Risks and Benefits Associated with Biotechnological/ Pharmaceutical Crops

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Motivation

- Recent Cases of Contamination and Near Contamination
  - Starlink 2000
  - Prodigene 2002
- Industry Concern
  - North American Millers Association
  - BIO

Conceptual issues and solutions

- A large number of possible avenues for contamination
  - Solution: we focus on an avenue (pollen drift) that exists in the Cornbelt and not in other states
  - We assume that weather stations are used in the source fields
- A zero tolerance is inconsistent with probability theory
  - Solution: We use tolerances

Conceptual issues and solutions

- "Harm" is difficult to define, most antibodies are safe for human consumption and detection is close to impossible
  - Solution: We define harm as the possibility of contamination
- The wind conditions that cause one pollen to move will also cause others to move, this breaks the link between probability and the level of contamination
  - Solution we measure the probability that tolerance levels are exceeded

Conceptual issues and solutions

- The average consumer overestimates small probabilities
  - Solution we express tolerances in terms of kernels per forty acre field, there are 540 million kernels in a forty acre field (90,000*150*40)
- We do not know which direction the wind will blow
  - We conservatively assume that wind always blows in the direction of the field of interest

Conceptual issues and solutions

- It is conceptually difficult to trade off risk against economic benefit
  - Solution we express the risk as the fair value of an insurance product that fully indemnifies the owner of the target field
- The failure levels for biological controls is not known with precision
  - Solution we assume a failure level of 1 in 100 for detasseling and male sterility

Phases of Research

- Pollen dispersal model

- Calibration

- Insurance pricing mechanism

Stochastic Modeling of Dispersion

- Description of wind behavior

- Lagrangian stochastic (LS) model

- Monte Carlo Simulation

Stochastic Modeling of Dispersion: Weibull Model of Wind Distribution

- Weibull is most common distribution used to model wind speeds (Seguro and Lambert)
- Parameters, c and k, are estimated using maximum likelihood techniques.

$$P(u < u_i < u + du) = P(u > 0)\left(\frac{k}{c}\right)\left(\frac{u_i}{c}\right)^{k-1}\exp\left[-\left(\frac{u_i}{c}\right)^k\right]du$$

Insurance Policy:
Fitting Local Wind Behavior to the Weibull Distribution

•Wind data from Boone, Iowa

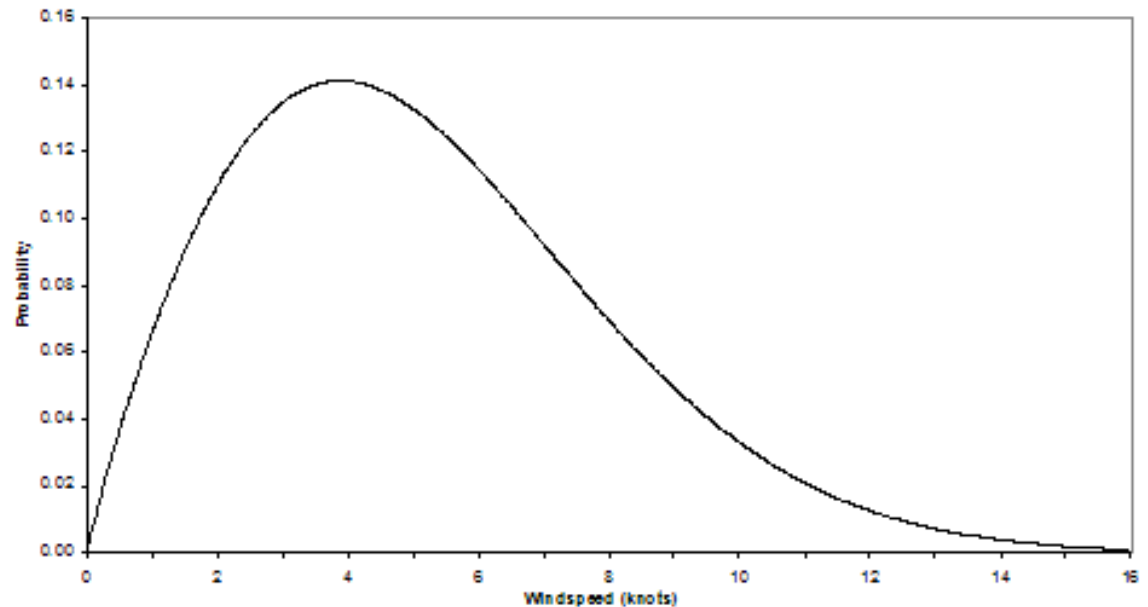•Collected during period of maize pollination (Miller)

