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Title: When to apply strobilurin fungicides for managing common rust of sweet corn

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Abstract:

Many preferred sweet corn hybrids grown in New York are susceptible to common rust, and therefore growers must use fungicides for effective disease management. Strobilurin fungicides work well, but are too costly to be applied to the crop more than once a season. The question then becomes one of the best timing to apply that single spray. If the application is made too early, rust may still build to damaging levels; if too late, rust levels may not be reduced sufficiently. A model was constructed to simulate common rust epidemics, and used to examine whether fungicide applications made according to pre-specified disease thresholds resulted in cost-effective disease control. Simulations were done for action thresholds between 1 and 15% disease severity. Simulation results indicated a linear increase in the chances of cost-effective rust control when the action threshold was increased from 1 to 15%. In summary, simulation results suggest that a strobilurin fungicide application made during the early stages of a rust epidemic is at greater risk of losing money because of ineffective disease control compared to waiting to make the application if and when disease severity increases to higher levels.

Background and Justification:

Growers invest a lot of effort in common rust control. Rich Wildman (Agricultural Consulting Services, Inc.) estimates that over the last five years 15% of scouted sweet corn received a fungicide spray recommendation. According to a report published by the CropLife Foundation, some 24,750 out of 104,445 acres of sweet corn across the Northeast are treated with fungicides (23.7% of the acreage). Assuming that fungicide application averages $25 per acre, the data indicate that each year Northeast growers spend over $618,000 trying to control common rust.

Strobilurin fungicides registered in New York (Quadris, Headline) are very effective in drying up rust pustules, preventing them from producing more spores. Strobilurins are also environmentally safer than the EBDC fungicides maneb and mancozeb. Unlike the EBDCs, strobilurin products are too expensive to be applied more than once during the season. Growers do question whether fungicide application is worth the effort, as it sometimes seems that reducing rust severity does not improve yields significantly over unsprayed fields. The problem may be one of spray timing: too early, and rust may still build to damaging levels; too late, and yield may have already been reduced.

An action threshold can be defined as the rust severity at which a fungicide application would provide cost-effective control. Control is cost- effective if the value of the yield improvement due to the fungicide intervention exceeds the costs of application. Previously developed action thresholds for common rust are outdated for several reasons: (1) they were developed for mancozeb and propiconazole, which could feasibly be applied more than once, but which are no longer preferred by growers, and which do not have the same curative properties as the strobilurins; (2) they were based solely on disease reduction and did not explicitly factor in the costs of application; (3) they were formulated on a limited range of field trials, and so do not account for the possible chance of success or failure in disease control in spite of adherence to an action threshold.

However, a recent study by Shah & Dillard (2006), funded by the Pennsylvania Vegetable Marketing and Research Program and the Pennsylvania Vegetable Growers Association, showed that in processing sweet corn a single strobilurin spray against common rust can be cost-effective 90% of the time if the spray resulted in a 12% reduction in rust severity at least one week before harvest. An action threshold should therefore achieve a minimum of a 12% reduction in rust severity compared to the unsprayed situation.

Objectives:

1. Synthesize, via computer modeling, the existing knowledge on the rates of common rust progression in the absence of and in response to strobilurin fungicides.
2. Apply the model to calculate probabilities of rust control exceeding the costs of application in response to a single strobilurin application.
3. Project Evaluation: does the model suggest the existence of field-measurable action thresholds?

Procedures:

Objective 1.

Plant disease progress curves have been described by any number of growth curves. Commonly used growth curves include the monomolecular, logistic and Gompertz (Campbell and Madden, 1990). The parameters of relevance in describing disease progress curves are the initial amount of disease, the rate of disease increase, and the maximum amount of disease attained (van Maanen and Xu, 2003). The first step then was to examine existing data on common rust disease progress to ascertain which growth curve model would be most appropriate for modeling disease progress. There were 16 data sets from 1997 to 2006 available. Of these, seven represented unsprayed common rust disease progress (no intervention), and nine represented disease progress in which there was a single strobilurin spray (intervention) at some time during the course of disease progress (Table 1). All hybrids shown in Table 1 are considered susceptible to common rust. It was apparent that maximum disease severity (y_{max}) was <100%. Disease progress curves also showed neither an inflection point nor asymptote, which are characteristic features of the logistic and Gompertz growth curves. It was found that disease progress curves could be described by a simple exponential growth model:

[illegible] (1)

where y is disease severity at time t, y_0 is the initial amount of disease, r is a rate parameter, and t

is days after planting. Fitted parameters are shown in Table 1.

