Special Topic

An Expert System for Diagnosing Muskmelon Disorders

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The development of computer software for plant disease management has progressed steadily for the past 20 years. Disease forecasting programs such as BLITECAST and the apple scab predictor were among the first to computerize an algorithm to identify local environmental conditions that favored disease development and to predict the outbreak of disease (3). Many such forecasters followed. A few are in use today, and others are being developed. They are programmed in conventional languages such as BASIC, C, and FORTRAN, because the algorithms require only objective, numerical data, i.e., hours of relative humidity greater than 90%, maximum and minimum temperatures, amount of precipitation, etc. Recent advances in storage capacity and speed of computers have resulted in a new generation of computer programs, expert systems, which are written in artificial intelligence programming languages and which handle problems with subjective nonnumerical data, rules of thumb, and judgmental knowledge (2). These systems are designed to capture the knowledge and problem-solving logic employed by human experts in a given field (6). Several expert systems with applications in plant disease management already have been developed in the areas of disease diagnosis (5) and decision support for fungicide use (1,7,9).

This report describes an expert system, the Muskmelon Disorder Management System (MDMS), for diagnosing disorders of muskmelon (*Cucumis melo* L. var. *reticulatus* Naudin), an economically important crop in Indiana and one subject to a wide range of infectious and noninfectious maladies. Because the midwestern muskmelon crop has a high unit value, growers can afford to rely on fungicides in their disease management programs. If farmers are to use their fungicide dollars wisely and plan intelligently for future crops, then accurate, timely identification of muskmelon disorders is essential. Inaccurate diagnoses result in direct losses associated with the disorder and indirect losses stemming from the cost of inappropriate treatments. A timely diagnosis is important because of the contagious nature of many diseases; in some cases, a delayed action is as costly as no action. The objective of the system is to provide accurate, accessible decision support in diagnosing muskmelon disorders.

How the system was developed

The system was developed using a knowledge engineering language or "shell" (Personal Consultant Plus, Texas Instruments Inc., Dallas). This expert system development tool employs a rule-based knowledge representation scheme that closely resembles the EMYCIN (10) development shell. The significance in the similarity is that EMYCIN was developed to build diagnostic expert systems. Its parent system, MYCIN (8), is dedicated to the diagnosis of human bacterial blood infections and prescription of appropriate remedial treatments. EMYCIN contains the essential components of the inference mechanism and support structures, but its knowledge base is empty. These features allow the shell to be developed for diagnosis and control decisions for plant diseases.

The rules that make up the knowledge base are structured in the form of IF-THEN statements. The IF portion of the statement includes a premise that consists of certain parameters and their values. Parameters are variables or attributes that are important to the identification of the disorder. In the simple rule for diagnosing root-knot nematode infection (Fig. 1), the first parameter is PLANT-SYMPTOM-TYPE. The possible values for that parameter are WILT and POOR-GROWTH. The second parameter is ROOT-GALL-PRESENCE, for which the value is YES (galls are present). The THEN portion of the expression specifies an action to be taken after the conditions of the IF portion are satisfied. The action is the conclusion that the disorder is root-knot nematode infection (Fig. 1).

All rules incorporated in the diagnostic knowledge base for muskmelon disorders were developed from a standard set of parameters and values (Fig. 2). The set of parameters follows a logical hierarchy of field patterns and plant symptoms used in the investigation of crop disorders. The values were selected on the basis of compiled experience in identifying muskmelon crop disorders common to Indiana and neighboring states. The standard parameters and values were structured so that, with few changes, they will apply to the diagnosis of disorders of other cucurbits and other vegetables.

The system in operation

The system serves as a computerized consultant. Users are prompted to indicate observed symptoms from a series of menus. The menus may involve a "yes-no" type of response or may require a single choice from a list of several possible responses. Also, in appropriate cases, the system offers other menus from which the user may choose all or none of the offered selections. The knowledge base contains rules for diagnosing 17 disorders of muskmelons, including 11 infectious diseases (Alternaria leaf blight, angular leaf spot, anthracnose, bacterial wilt, damping-off, downy mildew, Fusarium wilt, gummy stem blight, powdery mildew, root-knot nematode infection, and squash mosaic virus), three nutrient imbalances (magnesium deficiency, manganese toxicity, and molybdenum deficiency), and three noninfectious problems (ozone injury, injury from triazine herbicide carryover, and spray burn). The

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IF   PLANT-SYMPTOM-TYPE is WILT
     or POOR GROWTH
     and ROOT-GALL-PRESENCE is YES,

THEN DISORDER is ROOT KNOT
     NEMATODE INFECTION.
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Fig. 1. The rule for diagnosing root-knot nematode infection contains two parameters, PLANT-SYMPTOM-TYPE and ROOT-GALL-PRESENCE. The rule will execute and root-knot nematode infection will be concluded if the value for PLANT-SYMPTOM-TYPE is WILT or POOR-GROWTH and the value for ROOT-GALL-PRESENCE is YES.