Fig. 2 Distribution of Central Iowa Wind Speeds (knots) during Periods of Corn Pollination 1995-2002

Stochastic Modeling of Dispersion: Lagrangian Stochastic (LS) Model

- LS model closely follows that of Aylor

- Models movement of pollen in vertical direction (z) and horizontal direction (x)

$$dX = udt$$

$$dZ = (W - v_s)dt$$

$$dW = \left[-\frac{b_w^2}{2\sigma_w^2}W + \frac{1}{2}\frac{\partial \sigma_w^2}{\partial z}\left(\frac{W^2}{\sigma_w^2} + 1 \right) \right]dt + b_w d\xi_w$$

Parameter Values

- Available from Literature
    - Displacement level and roughness length for fallow, corn, and soybeans
    - von Karman's constant and settling velocity of corn pollen

Stochastic Modeling of Dispersion: Deposition and Temporal Conditions

- Pollen is considered viable for 2 hours

$$Q_T = \{Q_R(0, H, 0) : Q_R(x, z_o, t), t \le 7200\}$$

- Probability of pollination is the ratio of transgenic pollen to all pollen deposited

$$P = Q_T / Q_A$$

Stochastic Modeling of Dispersion: Physical & Biological Inhibitors of Gene Dispersal

- Physical methods
  - Bagging
  - Detasseling
- Biological methods (Daniell)
  - Male sterility

Stochastic Modeling of Dispersion: Contemporaneous Fertility

- Using corn silking as a proxy, determined probability of fields separated by time of planting sharing a period of fertility
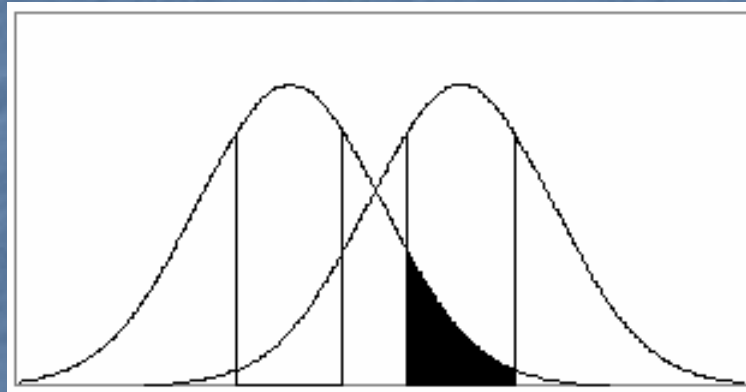
<- 4 weeks ->

- Probability of fields separated by 28 days or more sharing a period of fertility was less than one percent

Stochastic Modeling of Dispersion: Probability of Zero Contamination

- The probability that long distance pollen will succeed in fertilizing is the ratio of transgenic pollen, Q_T, to all pollen present, Q_A, times the probability that genetic seepage occurs, P_S, times the probability that the plots are fertile at the same time, P_F.

$$P = P_F \left(\frac{P_S Q_T}{Q_A} \right)$$

- The probability of *any* contamination occurring, P_c, approaches 1 as the number of size of production grows:

$$P_c = \left(1 - (1 - P)^K \right)$$

Calibration

- Model is calibrated using field data collected by Mark Westgate et al. during July 2000

- Gathered weather data including wind speed from station located in center of source plot

- Gathered and measured pollen daily from passive collectors located in eight directions at varying distances from source each day

Calibration Process

- Estimated deposition using LS model using characteristic wind speed for each day

