AN EXPERT SYSTEM FOR MANAGING INSECT PESTS OF STORED GRAIN

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Abstract

Management of insect pests of stored wheat is complex and involves many interacting factors, such as grain temperature and moisture, insecticide degradation, aeration, and fumigation. Determining whether or not insects will become a problem in stored wheat is primarily a problem of predicting population increase under future environmental conditions. We have recently developed an expert system, Stored Grain Advisor (SGA), that assists the grain managers in making pest management decisions. Stored Grain Advisor helps the manager to identify insects or other problems, predicts the likelihood of insect infestation, and selects the most appropriate prophylactic or remedial actions. Sophisticated computer models allow the expert system to predict future insect population growth, as well as the degradation of insecticides, and the effects of fumigating or aerating the wheat in relation to storage temperature and moisture. SGA was developed on Apple Macintosh computers using a frame-based shell in conjunction with a C language compiler. The shell has a graphical user interface, backward and forward chaining, explanation and help capabilities. This expert system should prove to be a valuable tool for producers, elevator operators, extension specialists and others concerned with grain storage, and should greatly.enhance our ability to store grain safely.

Introduction

Currently, most U.S. grain is stored unprotected because we cannot reliably predict the need for treatments or the economic benefits. The decision-making process tends to be based on the manager's past experiences. Often, wheat is either unnecessarily treated with insecticides or becomes infested with insects before any management action takes place. The stored-grain system is complex and involves many interacting variables such as insect immigration, grain temperature and humidity, length of storage, aeration, and insecticide degradation. The probability of insect populations reaching levels requiring control is directly related to grain moisture and temperature, and storage time (Hagstrum 1987, Hagstrum and Throne 1989).

Systems analysis is one of the most effective tools for understanding complex systems. We have recently developed an expert system that uses sophisticated insect simulation models to determine economically and environmentally sound methods to reduce insect damage and contamination of stored-wheat, while also minimizing the unnecessary use of insecticides and fumigants (Flinn and Hagstrum 1990b). We believe that our technique of incorporating results from model simulations into an expert system is the best approach for delivering timely and interpreted information to the grain manager. Expert systems have several advantages over conventional computer decision aids: 1) the knowledge base can incorporate both objective information (i.e. scientific reports) as well as more subjective information based on expert opinion, 2) they can incorporate new knowledge easily into existing knowledge bases, 3) the flow of control of the system is accomplished by pattern matching, which is a more flexible mechanism compared to traditional programming procedures, 4) because an expert system remembers its logical chain of reasoning, the user may ask the system to explain why it wants information or why it gave a particular recommendation, and 5) they provide a user-friendly environment that requires little previous computer skills.

Methods

The details of how SGA was developed are described in Flinn and Hagstrum (1990b). The purpose of this paper is to give a brief overview of the expert system's capabilities. The PennShell (Pennsylvania State Univ.) was selected for development and delivery of SGA. This is a frame-based shell that is used in conjunction with a C language compiler. The system was developed on an Apple Macintosh computer. The shell has a graphical user interface, backward and forward chaining, explanation, and help capabilities. Currently, "insects" is the main module in SGA. Submodules within "insects" include: management, identify, sampling, and fumigation. In the future, we plan to add an additional module for marketing.

Management submodule. Determining whether or not insects will reach economic densities in stored grain is primarily a problem of predicting population increase under forecasted environmental conditions. Insect population growth is a function of time, and grain temperature and moisture. Other management factors such as aeration, natural cooling, concentration of insecticide in the grain, and fumigation also affect insect population growth. Most stored-grain experts are unable to accurately forecast the quantitative effects that these variables will have on insects in stored grain. Thus, we turned to simulation modeling to give us the forecasting ability that was required for the SGA expert system.

Validated computer models are available that accurately describe population growth for five of the most important insect pests of stored wheat, as a function of time, and grain temperature and moisture (Hagstrum and Throne 1989, Flinn and Hagstrum 1990a, Hagstrum and Flinn 1990). While some expert systems have been developed that directly include simulation models, there are, however, certain drawbacks to this approach, the foremost of which is the time required to run a simulation. It takes approximately six to twelve minutes to run a simulation for one insect species on a Macintosh II computer. This results in an expert system that is unattractive to the user because of the inordinate amount of time required to diagnose a problem and make a recommendation. To solve this problem, we used the models as a source of expertise to develop rules for the management submodule. This allows the expert system to provide answers within a matter of seconds, and also provides explanations for a particular diagnosis or recommendation. In addition, the models predict the effects of various management actions such as fumigation, aeration (cooling the grain with fans), and protectants (insecticides applied to the grain during bin filling), on insect populations (Flinn and Hagstrum 1990a, Hagstrum and Flinn 1990). They can also predict the breakdown of insecticide in the grain as a function of time, temperature, and moisture, and the effects of insecticide concentration on insect survivorship. Thus, these models represent very powerful tools for forecasting if or when insects are likely to become a problem and the effects of management actions on the population.

