Components and Techniques of Integrated Pest Management Threshold Determinations for Aerial Pathogens

MERLE G. EVERSMEYER, Research Plant Pathologist, USDA-ARS, Department of Plant Pathology, and CHARLES L. KRAMER, Professor, Division of Biology, Kansas Agricultural Experiment Station, Kansas State University, Manhattan 66502

ABSTRACT

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Foliar disease forecasting systems have been developed to facilitate efficient use of fungicides in high-disease-hazard situations. Most predictive models use biometeorological "threshold" values to drive the model. These values are not the static control action or economic injury thresholds, as defined in the literature by entomologists and economists. Rather, the values vary with the components of each disease model. Thresholds can be misleading, because the definitions may suggest a level of precision that does not exist in the real world of integrated pest management programs. Normally, threshold determination is straightforward for a single disease system in a crop; however, development of multiple-disease thresholds for a single crop is extremely complex because of the interactions that occur among the disease systems and with yield. Determination of thresholds is limited by constraints of the data available for any given disease system. Spore concentrations, meteorological parameters, disease severity estimates, and biometerological parameters have been used to develop thresholds for models of foliar disease development.

The integrated pest management (IPM) approach to foliar pathogen control has received much emphasis during the past decade. This approach integrates all possible methods for effective disease control in maintaining pathogen populations below economic damage levels without adversely affecting the ecosystems of the crops. A variety of control measures have been used singly or in combination for effective integrated crop management programs.

It seems safe to assume that all crops have been subjected to a foliar disease epidemic at some time during their existence. There is little question that this has been true for all major crops. Southern corn leaf blight devastated the corn crop in the early 1970s (35). Severe wheat leaf or stem rust epidemics have occurred many times during the past 70 yr (3,10,11,16). Potato crops have been destroyed during late blight epidemics, resulting in widespread famine in Europe (19). Entire apple and pear orchards have been destroyed during fire blight epidemics (36).

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Genetic vulnerability of our major food and feed crops to the changing pathogen populations has increased. Several trends in modern crop production enhance the risk of severe foliar disease epidemics in the future. Minimum tillage and no-till methods and shorter crop rotation systems may increase the probability of accumulation of primary inoculum. Higher plant density, higher leaf area index, and increased use of nitrogen, irrigation, and growth regulators all may cause microclimatic changes that may affect disease development.

Infestation of a pathogen species in the field is not always a sign of impending crop loss. Disease control is usually justifiable when the increased yield is worth more than the cost of control measures. Ideally, two values, the economic injury threshold and the control threshold, must be known before a management decision can be made regarding the possible use of control measures. The economic injury threshold is the lowest population density that will cause economic damage. The control threshold is the pathogen or disease density at which control measures should be applied to prevent an increasing pathogen population from reaching the economic injury threshold (7).

Entomological literature is replete with research on the components and techniques of determining thresholds for insects; however, thresholds rarely have been determined for foliar pathogens. Because of the limited use of fungicides, except on high-value crops such as potato, models have not been developed using these defined thresholds.

Plant disease forecasting systems have been developed to provide guidelines for efficient use of fungicides in high-disease-hazard situations. Disease modeling systems have been developed on high-value crops for potato late blight (23) and apple scab (21) and for leaf (12) and stem rust (13) epidemics for wheat, a low-value crop. Although not so named, each of these models used a threshold concept. These thresholds were not the precise control or economic injury thresholds (7,14,15) used by entomologists or economists. Rather, the concept of thresholds used is one in which the values vary with the components and their interactions in each model.

Our present knowledge concerning thresholds of foliar epidemic development has come largely from experiments either to determine thresholds for individual diseases or to monitor disease development in the growing crop. A comprehensive review of the literature on threshold determination in plant pathology will not be included here. Instead, we will use examples in the wheat and potato systems to describe concepts, techniques, and problems pertinent to threshold determination and prediction of foliar disease development.

