Technology Transfer

Two Computer-based Diagnostic Systems for Diseases, Insect Pests, and Physiological Disorders of Citrus and Selected Tropical Fruit Crops

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ADDITIONAL INDEX WORDS. diagnosis, extension, computer programs, tropical fruits

SUMMARY. The TFRUIT-Xpert and CIT-Xpert computer-based diagnostic programs can quickly assist commercial producers, extension agents, and homeowners in the diagnosis of diseases, insect pest problems and physiological disorders. The CIT-Xpert system focuses on citrus (*Citrus* spp.), whereas the TFRUIT-Xpert system focuses on avocado (*Persea americana* Mill.), carambola (*Averrhoa carambola* L.), lychee (*Litchi chinensis* Sonn.), mango (*Mangifera indica* L.), papaya (*Carica papaya* L.), and 'Tahiti' lime (*Citrus latifolia* Tan.). The systems were

developed in cooperation with research and extension specialists with expertise in the area of diagnosing diseases, disorders, and pest problems of citrus and tropical fruit. The systems' methodology reproduces the diagnostic reasoning process of these experts. Reviews of extension and research literature and 35-mm color slide images were completed to obtain representative information and slide images illustrative of diseases, disorders, and pest problems specific to Florida. The diagnostic programs operate under Microsoft-Windows. Full-screen color images are linked to symptoms (87 for CIT-Xpert and 167 for TFRUIT-Xpert) of diseases, disorders, and insect pest problems of citrus and tropical fruit, respectively. Users can also refer to summary documents and retrieve management information from the Univ. of Florida's Institute of Food and Agricultural Sciences extension publications through hypertext links. The programs are available separately on CD-ROM and each contains over 150 digital color images of symptoms.

Expert systems have been developed from a branch of computer science known as artificial intelligence (Liebowitz, 1988). Artificial intelligence is primarily concerned with knowledge representation, problem solving, learning, robotics, and the development of computers that can speak and understand humanlike languages (Townsend, 1987). An expert system is a computer program that uses knowledge to solve problems that are difficult enough to require significant human expertise (Townsend, 1987). Simply stated, expert systems are computer programs designed to mimic the thought and reasoning processes of a human expert.

Expert systems can be developed for many kinds of applications involving diagnosis, prediction, consultation, information retrieval, control, planning, interpretation, and instruction (Edmunds, 1988; Liebowitz and DeSalvo, 1989; Peart, 1989). They are used in applications where the procedures or algorithms for the problem do not exist or are poorly defined, but good rules of thumb or heuristics are available. Although the use of expert systems in horticulture is still limited and their primary function is as a tool for human experts, expert systems are rapidly being accepted for use by the nonexpert to solve problems when human expertise is expensive, untimely, or unavailable. Today, better development tools are available as closer interdisciplinary cooperation is resulting in agricultural researchers' gaining more insight into the theory and concepts necessary to build effective systems (Crassweller et al., 1993; Holt, 1989).

Several notable expert systems have been developed for use in horticulture. For example, CALEX is an expert system that was developed for the diagnosis of peach and nectarine plant problems by the Univ. of California (Plant et al., 1989). Like most experts systems, CALEX is a rule-based system and uses certainty factors, so that the knowledge base consists of production rules in the form of IF-THEN statements. The inference engine pieces together chains of rules in an attempt to reach a conclusion. The knowledge base of the CALEX diagnostic system contains about 600 rules for the diagnosis of 120 problems of peaches and nectarines, representing most of the production problems in California (Plant et al., 1989). CITPATH, a computerized diagnostic key and information system, was developed to identify five major fungal diseases of citrus foliage and fruit

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Florida Agricultural Experiment Station journal series no. R-5658. Project supported by the Univ. of Florida, IFAS, Office for the Dean of Extension and USDA Grant No. 58-319R-3-015. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

in Florida (Ferguson et al., 1995). CITPATH also uses a rule-based approach that provides hypertext-linked descriptions and graphic displays of symptoms with reference to chemical control methods.