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system assumes only that the user knows the soil pH of the field in question and has a ×10 hand lens for close examination of lesion surfaces. A "help" function incorporated into the knowledge base provides descriptions of terms, plant symptoms, and field diagnostic procedures. A run-time version of the system will operate on an IBM XT-compatible computer with 640K memory and a disk drive.

One of the special features that distinguishes expert systems from conventional programs is their ability to address problems and offer solutions when given incomplete data or unknown information. The plant disease syndrome includes a few symptoms that are essential for an absolutely certain diagnosis of a disorder. If one or two of these key features are not apparent or not detected, then a reduced certainty may be associated with the conclusion. For example, essential features of a bacterial wilt diagnosis are wilting and the demonstration of bacterial slime exuding from cut stems (4). Figure 3 shows a sample consultation given these two symptoms.

The presence of bacterial slime is not easily detected. If the disease is bacterial wilt but the slime cannot be demonstrated, the program will eliminate other possible wilt diseases first, then return a diagnosis of bacterial wilt with less than 100% certainty (Fig. 4). The facility for handling uncertainty in diagnosis is incorporated into the development shell. The certainty values were assigned by the domain expert (i.e., the person with expertise in diagnosing muskmelon disorders) during development of the system.

More than one disease often exists in a commercial field. In such cases, the computer stores the PLANT-SYMPTOM-TYPE selections from the first menu before it proceeds with the prompts to achieve a diagnosis for PLANT-SYMPTOM-TYPE. Once the disorder is diagnosed, the computer recalls the selections chosen from the initial menu and offers an explanation based on these selections that another disorder may be present. It follows with a list of possible disorders for which the rules include the PLANT-SYMPTOM-TYPE selections. Thus, the user is alerted to the possibility of additional disorders and, in the case where no diagnosis was determined, is provided a reduced list of possibilities to pursue.

Validating the system

Validation involved nonexpert humans (nonexpert in the area of diagnosing muskmelon diseases) using the system to diagnose actual crop disorders. These people included technicians, graduate students, and county agents. All users had agricultural backgrounds, but none was familiar with muskmelon diseases. Diagnoses made by nonexperts with the system were compared with identifications given by the domain expert (the first author) and were classified into three categories: correct diagnosis with 100% certainty, correct diagnosis with less than 100% certainty, and incorrect or no diagnosis (Table 1). A correct diagnosis with 100% certainty indicates that the user included all essential symptoms and the system agreed with the domain expert. A correct diagnosis with less than 100% certainty indicates that the user failed to detect and enter one or two key symptoms. The computer diagnosis agreed with the expert, but not at the 100% certainty level. The bacterial wilt example previously mentioned can be classified in this category; a bacterial wilt conclusion drawn without the demonstration of bacterial slime is associated with less than absolute certainty. If the diagnosis made by the system did not match the expert's, an incorrect diagnosis was concluded. If selections made from the menus did not match any of the rules in the knowledge base, then no diagnosis was concluded.

A total of 113 samples representing 11 muskmelon disorders were diagnosed by nonexperts using the expert system during the 1987 growing season (Table 1); 71% of the conclusions resulted in a correct diagnosis with 100% certainty, 13% resulted in a correct diagnosis with less than 100% certainty,

