EXPERT SYSTEMS FOR MANAGEMENT OF PESTS OF AGRICULTURAL CROPS

W. G. Rudd

Department of Computer Science
Oregon State University
Corvallis, Oregon 97331

Krishna Uppuluri

George R. Cross

Sue Haley

Department of Computer Science
Louisiana State University
Baton Rouge, Louisiana 70803

TR 86-60-4

Expert Systems for Management of Pests of Agricultural Crops

W. G. Rudd[1]

Krishna Uppuluri

George R. Cross[2]

Sue Haley[3]

Department of Computer Science

Louisiana State University

Baton Rouge, Louisiana 70803

ABSTRACT

Expert advisory systems for agricultural pest management control offer the means to capitalize on the wealth of information that is currently tied up in research laboratories and human experts' minds. The ideal system would blend knowledge from three sources - human experts, dynamic simulation models, and historical databases - to identify pests and to produce advisories for their management. We describe the design of such a system and the progress to date in the construction of prototype systems.

June 25, 1986

1 Present address: Department of Computer Science, Oregon State University, Corvallis, Oregon 97333

2 Present address: Department of Computer Science, Washington State University, Pullman, Washington 99164

3 Department of Entomology, Oregon State University, Corvallis, Oregon 97331

Expert Systems for Management of Pests of Agricultural Crops

W. G. Rudd[1]

Krishna Uppuluri

George R. Cross[2]

Sue Haley[3]

Department of Computer Science

Louisiana State University

Baton Rouge, Louisiana 70803

1. Introduction

An expert system approach is ultimately the only way to remove one of the biggest barriers to agricultural productivity: the knowledge gap that lies between university and federal laboratories and the growers of crops. We must find a way to transfer the wealth of knowledge that has accumulated in these laboratories to those who need the knowledge in a usable form to help improve their productivity. There is no doubt that an enormous improvement in agricultural productivity would occur if all the knowledge in the agricultural community could be

---

1 Present address: Department of Computer Science, Oregon State University, Corvallis, Oregon 97333

2 Present address: Department of Computer Science, Washington State University, Pullman, Washington 99164

3 Department of Entomology, Oregon State University, Corvallis, Oregon 97331

brought to bear in individual cases in which a grower needs advice on how to proceed with managing his operations.

The form the information has and its widespread geographic dispersal block easy transfer of pest management information to farmers. Because of the competitive structure of the agricultural research system in this country, in which states compete with other states for funding and in which different laboratories and organizations within states similarly compete with each other, there is no real centralized organization in the agricultural establishment. The result is that there has been little motivation for interstate cooperative research efforts, and the information growers could use to help them manage their crop production is stored in many laboratories in many states for a single crop.

For example, there are about 20 states which have entomologists working on soybean insect pest control in the US. Louisiana researchers compete with Mississippi researchers for research support, even though they study the same insects in the same crop in states with similar climates and environments. The result is that there are two separate sets of research programs, two sets of data, and two sets of treatment recommendations for soybeans in Louisiana and Mississippi, even though there is virtually no difference between the two states in any area that would have an effect on the soybean crops and their insects.

There are also soybean entomologists in California, Illinois, and many other states. While it is true that there are differences in how soybeans and their insects grow between Illinois and Louisiana, it is still safe to say that there is information developed in Illinois that could be applied in Louisiana, if there were some way to move the information to where it could be used.

In all states, the current means for transferring information from agricultural research laboratories to growers is through their respective agricultural extension services, whose local spokespeople are extension agents. These agents get most of their information from agricultural researchers in their own states. There is no real attempt to share or combine information from across state boundaries.

A corollary to this competitive and non-cooperative research atmosphere is that we have little hope of getting researchers to cooperate in the development of a crop-wide expert system for any crop that is grown in several states. We cannot expect that a group of experts in pest management for a given crop would cooperate to the extent necessary to form a set of consensuses for an expert system.