The Penn State Apple Orchard Consultant is an example of another type of expert system that uses specialists from different areas to develop large integrated modules. Horticultural applications presently developed include modules for weed control, foliar analysis interpretation, trickle-irrigation scheduling, and visual diagnosis of nutrient deficiencies (Crassweller et al., 1989). VITIS, a grape disease management expert system, has also been developed in cooperation with specialists from Pennsylvania, New York, Ohio, and Michigan (Travis et al., 1992).

To limit effectively the negative impact of insect pests, diseases, and physiological disorders on crop production, correct symptom identification and rapid diagnosis is vital. Historically, major statewide extension programs in Florida have provided diagnostic services and pest management information to support growers and county extension faculty to minimize misdiagnosis and unnecessary agrochemical use. Currently, information is disseminated primarily via county commodity-oriented meetings, on-site orchard visits, by extension publications, and through databases such as the Florida Agricultural Information and Retrieval System (FAIRS) CD-ROM series and the World Wide Web (Johnson and Beck, 1986). FAIRS is a comprehensive electronic library, currently consisting of thousands of documents from major programs within the Univ. of Florida's Institute of Food and Agricultural Sciences (Beck et al., 1994; Johnson and Beck, 1986). The increasing awareness of producers of commercial computer applications in horticulture has led to the development of advanced computer technology with practical applications in horticulture. As a result, the need for the development of interactive computer-based expert diagnostic systems to assist growers and extension faculty with the diagnosis of diseases, insect pest problems, and physiological disorders of horticultural plants is needed.

Two interactive computer-based diagnostic expert sys-

tems, one for citrus and the other for avocado, carambola, lychee, mango, papaya, and 'Tahiti' lime were developed. These diagnostic systems are designed to perform at the level of knowledgeable human experts but can be easily understood and used by extension faculty and commercial producers for field diagnoses of diseases, insect pest problems, and physiological disorders of citrus and tropical fruit crops. The diagnostic systems have been integrated with FAIRS and are available on CD-ROM.

System design and operation

The TFRUIT-Xpert and CIT-Xpert systems were developed to operate under the Microsoft Windows environment. A schematic illustrates the general structure and a specific diagnostic example from the TFRUIT-Xpert system (Fig. 1). A user can navigate through both systems by using the mouse pointer and clicking on designated navigational buttons. Each system was developed using a diagnostic-prescriptive paradigm in which the user first identifies recognizable symptoms of an unknown problem by a morphological region (e.g., leaves, fruit) within a tree (Fig. 2). Second, a user selects a symptom class that most closely relates to the expressed symptom exhibited by the tree (Fig. 3). Many symptoms have thumbnail-sized (a small version of the image) images that can be expanded to a larger resolution (640 × 480) by clicking on the thumbnail image (Fig. 4). These full-screen images may assist the user in clarifying text descriptions of symptoms. The user may then select a symptom by highlighting the text and clicking the mouse pointer. Once clicked, a search is automatically executed based on the information selected. The user then may click on the INSPECT button to retrieve the conclusion or conclusions reached by the diagnostic system. The user then clicks onto a specific conclusion and a summary document is retrieved (Fig. 5). The user may subsequently browse the summary documents and view additional symptom descriptions, which may assist in confirming the diagnosis. A hypertext function provides links to more informative Univ. of Florida extension documents, which sometimes contain control recommendations. Hypertext is high-

Fig. 1. Schematic flow diagram representing the general diagnostic structure of TFRUIT-Xpert system and an example of a diagnostic pathway to identify nitrogen deficiency of lychee leaves.

lighted words that, when clicked on with the mouse pointer, directly link the viewer to additional text. A total of 56 Univ. of Florida publications can be retrieved through the hypertext linkage to CIT-Xpert and 75 for TFRUIT-Xpert. All summary documents and Univ. of Florida extension documents can be printed.

Program development

The methodology used to develop the diagnostic systems was divided into five areas: 1) including knowledge acquisition, 2) knowledge representation, 3) interface design, 4) verification and, 5) testing (Jones and Barret, 1989).