- Since actual amount of pollen is not known, deposition ratios are used with the first site of collection normalized to one

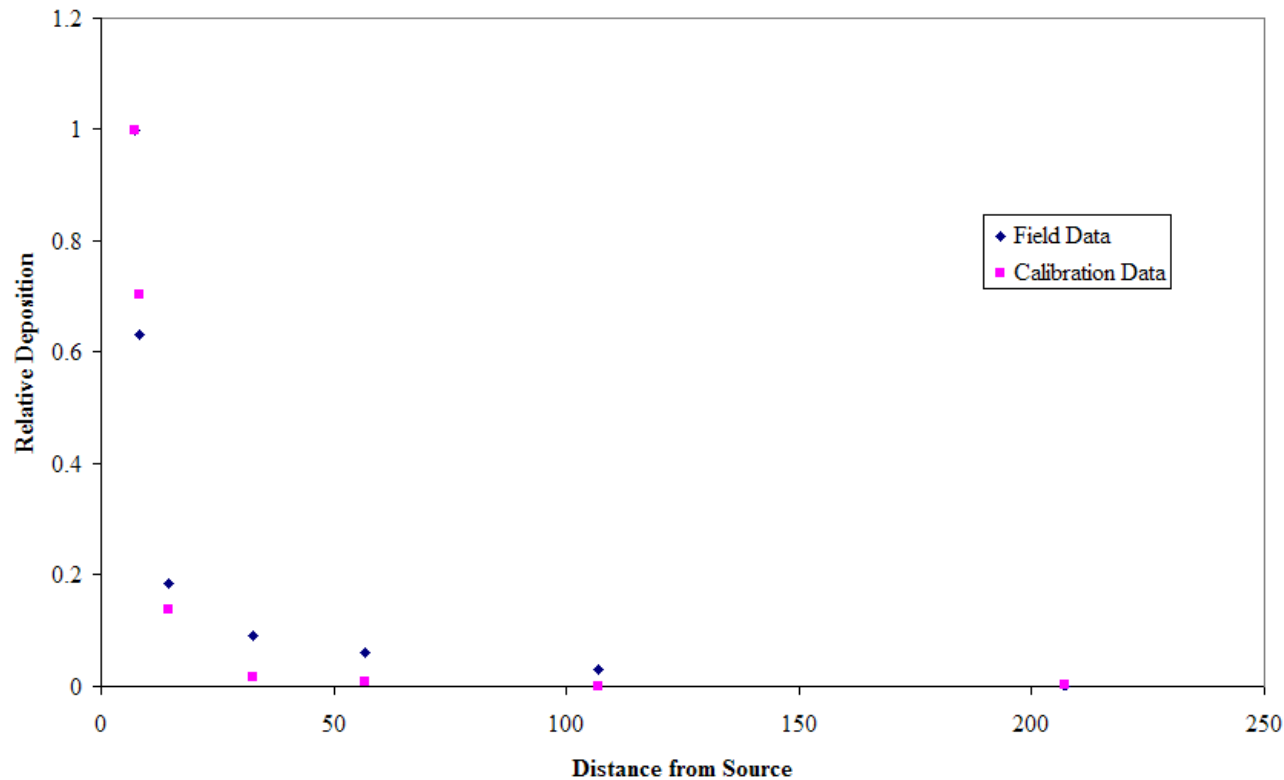# Calibration results for a wind speed of two miles per hour

Figure 1. Relative Deposition of Pollen

Calibration Results

- Model overestimated pollen deposition near the source and at furthest distance

- Calculated results can be seen as a higher bound on actual values, i.e. they are conservative

APHIS Production Guidelines

- Controlled Pollination (bagging or detasseling)
  - Corn allowed from ½ to 1 mile if planted 28 days before or after pharmaceutical corn
- Uncontrolled Pollination
  - No corn allowed within one mile
- Either case
  - 50 feet adjacent to pharmaceutical plot must be left fallow
  - No restrictions beyond 1 mile

