Special Topic

Teaching Computer-based Diagnosis of Plant Diseases

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Courses in plant disease diagnosis are offered in most plant pathology departments, but exercises in computerized diagnosis are not usually included. Expertise in disease diagnosis may not be readily available to extension agents and other field advisors, who may have to rely increasingly on computerized diagnosis. Thus, students in plant pathology need to become familiar with the use of computerized diagnostic systems and their limitations. Moreover, some students need to be trained to develop such systems.

Computer programs for data base management have been available in diagnostic clinics for some time (5,15). Programs to aid in the diagnosis itself are still rare, however. Descriptions of computer-based diagnostic and advisory systems have been published for diseases and disorders of soybeans (14), tomatoes (2), grapes (21), and carnations (7) and for pests, diseases, and nutrient deficiencies of woody plants (10,13). In addition, the Institut National de Recherche Agriculture (INRA) at Montfavet, France, is developing a system of diagnostic and advisory programs for about 20 crops (2). The programs mentioned are expert systems, also called artificial intelligence programs. Previously, such programs could be run only on mainframe computers, but they now are also available for microcomputers (13,17,22).

An expert system for diagnosis of peach tree diseases (developed by the IPM Program at the University of California at Davis) was tested with diseased samples by graduate students in a diagnosis course at U.C. Davis. However, the students were not seriously challenged to think creatively, but rather attempted to diagnose the diseases by trial and error. Developing a diagnostic program would be more challenging than using an existing program. Unfortunately, expert systems for disease diagnosis cannot be easily developed within the time frame of a course. Not many students (let alone teachers) have the highly specialized skills needed to construct such a program. Moreover, experts on diseases of various crops may not be readily available.

There are several alternatives to expert systems. Wilson and Partridge (24) mentioned three main types of computerized identification systems: 1) simultaneous matching of character sets; 2) sequential identification by means of multistate characters, in which the sequence of characters is determined by the user (synoptic keys); and 3) sequential identification by bistate characters with a fixed or variable sequence determined by the programmer (dichotomous keys). Simultaneous matching systems include data bases and sort records, comparing the record of the unknown entity with those of known entities (23). More elaborate programs compute similarity indices between records of unknown and known entities (19).

Dichotomous and, to a lesser extent, synoptic keys have traditionally been used in taxonomy. In dichotomous keys, the organization is highly structured, and completion of an identification requires the user to make the observations important to the author of the key. Synoptic keys are organized more flexibly because the user does not have to follow a prescribed path. A synoptic key generally consists of a list of numbered taxa (e.g., species) and a list of characters, each with two or more states (11). The numbers of the taxa that have a certain state are listed after that state. Because the order of taxa and characters is arbitrary, synoptic keys can be updated easily. Moreover, they are well suited for classifications with relatively small differences between taxa and high variability within taxa (19).

Plant taxonomists have used computers for plant systematics since the 1960s (1,8,16). Both synoptic and dichotomous systems have been employed (16,18). Within plant pathology, computerization of identification keys is still in its infancy. Some mycological synoptic keys have been entered into interactive computer programs (12). Nematologists have used simultaneous matching programs in combination with a digitizing tablet and microscope (3,19). Descriptions of virus diseases have been compiled in a data base by the VIDE (Virus Identification Data Exchange) project (4) and can be used in conjunction with DELTA (DEscription Language for TAxonomy), an integrated package of identification programs developed by the CSIRO (Commonwealth Scientific and Industrial Research Organization) at Canberra, Australia (6). DELTA accepts both binary and multistate characters. Despite the increasing use of computerized identification systems other than expert systems for the main groups of plant pathogens, these systems have not been used for plant disease diagnosis. Nevertheless, such systems seem to be appropriate for teaching students the principles of computer-based diagnosis.

Furlow et al (8) used a mainframe computer to teach students in plant taxonomy how to develop computerized keys for identification of taxa in plant communities. Korf (11,12) introduced his mycology students to computerization of taxonomic keys with the aid of two programs developed for microcomputers, namely, TAXADAT, developed by Doyle E. Anderegg (College of Letters and Science, Moscow, ID 83843), and PC-TAXON, developed by Fred Rhoades (Biology Department, Western Washington University, Bellingham, WA 98225). Synoptic keys can be entered into either program in an interactive manner so that no programming language is required. Both have the option of generating a dichotomous key based on the synoptic key entered (for PC-TAXON, in conjunction with the DELTA program).

