

Insuring Against Losses from Transgenic Contamination

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Concerns about contamination of the food supply and the financial losses that would result have limited the promise of certain genetically engineered plants. This article addresses the situation by constructing an insurance pricing model to protect against those losses. The model first estimates the physical dispersal of corn pollen subject to a number of parameters. This physical distribution is then used to calculate the premium for fair valued insurance that would be necessary to destroy contaminated fields. The flexible framework can be readily adapted to other crops, management practices, and regions.

Key words: contemporaneous fertility, insurance, Lagrangian stochastic model, pharmaceutical-corn, pollen dispersal

Advances in genetic engineering show great potential for revitalizing production agriculture. However, the adoption of certain technologies is hindered by stringent federal regulations and concern from industry and consumers alike. While there is justification for such positions following the Starlink and Prodigene episodes, government control and oversight have continually evolved in order to address changing needs. The principal source of this apprehension arises from the uncertainty of genetic contamination of the food and feed supply and the unprotected losses that would occur in that event. In response to this, we have constructed an insurance pricing model to determine the probability of contamination and the related losses.

The insurance pricing model consists of two parts. The first predicts the physical dispersion of pollen which is primarily a function of wind speed. The second attaches dollar values to the fair value of insurance to protect against losses from genetic contamination. Here the expected market price for commodity corn and the land's recent yield history are utilized.

Previous studies of pollen and gene dispersal in maize have relied upon sample data to estimate the true underlying spatial distribution. This research has depended upon either the physical collection of pollen or the pollination of maize and later identification of distinctive transmitted traits. Only those in the second category capture the relevant dispersal of genes instead of pollen(SOURCE). As a whole, these analyses are deficient for determining global isolation distances due to the small amount of data collected and the unique set of weather conditions that affected pollen flow for that particular experiment.

Theoretical models in contrast, allow one to use known physical parameters and relationships to approximate the actual distribution. Having thorough knowledge of fundamental determinants of particle dispersal, one can more accurately estimate the distribution of possible outcomes, especially those events that are rare in occurrence. These models also have the advantage of allowing for unique scenarios to be addressed by simply altering model parameters rather than conducting new field experiments.

Modeling Maize Pollen Dispersal

The Weibull distribution is used to represent the wind speed distribution (Seguro and Lambert). The equation

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

shows the construction of the distribution with k , the Weibull shape parameter; c , the Weibull scale parameter; and u , wind speed. It is important to note that only nonzero wind speeds are used in the calculation. The estimation of the shape and scale parameters

$$(2) \quad k = \left(\frac{\sum_{i=1}^n u_i^k \ln(u_i)}{\sum_{i=1}^n u_i^k} - \frac{\sum_{i=1}^n \ln(u_i)}{n} \right)^{-1}$$

$$(3) \quad c = \left(\frac{1}{n} \sum_{i=1}^n u_i^k \right)^{1/k}$$

are estimated using the maximum likelihood method described by Stevens and Smulders.

The physical dispersal of pollen is estimated by conducting a Monte Carlo simulation using a Lagrangian stochastic (LS) model. Here, the path of many individual particles rather than the concentration of a mass of particles are determined. A generalized first-order LS model takes the form

$$(4) \quad du_i = a_i dt + b_{ij} d\xi_j$$

$$(5) \quad dx = u dt$$

Here the change in velocity at time i , du_i ; is determined by the drift coefficient, a_i ; multiplied by the time step, dt ; and b_{ij} , a diffusion coefficient, times $d\xi_j$, increments from a Wiener process. The values of $d\xi_j$ follow a Gaussian distribution with mean zero and variance dt , with values of $d\xi_j$ independent of $\xi_j d\xi_k$, for $j \neq k$. So for each time period, dt , the movement of a particle, dx , is a function of the stochastic process (4).

The equations

$$(6) \quad dW = \left[-\frac{b_w^2}{2\sigma_w^2} W + \frac{1}{2} \frac{\partial \sigma_w^2}{\partial z} \left(\frac{W^2}{\sigma_w^2} + 1 \right) \right] dt + b_w d\xi_w$$

$$(7) \quad b_w = \left(\frac{2\sigma_w^2}{\tau} \right)^{1/2}$$

$$(8) \quad dX = U dt$$

$$(9) \quad dZ = (W - v_s) dt$$

which follow from Aylor, differ from the generalized model in that restrictions are placed on a_i and b_{ij} . The coefficient b_{ij} from (4) takes the form of (7) in order to uphold Kolmogorov's similarity theory assumption of choosing time increments within the sub-inertial time range. The term a_i is also altered in order to meet the well-mixed condition outlined by Thomson. The well-mixed condition is the most stringent criterion for such models and states that a particle that is well-mixed within a mass of particles will remain well mixed.