TECHNIQUES AND PROBLEMS IN DETERMINING THRESHOLDS

Spore concentration as threshold component. Adhesive-coated microscope slides have been used to trap urediniospores of *Puccinia recondita* and *P. graminis* in studies of wheat leaf and stem rust epidemics since 1917 (34). Asai (1) used coated rods to trap urediniospores in a study of spore movement in the upper Mississippi River Valley. By this method, urediniospores were trapped before uredinia were found locally. Others (6,29), however, have reported that the numbers of urediniospores deposited on microscope slides or glass rods were highly correlated with the local development of wheat rust. Romig and Dirks (29) concluded that the major portion of urediniospore concentrations measured by slide samplers represented locally produced inoculum rather than exogenous inoculum and that any fungicide recommendation for disease control must be based on data collected in the field to be treated. Roelfs et al (27) reported that rod samplers would detect urediniospores only after uredinial frequency reached levels of one uredinium per 100 culms, indicating that inoculum responsible for initial infection outside of overwintering areas is not trapped by these samplers. Rowell and Romig (30) collected rain samples and concluded that the initial infections of leaf and stem rust develop from urediniospores deposited in rainwater. In a similar study using rainwater samples, Roelfs et al (28) detected primary inoculum for stem rust development in all 42 location-year samples studied and in 94% of their trials with leaf rust.

Kramer et al (20) studied spore sampling with many fungi under various artificial and natural environmental conditions and developed several samplers that have been used for measuring primary inoculum for disease prediction models. Multiple-regression techniques (4,5,12,13) were used to determine the inoculum variables that gave maximum accuracy in predicting wheat leaf and stem rust development. Disease forecasting was most accurate when leaf or stem rust pustules were observed in the local area on the date of prediction. If only urediniospore counts were used as the inoculum threshold variable, the final disease severities and resulting yield reductions were often underestimated.

Disease severity and incidence as threshold components. In developing a wheat leaf rust prediction system for Oklahoma, Chester (8,9) used leaf rust severities observed during the last week of March as threshold values for determining epidemic potential. The number of leaf rust uredinia per 1,000 wheat culms was used to differentiate among levels of epidemics. During the development of the model, he found that seasonal temperature and moisture patterns in the fall and after 1 April did not markedly affect the rate of disease development. Buchenau (2) in South Dakota used a disease severity threshold that does not differentiate quantitatively among epidemics. Each producer uses the model to estimate rates of disease development from severities on the date of prediction and weather of the previous weeks and plots the course of rust development and potential yield loss. Both of the models used by Chester and Buchenau rely on estimates of disease severity (thresholds) taken early in the growing season on commercial fields in which cultivar response is not considered; however, cultivar response will influence the rate of rust development.

Burleigh et al (6) characterized wheat leaf and stem rust epidemics using uredinia and urediniospore counts obtained near or within wheat plots. They found that the threshold at which fungicidal control would produce an economic gain was 10% leaf rust severity as measured by the modified Cobb scale (26). Uredinia and urediniospore counts were nearly equivalent in predictive value in their studies. Although they obtained fewer stem rust data points, relationships between stem rust uredinia and urediniospore counts were similar to those observed for leaf rust.

Eversmeyer et al (13) and Burleigh et al (4) developed disease prediction models based on uredinia per culm, airborne urediniospore counts, temperature, and moisture variables from 24 winter wheat plots and 16 spring wheat plots. Disease severities (uredinia per culm) were better predictive measures than other variables considered in 7- to 30-day rust forecasts in the Great Plains.

There are several methods (18) used in making disease ratings for threshold determinations or for inoculum parameters for models of disease forecasts. Most errors are introduced into the estimate when percentages are determined from nonuniform frequencies or when unequal sample sizes are averaged. Disease ratings must be correctly determined by area covered in the plot or field. A 10-ha area of a field with 80% leaf rust severity averaged with a 30-ha area of the field with 10% leaf rust would give an overestimate of 45% disease severity within the field. However, an estimate for the field based on the proportion of the total field at each severity level $(10/40 \times 80) + (30/40 \times 10)$ produces an average estimate of 27.5% for the field. Novice observers will frequently use the highest severity observed on several culms as the severity for a plot, field, or area.