This means that recommendations for growers tend to be overly simple rules of thumb, with no consideration whatsoever of the details of the problems at hand. Again, to choose an example from soybeans, most advisories on how to control soybean insect pests are simple statements such as, "If you count more than 8 soybean loopers per foot of row of your crop, apply a pesticide." Such recommendations pay no heed to a number of factors that could have a profound effect on the economic and environmental advisability of applying a pesticide. A few of the more important of these factors are the time of the year, the stage of development of the crop, the possibility that natural enemies or climate could control the pests, the likely damage to the crop, the effect spraying would have on natural enemies, and the price the grower is likely to get for the beans. In other words, the correct decision depends on a complicated combination of many factors, only one of which is considered in the standard recommendation to the grower.

The current body of knowledge of pest management methodology for soybean crops, and many others, is sufficiently advanced to allow much better decision processes, based on factors like those listed above, to be brought to bear on individual pest management decisions. Two major influences - the distribution of human experts and data over many laboratories and states, and the lack of adequate manpower to permit experts to examine every case in adequate detail - prevent this body of knowledge from being properly applied.

There are a large number of agricultural products, each with its own set of pests and researchers. It will be economically impossible to provide an adequate supply of knowledge engineers to develop customized management systems of the necessary sophistication for each product. Therefore, we will have to rely on the agricultural community itself to construct its own custom systems. Our job is to provide the proper tools.

Our research objective is to develop well-designed user interfaces and knowledge acquisition tools, designed specifically for use in the development of agricultural pest management systems, so that agricultural experts can develop their own systems. This paper describes the first steps in our experiments with knowledge-based systems techniques for this purpose. Our objective is not to develop operational pest management systems. It is to try to understand how pest management decisions are and should be made and to build tools agricultural scientists can use to help transfer their knowledge to the agricultural producers.

In the next section, we examine the nature of the knowledge that can be used in making pest management recommendations and we describe how human experts seem to go about constructing advisories. We then discuss the system we have developed to date, and conclude with a description of the work that remains to be done.

2. Knowledge Sources for Pest Management Advisories

The goal is to develop the framework of an expert system that produces advisories to help with decisions on how to manage insects, diseases, and other pests. The system should be designed for interactive use by the growers themselves, presumably via dial-up communications with a central machine, or using a local computer or workstation.

In normal use, the system would be expected to produce case-by-case recommendations on which of three alternatives - apply a pesticide, monitor the system closely for a period of time, or do nothing - is preferrable economically and environmentally. Recommendations would be produced in response to requests entered by users. The system should prompt the user for the data that are specific to individual requests for advice.

In this effort, the emphasis has been on isolating and generalizing those aspects of the process of the construction of advisories that are common to all crop systems, so that the resulting framework will be as widely applicable as is possible.

The first step in this process is to identify the sources of knowledge that can be used to help generate advisories. We know that for each crop there are a number of human experts - researchers, extension agents, and some growers - who have accumulated knowledge and experience in pest management. As we pointed out above, these experts tend to be widely dispersed geographically and there is not much hope of having them join together to help build a system. Nevertheless, they are the primary source of the methodology for the pest management advisory process and they are the primary source of detailed information on how to manage pests in given crops.

A second knowledge source for pest management derives from efforts by researchers in pest management in many crops (see Huffaker[1] , for example) to develop mathematical and computer models that predict crop growth, the dynamics of pest populations, and the effect that the pests will have on future crop yields. Some of these models are quite sophisticated and accurate. But, in most instances, these models are inaccessible to the grop grower because they are housed in large research computers and because they require human experts to operate them.

The third source of knowledge is the enormous set of data that have been collected over many years by pest management researchers. It is difficult to compute the value of this information, but a conservative estimate is that about $60,000,000 has been spent on research on the management of soybean insect pests alone over the last 15 years. Much of this expenditure has been to collect data on insect populations and crop yields in experiments on the effectiveness of chemical pesticides, the use of biological control agents, pilot studies of pest management practices, and the determination of economic injury as a function of pest populations.

Most of this information lies buried in filing cabinets. Little of it is published, and what is published is not in a form that is directly usable in pest management systems. A portion of our research can be viewed as an attempt to "rescue" this expensive inaccessible resource.

