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Understanding Computers: Applications in Plant Pathology

In a previous article (PLANT DISEASE, Vol. 68, No. 5, page 365), we described the basic components of computers and computing systems and how they may be used to enhance the efficiency of plant pathologists. In this article, we focus on several areas in plant pathology whose development has been enhanced by the availability of computer technology: environmental monitoring and equipment control, field data recording, computer modeling, data management systems, and information delivery systems.

Environmental Monitoring and Equipment Control

Students in plant pathology are often taught some version of the disease pyramid or tetrahedron to show that disease frequently results from interactions between pathogen and host under the influence of environment and man over time. Thus, many studies involve repetitive measurements of some property of the pathogen, the host, the disease, or the environment. Computers, either alone or connected to other equipment, are specially suited to perform repetitive measurements. Computers are excellent "workhorses"—they do not suffer from work fatique and, barring a system failure, they maintain a high level of efficiency. Because of this new technology, epidemiologists can now conduct the kind of research that requires detailed knowledge of the interaction between disease and environment, the kind of research our predecessors could only dream about. Ten years ago, environmental monitoring, whether in the laboratory, the greenhouse, or the field, was expensive and relatively unreliable. Now, environmental monitoring systems are becoming more portable, more compact, and less expensive every year.

Many electronic devices, such as the sensors in environmental monitoring systems, are easily interfaced with computers to form self-adjusting control systems. Electronic devices generally produce signals that must be converted to a number or set of digits in the computer, commonly accomplished with an analog-to-digital (A/D) converter. An example would be temperature or relative humidity sensors sending analog signals to a microprocessor and the signals being converted to digits for storage.

Microprocessor technology with A/D conversion capability has resulted in many "homemade" and commercial environmental monitoring systems, ranging from simple electronic hygrothermographs to multichannel data loggers with high-resolution scan time. It is relatively simple to interface a temperature sensor that outputs analog signals to a microprocessor and, when desired, to "dump" the contents of that memory into another storage medium such as cassette (magnetic) tape. Along with the general trend toward miniaturization and cost reduction of microprocessors is the trend toward more portable, durable, and inexpensive data loggers. A commercial unit well known to plant pathologists is the CR21 Micrologger (Campbell Scientific, Inc., Logan, UT 84321), with up to nine channels available for environmental sensors. These new machines, exemplified by the CR21, are durable—we have seen them stand up to desert conditions and Minnesota winters! The availability of relatively inexpensive data loggers is a development auguring well for the study of plant disease epidemics.

Because of their efficiency in performing repetitive functions, computers have found usefulness as central control units for regulating greenhouse and phytotron environments. This is an area where hardware and software functions overlap; essentially, sensing is done by the hardware and corrective action is taken by instructions generated in the software. Mass spectrometers and gas-liquid chromatographs exemplify exciting developments in computer use in the laboratory. In the Department of Plant Pathology at the University of Minnesota, a mass spectrometer interfaced with a minicomputer forms the foundation for a national mycotoxin characterization data base. The flame signatures of unknown compounds obtained in the mass spectrometer are instantly matched with known signatures stored in computer memory. Other intricate tasks that need much repetition are being computerized and automated in the fast-growing biotechnology field.

Field Data Recording

The portable and hand-held computers (HHCs) now available are of much help to plant pathologists involved in the mundane task of recording large numbers of field observations, then transferring them for analysis. Until 2 years ago, identifying any HHC with enough memory and interface capability for use as a field device was difficult. Now, at least half a dozen brands are on the market, some with as much memory as a desktop microcomputer and with RS 232 interface and built-in modems. Because these HHCs allow for language programming as well as data acquisition, modeling and statistical analyses may be done in the field. The Panasonic Link and Radio Shack's PC-2 are examples of portables and HHCs. Some powerful portables with random-access memory (RAM) up to 64K, such as Radio Shack's TRS-80 Model 100, contain firmware for word processing, telecommunications,

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and BASIC programming. With the RS 232 interface, text (data or alphabets) can be transferred from these portable microcomputers to other microcomputers, such as the IBM-PC or the APPLE IIe.

The so-called electronic notebook is a simple form of computer equipment popular with plant pathologists involved in field experiments. This portable terminal with its own memory and power source can store digital data keyed into it in the field. Many brands are available. The very simple units with small memory storage and no prompt and edit abilities in the field usually cost much less than the more sophisticated ones. Three commonly available electronic notebooks (Fig. 1) are the Datamyte 1000 (DataMyte Corporation, Minnetonka, MN 55345), the Omnidata Polycorder (Omnidata International Inc., Logan, UT 84321), and the Norand Sprint 100 (Norand Corporation, Cedar Rapids, IA 52401).