PARAMETERS	VALUES
FIELD-SPATIAL-DISTRIBUTION	(BORDER, CLUSTER, HIGH-GROUND, LOW-GROUND, RANDOM, ROW, UNIFORM)
FIELD-TEMPORAL-DISTRIBUTION	(FAST, SLOW)
FIELD-SOIL-PH	
PLANT-GROWTH-STAGE	(SEEDLING, EARLY JUVENILE, LATE JUVENILE, MATURE, SENESCENT)
PLANT-SYMPTOM-DEVELOPMENT-RATE	(FAST, SLOW)
PLANT-SYMPTOM-SPATIAL	(UNIFORM, CLUSTERED-BOTTOM, CLUSTERED-TOP, RANDOM)
PLANT-SYMPTOM-TYPE	(MOLD, WILT, MOSIAC, LEAF-SPOT, BLIGHT, CHLOROSIS, POOR GROWTH, CANKER)
LEAF-LESION-COLOR	(BROWN, YELLOW, WHITE, GRAY, WHITE-MOLD, BROWN-PURPLE-MOLD)
LEAF-LESION-LOCATION	(MARGINAL, INTERVEINAL, INTRAVEINAL, UPPER-SURFACE, LOWER-SURFACE)
LEAF-LESION-SHAPE	(ANGULAR, CIRCULAR, UNKNOWN)
LEAF-LESION-SIZE	(SMALL, LARGE, NEITHER)
LEAF-LESION-TRAITS	(FUNGAL-STRUCTURES, CONCENTRIC-RINGS, WATERSOAKED-MARGINS, MOLD)
STEM-EXT-GUMMY-EXUDATE	(YES, NO)
STEM-INTERNAL-NECROSIS	(YES, NO)
STEM-INTERNAL-STREAMING	(YES, NO)
STEM-LESION-COLOR	(BROWN, TAN, WHITE-MOLD)
STEM-LESION-LOCATION	(RANDOM, CROWN, GROWING-POINT, NONE)
STEM-LESION-TRAITS	(FUNGAL STRUCTURES, WATERSOAKED, CRACKS, CANKER, NONE)
ROOT-GALL-PRESENCE	(YES, NO)
ROOT-LESIONS	(YES, NO)
ROOT-PRUNING	(YES, NO)
FRUIT-LESION-COLOR	(WHITE, BROWN-BLACK, SALMON-PINK)
FRUIT-LESION-ELEVATION	(SUNKEN, LEVEL-WITH-FRUIT-SURFACE, RAISED)
FRUIT-INTERNAL-ROT	(YES, NO)
FRUIT-LESION-LOCATION	(BLOSSOM-END, STEM-END, NIETHER)
WEATHER-CONDITIONS	(DROUGHT-CONDITIONS, HOT-DRY, HOT-WET, COLD-DRY, COLD-WET, NORMAL)

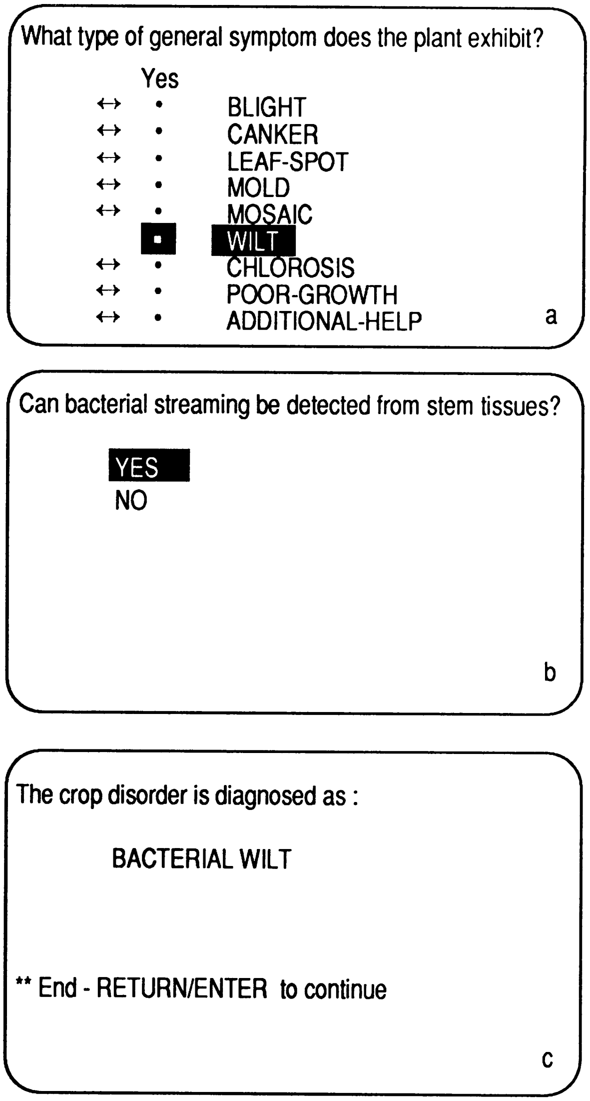
Fig. 2. Standard parameters and their values used for constructing rules. The parameters are variables or attributes that follow a logical heirarchy of field patterns and plant symptoms used in the investigation of disorders.

