A Model of Corn Growth and Disease Development for Instructional Purposes

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Computer models that can be used to help students understand principles of disease management and basic epidemiology are valuable instructional aids (14). Such models should reflect reality, be easy to use, and be readily accessible. One model, available for use on a microcomputer, is APPLESCAB, a pest management program for control of scab in apple orchards (1). Although APPLESCAB provides an excellent understanding of the complex nature of pest control in apple orchards, we felt that students in geographic areas where apples are not widely grown might hesitate to work with this model. Corn (*Zea mays* L.), however, is a crop that is familiar to many students, and disease management is commonly practiced in certain corn crops. Corn inbreds and sweet corn, for example, are high-value crops and may be severely affected by diseases, including northern leaf blight (NLB) caused by *Exserohilum turcicum* (Pass.) Leonard & Suggs (3,4).

Field studies of NLB on corn inbreds in Illinois (3) provided a model system for which a computer simulation of disease development was constructed. This disease model was integrated into the corn growth model, CORN-AP (8), so that disease development and yield losses, along with disease management, could be simulated on microcomputers. Although the resulting instructional model, CORN-Ill, was not intended to be accurate in estimating disease or losses due to disease, its results are expected to reflect the relative influence of weather, cultivar, and management on disease progress.

CORN-AP, the growth model

CORN-AP, a simulation model of corn growth and development, was developed to "allow users to become familiar with microcomputer models, their limitations and potential" (8). CORN-AP describes the morphology of the corn plant, simulates daily leaf area increase, and calculates dry matter accumulation based on intercepted solar radiation, water stress according to available soil moisture, and the evapotranspiration rate. CORN-AP simulates daily corn growth and development with daily weather, crop planting environment, and management data. Feedback mechanisms in the model can be employed to correct simulated leaf areas, date of germination or anthesis, etc., according to field observations. We chose this model because its structure allowed incorporation of a disease model and host growth could be simulated under different conditions and management options.

Environmental descriptors in CORN-AP, such as solar means and amplitudes, soil evaporation coefficients, soil/air temperature ratio, etc., were changed to reflect conditions in Champaign County, Illinois. Real climatic data files for each growing season from 1984 through 1986 and stochastic "normal" climatic data files were constructed for two locations (Monmouth in northwestern and Urbana in east central Illinois) from published state climatological data (National Climatic Data Center, Asheville, NC). The climate data files include daily values for maximum and minimum temperatures and relative humidities, precipitation, and a relative dew indicator.

Table 1. Values of environmental parameters affecting the establishment of new northern leaf blight lesions in the model CORN-Ill

Parameter	Variable	Unit	Limiting value
Dew indicator	DEW	None[a]	DEW <=0*[b]
Precipitation	R7	Centimeter	R7 <=12.7*
Relative humidity			
Maximum	RH1	Percent	RH1 <94*
Minimum	RH2	Percent	RH2 <60*
Temperature			
Maximum	T1	Centigrade	T1 >35
Minimum	T2	Centigrade	T2 <10

[a] Relative dew indicator, where 0 = no dew and 5 = very heavy dew.

[b] Variables marked with an asterisk interact and must all be limiting to prevent an increase in lesion number.

CORN-Ill, the disease model

A disease model was developed and incorporated into CORN-AP as a subroutine. Simulated disease was interfaced to host growth at specific developmental stages in the maize life cycle. Points of interface were established from the results of previous research (3). The modified CORN-AP model, with the disease subroutine, is referred to as CORN-Ill. The disease model is initiated by: 1) simulating inoculation at a given date or 2) specifying a date and "observed" disease severity. Inoculation may result in a maximum of 2% disease severity, after a latent period, when conditions are optimal for disease development. The disease severity that results from inoculation is also corrected for plant growth during the latent period. After initiation of disease, daily climatic data are checked for conditions favorable for infection. Infection is the result of many processes not considered separately in the model, including sporulation, dissemination, conidial germination, and mycelial growth within host tissue. These processes ultimately lead to an increase in lesion numbers. Increase in NLB severity is due to new lesions as well as lesion expansion, and both types of increase are described by mathematical models in the disease subroutine of CORN-Ill. Increase due to new lesions is modeled logistically (11), with symptom expression occurring after a calculated latent period. Lesion expansion is calculated from a linear model (15).

The logistic model, for increase in lesion numbers, is updated only when there is sufficient moisture (dew, rainfall, and relative humidity) (Table 1) for conidial germination and appressorial formation (10). Numbers of new lesions are then decreased in proportion to the number of degrees in temperature from optimum, 20 C (10). The period of time until areas of new lesions are added to simulated disease severity (= latent period = 6 days at optimum temperature) is increased in proportion to degrees of temperature from optimum.