Table 1. Exponential growth curve parameters fitted to common rust disease progress data

					Exponential curve parameters	
Data set	Hybrid	Year	c[1]	y_{max} (%)	y_0 (%)	r
1	Zenith	1997	1	19.54	0.3512	0.0474
2	Rival	1997	1	6.89	0.6005	0.0289
3	Zenith	1998	1	19.39	0.0062	0.0902
4	Zenith	1999	1	2.26	0.1068	0.0408
5	Silver Queen	2000	1	24.30	0.0404	0.0687
6	Bold	2001	1	77.11	0.5154	0.0597
7	Bold	2001	0	33.66	1.7600	0.0651
8	Snow White	2001	0	65.00	2.5016	0.0469
9	Snow White	2001	0	31.00	5.0000	0.0516
10	Snow White	2001	0	25.33	15.0000	0.0234
11	Sterling	2001	0	59.00	3.7489	0.0400
12	Sterling	2001	0	20.33	5.0000	0.0360
13	Sterling	2001	0	30.67	15.0000	0.0287
14	Bold	2006	1	22.09	0.8993	0.0402
15	Bold	2006	0	14.15	3.1600	0.0413
16	Bold	2006	0	19.96	14.1400	0.0166

[1] c = 1 if disease progress represented an unsprayed situation. c = 0 if a spray had been applied. If c = 0, y_0 was fixed at the disease severity at the time the spray was applied, and data modeled from the time of application onwards.

The y_0 values for disease progress curves representing unsprayed situations were generally <1%, consistent with the idea that rust epidemics begin from very low initial populations. The exceptions are data sets 8 and 11; here the relatively higher values of y_0 (these were unsprayed plots) reflected the fact that the plots from which the data were collected were artificially inoculated to start epidemics. These two data sets were removed before further analysis.

Data plotting revealed that y_0 and r were related, but differently in sprayed and unsprayed situations. Figure 1 shows a clear separation of (y_0, r) values for unsprayed disease progress curves, and disease progress curves post-application of a strobilurin fungicide. For the unsprayed disease progress curves, $y_0 < 1$, but was related to r by an exponential decline model:

(2)

where a = 1.5397 and b = -29.2281. The parameter r is restricted to the range (0.028, 0.092). A frequency distribution of 5,000 simulated disease progress curves based on Equation 2 showed that the parameterization was realistic (Figure 2), in that most simulated progress curves led to final disease severities <40%, in accordance with observed common rust epidemics (Table 1). The minimum simulated disease severity was about 6.4%.

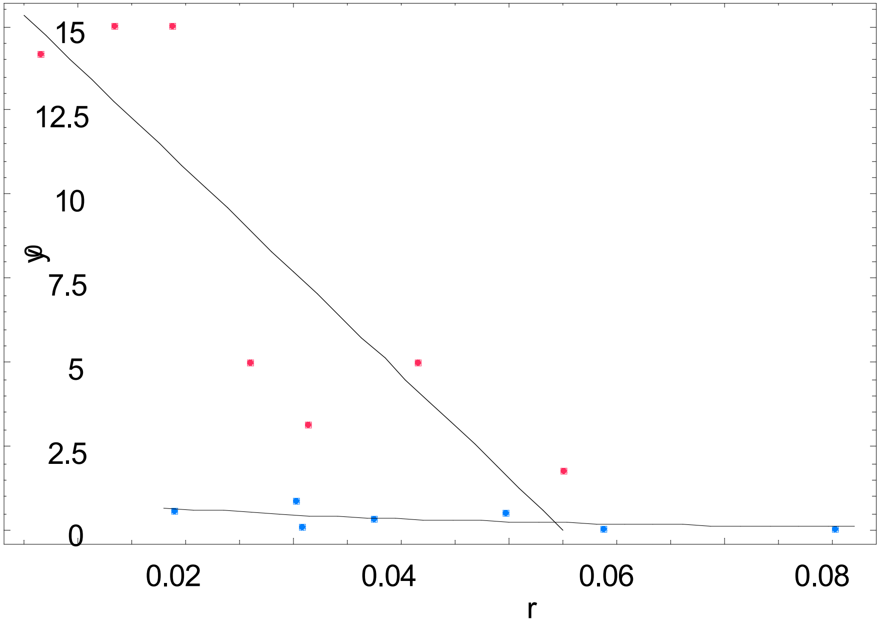

Figure 1. (y_0, r) values of the exponential growth curve fitted to common rust disease progress in unsprayed (blue dots) and sprayed (red dots) situations. The lines are linear and exponential decline curves fitted to the data independently.