3. Producing Pest Management Advisories

The overall plan for our pest management research program is to construct a framework for an expert system that combines these three knowledge sources into one package. We are using as a model the methods that human entomolgists apparently would use, given free access to the three sources.

At the top level, the generation of a pest management advisory is much like the diagnose-treat process in medicine. The three important steps involved are to identify the pest(s), to determine the magnitude of the threat, and to recommend a treatment.

Biological scientists use what they call "keys" to identify species. A key is simply an English-language decision tree. At each level, the user selects from a number of choices characteristics of the pests to be identified. The selection made determines the possible choices at the next level, and so on until the pests have been identified. In our systems, described below, the pest identification procedure appears to the user as if it is a simple key.

The search of the decision tree is complicated by the facts that there can be several pests of different types which interact in complex ways. For example a disease which has its own distinguishing symptoms might also make the crop more susceptible to damage by certain insects. Another fact that makes the search process more difficult is that the user will not always be able to determine the information required to search the decision tree.

In determining the magnitude of the threat, the objective is to discover whether the potential economic damage to the crop because of the pests will be severe enough to justify some control action. As we indicated above, this decision depends on many factors, including the pests, whether, condition of the crop, economic conditions of the market and the grower, and the possibility that treatments might lead to secondary problems by other pests that have benefited from attempts to treat the first pests discovered. Much of the recent research in pest management has focused on this problem. The object is to determine the future effects of pests given our current knowledge of the system. Researchers have developed sophisticated predictive models for this purpose and there is a large body of practical experience, research results, and folklore that could be used in assessing probable damage to crops.

Once the probable crop loss due to the pests has been estimated, it then becomes necessary to decide what to do. Normally, the decision is to treat, to continue to monitor the system with the object of determining later whether a treatment is then justified, or to ignore the threat. If a treatment is called for, the decision of how to treat the pest(s) - whether to use chemicals and, if so, which ones, whether to use biological control agents, when to apply the treatment, what kind of follow-up monitoring to do - also is a complex one that depends on many factors, such as weather, the state of the crop, economic factors, and the complex of pests and beneficial biological agents that are present in the system.

We now turn to a description of our efforts to construct tools to help pest management experts to create advisories as we have described above.

4. Prototype Systems

We have constructed a prototype for a large portion of a system for management of soybean insect pests. The system helps the user determine what the pest is, and then uses human expert recommendations and models of crop growth and insect population dynamics to produce its recommendations.

We chose not to use a rule-only tool, such as EXPERT[2] or one of its descendants. Few of the commercially available packages for small systems, for example, allow one to call external programs,[3] which would make it virtually impossible to connect the model and history database components to the system. We also wanted the freedom to establish our own search strategies and user interfaces.

We actually developed this system from the beginning twice. In the first attempt, we used the OPS5 [4] production system tool. Most of the basic ideas discussed below were implemented in this first system, but we eventually discarded it for several reasons, the most important of which were the lack of ability to call functions in the left or right side of the productions, the slow speed of execution of our search strategy, and the limited variety of functions that can be implemented in the rhs of an OPS5 rule. Another problem was that we wanted as much as possible of the knowledge of the system to be separate from the code itself, so that our search and advisory package would be independent of the data. We wish not to have to alter the logic of the search and advisory strategies in changing from one pest to another. We were unable to devise a way to construct such a "table-driven" scheme within the bounds of OPS5.

The second implementation of the system is written in Maryland version of FRANZLISP, using the Flavors enhancement, and the YAPS production building system.[5] This version is much cleaner, faster, and we did manage to extract the data from the search logic.

In the soybean implementation, the attributes for each insect are stored as instances of the *insect* flavor, as shown in Fig. 1. The attribute names (*Number of prolegs*, for example) are exactly the questions that the user answers when going through the search procedure. The attribute values are the answers to the questions for the individual pest. Figure 2 shows the attribute-value pairs in the Flavors instances that represent some of the soybean insect pests. For a pest for which there is more than one search path, we store one instance per path.