Meteorological parameters as threshold components. Meteorological parameters have been widely associated with threshold determinations and disease development (9). Their widespread use can probably be traced to the availability of data recorded by many governmental agencies, at low or no cost. Hyre (17) proposed a moving mean of daily maximum and minimum temperatures and precipitation to forecast potato late blight. The primary late blight infections are forecast 8–14 days after a threshold of 10 consecutive blight-favorable days. A day is considered blight-favorable when the 5-day average temperature is below 25.5 and above 7.2 C and the precipitation total for the last 10 days is $\geqslant$ 3 cm. Wallin (39) developed a model of potato late blight forecast based on relative humidity $\geqslant$90% and the average temperature. Prognostic surface and 500-mbar weather charts have been used as a basis for forecasting disease epidemics. Wallin and Riley (40) used daily, 5-day, and 30-day charts to forecast potato late blight development. Lambert (24) used daily surface charts to determine pressure areas that aided in the movement of stem rust urediniospores to serve as primary inoculum in the spring wheat area.

Forecasts using biometeorological parameters as threshold components. Miller and O'Brien (25) and Krause and Massie (22) reviewed predictive systems and suggested that disease prediction was more precise when inoculum was present in an area than when it was absent. Burleigh et al (4) and Eversmeyer et al (12,13) developed predictive models for wheat leaf and stem rust using stepwise multiple-regression equations. Fifteen biometeorological parameters that correlated with disease development 7, 14, 21, and 30 days after the date of disease prediction were found. Different equations were required to precisely predict epidemic development at locations where inoculum data were not available either as uredinia or urediniospore counts. A measure of host growth was used that improved precision in the predictions. It also was found, as has been pointed out in most of the preceding works, that the determination of a threshold value for economic control of disease is not a precise, concrete value from field to field or from year to year. Similarly, Schrödter and Ullrich (31,32) developed a prediction model for potato late blight using multiple-regression techniques to relate blight occurrence with environmental factors. The accumulation of ratings from the average time of plant emergence was used as a threshold for blight alerts.

Simulation models have been developed for a number of disease systems including potato late blight (23,37), tomato early blight (37), southern corn leaf blight (38), stripe rust of wheat (33), and apple scab (21) among others. Blitecast (23) combined the systems developed by Wallin (39) and Hyre (17) to provide recommendations to growers on control measures for potato late blight. These simulations and the prediction models mentioned previously were developed for a single-disease situation, although many of them use multiple-threshold indices in modeling disease development.

CONCLUSIONS

The scope and choice of factors for threshold determination is limited by the constraints of available environmental data and quantitative data available on the organisms involved in the disease system. The adequacy of the thresholds as determined is limited by the least adequate of three phases of their determination: 1) developing the fundamental knowledge for the biotic systems involved, 2) representing that knowledge by decision aids, and 3) monitoring the biotic/abiotic and environmental factors that determine the threshold.

In an IPM system, all thresholds must be based on an economic level. The benefits from pest control differ from the crop loss obtained from disease damage without control. Crop loss from disease is the difference between the potential yield and the yield without disease control measures applied. The expected benefits from disease control are the differences between yields obtained with control measures and yields obtained without disease control measures. Clearly, yields obtained with control measures are always less than potential yields because foliar disease control is rarely 100%. Thus, it is difficult to predict an expected benefit or yield increase from the control of different disease severities at different crop growth stages. If we look for factors directly affecting threshold determination, we have to know the kind of damage the disease does and its interactions with yield.

Normally, the development of thresholds is fairly straightforward for a single-disease complex in a crop. When we become interested in developing multiple-disease thresholds for a single crop such as wheat, however, the complexity increases manyfold. Cultural practices, such as delayed seeding, may effectively control pests such as wheat streak mosaic virus or Hessian fly; however, the later seeding date may cause the crop to mature later, increasing the probability of a stem rust epidemic. Minimum or no-till practices will contribute to an increase in inoculum accummulation and result in increased tan spot epidemics. Chemical or genetic control mechanisms of one pathogen without concurrent control of other pathogens may lead to severe epidemics. For example, use of fungicides effective against *P. recondita*, to control leaf rust epidemics, increased yields by 40% over rusted plot yields. In plots in which both *P. recondita* and *P. graminis* were controlled, yields averaged 50% higher than in those where no control measures were applied. Plots in which *P. recondita* was controlled but *P. graminis* was allowed to develop resulted in yield reductions of 75%.