The second mathematical model, for increase in lesion size, is linear and is affected only by temperature. Optimal lesion growth occurs when minimum temperature is above 20 C and maximum temperature is below 28 C. Lesion expansion stops when minimum temperature is less than 15 C and maximum temperature is greater than 35 C. Simulated increases in disease severity due to lesion expansion are manifested in the next time interval.

Rates of increase for the two submodels were initially estimated from data reported elsewhere (9,10), then fine-tuned by verifying with Urbana 1985 field data. Both models are based on actual necrotic area (square centimeters) caused by disease rather than the percentage of diseased leaf area. Enlargement of corn leaves, before tasseling, may be more rapid than the increase in the percentage of diseased leaf area; this may result in the calculation of a negative rate of disease increase (16). Use of unit rather than percentage of diseased area prevents calculation of such negative rates of disease increase.

Disease control. Users can specify the relative resistance of the simulated crop by entering a constant, 0–5, with 0 simulating complete resistance. They also can specify one of two fitness levels for the pathogen (12), in the event that a new, more virulent race develops. Rate parameters in both mathematical submodels are adjusted upward if the simulated pathogen has high fitness and adjusted downward with increasing levels of resistance. Fungicidal disease control options also can be simulated, along with "scouting" for disease. Users can simulate application of either a protectant or a systemic fungicide. Parameters for simulating properties of fungicides were generalized for modeling purposes based on greenhouse and field observations with fungicide tests (2); no specific fungicide was represented. The protectant fungicide has a simulated residual effect for 5 days and reduces only the number of resultant new lesions. The systemic fungicide reduces both the numbers of new lesions and the rate of lesion expansion and has a residual effect for 15 days.

Simulating disease effects on yields. In CORN-Ill, disease has a direct effect on the plant's total photosynthetic leaf area prior to anthesis. After anthesis, percentage disease severity is based on maximum leaf area of the plant, and disease affects yields by 1) decreasing potential kernel numbers per plant and 2) decreasing individual kernel weight. In field epidemics, decreases in kernel numbers were most highly correlated with disease severity near the end of anthesis (3). This effect is simulated by decreasing kernel numbers by 1% for each 1% disease severity (DSU) on the day of initiation of silking.

Kernel weight was shown to be most highly correlated with assessments of disease severity made 4–6 wk after silking (early dent [6]). Loss models previously reported (3) were critical-point models that indicated as much as 0.75% loss in kernel weight for every DSU above 36.4% severity. The model assumes a more dynamic effect of disease on kernel weight and decreases weight by 0.7% per DSU greater than 40% each day of plant development after the blister stage.

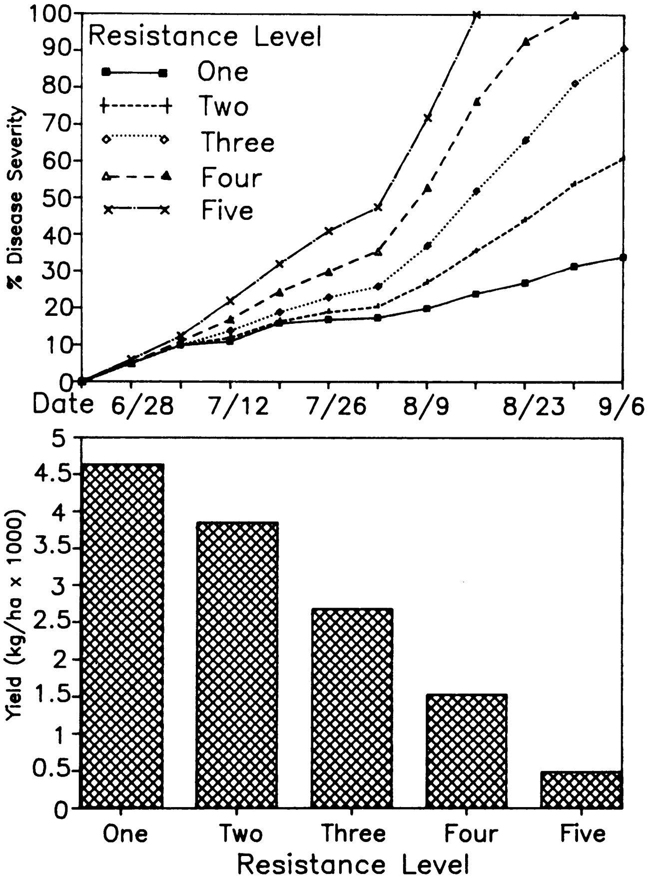

Fig. 1. The effect of five levels of simulated relative resistance, with "one" representing high resistance, by CORN-Ill with identical conditions and varietal characteristics on northern leaf blight progress and yields.