KNOWLEDGE ACQUISITION. An expert system is primarily based on reasoning methods that reflect expert human logic (Jones, 1989). Therefore, each diagnostic system was developed based on the diagnostic reasoning process and expert knowledge acquired from a single specialist. The

Fig. 2. An example of an interface screen (lychee tree) used to select the morphological region of the tree showing symptoms of a disease, insect pest, or physiological disorder.

Fig. 3. An example of an interface screen used to select a symptom class (e.g., leaf drop, change in color, change in shape, necrosis) that most closely relates to the symptom exhibited by the tree.

reasoning strategy separated specific disease, insect pest, or physiological disorder symptoms by major morphological regions of the tree. The morphological regions for citrus, avocado, lime, mango, and papaya are the roots, trunk, major limbs and scaffold branches, small branches and twigs, leaves, blossoms, and fruit. The entire tree is also an option. Roots are not a choice for lychee. For CIT-Xpert, a further breakdown was required for two morphological regions—the roots (subregions were fibrous feeder roots, crown roots, main lateral roots, entire root system) and trunk (subregions were the rootstock, bud union, scion, trunk). Broad classes of disease, insect pest, or physiological disorder symptoms were then identified, such as change in color, change in shape, and presence of insects. In some instances, subclasses were used to distinguish between specific colors of a symptom (e.g., brown, yellow). Specific plant symptoms were placed into one or more of these symptom classes or subclasses for each morphological region or subregion of the tree.

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Fig. 4. An example of an interface screen with thumbnail sized images that can be expanded to a larger resolution by clicking on the image.

Fig. 5. An example of an interface screen showing the specific conclusion of a diagnosis and a part of the summary document on lychee leaf nitrogen deficiency.

tural and Consumer Services, Division of Plant Industries publications were used to develop an initial list of diseases, insect pests, and physiological disorders. This list was reviewed and additional plant problems were included if they were deemed important by the participating specialists. Each participating specialist wrote a summary document for each plant problem which provided a concise review of the major symptoms for each disease, insect pest, and physiological disorder. Key words in the summary documents were highlighted to use as hypertext links to additional Univ. of Florida extension publications. A total of 87 summary documents were prepared for CIT·Xpert and 167 documents for TFRUIT·Xpert.

After the summary documents were completed, a comprehensive list summarizing the visual symptoms for each diagnostic system was generated. To provide the user with on-screen color images to illustrate symptoms, 35-mm slides were acquired for each symptom. Images were provided in 35-mm color slide format by the specialists. An attempt to obtain a slide image for each of the 269 symptoms detailed for CIT·Xpert and the 400 symptoms for TFRUIT·Xpert was made. However, in some instances, slides detailing specific symptoms either did not exist or could not be obtained. The CIT·Xpert and TFRUIT·Xpert systems have 154 of 269 and 153 of 400 photographic images of symptoms, respectively.

All acquired 35-mm slides were processed digitally by either using Kodak photo compact disk (CD) technology or by manually scanning the slide images on to a CD-ROM. All images were stored as 8-bit color images using 640 × 480 (256 colors) pixel resolution. When a range of symptoms could not be fully represented by a single photograph, two to four images were combined into one composite image to create a representative full-screen color image showing the range of symptom expression.

KNOWLEDGE REPRESENTATION. The strategy used for representing the knowledge base was a decision matrix in which the logic could be easily represented, verified, and periodically updated or expanded to include additional fruit crops. A decision matrix is a table with the column headings representing the symptoms and the row headings representing the disease, insect pest, or plant physiological disorder.

The next step in representing the knowledge base included identifying specific disease, insect, and physiological disorder symptoms from the summary documents and

placing similar symptoms together within the same morphological region (e.g., roots, leaves) of the tree. When a description of a specific problem is identified as a symptom of a plant problem listed in the matrix, an "x" is placed in each corresponding cell of the decision matrix to represent the relationship between the symptom and plant problem.

