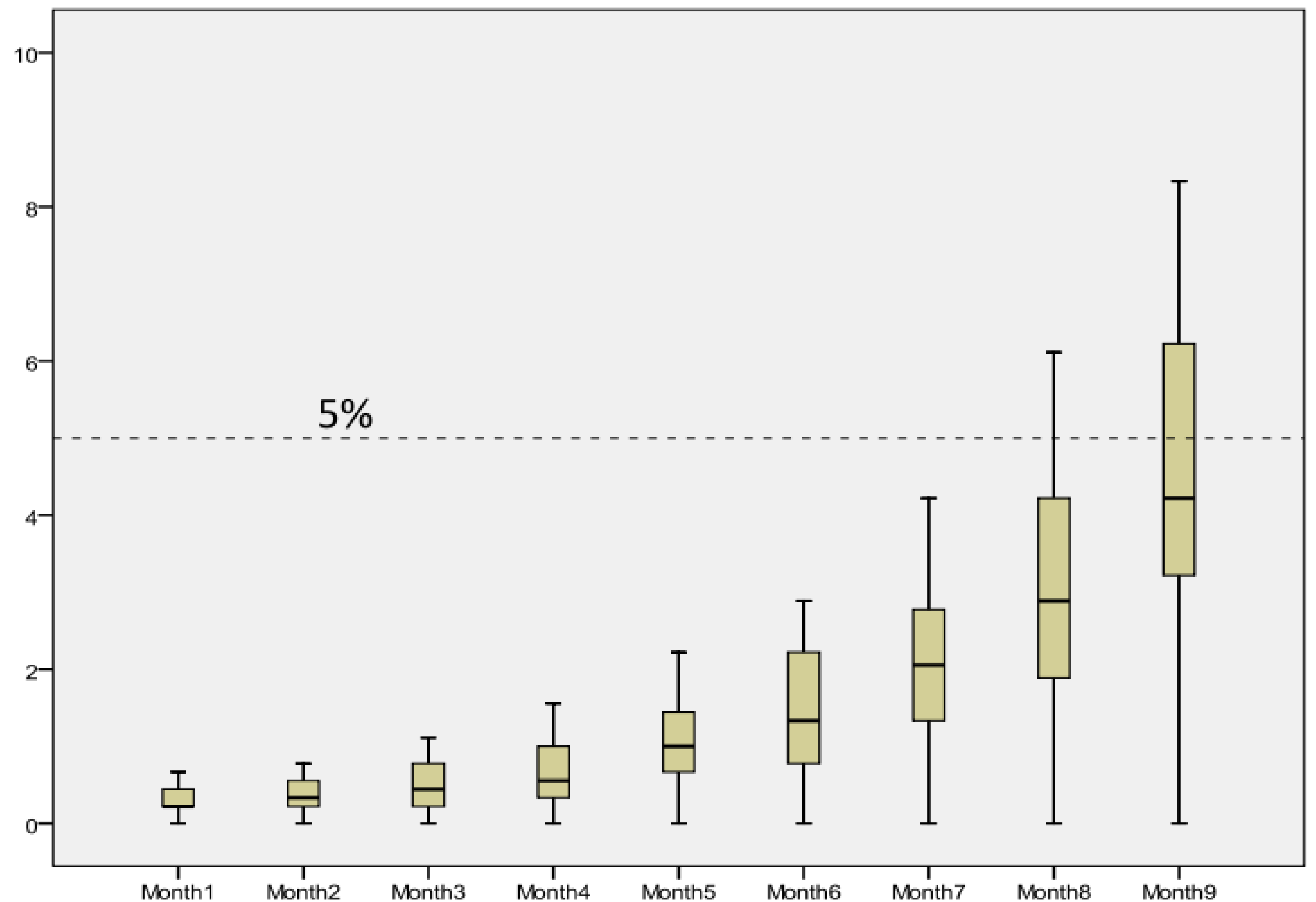






(a) local spread only
(b) local & global spread
(c) increasing susceptibility

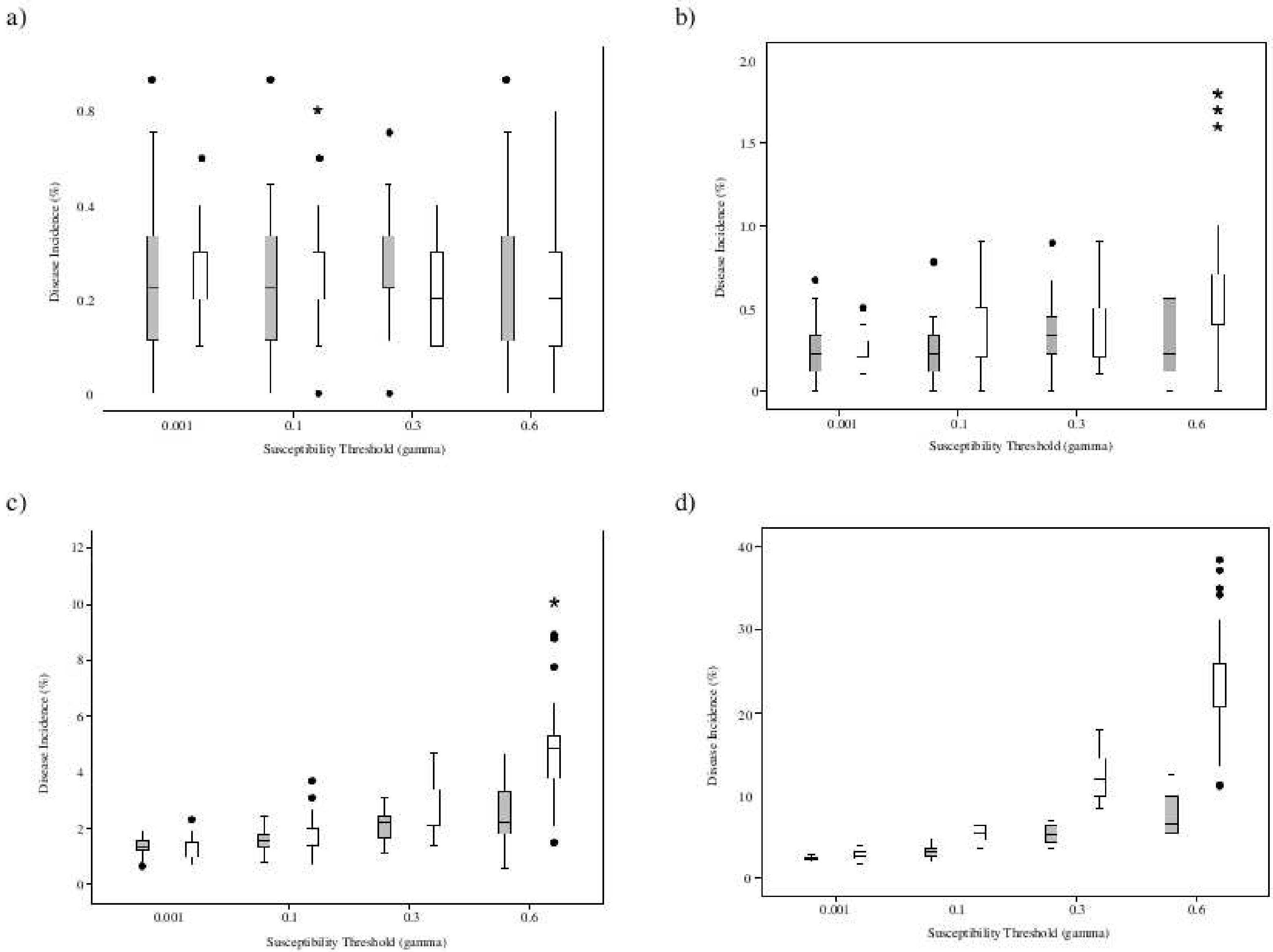
Results - Storage Duration



Results - Rate of Infection Spread

		Storage Duration (months)		
Factor	Treatment	2	5	9
Location	Center	0.47	2.20	10.23
	Side	0.23	1.33	5.20
	Corner	0.20	0.70	2.77
Aggregation	Clumped	0.50	3.20	13.17
	Dispersed	1.57	9.57	41.80

Results - 3D



a)
Disease Incidence (%)
0.8
0.4
0.2
0
0.001
0.1
0.3
0.6
Susceptibility Threshold (gamma)
b)
Disease Incidence (%)
2.0
1.5
1.0
0.5
0
0.001
0.1
0.3
0.6
Susceptibility Threshold (gamma)
c)
Disease Incidence (%)
12
10
8
6
4
2
0
0.001
0.1
0.3
0.6
Susceptibility Threshold (gamma)
d)
Disease Incidence (%)
40
30
20
10
0
0.001
0.1
0.3
0.6
Susceptibility Threshold (gamma)