The memory capacity for electronic notebooks ranges from about 4 to 48K. They can be programmed to display prompts appropriate to a specified format, and at the end of a data collection period, the contents of memory can be dumped to another microprocessor or computer. We tested a 4K hand-held terminal in our plant disease surveys in Minnesota and did not find it generally useful. A possibility with electronic notebooks is that data stored in memory may be erased accidentally, with no backup remaining. Most electronic notebooks may be viewed as portable "disk units" and have been designed for the exclusive purpose of temporary data storage.

Portable computers appear to have a role in all field data recording, but we advise a cautious approach to choosing a method. We recently compared four methods of recording disease/host data from small-plot experiments in Minnesota: 1) handwritten observations, 2) tape recordings, 3) digitizing board (Fig. 2), and 4) two electronic notebooks, the Datamyte and the Polycorder (K. L. Brown and P. S. Teng, *unpublished*). To our surprise, recording observations by hand and with the digitizing board ranked high in terms of cost and time efficiency. We foresee that entering data via a keyboard into a computer will become less necessary as electronic sensing equipment is improved. The digitizing board is a simple way to enter data; special "mark-sense" cards or paper is "read" by an optical scanner, which converts the markings to digital form within the computer. Bar code readers are available with many portable computers, and research is under way on hardware and software that will use design principles resembling the human eyeball interface with the human brain (memory) to distinguish characters.

Fig. 1. Commonly available electronic notebooks (left to right): Norand Sprint 100, Datamyte 1000, and Omnidata Polycorder.

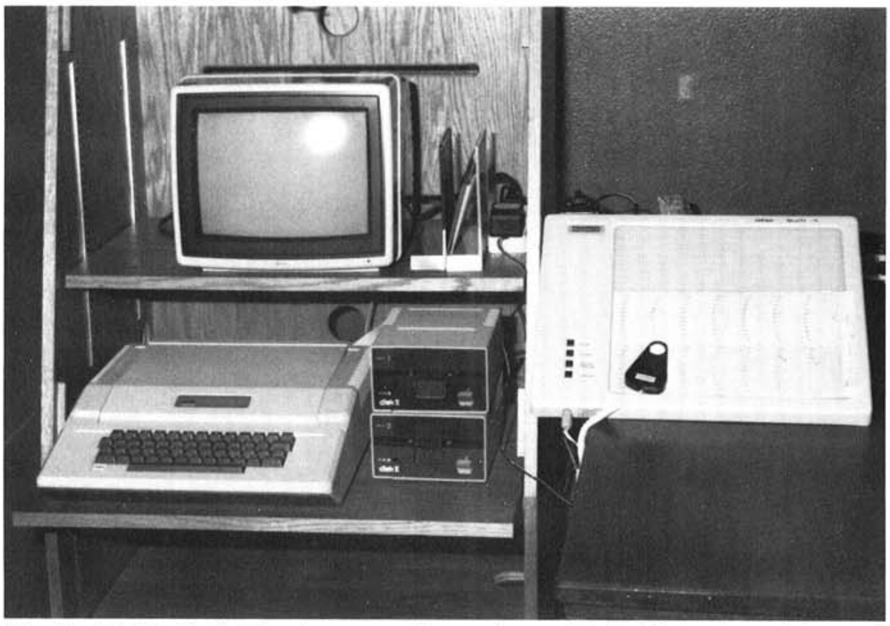

Fig. 2. APPLE II PLUS microcomputer system with digitizing board to read hygrothermograph charts.

Computer Modeling

Of the many uses for computers in research, extension, and teaching, system modeling offers the most exciting challenge and the greatest potential. In fact, without the advances in hardware and software technology during the past decade, modeling would not have reached its current preeminent role. Science has historically vacillated between inductive and deductive approaches. Computer models provide us with a modern means of lucid conceptualization of any problem (system) at hand, of translating the conceptualization into a tangible entity (model), and of testing the validity of that conceptualization. A validated model represents a powerful synthesis of knowledge on any system and therefore has value in dissemination of current knowledge through either extension or formal classroom instruction. At the same time, the process of computer modeling is a self-educating, if not humbling, exercise in revealing ignorance or misunderstanding of pathosystems (6). A computer remains a static machine unless we use it to capture some of the dynamics of the real, natural world.