The wind speed profile represented by the Weibull distribution (1) provides the basis for the derivation of other necessary atmospheric values. The first of these is the frictionless wind speed, u^* , needed to find σ_u , σ_w , and T_l . Rearranging

$$(10) \quad u(z) = (u^* / k) \ln[(z - d) / z_0]$$

one can calculate the frictionless wind speed given the distance from ground level, z , the zero displacement level, d , and the roughness length, z_0 (Monteith). The zero displacement level for maize has been estimated at 1.7 and the roughness length to be .3 (Hosker and Lindberg). In the case of soybeans, z_0 and d take values of .13 and .47 meters (Perrier, et. al.). The value k , von Karman's constant, is approximately .4.

Using the value of frictionless wind velocity, one is able to determine the values of σ_w and T_l , the standard deviation of vertical wind velocity and the Lagrangian time scale, using

$$(11) \quad \sigma_w = 1.3u^*$$

$$(12) \quad T_l = \frac{ku^* z}{\sigma_w^2}$$

The model is modified to address the relatively large size of the maize pollen. Walklate recommended the adjustment of the variance of the fluid downward to reflect the drag associated with larger particle sizes. Wilson; however, found the difference between those with altered and unaltered variance negligible and thus the adjustment is ignored by the model. We include a scaled time step using the equation derived by Sawford and Guest and used by Aylor in his study of spore dispersal. Equations

$$(13) \quad \tau = fT_l$$

$$(14) \quad f = \frac{1}{\sqrt{1 + (\beta v_s / \sigma_w)^2}}$$

present the relationships between the the Lagrangian time scale, T_l and τ , the velocity time scale. In (9), β is a constant relating the Eulerian timescale to the Lagrangian timescale and is placed equal to 1.5 in this study as by Sawford and Guest, and Aylor.

Next, the deposition from the air onto either open ground or other crops is addressed. The deposition of pollen onto open ground and non-fertile maize occurs when the pollen crosses a certain height, z_s . This height is set equal the zero plane displacement level, d . From the literature these values are taken to be 0 for open ground, .47 for soybeans, and 1.7 for maize (McIntosh and Thom).

For deposition onto fertile maize, the biological processes involved are discounted. The probability of pollination of a plant by source pollen is defined as a ratio

$$(15) \quad P = Q_T / Q_V$$

where Q_T is the amount of transgenic pollen and Q_V being the total amount of viable pollen in the vicinity of the plant. However, not all pollen will still viable by the time it comes in contact with the fertile maize. This is accommodated by classifying all pollen that has been airborne for more than two hours, or seventy two hundred seconds, as an unviable transmitter of transgenes. The temporal condition is described by

$$(16) \quad Q_T = \{Q_R(0, H, 0) : Q_R(x, z_o, t), t \leq 7200\}$$

with $Q_R(0, H, 0)$ the quantity of pollen released at time zero at the source where x is equal to zero and z is the initial height, H .

It can be further assumed that the pharmaceutical maize seed used will make use of a biological mechanism, such as those described by Daniell, to reduce the likelihood of

gene dispersal. The mechanism used is assumed to be imperfect, failing a certain percent of the time. This failure results in the release of pollen containing restricted transgenes that can be transferred to other maize. Because the model is linear this probability can be adjusted for different failure rates in these biological mechanisms. For example if the biological process had a failure rate of 0.01 then the resulting probabilities would be one hundredth the size of those presented. The model can also be adapted to incorporate detasseling by dividing through by the rate of human error in the detasseling process.

The federal regulations that require a temporal separation of planting times of maize likely have further reaching effects. This results from the assumption that producers of pharmaceutical maize do not dictate the time of maize planting outside their field, but rather delay their planting relative to surrounding maize production by the time denoted by federal regulations. While federal timing conditions must be met within designated distances, it is possible that maize production beyond this distance, due to being planted relatively late or developing more slowly, share a period of fertility with the pharmaceutical producing crop.