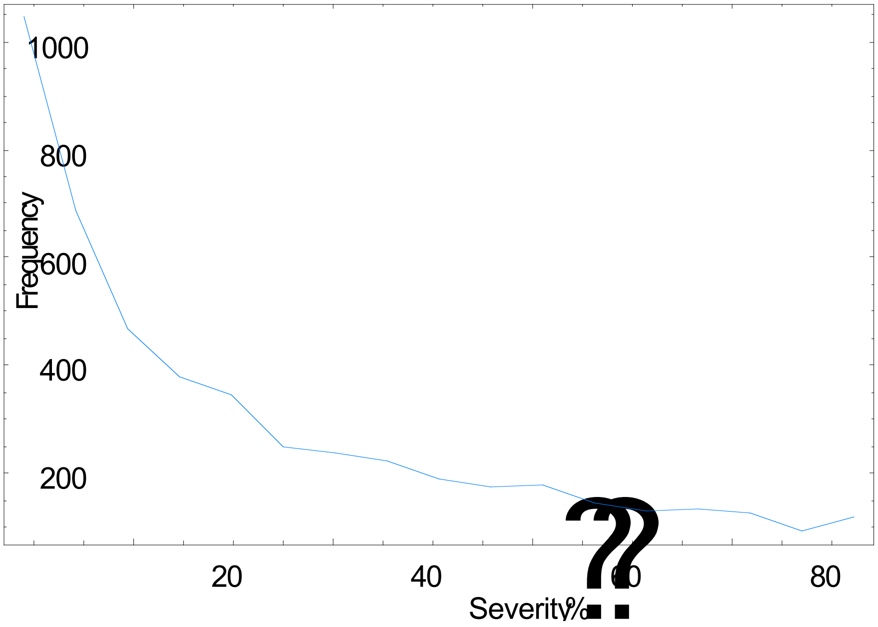

Figure 2. Frequency distribution of final disease severity from simulations representing non-intervened common rust disease progress, as described by Equations 1 and 2. Notice that most simulated progress curves lead to final disease severities that are less than 40%.

For disease progress post-application of a strobilurin fungicide, the y_0 versus r relationship was linear:

(3)

where in this case $y_0 < 15$ (Fig. 1). Equations 1 to3 form the basis then for modeling common rust disease progress when fields are unsprayed, and after the application of a fungicide.

Objective 2.
The model structure will be described. Let $r1$ be the initial rate of disease progress (also the rate in the absence of any fungicide intervention). An initial value for $r1$ was generated from a uniform probability distribution, assuming $r1$ was confined to the range (0.028, 0.092), as seen in Fig.1. The corresponding value for y_0 was calculated from Equation 2. A disease threshold (y_t) was chosen. The time t_{lim} at which y_t is reached can be calculated as:

(4)

t_{lim} therefore represents the time (days after planting) at which the action threshold for fungicide application is reached. However, in reality fungicide applications are made some time after disease has crossed the action threshold, due to weather, logistics, or otherwise. The model assumed that this time delay (t_d) between reaching the action threshold and the actual application of a fungicide in response to the threshold being reached was between 1 to 6 days. t_d was chosen from a uniform probability distribution scaled so that t_d was in the range (1, 6). That is, disease was allowed to progress for another t_d days beyond t_{lim}.

At $t_{\text{lim}} + t_d$ days, disease progress was altered in response to a fungicide application. The disease severity at $t_{\text{lim}} + t_d$ was taken to be the new y_0 value for post-application disease progress, and the corresponding value of r was calculated from Equation 3. Disease progress (unsprayed and sprayed situations) was allowed to continue for a total time period of 80 days (representing disease progress up to 1 week before harvest). The final disease severity difference between the disease progress curves representing the sprayed and unsprayed situations was then calculated.

Objective 3.
For each action threshold, 5,000 disease progress simulations were done, which enabled the calculation of the percentage of times a fungicide application led to at least a 12% reduction in final disease severity, conditional upon the action threshold being reached (i.e. not all simulated disease progress curves reached the action threshold). This cost-effective return rate was plotted against action threshold to identify whether there was a particular action threshold which maximized the cost-effective return rate.