Allied to computer simulation is the systems approach—as much a philosophy as a methodology. The systems approach proposes a holistic view of life and ecosystems, stressing that ad hoc studies on components of systems are inadequate for understanding and managing complex systems, especially man-created agricultural systems. The systems approach promotes an interdisciplinary look at the structure and function of plant pathosystems and their management. Application of the approach generally results in the development of a model, whether conceptual or computer simulation. Because of the holistic, interdisciplinary view taken and the specification of linkages between the components/processes of a system, a complex situation arises that can be handled only with a computer. A model frees the human investigator from the details while providing room for creative exploration of the system. The model also can be used to simulate the behavior of the system under defined environments. In this activity, we see a balanced and rational communication between man and machine—and an expansion of the capabilities of both!

Simulation modeling of plant pathosystems involves a number of activities that, although separate, may affect each other (Fig. 3). Many models of plant disease epidemics have been developed since the pioneering efforts at the Connecticut Agricultural Experiment Station in New Haven and at the Agricultural University in Wageningen, the Netherlands, during the late 1960s. The list includes EPIDEM for tomato early blight, EPIVEN for apple black spot, BARSIM for barley leaf rust, and EPIDEMIC, a general-purpose epidemic simulator (5). These are considered logical system models because they try to capture the complexities of the particular pathosystems using mathematical equations that relate specific system functions with driving variables from the environment. This is in contrast to single-equation mathematical models, which operate at a much higher level and are of lower resolution in representing biological processes. A system model may be simplistically viewed as a series of linked equations, an equation representing some particular function performed by a component in the structure of the system, as driven by some environmental factors. Because plant disease epidemics are complex, multicomponent systems, their simulation models generally possess much computer code. The process of conceptualizing a system and translating this into computer code for modeling involves an iterative series of activities (Fig. 3). For example, the final form of the detailed system model may be decided by the availability of biological data, which in turn may modify the objectives.

The memory size of a computer has limited the application of epidemic simulation models. Apart from the computer code, memory is needed for the environmental data that drive models. Consequently, most epidemic simulations are performed on large mainframe computers. We are optimistic that, as microcomputers become more powerful and less expensive, epidemic simulations will become part of the arsenal of plant pathologists in strategic planning for disease management. The dilemma of whether to sacrifice the biological reality of models by reducing their size and running them on microcomputers or to maintain them on mainframes as relatively inaccessible tools may yet be resolved.

Computer models have been developed into games for teaching principles of epidemiology and of disease management, for example, APPLESCAB at Michigan State University, SPUD CROP at Pennsylvania State University, and LATE BLIGHT at Cornell University. These games are based on simulations of disease progress given certain environmental conditions and control decisions but capture sufficient of the stochastic nature of management to be useful. GAMERUST, an interactive version of BARSIM simulating barley leaf rust, is used at the University of Minnesota to teach the relationships among components of partial resistance, host growth, apparent infection rate, and yield loss. The logistic equation has also been simulated on programmable calculators and HHCs. With use of the differential form of the logistic equation for disease progress, $dy/dt = ry\ (1.0\text{-}y)$, students can explore the effect of changing infection rate (r) and amount of disease (y) on disease increase per time period.

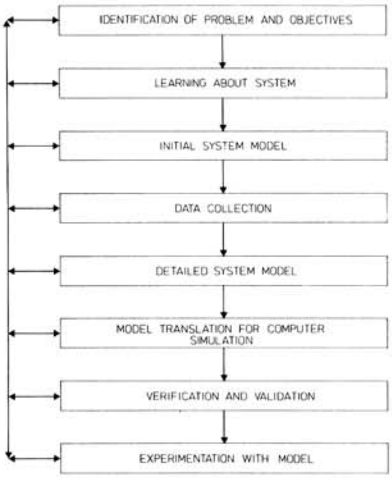

Fig. 3. Steps in simulation modeling of plant pathosystems. (After Teng and Zadoks [6])

One well-known computer-based predictive system is BLITECAST, developed at Pennsylvania State University for timing fungicide sprays to control potato late blight. The system is a computerized version of older late blight forecasting schemes and originally used a mainframe computer, hygrothermographs, and standard phone lines for communication between grower and system. Now, BLITECAST is an independent unit with its own sensors and microprocessor to calculate criteria for spray warnings (2). BLITECAST is a good example of a technological innovation in plant disease control that is almost infallible mechanically but is subject to human error when recommendations are followed—or not followed! Also, even though given a system that is technologically sound, growers may still prefer to practice "insurance spraying."

Most disease predictive systems are for single pathogens. Recognition of the inherent dangers of attacking just one disease among a multitude has led to attempts at developing multidisease and multipest predictive systems. Other systems may offer a choice of several predictive methods for one disease. For example, ANALYSIS, developed at the University of Minnesota for timing sprays to control potato early blight, has a menu of three methods for forecasting disease development, each based on different criteria.