To accommodate for the contemporaneous fertility of the pharmaceutical and neighboring maize crops, a distribution of periods of fertility is constructed. This distribution is derived using USDA Crop Progress Reports' data on silk emergence, a proxy for fertility, in the state of Iowa. The time of silk emergence is assumed to follow a normal distribution. A test plot planted twenty-eight days after those within one-half and on mile will share a period of fertility with fields outside the regulated one mile distance with a probability less than .01.

The final portion of the analysis is to compare the amount of viable pharmaceutical pollen to the amount of non-pharmaceutical pollen located in the vicinity of receptive non-pharmaceutical silks. Adjustments to equation (15) must be made to account for the dispersal of pharmaceutical maize grown in accordance with federal regulations. The first modification is made to address the one-percent likelihood that genetic seepage occurs, P_S . The second adjustment is made to account for the possibility of contemporaneous fertility, represented by the probability P_F .

$$(17) \quad P = P_F \left(\frac{P_S Q_T}{Q_A} \right)$$

Industry groups such as the North American Millers Association have set zero tolerance levels for contamination. This probability of any contamination can be determined by

$$(18) \quad P_C = (1 - (1 - P)^K)$$

where P_C is the probability of contamination and K is the number of kernels in the receptor crop. Clearly, as the number of kernels, K , approaches infinity, the probability of contamination nears one.

Calibration of the model. The model is calibrated using data from Bateman. In this study, maize pollen was collected over the course of five days at sites spaced twenty feet apart up to 120 feet away from the source plot in three cardinal directions. Calibration is done by comparing the ratio of pollen located downwind from the plot relative to the amount of pollen found at the first site outside the maize plot, twenty feet from the source.

It should be noted that the first three experiments were conducted under relatively mild winds. This is evident in the higher ratio that is present at distances of 80 and 100

feet for the fourth trial. It should be noted that Bateman did not provide numerical descriptions of weather behavior, but rather verbal accounts for each day of pollen collection, including wind direction. In cases where the wind was not blowing in a cardinal direction, data from the nearest cardinal direction is used.

Simulations using the advection-diffusion model were conducted by creating sinks elevated three feet from the ground and spaced twenty feet apart away from the plot. For each of three wind speeds, 100,000 grains of pollen were released at a height of 1.7 meters above the ground. The ratio of pollen captured by each sink relative to the one located twenty feet from the source is presented, with the ratios from Bateman, in figure 1. The results show that the model closely replicates the Bateman results given the limited data that he presents. This is especially true at larger distances which are of concern in this model.

Figure 1.

Insuring against Losses from Contamination

Though equation (18) rules out the possibility of eliminating pharmaceutical pollen contamination in a theoretical sense, in cases where minute levels of contamination are acceptable it allows for the construction of risk management tools that offset financial losses that would result from contamination. While the contaminated maize could be blended to meet minimum acceptability levels, possibly resulting in costs less than those of destroying the crop, this practice is not permitted. Instead, it is assumed that the crop is purchased and destroyed immediately following knowledge of possible contamination.

Since the amount the acceptable threshold of genetic contamination, C , the ratio of contaminated kernels to total kernels, decreases as pollen moves away from the source,

there must be some distance, D , where the amount of contamination is acceptable. Although the crop produced from the test plot to distance, D , is not acceptable commercially, the producer can be reimbursed $R * D$, where R is the revenue from the crop per unit of distance, and be no worse off. The premium, Φ , to insure against such losses is presented in (19). Expected revenue, denoted $E(R)$, can be determined using previous years production data and the expected market price of the commodity. While the expected distance, $E(D)$, can be determined with local wind data and the theoretical model previously presented.

$$(19) \quad \Phi = E(R)E(D)$$

Results

The data used for the calculation for the Weibull distribution were collected at the Boone Municipal Airport in Central Iowa. Wind speed, in knots, were collected at twenty minute intervals in mid-morning from mid to late July from 1995 to 2002 are used. This is the approximate time of maize pollination during recent years in Iowa (Miller).

Figure 2.