Results & Discussion:
Figure 3 shows the frequency of the simulated differences in final rust severities between sprayed and unsprayed fields when applications were made at one of the following action thresholds: 1, 5,

10 and 15%. It is apparent that the action threshold of 1% leads to the risk of negative control, i.e. rust severity post-application can eventually exceed that in sprayed plots. This result will require empirical validation. Figure 3 also shows that in some cases the severity reduction in response to a strobilurin spray can be quite high, over 40%. Figure 3 does not however distinguish between situations in which the action threshold was exceeded (triggering a fungicide application) and those in which disease severity never increased to above the action threshold (no spray would have been applied).

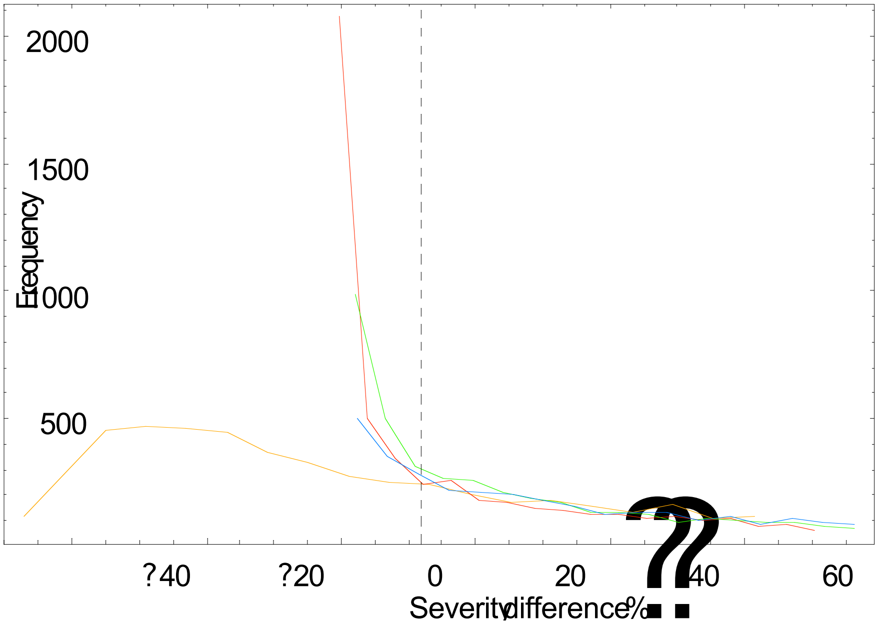

Figure 3. Frequency plot of the difference between unsprayed and sprayed final common rust severity when the fungicide application was made in response to a specified threshold being met: 1% (orange line), 5% (red line), 10% (green line), 15% (blue line). The dashed line indicates 12% severity difference, which is the minimum difference for a 90% cost-effective return rate on a fungicide application.

Simulated data were therefore analyzed in terms of (1) the percentage of simulated disease progress curves in which the final disease severity exceeded the action threshold; and (2) for those disease progress curves in which a fungicide application was triggered in response to the action threshold being exceeded, was the resulting reduction in final disease severity greater than 12%. As noted above, the minimum final disease severity allowed by the simulation structure was about 6.4%. Therefore, action thresholds <6% were always met, as indicated by Fig. 4. As the action threshold increased to 15% there was a corresponding drop in the percentage of simulated disease progress curves in which the final disease severity was above the action threshold (Fig. 4). These represented cases in which epidemics were not severe enough to warrant the application of a fungicide depending on the particular action threshold. Simulated data were then restricted to those situations in which the action threshold was exceeded, in which case a fungicide would have been applied, thus modifying the disease progress curve. For those situations, the percentage of cases in which the disease severity reduction was >12% increased in a linear manner as the action threshold was increased from 1 to 15% (Fig. 5). The results indicate that holding off a fungicide application until disease severity increases to 15% (if it does) can lead to a cost-effective rate of return of up to 60% (Fig. 5).