and 16% resulted in an incorrect or no diagnosis. Seventeen of the 18 conclusions in the last category involved three diseases—Alternaria leaf blight, anthracnose, and gummy stem blight—that produce brown spots on leaves. The computer diagnoses that did not agree with the domain expert signaled problems in the rule structure. Rule corrections were implemented and verified after appropriate changes were made in the parameter-value combinations for each of the three diseases. Results of the 1988 survey for validation showed improved performance of the system. However, poor disease development during the growing season limited the scope of the survey (Table 1).

Utility of the system

Expert systems for diagnosing disorders are intended to supplement rather than replace printed diagnostic guides that rely on black and white or color photographs for symptom descriptions. Computer programs cannot match the portability of a printed field guide, but their interactive format helps overcome some of the drawbacks associated with printed media. The color plates tend to focus on one or two major symptoms of an affected plant. Although a single photograph sometimes suffices for identification, most situations require a more complete description of symptoms. Also, affected plants may not always express major symptoms and photographs may not accurately represent the symptom(s) in question. Because an expert system rule considers all of the features of a particular syndrome, a diagnosis may be made even though one or more symptoms are not expressed by the plant or recognized by the user. The interactive environment of an expert system also provides the advantage of quickly eliminating many possibilities, narrowing the search for a solution to a few disorders based on the user's responses during a consultation.

This system will be used by non-plant pathologists and nonexperts in the area of diagnosing cucurbit disorders. Therefore, some visual representation of plant symptoms is needed. We include 28 color plates in the MDMS user's guide to address this need; the plates show certain types of symptoms that are referred to during a consultation. The guide also lists all parameters and defines all terms. For example, one color plate shows bacterial streaming plus a paragraph on how to perform the field test for streaming. The list and descriptions of parameters and values also are available on the screen and are accessed through the "help" feature within the program.


What type of general symptom does the plant exhibit?

Yes
↔ • BLIGHT
↔ • CANKER
↔ • LEAF-SPOT
↔ • MOLD
↔ • MOSAIC
▪ WILT
↔ • CHLOROSIS
↔ • POOR-GROWTH
↔ • ADDITIONAL-HELP

Can bacterial streaming be detected from stem tissues?

YES
NO

The crop disorder is diagnosed as :

BACTERIAL WILT

** End - RETURN/ENTER to continue

Fig. 3. Menus used for diagnosis of bacterial wilt. **(A)** Selecting WILT from the initial menu, which prompts the user for the plant symptom type, and **(B)** responding YES to the next question about bacterial streaming results in **(C)** a diagnosis of BACTERIAL WILT.