The concept of system analyses is fairly new in epidemiological research, but during the past decade, it has begun to be used to solve some of the major problems in developing thresholds for IPM programs. The primary causes of a foliar disease epidemic are a virulent pathogen population and a susceptible host population interacting in a favorable environment. It also becomes obvious that the effects are actually determined by the interaction of the components of the system, which change constantly with time and space. Each of these components may be indispensable in the determination of the threshold, but they vary in their importance in time. Development of multiple foliar disease thresholds is determined by the interaction of at least four factors: environment, pathogen, host, and human activity. These interactions are complex and, even if understood, are extremely difficult to monitor in the field.

All thresholds can be misleading because the definitions may suggest a level of precision that does not exist in the real world of IPM. Most simulations or disease forecast models have been developed by monitoring of disease epidemics followed by appropriate experimentation. The experiments usually determined the cardinal points for germination, infection, incubation, and fungal development within the host plant. Those cardinal point values were then used as threshold values in developing prediction models of a single-disease system.

If usable thresholds for foliar pathogen management programs are to be developed, we must formulate and test concepts for foliar disease control in cropping systems by simulation or other modeling techniques. Fundamental knowledge of the biological and meteorological systems operating within the crop production system must be refined to formulate disease control concepts. New information and present knowledge of the biometeorological system must be represented accurately in an automated disease control decision aid or model. Factors, both biological and meteorological, that collectively propel these models must be monitored or measured automatically and be available in real time.

