Disease Modeling: What is it all about?

By Dr. Douglas I. Rouse

Modern Scientific inquiry depends upon models; a model being a simplified approximation to reality. This is because the goal of science is to extract from the seemingly complex world around us the important relationships (laws) that explain the behavior of physical entities. These important relationships are often hidden by the complexity of the real world. For example, how does the scientist approach an understanding of this complex phenomenon we call Pythium blight or turf grass? By simplifying! There are many factors that can be imagined to influence the occurrence of Pythium blight on turf grass. Presence of the pathogen, of a susceptible host, and proper environmental conditions each play a role. Plant pathologists are interested in knowing what the relationships are among these factors and which ones are most important for development of disease.

Models are used as a way of stating a hypothesis. The model may begin as a conceptualization of how Pythium blight develops. The hypothesis may be that the fungus resides in soil or plant debris as mycelium and as spores, that wet conditions and warm temperatures result in growth and subsequent infection of the host. To formulate this conceptual model initial decisions based on observations must be made as to the most important factors influencing Pythium blight disease development. These are the factors that will be included in the conceptual model and studied first. At some point this conceptual model (hypothesis) must be tested. Experiments must be conducted. The approach usually taken is to choose one factor as a variable and study its effect on disease. For example, the effect of wet conditions on disease development may be studied. But how do we determine that wet conditions are necessary for development of the disease? First we must be precise about what we mean by 'wet conditions.' At this point a portion of our conceptual model must be refined to reflect the quantitative or mathematical relationship that hypothetically exists between some aspect of 'wet conditions,' such as duration of leaf wetness, and amount of disease. An experiment may be designed where treatments consist of turf grass kept wet for several different time intervals. The result may be represented by a mathematical equation. Of course all of the treatments with respect to other factors (i.e. same temperature and turf grass cultivar, etc.) remain constant, otherwise we would not know whether the different responses of the treatments were due to duration of leaf wetness or not.

Does that mean that the resulting mathematical model is only valid for one set of conditions (those of the experiment)? How do we incorporate the effect of temperature into our mathematical model? To do this it will be necessary to repeat the experiment under a number of different temperature conditions. The result will be a mathematical model with two variables. What about the effect of solar radiation, soil temperature, soil moisture, and other variables? We cannot hope to conduct our leaf wetness by temperature experiment a million and one times to include every possible variable. In addition the development of Pythium blight depends on much more than the presence of appropriate environmental conditions. Also important is the presence of the pathogen itself. Thus, we might embark on a study of the relationship between amount of inoculum and the chance of disease development. This might lead to a relationship between dose and response that would be potentially useful if we had a means of assaying for the presence of the pathogen prior to development of the disease. We already know that even if the pathogen is present, without adequate moisture the disease will not develop. Thus, a complete explanation for why disease develops when it does is dependent on a very large number of factors, interacting in complex ways, several of which we have just mentioned.

Empirical models derived directly from experimental data as described above represent a reductionist approach to scientific inquiry. As illustrated above this approach may lack the ability to explain the entire host-pathogen system because of the complexity of that system. In other words, in the scientist's endeavor to simplify the system in such a way that the important relationships between components of that system are distilled out there is the danger of missing important relationships. In this way scientific inquiry is an iterative process of searching out relationships. Nevertheless simple empirical models may have predictive value if they represent the important driving variables of the system. Alternatively a variable may be chosen that represents a composite of several variables at least one of which is important. For example, a decision could be made to relate rainfall to disease as the key factor in predicting disease development. Notice that rainfall influences leaf wetness and soil moisture as well as many other variables each of which may be the variable that actually explains disease development. It may not be necessary to know why

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rainfall is important to disease development for predictive purposes.

In contrast to the purely reductionist/empirical approach just described there has developed a systems science approach to the study of plant diseases. With this approach an attempt is made at the very outset of a scientific investigation to develop a complex mathematical model using logic and best guesses or opinions as well as existing empirical results to describe the entire plant disease system. This type of model may have hundreds of variables and require considerable computer resources to implement. This approach to modeling attempts to put the conceptual model of the entire disease system into a mathematical framework initially. The systems model represents a complex hypothesis or a complex of hypotheses that explain the entire system.

Testing of this hypothesis is referred to as model validation. Partial model validation is obtained simply by comparing results generated by the model with results of field observation of disease development. The systems approach has been attempted for a number of plant diseases. In most cases it has been possible to obtain a model that compared favorably with observed disease development. However this test alone is not sufficient to determine the validity of the model. Systems models have so many variables it is possible for such models to give the right answers for the wrong reasons. Adequate validation requires actually conducting many of the same experiments the reductionist would perform to confirm that the systems model has incorporated the correct opinions. The systems scientist would argue however that the systems approach is more likely to guide the researcher to the 'critical' experiments.

It is clear that both simple empirical models and complex systems models are imperfect as tools useful to the disease manager. The disease manager is in need of a model that is more than a hypothesis but actually has substantial proof via experimentation of its validity. In most cases the manager wants a model that can provide an unequivocal statement to treat or not to treat with a chemical for control of a disease. Both empirical and systems models may be useful in this regard despite their imperfections. For example, in the case of Pythium blight there is a model that has been developed to aid the timing of fungicide applications based on moisture. With this disease wetness is such an overriding factor that such a model is quite useful. Notice that it cannot be expected to be perfect however. Systems models on the other hand are often thought of as research tools as opposed to management tools. However, with continued research and the development of powerful but affordable desktop computers these models will find increasing usefulness for management.

In summary, models are an essential part of scientific inquiry. They are statements of the hypotheses that we wish to test and they relate directly to the questions that we want answers to. The various types of models which are employed represent the diversity of thought as to how scientific inquiries should be conducted. Both simple empirical models and complex systems models have potential as useful tools for the disease manager who must make decisions on the basis of available knowledge.

Editor's note: Dr. Doug Rouse is an Associate Professor in Wisconsin's Plant Pathology Department. He came to Wisconsin in 1979 after training at Ottawa, Kansas (B.S., 1974), Colorado State (M.S., 1976), and Penn State (Ph.D., 1979). His research work focuses on the mathematical characterization of pathogen variation and plant epidemics.

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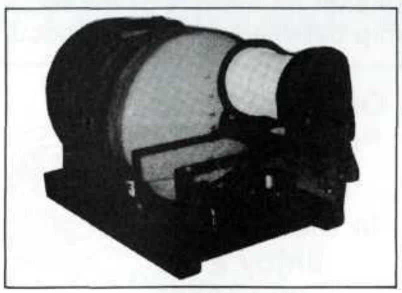

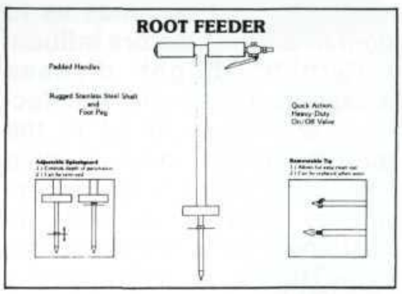

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