From this distribution, 1,000 wind speeds are drawn. For each of these wind speeds, the dispersal of 1,000 grains of pollen is simulated and the location of their point of deposition recorded. Figure 2. presents the physical distribution of viable pollen predicted by the model 500 to 2000 meters from the source for crops grown under controlled and uncontrolled pollination as defined by APHIS. Under current guidelines, pharmaceutical maize produced under controlled pollination, where either bagging or detasseling occurs, may be located as close as one-half mile from neighboring corn if it is seeded at least twenty eight days before or after the neighboring field. When pollination

is not controlled, no maize is allowed within one mile of the of the test plot. In either case, fifty feet immediately adjacent to the plot must be left fallow, while no federal regulations apply to distances beyond one-mile from the plot. These cases will be referred to as “controlled” and “uncontrolled” pollination, respectively.

The detasseling or bagging under controlled pollination is assumed to have a one-percent failure rate. As a result, the values for controlled pollination, read using the axis on the right side of the chart, are approximately one one-hundredth of the level of the pollen from uncontrolled pollination. The location of the transition from soybean to maize production is apparent from the spikes which occur at 800 meters for controlled pollination and 1600 meters for uncontrolled pollination.

Figure 3.

With knowledge of the dispersal of maize and an acceptable threshold for transgene presence, the probability of contamination can be determined. When combined with the expected yield and price of commodity corn an insurance policy can be constructed in which the owner of neighboring fields will be no worse off after contamination than if the crop was harvested and sold. We assume an expected yield of one-hundred fifty bushels per acre and a price of two dollars per bushel.

It is assumed that the transgenic and neighboring plants normally release the same amount of pollen. Under controlled pollination plants are detasseled or bagged with a one-percent error rate, in other words they release one hundredth the amount of pollen they would otherwise. All transgenic plants are also assumed to be male sterile, but that technology is expected to fail one-percent of the time. The degree of contamination is dependant on the size of both the transgenic and neighboring fields. We set the size of

the transgenic field at one acre square with thirty six, sixty meter long rows. The receptor fields are forty acres square.

The cost of insuring against genetic contamination is presented in table 1. Dollar values are given for the fair value of insuring one acre of transgenic crop against contamination of neighboring fields. No values are reported when the value of insurance is nil. In the case of controlled pollination and a tolerance level of one per five hundred million (2.00E-09) the cost of insuring against contamination of the first field is \$11.52, the second \$0.14, and nothing for the third which under even the most rare wind condition will not be contaminated. Thus, for \$11.66 per acre the producer can protect against all losses that would occur. At higher tolerances more than the three fields may be contaminated although the fair value of insurance for these cases is presented.

Two items of this presentation of the data are of particular note. First, the cost of insurance quickly increases beyond a certain tolerance level. This is evident in the relatively high values when the tolerance is greater than one per fifty million. At these levels insuring against losses are likely cost prohibitive. Second, the assumed failure rates of detasseling and male sterility with values of .01 are extremely high.

Table 1.