In order to minimize the number of questions the user must answer in the search phase, we ask the questions in the order that, on the average, eliminates the largest number of candidates at each stage. To do this, at each stage in the search, we prepare a list of the attributes remaining to be determined and the number of pest instances remaining in the list of possibilities that has each attribute. We sort the list by that number in descending order and, usually, ask the user for the value for the attribute that comes first in that list. Upon determining the value of an attribute, we mark all those instances that do not have that value of that attribute as no longer possible candidates for the pest being sought.

The search procedure includes what might be called a crude guessing mechanism, in that, if the user does not know the value of an attribute, or if none of the values presented to him or her is correct, the system proceeds to the next level in the search tree by asking the for the next attribute value in the sorted list, leaving the attribute value marked as undetermined for the attribute that was unknown. The system counts the number of questions answered in this way and uses this count to produce a crude certainty value for the identification of the pest when the search is completed.

We also provide the rudiments of an explanation mechanism, by tracing the path through the search tree that was taken, and at each stage, giving the user a list of the pests that were still possible candidates. While this is certainly inadequate for an operational system, it includes the rudiments for answering why and why not questions.

Once the pest is identified, we enter a YAPS rule-based system to produce an advisory. This procedure is straightforward. For some pests, we call some population dynamics and crop yield prediction models that are essentially response surface equivalents of those described in Rudd[6] , et al.

Implementation of a prototype history database comparison package is now in progress.

An example of a search and advisory script is provided in the Appendix to this paper.

Recent efforts have focussed on the development of automated tools for the construction of similar systems for other crops. Because our control structure is independent of the actual crop, we have been able to construct the pest identification component of an apple orchard pest management system within a week, and have no reason to suspect that the technique will not work as well for pests of other crops.

In designing the software and procedures for the general case, we took advantage of the fact that most applied biologists are familiar with the construction and use of search keys. The tree diagram for the key in the original data for the apple system was drawn on a long roll of brown wrapping paper. This tree was converted into a lisp "question and answer" file of attributes and values, a portion of which is shown in Figure 3. Each attribute name (a question on a menu in the search routine) is followed by a series of attribute values (answers to the question). The lists of numbers preceding the answers are the paths to take to get to the answers. All that remains is to connect that pest species with the paths in the tree. This is done via the "critters" file, a portion of which is shown in Figure 4. The path to the leaf at which each pest resides is followed by the name of the pest.

Once these two files are created, a simple program combines the files into the flavors instances, like those in Figure 2, for the search procedure. While we do not claim that this procedure could be called "user friendly," we have found that the biologists working with us have had little difficulty in understanding how to construct and modify the question and answer and critters files. We are currently building an editor program for users to use in creating and modifying these files by following the same lines of reasoning they use in constructing the keys with which they are more familiar.

We are also experimenting with a Prolog implementation of the prototype system.

5. Implications and Further Work

Attempts to build expert systems for management of agricultural systems offer motivation for further research in expert system technology. Several of the problems we face are still open questions in artificial intelligence. For example, we have indicated above that there are at least three independent knowledge sources from which advisories should be generated. We must therefore learn to incorporate a meta-level component of the system that understands how to reconcile differences in the recommendations that will arise from these three sources.

We need to incorporate certainty factors into all the sub-systems as as means for evaluating decisions and recommendations from them. To this end, our coworkers have developed a new version of YAPS for this purpose called YAPS_CF.[7] This system includes MYCIN-like certainty factor processing.

Furthermore, because of the geographic and organizational structure of the agricultural establishment, the system must be able to incorporate advice from several different human experts. These experts have little incentive to agree with each other. But, even if it might be possible to obtain consenses from groups of these experts, the costs of doing so would be prohibitive. We must therefore develop methods, presumably based on a modified Dempster-Schafer[8] approach, to evaluate and resolve conflicting opinions that come from the machine realization of different experts.

There is a need for the study of common principles that pest management experts use to solve such problems. The reasoning paths and domains are different from those in other disciplines, as are the final objectives. We need to undertake a protocol analysis study to determine, as closely as we can, the sets of principles and deductive strategies pest management experts use in order to reach their decisions.