Predictive systems issue a recommendation to spray without any associated economic criteria; they assume that a no-spray situation will lead to uneconomic results for a crop. With recent advances in crop and yield loss modeling, programs are now available that estimate the cost benefit of applying a spray or a spray program during the growing season. The RUSTMAN program, developed at the University of Minnesota to evaluate profitability of spraying to control sweet corn common rust, uses current data on crop growth stage and disease intensity to estimate yield loss from a series of equations, then calculates a per dollar return to spray costs on the day of fungicide application. The grower is also given a risk assessment—calculated from past and forecasted weather, cultivar susceptibility, and inoculum potential—if spraying is not done that day.

Although we have been stressing disease modeling, we do not wish to understate developments in modeling the host plant. Crop models provide a means for quantifying the effects of stress factors, including pathogens, on yield and thus a basis for evaluating crop management strategies. The physiological models available for the major crops grown in the United States predict yield in experimental plots with reasonable accuracy but have not been of much practical use in pest management because of their hardware demands. They are likely to become more accessible in the future.

Data Management Systems

Many activities in plant pathology generate voluminous data whose usefulness may be lost by inefficient handling. Because of the popularity of electronic data processing (or automated data processing) at most research institutions, many computer companies now support one or more data base management systems (DBMS). A DBMS may be considered a collection of computer programs allowing storage, manipulation, update, and retrieval of data within a computer. In modern computing, not to have a DBMS for handling large sets of data, such as those from disease surveys, is inconceivable. Furthermore, a DBMS commonly allows data to be summarized into a format compatible with a separate statistical analysis program or with graphics software. DBMS are not restricted to mainframe computers; many are available for microcomputers.

Information systems generally have at

their core one or more data bases managed with a system developed locally or patterned on a commercial system. For example, with MINPEST, we have used both System 2000 (S2K) and SIR. The USDA/APHIS Cooperative National Plant Pest Survey and Detection Program (CNPPSDP) data base contains abundance and damage data on insects, diseases, and weeds contributed by over 45 states. Another national data base of interest to plant pathologists is the pesticide data base (NPIRS) at Orlando, Florida, developed under the auspices of the U.S. Environmental Protection Agency. The Consortium of International Crop Protection (CICP) in Berkeley, California, maintains a data base on plant protection human resources to facilitate timely identification of persons who can respond to disease epidemics overseas.

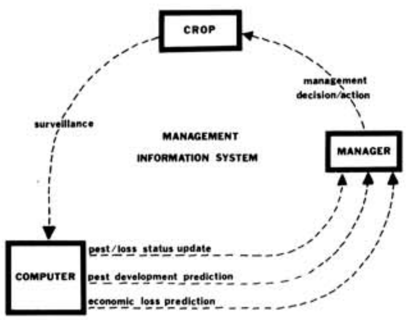

Fig. 4. Components of a disease management information system.

The creation of large data bases raises many difficult questions about accessibility and quality of the data. In the CNPPSDP, participating states use different collection methods for the same pest, and establishing a common data base through synthesis of several state data bases is difficult. Should pest data provided by different sources be used to set national policy? Also, many data bases are in the public domain and supported by tax dollars and thus theoretically available to all who want to use them. The commodities market, a private institution, could be manipulated with information on disease epidemics, with consequences for the plant pathologist's eventual client—the farmer. Some private agricultural data bases may use public data bases and information systems. The Control Data Corporation (CDC), a Minneapolis-based computer company, recently marketed a large information data base called DEVELOP that contains many publicly available sources. CDC also uses models licensed from the public sector to run an information system providing forecasts of crop yield. With the increasing number of data bases serving agriculture, we can foresee issues of public vs. private access and of the ethics of data base use in general, demanding more scrutiny by plant pathologists.

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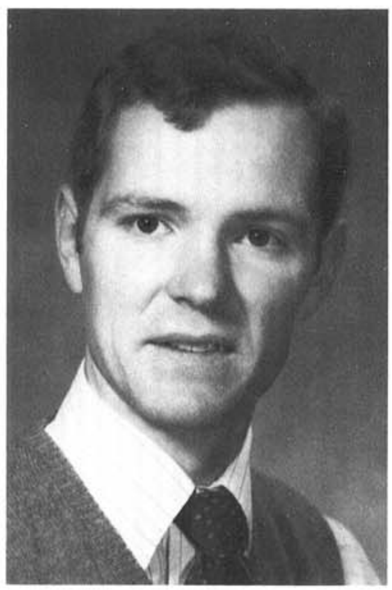

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Information Delivery Systems

Data from large data bases need to be delivered in a timely manner for various decision-making activities. Many institutions have developed information systems for easy, systematic interaction of users with data bases through well-defined procedures. Most information systems in plant pathology link surveillance data on crop and pest to a computer, then to a manager (Fig. 4). At present, most data are on pest intensity and loss. The Dutch national system for supervised disease control, EPIPRE, provides these data and also large-area predictions of disease development. Prediction of economic loss during the cropping season and its use in a management system are being researched by many scientists, but application is limited as yet.