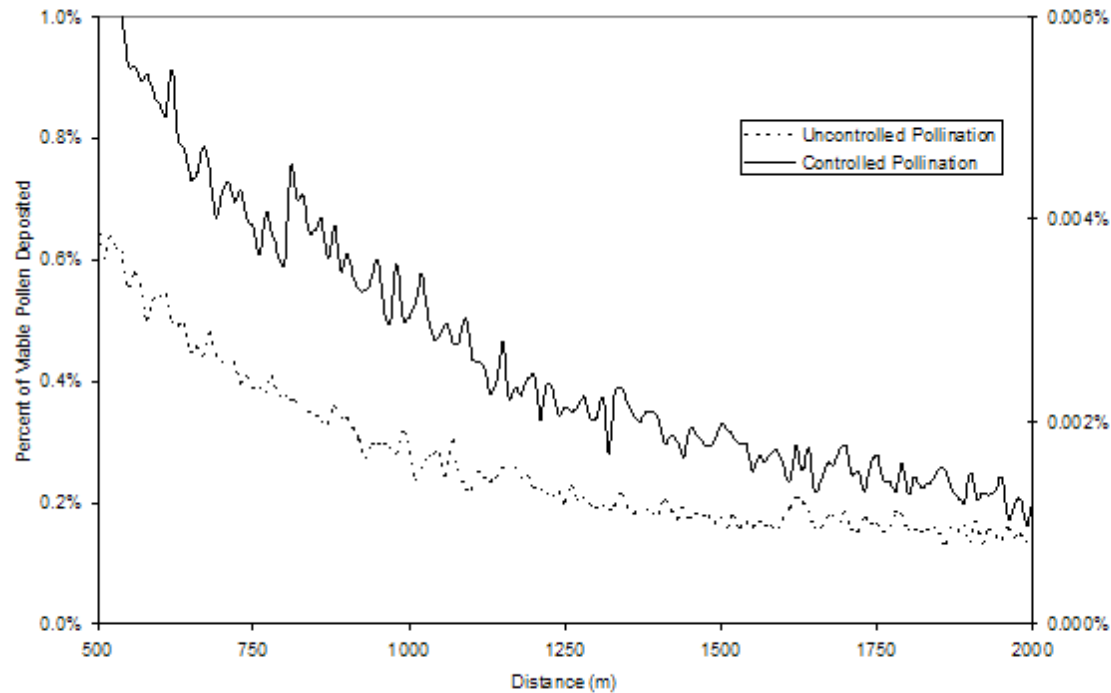# Long Distance Pollen Dispersal

Figure 3. Long Distance Pollen Dispersal

Insurance Policy: Assumptions and Parameters

- Assumptions
  - Size of fields
    - One acre pharmaceutical field
    - 40 acre conventional corn fields
  - One-percent failure rate of detasseling/bagging and biological mechanism

- Exogenous Parameters
  - Price: $2.00/bu.
  - Yield: 150 bu./acre
  - Social tolerance level

Insurance Policy: Results

Table 1. Cost of Insuring against Genetic Contamination in Dollars per Acre

Tolerance [kernels/field]	Controlled Pollination			Uncontrolled Pollination		
	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
100	-	-	-	0.06999	-	-
50	-	-	-	0.50643	0.18869	-
10	-	-	-	2003.43	1730.43	1042.8
5	0.00039	-	-	4268.859	4092.583	4006.853
1	11.52838	0.13745	-	4359.427	4179.914	4049.519
0.5	17.87641	9.22446	0.92088	4313.94	4224.184	4075.309

Insurance Policy: Results

- Insurance premiums are calculated in a very conservative way (detasseling and biological inhibitor, wind direction and calibration)

- With a tolerance level of one kernel per forty acre field the fair cost of the insurance product is $11.50

- Cornbelt Policy makers need to compare this cost against the economic benefits of the field

- Larger scale production of pharmaceutical corn will result in lower premiums as relatively less pollen will escape from the field

Summary

- Constructed a pollen dispersal model and calibrated it against data

- Calculated the fair value of an insurance policy that indemnifies against contamination

- Model is extremely flexible and can address different production scenarios, assumptions