A two-, three-, or four-layer hierarchy in the decision matrix was developed to separate the various disease, insect pest, and physiological disorder symptoms. The decision matrix includes all the information needed, including text and image file names used in generating and creating the menus seen on the computer screen. The first level of the decision matrix was based solely on the major morphological regions of the tree. The second level grouped symptoms into one of several morphological subregions such as fibrous roots, bud union, or scion. A third level was broken down further into symptom classes such as growth abnormality, fungal growth, girdling, gumming, death, decay or sloughing of bark, and lesions or cankers. The fourth level of the hierarchy included the detailed text description of the disease, insect pest, or physiological disorder symptoms.

USER INTERFACE DESIGN. The user interface was developed using an existing software library program written in Borland C++ v. 3.0. The program language C++ was used to generate interface features such as buttons, windows, hypertext, pop-up menus, and dialogue boxes on the computer screen. A key feature of the program is that the interface is generated automatically once the decision matrix has been created. In the future, if minor modifications are made to the matrix, it can be retranslated to generate an updated interface.

VERIFICATION OF THE SYSTEMS. Symptoms of each disease, insect problem, and physiological disorder were verified periodically throughout the development of the diagnostic systems. Symptoms of the plant problems were also reviewed by experts in relevant disciplines not directly involved with the design of the diagnostic programs. Several other experts were involved with verification of images expressing symptoms and served as reviewers of the summary documents. Before transferring the prototype programs to individual CD-ROMs for testing, each system was reviewed by randomly selecting possible diagnostic pathways with known conclusions to verify that the conclusion matched the data represented in the matrix.

TESTING THE SYSTEMS. Each diagnostic program was

Table 1. Test results of the CIT·Xpert and TFRUIT·Xpert diagnostic systems.

Diagnostic system	Test group	Type of diagnosis	Percentage		
			Correct diagnosis ^a	Incorrect diagnosis ^b	Uncertain ^c
CIT·Xpert	Experts	Subjective ^w	84	11	5
		CIT·Xpert ^w	77	14	9
TFRUIT·Xpert	Growers	Subjective	29	31	40
		TFRUIT·Xpert ^w	50	46	4
	County agents	Subjective	67	22	11
		TFRUIT·Xpert	61	33	6
	Experts	Subjective	70	30	0
		TFRUIT·Xpert	64	36	0

^aCorrect diagnosis of test sample.

^bIncorrect diagnosis of test sample.

^cPercentage of test samples for which no diagnosis could be made.

^wSubjective, diagnosis without the aid of the computer-based diagnostic program; CIT·Xpert and TFRUIT·Xpert, diagnosis made with the aid of the diagnostic system.

subjected to a brief testing phase. Extensive testing was precluded by a lack of resources (financial and personnel), the limited number of people available to test, and time constraints. The purpose of the testing was to compare the capability of subjective human diagnosis with the computer-based diagnostic expert systems to determine if the diagnostic system could improve nonexpert diagnostic capabilities (Hollnagel, 1989). A secondary purpose was to test the user interface.

Before testing, an evaluation questionnaire was given to each user, which requested basic information about the experience of each participant's familiarity with computers and their diagnosis of diseases, physiological disorders, and insect pest damage of subtropical citrus or tropical fruit crops. Comments on the design of the graphics, the diagnostic reasoning process, and the content of the summary documents was requested verbally and in writing. Each user was given a brief explanation of the function and operation of each system and was encouraged to ask questions and provide input during the testing session.

The CIT-Xpert system was tested by 12 citrus research or extension specialists (experts) that had 5 to >20 years experience in diagnosing citrus plant problems. No nonexperts were available. The experts had, through education, training and experience, in-depth familiarity with the possible plant problems encountered by citrus during production. Ten of the twelve citrus experts used computers routinely.

The TFRUIT-Xpert system was tested by four commercial producers, three county agents, and four experts. The tropical fruit experts had 5 to >20 years experience in diagnosing tropical fruit plant problems and used computers from occasionally to routinely. Of the county agents, one had 5 to 10 years diagnostic experience with tropical fruit problems and the other two had <5 years experience; all routinely used computers. One producer had 5 to 10 years diagnostic experience with tropical fruit problems and the other three producers had <5 years experience. Two of the four producers were familiar with and used computers routinely.