The majority of rules in the management submodule were derived from over 500 simulations conducted with the computer models. We categorized the range of initial storage conditions into six possible combinations of temperature and moisture. In the simulations, grain could be treated with a protectant, aerated or both. The length of time that the grain is stored above 60°F, before it is either aerated in the fall or cools naturally, is a critical variable that affects population growth potential, and it varies considerably between grain-growing regions of the U.S. For example, wheat is usually harvested in June in Oklahoma, but in South Dakota wheat is normally harvested in August. We used three storage dates: June 1, July 1, and August 1 to simulate wheat storage in the southern, middle, and northern growing regions of the U.S. The results of these simulations were then translated into rules that are used by the expert system. The storage duration required for insect numbers to exceed set thresholds, under certain management conditions, were used to write the rules.

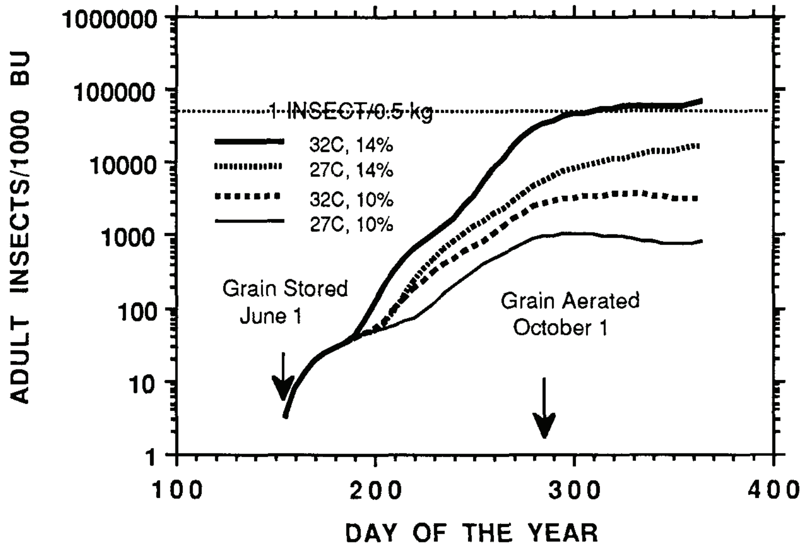

Figure 1. An example of simulation output from the model in which initial grain temperature and moisture were varied. The horizontal dashed line indicates an insect density that is likely to be detected with current marketing practices.

The rules were generated by examining graphs of predicted insect density vs time (Fig. 1). Low, moderate, and high potentials for insect infestation were assigned if the predicted number of insects was less than 1 adult/bu, 1 to 100 adults/bu, and greater than 100 adults/bu, respectively. These thresholds came from interviews with stored-grain experts. If a high probability of infestation is indicated, the manager is advised of several options: aerate if possible, consider selling the grain early, sample the grain for insects, and if insect thresholds are exceeded then fumigate if the grain temperature is above 60°F. If a moderate probability of infestation is diagnosed, the manager is advised that he should sample the gain for insects about 60 days after storage to see if treatment is needed. The manager also has the option of selling the grain earlier than planned. If a low probability of infestation is diagnosed, the manager is advised that the grain will probably be safe and that it is unnecessary to sample the grain for insects unless he decides to sell the grain at a later date.

Identify submodule. The purpose of this submodule is to aid managers in the identification of insects found in stored grain, and thus it is used in conjunction with the management submodule. It is important that insects be identified correctly because some insect species cause more damage to stored grain than others. Specifically, internal feeders cause the most damage, followed by the so called "bran bugs", and finally there are insects that feed primarily on fungus and do not damage the grain. Criteria for determining whether the insect is included in the identification key were: 1) pest of major importance or 2) commonly found insect in stored grain. This resulted in a list of 20 insect species. We developed our own rules for identification rather than relying on existing keys, because the latter were developed for larger numbers of insect species and rely on subtle characters requiring use of a microscope. The identification is broken down into a series of steps: 1) determining whether the specimen is a moth or not, 2) the size of the insect, 3) whether the head is tucked under, and 4) the color of the insect. This leads to a possible species identification, that could include up to three similar species. Pictures of each species are then presented to the user to make the final identification visually (Fig. 2). The user can page through the pictures using the "next" and "previous" buttons.

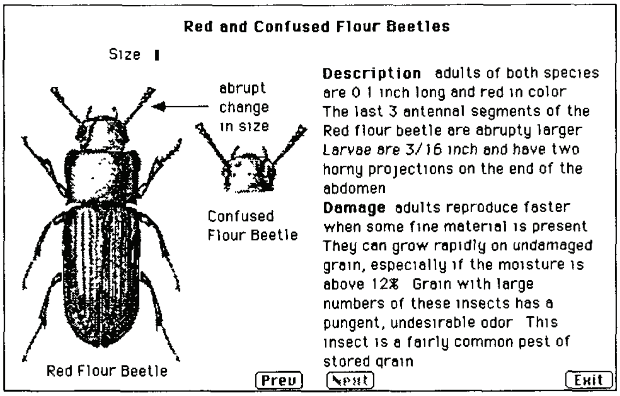

Figure 2. Example of a picture used in the "identify" submodule to help the user identify insect pests of stored grain. The "Prev" and "Next" buttons are used to browse through the insect species that the system has selected.