Sensitivity analysis and validation of CORN-III

CORN-Ill simulated differential corn growth and development with different climatic data and with various

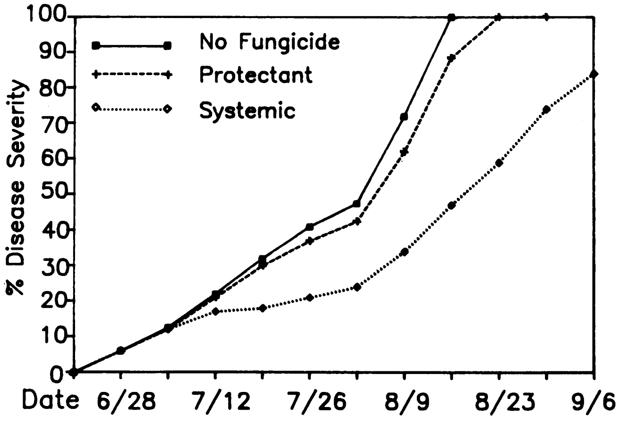

Fig. 2. The effect of biweekly applications of a protectant or a systemic fungicide vs. no fungicide applications on northern leaf blight disease progress on corn, simulated by CORN-Ill with identical parameters.

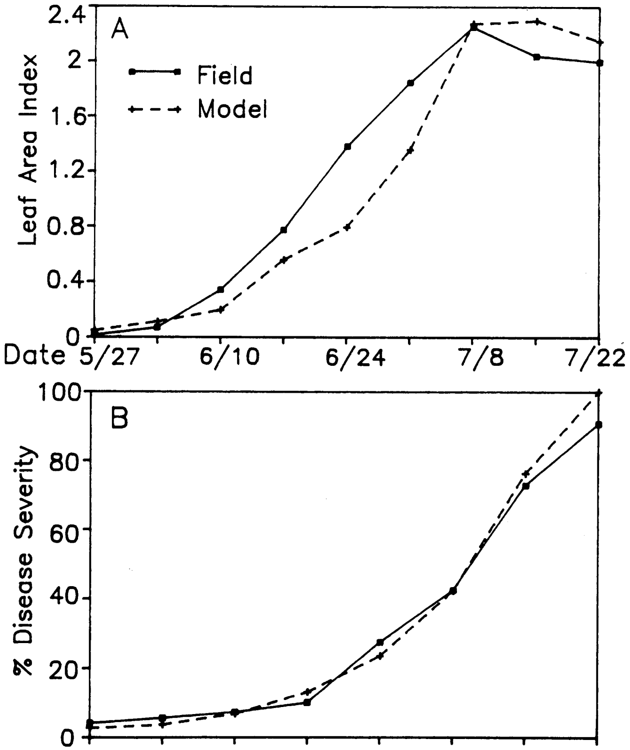

Fig. 3. Comparisons of field measurements and simulated (**A**) corn leaf areas and (**B**) northern leaf blight disease development, based on environmental conditions from Urbana in 1986 and on characteristics describing the corn inbred A632.

simulated genotypic characteristics. Certain genotypic characteristics of the crop, such as relative maturity, total number of leaves, and size of the first leaf (which ultimately affected total potential leaf area), had little or no effect on NLB epidemics simulated by CORN-Ill. Higher levels of resistance, however, resulted in less severe simulated epidemics and greater simulated yields (Fig. 1). Similarly, epidemics simulated with high fitness were more severe than those simulated with low fitness. Disease progress was less with simulated applications of systemic or protectant fungicides at 2-wk intervals than with no fungicide applications (Fig. 2); the systemic fungicide was more effective than the protectant fungicide.

Data from field experiments previously described (3) were used to validate CORN-Ill. Field studies consisted of two corn inbreds grown in six environments (3 yr, 1984 through 1986, at two locations, Monmouth and Urbana). Different levels of disease were obtained in each of the inbreds by inoculations and fungicide applications. Two fungicides were used at recommended rates, a protectant (mancozeb) and a systemic sterol-biosynthesis inhibitor (propiconazole). Leaf areas were measured from emergence to completion of anthesis in 1985 and 1986, disease severity was assessed weekly, and yield components and total yields were evaluated in all 3 yr.