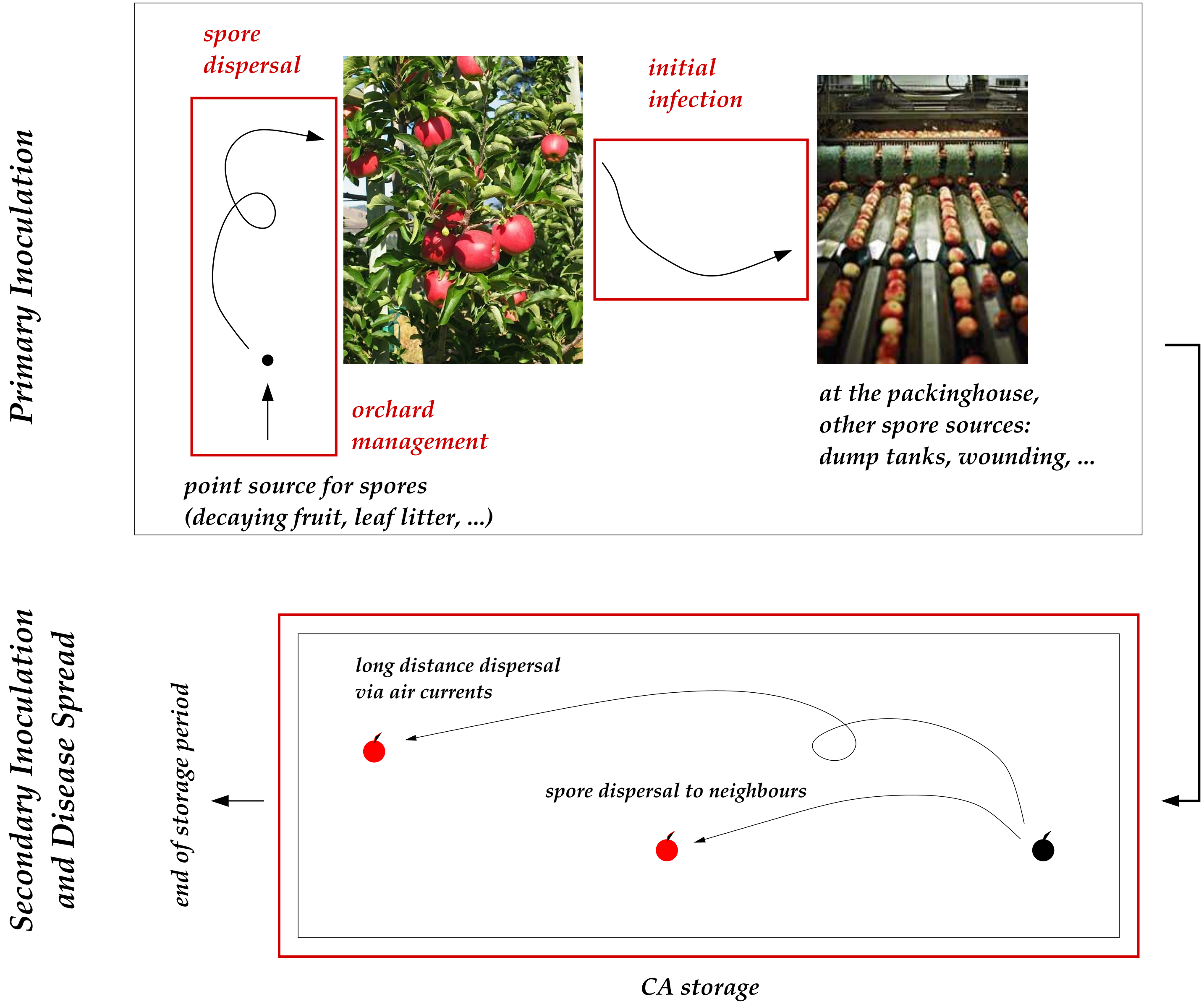
Conclusions

The accumulation of rare events over a long period of time mean high variability in the outcome.

Predictable:

- number and placement of orchard receptors needed to obtain reliable measure of spore presence
- storage time for which risk of unacceptable crop loss is acceptable

Hypothesis


Primary Inoculation
spore dispersal
orchard management
point source for spores (decaying fruit, leaf litter, ...)
initial infection
at the packinghouse, other spore sources: dump tanks, wounding, ...
Secondary Inoculation and Disease Spread
end of storage period
long distance dispersal via air currents
spore dispersal to neighbours
CA storage

Correlations with Spore Presence

Significant correlations between:

1. air DNA
   - wind direction ($p = 0.01$)
2. tissue DNA
   - average temp ($p = 0.017$)
   - average temp day before measurement ($p = 0.028$)
   - rainfall day before measurement ($p = 0.038$)
   - maximum wind speed ($p = 0.014$)

Regression of (2) gives $R^2 = 0.023$ and $\sigma = 0.001$.