LITERATURE CITED

1. Asai, G. N. 1960. Intra- and interregional movement of uredospores of black stem rust in the upper Mississippi river valley. Phytopathology 50:535-541.
2. Buchenau, G. W. 1970. Forecasting profits from spraying for wheat rusts. S.D. Farm Home Res. 21:31-41.
3. Browder, L. E., Johnston, C. O., and Pady, S. M. 1961. Cereal rust epidemiology in Kansas in 1959. Plant Dis. Rep. 45:894-898.
4. Burleigh, J. R., Eversmeyer, M. G., and Roelfs, A. P. 1972. Development of linear equations for predicting wheat leaf rust. Phytopathology 62:947-953.
5. Burleigh, J. R., Roelfs, A. P., and Eversmeyer, M. G. 1972. Estimating damage to wheat caused by *Puccinia recondita tritici*. Phytopathology 62:944-946.
6. Burleigh, J. R., Romig, R. W., and Roelfs, A. P. 1969. Characterization of wheat rust epidemics by numbers of uredia and numbers of urediospores. Phytopathology 59:1224-1237.
7. Carlson, G. A., and Headley, J. C. 1986. Economic aspects of integrated pest management threshold determination. Plant Dis. 71:459-462.
8. Chester, K. S. 1942. A suggested basis for the prediction of wheat leaf-rust epiphytotics. Plant Dis. Rep. 26:213-217.
9. Chester, K. S. 1946. The Nature and Prevention of the Cereal Rusts as Exemplified in the Leaf Rust of Wheat. Chronicles of Botany, Waltham, MA. 269 pp.
10. Eversmeyer, M. G., and Browder, L. E. 1974. Effect of leaf and stem rust on 1973 Kansas wheat yields. Plant Dis. Rep. 58:469-471.
11. Eversmeyer, M. G., Browder, L. E., and Young, H. C., Jr. 1975. Effect of leaf and stem rust on 1974 Kansas wheat yields. Plant Dis. Rep. 59:604-607.
12. Eversmeyer, M. G., and Burleigh, J. R. 1970. A method of predicting epidemic development of wheat leaf rust. Phytopathology 60:805-811.
13. Eversmeyer, M. G., Burleigh, J. R., and Roelfs, A. P. 1973. Equations for predicting wheat stem rust development. Phytopathology 63:348-351.
14. Ferris, H. 1987. Components and techniques of integrated pest management threshold determinations for soilborne pathogens. Plant Dis. 71:452-455.
15. Gholson, L. 1987. Adaptation of current threshold techniques for different farm operations. Plant Dis. 71:462-465.
16. Hamilton, L. M., and Stakman, E. C. 1967. Time of stem rust appearance on wheat in the Western Mississippi Basin in relation to the development of epidemics from 1921 to 1962. Phytopathology 57:609-614.
17. Hyre, R. A. 1954. Progress in forecasting late blight of potato and tomato. Plant Dis. Rep. 38:245-253.
18. James, W. C. 1971. An illustrated series of assessment keys for plant diseases, their preparation and usage. Can. Plant Dis. Surv. 51:39-65.
19. Klinkowski, M. 1970. Catastrophic plant diseases, Annu. Rev. Phytopathol. 8:37-60.
20. Kramer, C. L., Eversmeyer, M. G., and Collins, T. I. 1976. A new 7-day spore sampler. Phytopathology 66:60-61.
21. Kranz, J., Mogk, M., and Stumpf, A. 1973. EPIVEN: ein Simulator fur Apfelschorf. Z. Pflanzenkr. 80:181-187.
22. Krause, R. A., and Massie, L. B. 1975. Predictive systems: Modern approaches to disease control. Annu. Rev. Phytopathol. 13:31-47.
23. Krause, R. A., Massie, L. B., and Hyre, R. A. 1975. Blitecast: A computerized forecast of potato late blight. Plant Dis. Rep. 59:95-98.
24. Lambert, E. B. 1929. The relation of weather to the development of stem rust in the Mississippi Valley. Phytopathology 19:1-71.
25. Miller, P. R., and O'Brien, M. 1952. Plant disease forecasting. Bot. Rev. 18:547-601.
26. Peterson, R. E., Campbell, A. B., and Hannah, A. E. 1948. A diagrammatic scale for estimating rust intensity of leaves and stems of cereals. Can. J. Res. C. 26:496-500.
27. Roelfs, A. P., Dirks, V. A., and Romig, R. W. 1968. A comparison of rod and slide samplers used in cereal rust epidemiology. Phytopathology 58:1150-1154.
28. Roelfs, A. P., Rowell, J. B., and Romig, R. W. 1970. Sampler for monitoring cereal rust uredospores in rain. Phytopathology 60:187-188.
29. Romig, R. W., and Dirks, V. A. 1966. Evaluation of generalized curves for number of cereal rust uredospores trapped on slides. Phytopathology 56:1376-1380.
30. Rowell, J. B., and Romig, R. W. 1966. Detection of urediospores of wheat rusts in spring rains. Phytopathology 56:807-811.
31. Schrödter, H., and Ullrich, J. 1966. Weitere Untersuchungen zur Biometeorologie und Epidemiologie von *Phytophthora infestans* (Mont.) de By. Ein neues Konzept zur Lösung des Problems der epidemiologischen Prognose. Phytopathol. Z. 56:265-278.
32. Schrödter, H., and Ullrich, J. 1967. Eine mathematisch-statistische Lösung des Problems der Prognose von epidemien mit Hilfe meteorologischer Parameter, Dargestellt am Beispel der Kartoffelkrautfaule (*Phytophthora infestans*). Agric. Meteorol. 4:119-135.
33. Schrum, R. 1975. Simulation of wheat stripe rust (*Puccinia striiformis* West) using EPIDEMIC, a flexible plant disease simulator. Penn. State Univ. Agric. Exp. Stn. Prog. Rep. 347. 81 pp.
34. Stakman, E. C., and Christensen, C. M. 1946. Aerobiology in relation to plant disease. Bot. Rev. 12:205-253.
35. Ullstrup, A. J. 1972. The impacts of the southern corn leaf blight epidemics of 1970-71. Annu. Rev. Phytopathol. 10:37-50.
36. Van der Zwet, T. 1968. Recent spread and present distribution of fire blight in the world. Plant Dis. Rep. 52:698-702.
37. Waggoner, P. E., and Horsfall, J. G. 1969. EPIDEM: A simulator of plant disease written

for a computer. Conn. Agric. Exp. Stn. Bull. 698. 80 pp.
38. Waggoner, P. E., Horsfall, J. G., and Lukens, R. J. 1972. EPIMAY: A simulator of southern corn leaf blight. Conn. Agric. Exp. Stn. Bull. 729. 84 pp.
39. Wallin, J. R. 1951. Forecasting tomato and potato late blight in the North-Central region. Phytopathology 41:37.
40. Wallin, J. R., and Riley, J. A., Jr. 1960. Weather map analysis—an aid in forecasting potato late blight. Plant Dis. Rep. 44:227-234.