Description of an exercise in computerized diagnosis

Since 1987, the first author has taught a diagnosis course (four credit units) for graduate students at U.C. Davis. Besides the traditional methods of isolation and identification, some advanced diagnostic techniques have been introduced, one of which is a special project in computerized diagnosis. The special project takes about 5% of the class time. The main emphasis of the course is on field trips (40%) and laboratory diagnosis of collected specimens (25%), followed by organized laboratory exercises (20%) and lectures (10%).

For the special project, groups of two or three students are asked to develop a computerized synoptic key for the diagnosis of approximately 25 diseases

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and disorders of one crop in California. The students' objectives in the exercise are: 1) to become familiar with computer-based diagnosis, 2) to recognize and develop concepts of diagnosis to such an extent that the students learn to create a diagnostic key, 3) to enter a diagnostic key in a computer program, and 4) to validate the program, using diseases observed in the field and laboratory. The development and evaluation of the key are described in a term paper prepared by the students. The special projects are graded according to the quality of presentation of the term paper (50 points) and the quality of construction of the key (20 points for logic, 10 points for assignment of character states to diseases, 10 points for description of character states, and 10 points for user friendliness).

The students are instructed in how to create a synoptic key. They are advised to start with a definition of the system and its units (e.g., the 25 most important diseases of lettuce in California, the 25 most common leaf spot diseases of cereal crops in California), to list the diseases to be included, and to define characters and their states based on personal experience and descriptions in the literature. The students have been warned not to combine more than one concept into one character or state and to avoid states that are so specific that only one disease fits the description.

PC-TAXON (version 2.4, distributed by COMPress, Wadsworth, Inc., P.O. Box 102, Wentworth, NH 03282) was used to input the keys because it is easily learned and allows the user to identify an unknown taxon (i.e., disease in the case of a diagnostic key), describe the character states of a given taxon, compare the character states of two taxa, print out the details of the synoptic key, and enter a new synoptic key. Up to 255 taxa, each with up to 99 characters and 99 character states, can be entered. After a new key has been entered, it can be modified using the "UPDATE" option. Supplemental information for each disease can be entered in a separate file that can be invoked by future users who desire a complete description of a disease.

Synoptic key to tomato diseases

As a student project, the second and third authors developed a synoptic key to 51 disorders and diseases of tomato. Included were conditions caused by 8 viruses, 23 fungi, 5 prokaryotes, 1 nematode, and 14 abiotic factors. Eleven characters were selected for symptoms (e.g., systemic leaf symptoms, leaf lesion color, leaf lesion size and form), three for signs of fungal and bacterial pathogens, and five for host and environmental factors. The choice of characters was based on relative ability to differentiate between diseases and disorders. Diagnostic characters (symptoms and signs) were listed first, followed by associated characters (physiological age of plant, distribution of symptoms in field, soil characteristics, cultural practices, and weather).

The choices of states within each character were based on personal experience and on disease descriptions in textbooks on vegetable or tomato diseases. The students found that choices presented in their first version of the key narrowed the options too early, thus forcing a user to diagnose a disease based on one character (sometimes a nondiagnostic one) rather than on a composite of characters. In later versions, monospecific states were eliminated and descriptions of the states were more general, so that each disease was placed in at least one state for each character. The state "DO NOT WISH TO CONSIDER" was added under each character to allow a user to avoid a character for which no information was available and to prevent reselection of the same character by the program if the user asked the program to select a "good character" (based on a mechanical selection procedure).

Additional information about each disease or disorder was incorporated as disease descriptions in a separate file. The descriptions included causal agent, alternative hosts, geographic distribution, diagnostic features, control measures, comments, and references. For viral and mycoplasmal diseases, the vectors were listed.

The students wrote instructions for potential users, with helpful hints for use of the software package. Experience with the package taught them to avoid the "NOT" option when selecting states. This option excludes taxa (or diseases) that have the state for which the "NOT" option was used. It may be useful for deterministic taxonomic keys but not for diagnostic keys, because certain symptoms may be absent from a given specimen but may occur on other specimens with the same disease.