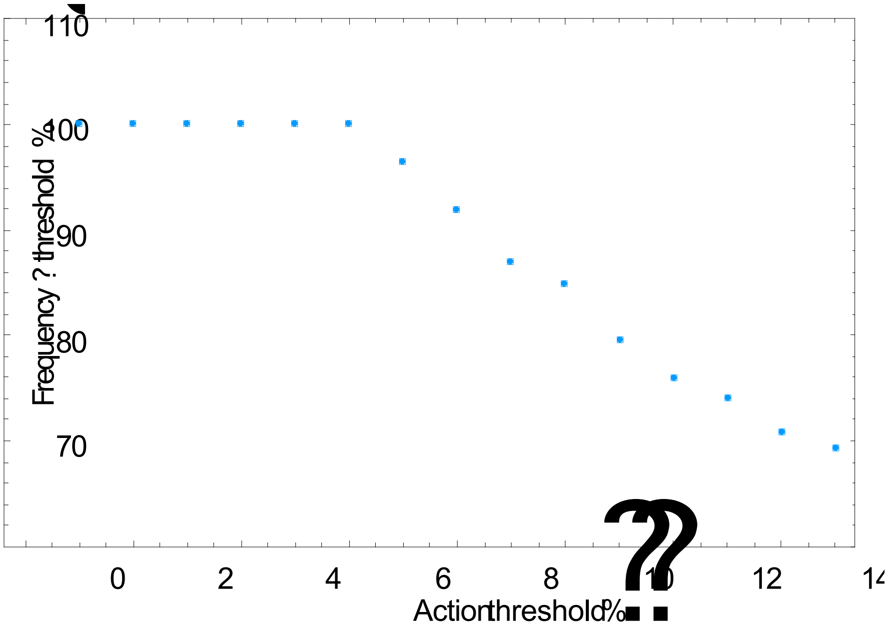

Figure 4. Frequency of simulated final disease severities exceeding a specified action threshold. Note that simulated final disease severities were always above about 6%.

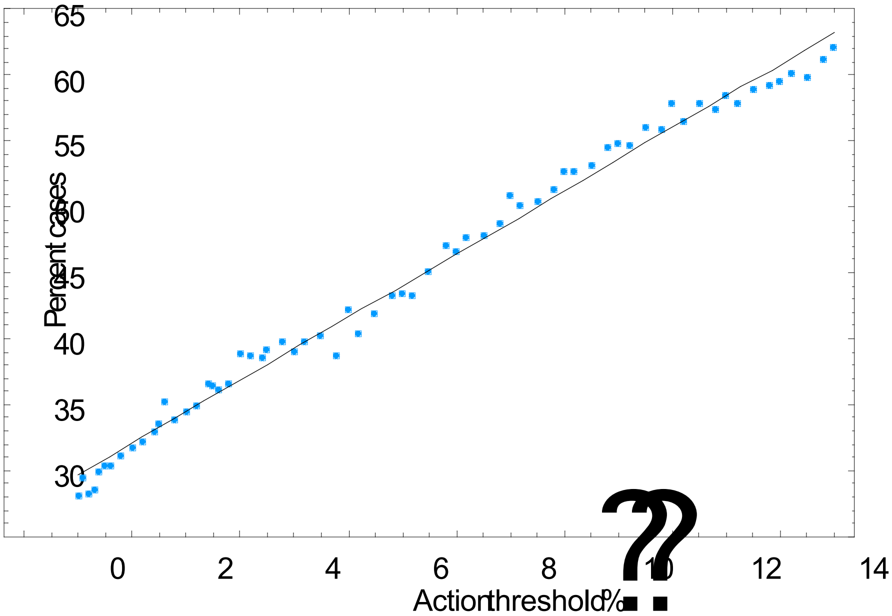

Figure 5. Percent of simulations in which a fungicide application in response to an action threshold led to a final disease severity reduction >12%, conditional on the action threshold being exceeded in the first place.

The model does have certain limitations. One obvious limitation is the relatively few data sets available for parameter estimation. The limited number of available data sets probably led to conservative restrictions on the parameter space for y_0 and r. This was the reason why simulations were not done for action thresholds above 15%. Field validation is certainly desirable, but given the wide range of possible disease progress curves (as seen in the simulation results) it may be a difficult task to collect enough validation data to verify the trends the simulations indicate.

Nevertheless, the simulation results do indicate that the greatest chances of cost-effective return on a strobilurin spray for common rust control (i.e. minimum risk of financial loss on the spray) are achieved if the spray is delayed to if and when an action threshold of 15% rust severity is reached.

References:

Campbell CL and Madden LV (1990) Introduction to Plant Disease Epidemiology. John Wiley & Sons, New York

Shah DA and Dillard HR (2006) Yield loss in sweet corn caused by *Puccinia sorghi*: A meta-analysis. Plant Disease 90:1413-1418

van Maanen A and Xu XM (2003) Modelling plant disease epidemics. European Journal of Plant Pathology 109:669-682

Project Locations:

Part of the data set (Table 1, 2006 data) came from a field experiment done in Le Roy, Genesee Co. The results of the simulation effort are applicable to all processing sweet corn regions in the Northeast.

Photographs:

Some jpeg images of common rust at the Le Roy trial will be emailed along with the electronic copy of this report.