Computerized management systems are used in plant pathology at many levels of organization, from systems for single farms or fields to state and national systems. In its simplest form, an information system consists of an input component (raw data collected or monitored) feeding into a processor (computer) and outputting information. Management information systems are characterized by structures that allow for the control function of a manager, ie, feedback to the system being monitored to change its course if that course deviates from the one planned. The rationale for exercising the control function is embedded in the concept of cybernetics, describing dynamically monitored and evaluated systems. Management information systems are an application of the systems approach to management, and a basis for their use is that no modern business can operate efficiently without up-to-date information on the status of its performance (1). In plant disease management, we are dealing with a dynamic system functioning in a stochastic environment, so the activities of monitoring and system control via a timely information system are singularly appropriate.

Many state pest, disease, and crop surveys use a computer-based information system to accept and deliver information from and to their clientele. Systems have developed largely along state lines and reflect the emphasis of the investigators. The Michigan State University CCMS depends on volunteers and paid scouts to collect pest and crop data, which are recorded on mark-sense paper. The system is very much centralized, with data forms sent to one site for processing. Information on pest abundance and damage is delivered to CCMS cooperators through cathode ray tubes or as hard copy. CCMS also provides degree-days for key insects.

MINPEST, a statewide pest surveillance information system developed by the University of Minnesota, uses a weekly scouting program on major crops to generate information on pest intensity and crop loss. Electronic mailboxes for wheat, sugar beet, and potato allow rapid sharing of pest status data among growers, extension personnel, and researchers, and tables and charts of the weekly spread and intensity of major pests can be selected from a menu of information. MINPEST is a component of EXTEND, the statewide agricultural extension information system that contains timely data on crop growth degree-days, weather forecasts, soil moisture status, and many other types of information. MINPEST exemplifies the efforts of one state, Minnesota, in relation to the USDA/APHIS national survey program, CNPPSDP.

Many state agricultural extension systems are developing their own information delivery systems, usually a database management system unique to their computers. EXTEND in Minnesota and WISPLAN in Wisconsin, for example, offer a whole menu of information, including pest (insect, disease, and weed) control information. WISPLAN's "electronic factsheets" on controlling specific disease resemble the disease control bulletins of old. EXTEND has *Plant Pest Control*, a weekly newsletter containing the observations of an interdisciplinary group of plant protectionists and of MINPEST. On a regional basis, the AGNET service run by the University of Nebraska is used in many north central states but has limited plant disease information.

Although management information systems are often thought of as extensive networks, "micro" systems, such as farm accounting/bookkeeping systems and confined livestock monitoring systems, do exist for individual users. Micro systems for use in plant pathology are still fairly uncommon, but the Kellogg Foundation recently funded Kansas State University to develop software containing disease control modules as part of a crop management package for individual farms. The information system concept has also been extended by "expert systems," software capable of a limited form of artificial intelligence. In plant pathology, the Illinois soybean disease diagnosis program is a start in this direction (3). Eventually we may see not just software for diagnosis but hardware and software for visually sensing symptoms and conducting verification tests on a symptom.

Toward Computer Literacy

Strassman (4) outlined several stages of growth in the application of computers in private industry. The predominant use in plant pathology is still in a lower stage, ie, we are using computers as unintelligent data devices. The use of models in predictive systems, in understanding pathosystems, and even in guiding economic decisions is increasing, but too little use is made of simulation as a strategic tool in plant protection, a stage Strassman (4) felt represented mature use of computers. We have barely explored the application of robotics, artificial intelligence, and expert systems to plant pathology.

Computer hardware and software technology is developing so rapidly that we can only attempt to project some growth areas in plant pathology, according to what we know of current trends. Certainly the safest statement is that more plant pathologists will become computer-literate. And unless microcomputers become as indispensable as microscopes, the "knowledge explosion" may lead us into a "knowledge void" regarding the world impinging on plant pathology. Instantaneous communication and information will become a relied-on facility and not a luxury. These will all lead to increased personal and professional productivity by plant pathologists and to the delivery of a better service to the agricultural community. We need the computer to increase our understanding of plant health.

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