The students were encouraged to make the key accessible to users unfamiliar with plant pathology. Some plant pathology terms (e.g., lesion) were used, however, and many states under the character "signs" required a basic knowledge of mycology. Therefore, a glossary of mycological terms was also prepared for potential users.

An important part of the exercise was to validate the key with specimens collected during field trips. The tomato key was evaluated by 6 laypersons, by 18 plant pathology graduate students who were not involved in creation of the key, and by 4 tomato experts (an extension specialist, a farm advisor, and two researchers). The laypersons attempted to diagnose three tomato diseases but had only slight success. All plant pathology graduate students arrived at the correct diagnosis of three diseases each. The experts tested the key for identification of 14 diseases, of which 12 were correctly identified. Three of the four experts commented that computerized synoptic keys would be useful diagnostic tools for farm advisors, students, and teachers but not for growers. One researcher found the large number of choices for each character confusing and would have preferred a dichotomous key. The instructions were considered adequate, but there were some software limitations.

Accurate diagnosis was most reliably achieved when the characters of symptoms and signs were used. The characters "cultural practices," "weather," "soil characters," and, to a lesser extent, "field distribution" sometimes led to improper diagnosis if they were used before the characters of the various symptoms were exhausted.

Diseases with unique symptoms—e.g., root knot, early blight, late blight, southern blight, Phytophthora root rot, blossom end rot, buckeye rot—were easily identified. The key failed to adequately differentiate diseases with similar or overlapping symptom descriptions, such as Fusarium wilt vs. Verticillium wilt. Symptoms of viral diseases were difficult to classify into distinct categories, since symptom expression depends on many factors, including cultivar, environmental conditions, and stage of plant growth.

Evaluation of the key also revealed that synoptic keys are not well suited for diagnosis of diseases of complex etiology. Traditionally, keys have been used to identify single taxa. However, the students noted that complex or multiple diseases could be diagnosed by using the "OR" option in the computer program, which prevents premature elimination of a disease option.

Discussion

The synoptic approach to disease diagnosis proved useful for teaching students the concepts of etiology underlying the diagnostic process, such as the dynamic and complex character of plant disease resulting from the interaction of host, pathogen, and environment (9). The most difficult part of the exercise was the construction of a logical framework of characters and their states, and some students had difficulty with the conceptual analysis of the diagnostic process. Most students, however, learned which diseases could be separated on the basis of symptoms, signs, and environmental and host parameters.

Many students noticed that the usefulness of synoptic keys for diagnosing field problems is limited by variability in symptoms caused by secondary pathogens and disease syndromes induced by complexes of pathogens. Artificial intelligence programs may be better suited than synoptic keys for coping with diagnosis of disease complexes, because the expert who helps construct the program would realize the possibility of complexes involving more than one pathogen.

Another advantage of artificial intelligence programs is that they are more interactive than synoptic keys in that the next question asked depends on the answer to the current question, thus enhancing the probability of a correct diagnosis. The software used to enter the synoptic keys has an option to choose a "good character," but this character is selected in a mechanical way according to the least number of characters needed to separate potential diseases. Sometimes this selection results in a suggested character that is only of minor importance for correct diagnosis of the problem. Wilson and Partridge (24) described a dichotomous program in which biological and logical criteria were incorporated to select a question and in which questions and answers during previous identification sessions were used to optimize the questions asked in successive sessions.

Another aspect that would aid in correct diagnosis but is missing in computerized synoptic keys is a set of images of symptoms and signs. Interactive videodiscs with high-quality images would be ideal (20). At present, however, videodiscs cannot be used to record data, and students would not be able to develop their own diagnostic programs. A compromise within the current state of hardware would be to digitize single frames from a videotape recording, assuming that programs would be written to incorporate graphics fields and software and hardware compatibility. Some producers of expert systems have taken this approach (21).

Despite the imperfections of synoptic keys and the computer program currently used in our diagnosis course, the students generally reacted favorably to the exercise. They experienced the difficulty of mastering concepts of diagnosis and learned the importance of validating a diagnostic program.

The synoptic key to tomato diseases was not meant to be widely distributed. However, if teachers would like to receive a copy to determine if they would be interested in developing a similar exercise, they are welcome to contact the first author.

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