We have indicated the need to develop means by which to locate, from a database, those data sets that are "similar" to the situation in the instance currently under consideration by the system. We have constructed a list of about thirty attributes to be used in determining degrees of similarity between data sets. We are now developing a weighted partial matching scheme (after Hayes-Roth[9]) that will eventually be used in retrieval from our pest management experiment history database.

In summary, we have described the problem of developing expert systems for management of agricultural pests. We have made some progress in the development of prototype systems, but there is a lot of interesting work that must be done before we can say that we have conquered the problem.

```
(defflavor insect
        (name
        |Insects found above or below ground|
        |Developmental stage|
        |Body covering|
        |Type of mouth|
        |Color of larvae|
        |Kind of head|
        |Head compared with thorax|
        |Size of hind legs|
        |Color of hind legs|
        |Shape of legs|
        |Total length|
        |Wing shape, covering|
        |Shape of body|
        |Kind of body|
        |Style of living|
        |Characteristics of abdomen|
        |Characteristics of wing covers|
        |Number of prolegs|
        |Color of body|
        |Characteristics of skin|
        |Characteristics of antennae|
        |Where feeding|
        |When were the plants damaged|
        |Germination characteristics |
        |External injury|
        |Appearance of leaf damage |
        |Appearance of plant damage |
        |Damage to pods |
        |Appearance of seed damage |
        |Effect of damage | )
        nil
        :gettable-instance-variables
        :settable-instance-variables)
```

Figure 1. The flavor *insect* defines the attribute names the pests can have. Attribute names are the questions the search procedure asks the user.

```
(store (pest 47)
 (make-instance 'insect
      'name '|Southern green stink bug|
       '|Insects found above or below ground| '|Above ground|
       '|Developmental stage:| '|Adult|
       '|Type of mouth| '|Piercing and sucking|
       '|Kind of head| '|Elongated into a beak|
       '|Total length| '|1/4 to 1/2 inch|
       '|Shape of body|  'Shield
       '|Color of body| '|Dull green|))

(store (pest 48)
 (make-instance 'insect
       'name '|Velvet-bean caterpillar|
       '|Insects found above or below ground| '|Above ground|
       '|Developmental stage:| 'Immature
       '|Body covering|   'Smooth
       '|Color of larvae| 'Green
       '|Number of prolegs| '|4 pairs|
       '|Color of body| '|Approximately 7 longitudinal white stripes|))

(store (pest 49)
 (make-instance 'insect
       'name '|3-Cornered alfalfa hopper|
       '|Insects found above or below ground| '|Above ground|
       '|Developmental stage:| 'Immature
       '|Type of mouth| '|Piercing and sucking|
       '|Total length| '|Less than 1/4 inch|
       '|Wing shape, covering| '|Wide, no fringe of hair|
       '|Shape of body|  'Triangle))
```

Figure 2. Pests are represented as an array of instances of the *insect* flavor. Attribute values are the answers to the questions the search procedure asks.

```
(
(1) '|Other than weeds|
(2) '|Weeds|
)
(
(1 1) '|Crown or roots|
(1 2) '|Fruit|
(1 3) '|Trunk or scaffold limbs|
(1 4) '|Small branches|
(1 5) '|Flowers or blossoms|
(1 6) '|Terminal leaves or shoots|)
('|How are crown or roots affected|
(1 1 1) '|Band of bark clearly removed at soil line, 1 inch diameter
        runways in and below snow cover or litter at base of tree|
(1 1 2) '|Tree anchorage weakened by destruction of roots, mounds of
        soil pushed up near tree|
(1 1 3) '|Band of rotting bark partially or completely girdling tree
        below soil line|
(1 1 4) '|One or more swellings at crown and/or on roots|
)
(
(1 2 1) '|Premature fruit drop|
(1 2 2) '|Fruit quality reduced|
)
(
(1 2 2 1) '|Normal shape with only superficial marks|
(1 2 2 2) '|Deformed by cracks, dents, deep holes, or bumps|
)
(
(1 2 2 1 1) '|Discolored spots or patches|
(1 2 2 1 2) '|Fruit of normal size and color|
(1 2 2 1 3) '|Whole apple small and undercolored|
(1 2 2 1 4) '|Whole apple oversized and undercolored|
(1 2 2 1 5) '|Apple small and highly colored|
(1 2 2 1 6) '|Russetted|
)
('|Spots or patches rough or smooth|
(1 2 2 1 1 1) '|Spots or patches rough or raised|
(1 2 2 1 1 2) '|Spots or patches smooth|
)
```