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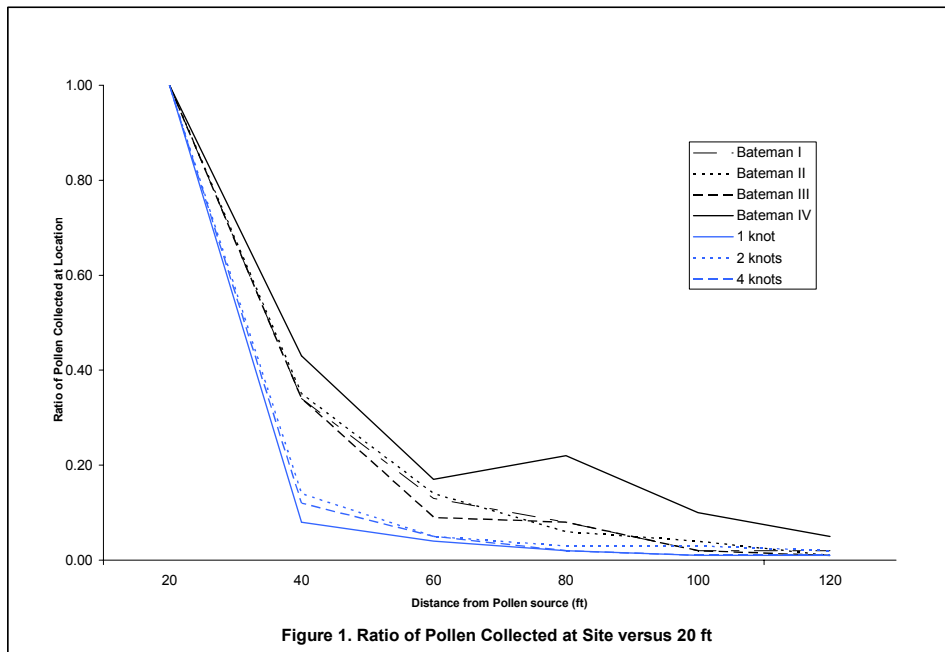
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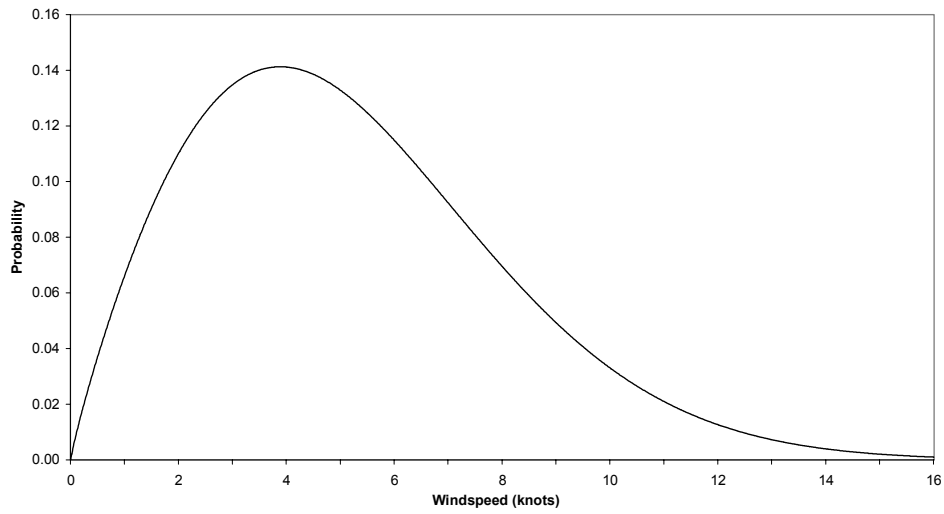


Fig. 2 Distribution of Central Iowa Wind Speeds (knots) during Periods of Corn Pollination 1995-2002

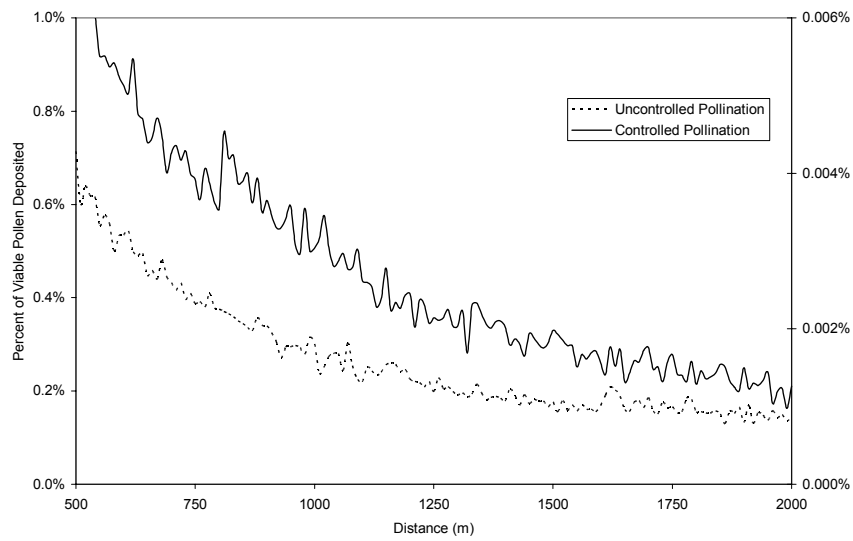


Figure 3. Long Distance Pollen Dispersal

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

Tolerance (C)	Controlled Pollination			Uncontrolled Pollination		
	Field 1	Field 2	Field 3	Field 1	Field 2	Field 3
2.00E-07	-	-	-	0.06999	-	-
1.00E-07	-	-	-	0.50643	0.18869	-
2.00E-08	-	-	-	2003.43	1730.43	1042.80
1.00E-08	0.00039	-	-	4268.859	4092.583	4006.853
2.00E-09	11.52838	0.13745	-	4359.427	4179.914	4049.519
1.00E-09	17.87641	9.22446	0.92088	4313.94	4224.184	4075.309