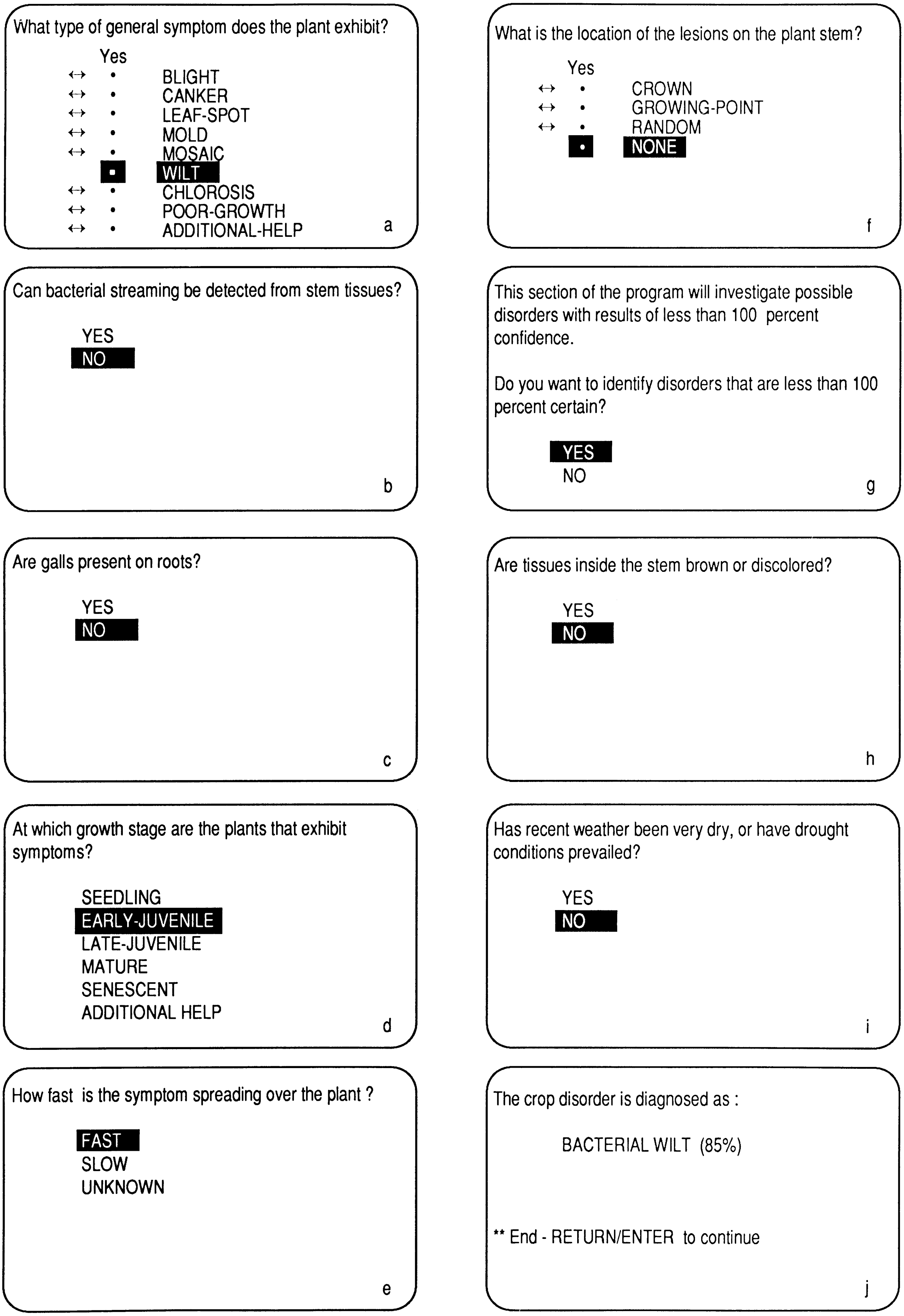
Further study and future goals

Much of the power and flexibility of expert systems are due to the fact that the knowledge base is separated from the inference mechanism (11). The knowledge base can be modified or rules can be added or deleted without interfering with the operation of the system or the performance of other

Table 1. Results of surveys during 1987 and 1988 for validation of the muskmelon disorder diagnostic expert system

			Expert system diagnoses					
	No. of samples		**Correct 100%**[a]		**Correct <100%**[b]		**Incorrect or no diagnosis**[c]	
Muskmelon disorder	**1987**	**1988**	**1987**	**1988**	**1987**	**1988**	**1987**	**1988**
Alternaria leaf blight	17	7	10	4	0	2	7	1
Anthracnose	12	1	4	0	4	1	4	0
Bacterial wilt	15	9	12	5	3	4	0	0
Fusarium wilt	7	0	4	...	3	...	0	...
Gummy stem blight	18	0	9	...	3	...	6	...
Magnesium deficiency	5	0	5	...	0	...	0	...
Manganese toxicity	10	1	7	1	2	0	1	0
Molybdenum deficiency	9	1	9	1	0	0	0	0
Ozone injury	1	2	1	2	0	0	0	0
Powdery mildew	11	6	11	6	0	0	0	0
Root-knot nematode infection	8	13	8	13	0	0	0	0
Totals	113	40	80	32	15	7	18	1