Figure 3. A portion of the apple pest search tree or key. Each question (attribute name) is followed by all possible answers (attribute values) for it. The lists of numbers define the paths through the search tree to follow to get to the answer.

```
(1 1 1) '|Vole|
(1 1 2) '|Pocket gopher|
(1 1 3) '|Crown rot|
(1 1 4) '|Crown gall|
(1 2 1) '|Genetic deficiency|
(1 2 1) '|Magnesium deficiency|
(1 2 1) '|Codling moth|
(1 2 1) '|Hail|
(1 2 2 1 1 1 1) '|Apple scab|
(1 2 2 1 1 1 2) '|Oblique banded leaf roller|
(1 2 2 1 1 1 2) '|Three-lined leafroller|
(1 2 2 1 1 1 2) '|Eye-spotted budmoth|
(1 2 2 1 1 1 3) '|Leafhopper|
(1 2 2 1 1 1 4) '|San Jose scale|
(1 2 2 1 1 1 5) '|Sooty mold|
(1 2 2 1 1 2 1) '|Sunburn|
(1 2 2 1 1 2 2) '|Western flower thrips|
(1 2 2 1 2 1) '|Codling moth|
(1 2 2 1 2 2) '|European fruit scale|
(1 2 2 1 2 3) '|European red mite|
```

Figure 4. A portion of the critters file. The name of each pest follows the path to the leaf the pest occupies.

APPENDIX: SCRIPT OF A SESSION WITH THE SOYBEAN PEST MANAGEMENT SYSTEM

We present below an edited script of a session with the soybean pest management system. User inputs are in **bold-faced** type. Comments we have inserted into the script appear in *italics*. *New menu* indicates the beginning of a new menu on the screen.

After the user loads and starts the system, the first question determines what the user wants to do. The user should have knowledge of either the insect pests, characteristics of the damage to the crop, or both, in order to identify the pest.

New menu

Select option ?
1. Start search with insect attributes
2. Start search with plant damage
3. Start search with both insect attributes and plant damage
4. Terminate Session

Enter => **1**

New menu

Insects found above or below ground ?
1 Below ground
2 Above ground
d)ont know

Enter => **2**

New menu

Developmental stage: ?
1 Immature
2 Adult
d)ont know

Enter => **1**

New menu

Body covering ?
1 Smooth
2 Covered with long thin hairs
3 Totally covered with branched spines
4 Partly covered with branched spines
d)ont know

Enter => **1**

New menu

Number of prolegs ?
1 4 pairs
2 3 pairs
3 2 pairs

4 1 pair
d)ont know

Enter => **1**

New menu

Color of larvae ?
1 Green
2 Mottled dark brown or black
d)ont know

Enter => **1**

New menu

Color of body ?
1 Lateral white stripes
2 Approximately 7 longitudinal white stripes
d)ont know

Enter => **2**

At this stage, the system has eliminated all but one candidate for the pest, and tells the user it has identified the pest.

New menu

**** IDENTIFIED ****

INSECT Velvet-bean caterpillar
CERTAINTY FACTOR 1.0
Hit <return> to continue

New menu

Do you wish to see the the
process of identification?
Enter yes or no => **yes**

The following is an abbreviated script of the explanation phase. The system retraces the path through the decision tree, listing the pests that were still possible candidates after each attribute value was determined.