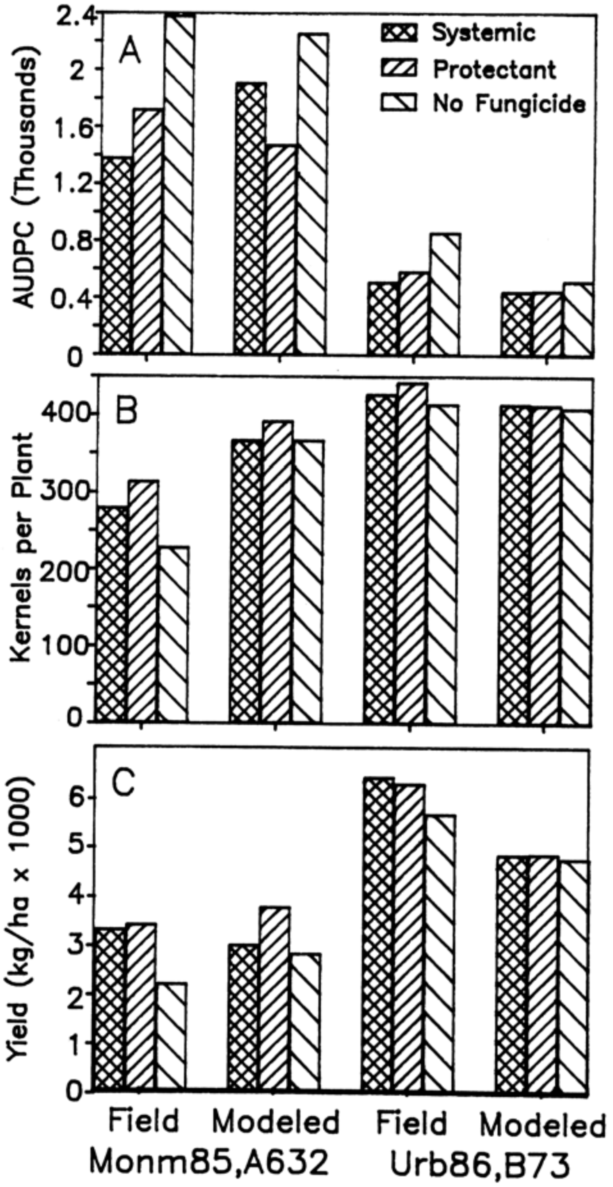

Fig. 4. Comparisons of treatment differences observed in field trials on corn and simulated by CORN-Ill on: **(A)** areas under the disease progress curves for northern leaf blight, **(B)** kernel numbers, and **(C)** yields on corn inbred A632 at Monmouth in 1985 and on B73 at Urbana in 1986. Systemic = inoculated, systemic fungicide applied at 3-wk intervals, initiated on observation of disease; protectant = inoculated, protectant fungicide applied weekly, initiated on observation of disease; and no fungicide = inoculated, no fungicide applied.

To validate CORN-Ill, simulated results must be shown to compare favorably with field data not used in model development (13). Growth of the inbred A632, as measured in the field and simulated for Urbana in 1986, was accurately simulated by the model. Disease development, simulated as inoculated, untreated field plots, was also accurately reflected (Fig. 3).

Disease control treatments applied in the field also were simulated with CORN-Ill. Areas under disease progress curves (AUDPCs), kernel numbers per plant, and yields in kilograms per hectare at 15% moisture for each of the treatments on two inbreds in different environments differed from observed results. Relative responses among treatments, however, were similar between actual and simulated values (Fig. 4). For example, highest AUDPCs, lowest kernel numbers, and lowest yields were observed in inoculated, untreated (no fungicide) field plots and were simulated by CORN-Ill.

Summary

CORN-Ill accurately simulated corn growth and NLB epidemics with input values that re-created field experiments in Illinois. We were, therefore, confident that students in a course offered in the Department of Plant Pathology at the University of Illinois could use CORN-Ill for "conducting" research in experiments of their own design. This simple crop simulation model allowed the students to visualize the growth of a plant (7) and the increase in disease severity in response to different environmental conditions or management practices, without spending the resources needed for field trials.

CORN-Ill currently lacks the accuracy needed to predict the effects of disease and disease control on final yields. It does, however, have potential for use in predicting relative yield responses to management practices. In the process of developing the model, subject areas were eludicated in which specific quantitative relationships between epidemiological variables were lacking (5,14). For example, the quantitative effect of increased pathogen fitness on epidemics is unknown. Once research is conducted to elucidate these relationships where data are lacking, a more accurate predictive computer model can be developed.

CORN-Ill is a user-friendly model that requires no special computer knowledge to run. The model has built-in checks for initialization data, and the simulator will not run without certain data. Values for input parameters are limited to a certain range concerning disease development so that errors can be avoided. Total leaf area and diseased leaf area for each simulated day are presented on the computer monitor and are printed for alternate days when a user wants a hard copy. Hard copy of the data allows storage and study of the simulated results. Also, for users who wish to run graphics on simulated data without reentry of that data, weekly data are stored in a separate file in computer memory. The CORN-III program runs on IBM-compatible equipment. It is available, at the cost of a 5.25-in. diskette, from either author and includes a user's guide.

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