Correlations with Disease Incidence

Significant correlations between:

- percent infected
  - m, number of months in storage ($p = 0.000$)
  - C_i, average temp last i days ($p = 0.005$, 0.000 & 0.003)
  - R_i, rainfall during last i days ($p = 0.000$ & -0.032)
  - Sp_i, average tissue spore count last i days ($p = 0.0006$ & 0.000)
  - $i =$ 50, 14 or 1

R^2	parameters included
0.325	R_{14}
0.416	R_{14} and m
0.491	R_{14}, m, and C_{14}
0.501	R_{14}, m, C_{14}, and Sp_{14}

Modified Model with Absorption

$$C(x,y,z) = \frac{Q}{2\pi u}\frac{1}{\sigma_z}\exp\left(\frac{-y^2}{2\sigma_y^2}\right) \times \frac{1}{\sigma_z}\left[\exp\left(\frac{-(H-z)^2}{2\sigma_z^2}\right) + R\exp\left(\frac{-(H+z)^2}{2\sigma_z^2}\right)\right]$$

where

$$\sigma_z = K(z_0)ax^b, \qquad \sigma_y = K(z_0)10^p x^q$$

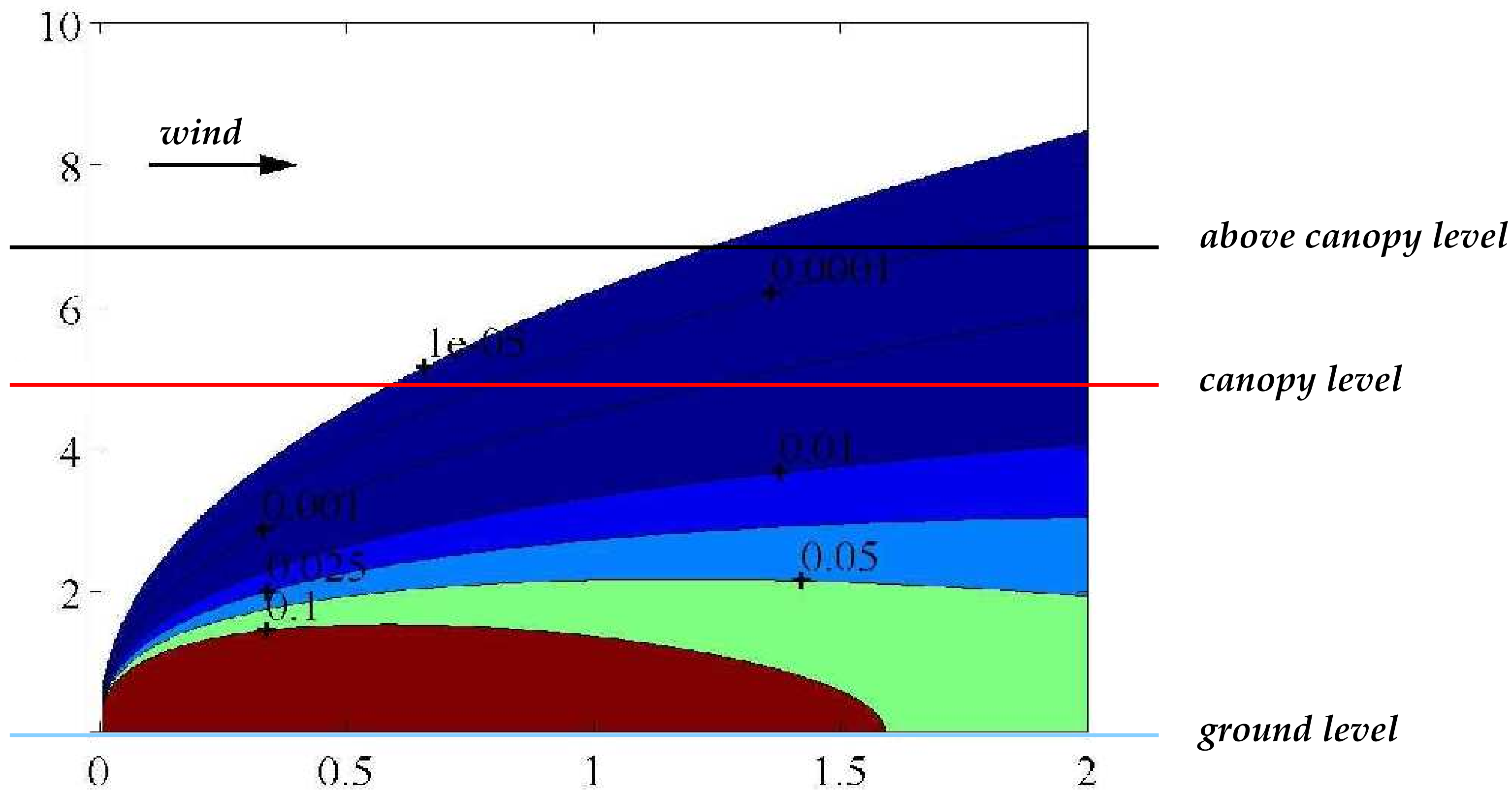
$a,\ b,\ ,p\ ,q =$ stability class constants, empirical

$z_0 =$ roughness length

$R =$ absorption at ground level (1 - reflection, 0 - absorption)

Source: Spijkerboer et. al. (2002) Ability of the Gaussian Plume Model to predict spore dispersal over a potato crop. *Ecological Modelling* **155**:1-18

Vertical Plume



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