The second section of the testing was designed to evaluate the ability of the diagnostic computer systems to help a user correctly diagnose specific plant problems. This section consisted of two separate evaluation components. In the first part, each participant was asked to identify 10 to 12 randomly selected disease or insect pest or physiological disorder problems (e.g., root lesions caused by citrus root weevils, zinc leaf deficiency, scab on fruit) based on their personal knowledge and experience without assistance of the computer based diagnostic system. Samples were obtained from nearby orchards. In the second part, each participant was asked to use the computer based diagnostic system to diagnose the same 10 or 12 randomly selected samples. Testing of each participant generally took 1 to 2 hours.

Citrus experts were able to correctly diagnose an average of 84% of the selected cases without the CIT-Xpert system and 77% with the system (Table 1). This decrease of 7% was not considered a large reduction considering two of the twelve experts were not familiar with computers and the diversity of samples tested. There was a slight increase (5% to 9%) in the percentage of test samples for which no diagnoses was made. However, nine of the twelve citrus

experts found the computer interface design (e.g., print, illustrations, and colors) of good quality, the information accurate, and the system able to make diagnoses quickly. Two experts found navigating through the computer-based system somewhat difficult. This may have been due to their unfamiliarity with computers.

Tropical fruit producers correctly diagnosed 29% of the test cases on their own and 50% of the cases with assistance from the TFRUIT-Xpert system (Table 1). Correct diagnoses by county extension agents was nearly the same with (61%) and without (67%) the expert system. Tropical fruit experts correctly diagnosed 64% with and 70% without the expert system. Thus, the system was able to improve the diagnostic ability of the commercial producers tested but not of the county agents and experts. Again, the slight decrease for agents and experts using the computer-based system was not considered large due to the diversity of the samples tested. Eighty percent of the people testing the system found the computer interface design of good quality and 60% found the TFRUIT-Xpert system easy to navigate.

Based on the test results, recommendations for improving the expert systems were identified. Recommendations included improving the interface among various components of the diagnostic program, simplification of plant problem symptom descriptions, and incorporation of basic instructions for novice computer users. Revised versions of the diagnostic programs are being completed for release.

Summary

The CIT-Xpert and TFRUIT-Xpert systems were well received by Univ. of Florida research and extension specialists. Growers and county extension agents were also receptive to the diagnostic systems. Generally, all of the people who operated the expert systems believed that the computer systems had significant management and educational value. Some suggested that their greatest value may in fact be as an educational tool for students and possibly for the Master Gardener training program rather than simply a diagnostic tool for growers or consultants. Additionally, many people favored using the expert system as an extension tool to increase the availability of expert diagnoses at county extension offices. This would be accomplished by having the computer-based diagnostic systems available to extension clientele at county offices.

The decision matrix provided a convenient way to organize the knowledge base. New symptoms can be added and existing symptoms can be modified, allowing the systems to be easily altered or updated. Results of the testing indicated that the diagnoses of the expert systems generally agreed with the diagnoses of the extension and research faculty in most of the cases tested. Evaluation of the diagnostic expert systems suggested that nonexpert users are able to make diagnoses using the expert systems. Suggestions provided by the participants concerning the user interface, the selection of representative slide images, and symptom text descriptions were considered for improving the systems. Plant problems taken from the field were very useful for testing the expert systems.

Program requirements

The hardware required to operate the diagnostic programs includes an IBM-PC or clone with at least a 80386SX CPU coprocessor; at least Microsoft-Windows 3.0; a mouse,

CD-ROM drive, and a hard drive with 4 MB of available memory; a SuperVGA video card with at least 512 K of RAM; and a laser printer. Currently, all county extension offices in Florida have the requisite hardware for delivering such a system.

Program availability

This software is available on CD-ROM and can be purchased directly from IFAS—Information Technologies, Building 162, P.O. Box 110495, University of Florida, Gainesville, FL 32611-0495; phone 352.392.3196, facsimile 352.392.3920.

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