New menu

Attribute => Developmental stage: Value => Immature

Insects possible:

Alfalfa caterpillar Green cloverworm
Soybean, cabbage, or other loopers
Geometrid larvae
Fall armyworm Corn earworm
Yellow-striped armyworm Black cutworm
Wollybear Webworm
Mexican bean beetle Painted lady larvae
Velvet-bean caterpillar 3-Cornered alfalfa hopper

Hit <return> to continue

New menu

Attribute => Body covering Value => Smooth

Insects possible:

Alfalfa caterpillar Green cloverworm
Soybean, cabbage, or other loopers
Geometrid larvae
Fall armyworm Corn earworm
Yellow-striped armyworm Black cutworm
Velvet-bean caterpillar

Hit <return> to continue

New menu

Attribute => Number of prolegs Value => 4 pairs

Insects possible:

Alfalfa caterpillar Fall armyworm
Corn earworm Yellow-striped armyworm
Black cutworm Velvet-bean caterpillar

Hit <return> to continue

New menu

Attribute => Color of larvae Value => Green

Insects possible:

Alfalfa caterpillar Velvet-bean caterpillar

Hit <return> to continue

New menu

Attribute => Color of body Value => Approximately 7 longitudinal white stripes

---

Insects possible:

Velvet-bean caterpillar

Hit <return> to continue

The system now switches to the treatment recommendation phase. It first determines some factors the human expert needs to determine the extent of the threat to the crop.

New menu

Insect => Velvet-bean caterpillar

Please enter the month in which
the data were collected ?

Enter => **August**

New menu

Are many of the insects turning black or fuzzy white?
Enter yes or no => **no**

(The expert wants to know if there is a chance that a naturally occurring fungus disease will provide a natural control without a pesticide application).

New menu

What was the population count (number of large larvae per foot of row)?
Enter => **10**

(This number is the initial condition for the management model).

New menu

Are the insects of uniform size?
Enter yes or no ==> **no**

The system makes its recommendations. Note that there is no attempt to reconcile the recommendation from the expert with that from the model.

New menu

The expert says:

Since

there will probably be no natural control from disease
non-uniform size of larvae indicates long-term damage period
population is above 8 per foot threshold

aerial application of malathion at 1/4 pound per acre is recommended.

Hit <return> to continue

New menu

The model predicts a loss of 1.26 bushels per acre due to this pest.
Control by aerial application of malathion at 1/4 pound per acre is recommended
if anticipated sale of soybeans will bring $4.13 per bushel or more.

References

1. Huffaker, C. B. (Ed.), *New Technology of Pest Control,* 500 pp., John Wiley and Sons, New York, 1980.
2. Sholom M. Weiss, Kevin B. Kern, Casimir A. Kulikowski, and Michael Uschold, "A Guide to the Use of the EXPERT Consultation System," Technical Report CBM-TR-94, Department of Computer Science, Rutgers University, New Brunswick, NJ, (1983).
3. G. R. Cross, "Tools for Constructing Knowledge-Based Systems," *Optical Engineering,* vol. 25, no. 3, pp. 436-444, March, 1986.
4. Charles L. Forgy, "OPS5 User's Manual," CMU-CS-81, Department of Computer Science, Carnegie-Mellon University, Pittsburgh, PA, (1981).
5. Elizabeth M. Allen, "YAPS: Yet Another Production System," TR-1146, University of Maryland, Computer Science Department, College Park, MD, (December 1983).
6. Rudd, W. G., W. G. Ruesink, L. D. Newsom, D. C. Herzog, R. L. Jensen, and N. F. Marsolan, *The Systems Approach to Research and Decision Making for Soybean Pest Control,* in Huffaker, op. cit., pp. 99-122, 1980.
7. M. Nasiruddin, M. Srikanth, and G. R. Cross, "A Confidence Factor Extension to the YAPS Expert System Construction Tool," *submitted for publication.*
8. G. Schafer, *A Mathematical Theory of Evidence,* Princeton University Press, Princeton, NJ., 1976.
9. Frederick Hayes-Roth, "The role of partial and best matches in knowledge systems," *Pattern-directed inference systems,* D. A. Waterman and F. Hayes-Roth, eds., pp. 557-574, Academic Press, Inc., New York, 1978.