[a] Computer diagnoses agree with 100% certainty with those of the domain expert.
[b] Computer diagnoses were the same as those of the domain expert but with less than 100% certainty.
[c] Computer diagnoses did not agree with those of the domain expert.



```
What type of general symptom does the plant exhibit?
            Yes
   ↔    •        BLIGHT
   ↔    •        CANKER
   ↔    •        LEAF-SPOT
   ↔    •        MOLD
   ↔    •        MOSAIC
      [✓ ■]      [✓ WILT]
   ↔    •        CHLOROSIS
   ↔    •        POOR-GROWTH
   ↔    •        ADDITIONAL-HELP
```

```
Can bacterial streaming be detected from stem tissues?

      YES
      [✓ NO]
```

```
Are galls present on roots?

      YES
      [✓ NO]
```

```
At which growth stage are the plants that exhibit
symptoms?

      SEEDLING
      [✓ EARLY-JUVENILE]
      LATE-JUVENILE
      MATURE
      SENESCENT
      ADDITIONAL HELP
```

```
How fast  is the symptom spreading over the plant ?

      [✓ FAST]
      SLOW
      UNKNOWN
```

```
What is the location of the lesions on the plant stem?

            Yes
   ↔    •        CROWN
   ↔    •        GROWING-POINT
   ↔    •        RANDOM
      [✓ •]      [✓ NONE]
```

```
This section of the program will investigate possible
disorders with results of less than 100  percent
confidence.

Do you want to identify disorders that are less than 100
percent certain?

      [✓ YES]
      NO
```

```
Are tissues inside the stem brown or discolored?

      YES
      [✓ NO]
```

```
Has recent weather been very dry, or have drought
conditions prevailed?

      YES
      [✓ NO]
```

```
The crop disorder is diagnosed as :

          BACTERIAL WILT  (85%)


** End - RETURN/ENTER  to continue
```

Fig. 4. An example of an uncertain diagnosis. **(A)** When the symptom is wilt but **(B)** bacterial streaming cannot be detected, the system eliminates **(C)** root-knot nematode, **(D)** damping-off, **(E–H)** Fusarium wilt, and **(I)** drought stress before **(J)** concluding, with 85% certainty, that the disorder is bacterial wilt.

rules. This feature allows the construction of large systems from a series of smaller, more manageable units. The knowledge base of this system currently is being enriched with rules for diagnosing diseases and disorders of watermelons and other cucurbits. Also, rules that specify recommendations for managing each problem diagnosed are being developed.

The goal is to develop a comprehensive crop disorder management system that will serve individuals who influence on-farm decisions. These individuals include county extension personnel, private crop consultants, and agribusiness representatives. Most already have the required computer hardware; they all have a need for expert knowledge about diagnosing and managing crop problems. The system will provide decision support and advice in lieu of expert extension specialists and serve as a tool to teach users the art of diagnosis and the basis for disease control decisions.

LITERATURE CITED

1. Caristi, J., Scharen, A. L., Sharp, E. L., and Sands, D. C. 1987. Development and preliminary testing of EPINFORM, an expert system for predicting wheat disease epidemics. Plant Dis. 71:1147-1150.
2. Huggins, L. F., Barrett, J. R., and Jones, D. D. 1986. Expert systems: Concepts and opportunities. Agric. Eng. 67:21-23.
3. Krause, R. A., and Massie, L. B. 1975. Predictive systems: Modern approaches to disease control. Annu. Rev. Phytopathol. 13:31-47.
4. Latin, R. X., Miles, G. E., and Rettinger, J. C. 1987. Expert systems in plant pathology. Plant Dis. 71:866-872.
5. Michalski, R. S., Davis, J. H., Bisht, V. S., and Sinclair, J. B. 1983. A computer-based advisory system for diagnosing soybean diseases in Illinois. Plant Dis. 67:459-463.
6. Rennels, G. D., and Shortliffe, E. H. 1987. Advanced computing for medicine. Sci. Am. 257(4):154-161.
7. Roach, J., Virkar, R., Drake, C., and Weaver, M. 1987. An expert system for helping apple growers. Comput. Electron. Agric. 2:97-108.
8. Shortliffe, E. H. 1976. Computer-Based Medical Consultations: MYCIN. Elsevier, New York. 264 pp.
9. Travis, J. W., Hickey, K. D., and Rajotte, E. G. 1988. An expert system to aid in the application of a sterol-inhibiting fungicide in controlling apple scab. (Abstr.) Phytopathology 78:1562.
10. van Melle, W., Shortliffe, E. H., and Buchanan, B. G. 1981. EMYCIN: A domain-independent system that aids in constructing knowledge-based consultation programs. Pages 249-263 in: Machine Intelligence. A. H. Bond, ed. Infotech State of The Art Report, Ser. 9, No. 3. Pergamon Infotech Limited, Maidenhead, U.K.
11. Waterman, D. A. 1985. A Guide to Expert Systems. Addison-Wesley, Reading, MA. 419 pp.