Sampling submodule. The purpose of this submodule is to tell the manager how, when and where to sample for insect pests of stored grain. In the past, managers have been asked to sample the grain monthly or bimonthly. This advice is often not followed because of the amount of labor involved. Results from the simulation studies indicate that sampling once or twice at certain times after storage would be equally reliable. This is because probe traps and grain probes used for detecting grain insects are more accurate at high than at low insect densities. Therefore, depending on the initial storage conditions, the expert system is able to tell the manager how long to wait after storage to sample the grain. This module also graphically displays the proper locations for insertion of probe traps within the grain mass or where grain samples should be taken. Managers can use it to calculate the accuracy of the estimate, based upon the number of traps used and the insect density or, the number of traps necessary to achieve a certain level of accuracy.

Fumigation submodule. The purpose of this submodule is to calculate the amount of fumigant necessary based on bin volume and grain temperature, specify where the fumigant pellets should be placed within the grain mass, and how long the bin should be left sealed. In addition, the module will describe for the manager the proper use of fumigation equipment, and the necessary safety precautions. Fumigation with phosphine gas is relatively dangerous and requires that self contained breathing apparatus be available. Many managers choose to fumigate their grain themselves rather than contract with a fumigation company. Thus, it is important that the managers take proper safety precautions. Bins must be properly sealed so that gas leakage is minimized and the correct amount of fumigant needs to be used.

Expert system operation. The expert system has the typical Macintosh pull-down menus (Fig. 3). The main menus are: file, edit, and insect. Under the "file" menu, the user can load or save a bin profile, change the current date and time, or quit the program. The bin profile contains stored information about the management facility and individual bins (one profile is used for each bin). Information stored in the profile is relatively static. Some examples are: location of facility within the U.S., bin size, storage date, protectant applied, initial grain temperature and moisture.

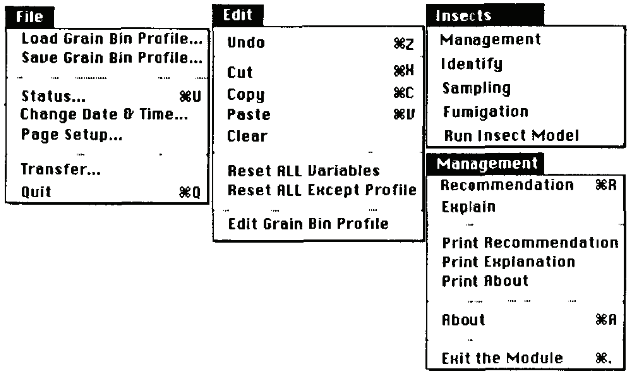

Figure 3. Menu headings available in the main start up screen and headings within the "management" submodule. Selections are made by clicking on the top heading with the mouse and then "pulling down" and releasing the mouse button on the desired selection.

Upon starting the expert system, the manager is greeted with the start-up screen and a dialog box asking whether the manager wishes to open a bin profile. If the manager selects yes, then the manager is asked to select from previously stored profiles. If he selects no, then he is asked for information that the system would otherwise obtain from the profile. Ideally, a grain manager would have one bin profile for each bin. Upon exiting the expert system, the manager is asked if he or she wants to save the current bin profile. If yes is selected, then the profile is saved under the same file name, or it can be renamed.

Submodules under the insect menu are: "management", "identify", "sampling", "fumigation", and "run insect model". For simplicity, we will only provide an example of how the "management" submodule works. After selecting "management" from the menu, the user answers the following questions: 1) the user is asked if the grain was sampled for insects, he clicks the no button; 2) the user is then asked to enter the storage date and the expected date of sale, he enters June 15 and December 30; 4) the user is then prompted for the initial storage temperature and moisture of the grain, he enters 32°C and 12%; 5) the user is asked if the grain will be aerated in the fall, he enters no. After answering these questions, the user is presented with the following recommendation.

> "This bin has been diagnosed as having a high probability for insect infestation. We advise:
>
> 1) Sampling the grain using probe traps or a grain trier about 60 days after the grain was harvested to be sure you do not have an insect problem.
>
> 2) Aerating this grain in early September or October if you plan to hold the grain past the end of October. This may eliminate the need to fumigate the grain."

If the user selects "explain" from the menu, the following explanation is presented.

> "The fact that you intend to store the grain longer than 140 days and that it was put into storage before July 1, increases the chances that a high insect population will develop in this bin. The combination of high initial grain temperature and moisture will cause the insect populations in the grain to increase rapidly. The fact that you are not aerating this bin increases the chances that a large insect population will develop."

An important capability of the system is its ability to investigate different management scenarios. This is accomplished by selecting "reset all variables" from the menu, and then selecting "recommendation". This erases any previous investigations from memory and begins the consultation again. For the next example we will investigate a scenario in which the manager has sampled the grain for insects. In this case the recommendation does not depend upon rules generated from the simulation models. Instead, the recommendation is based on the number and kinds of insects caught in traps, time until sale or fall cooling, and current temperature of the grain. Fumigation has no residual protection, so it is important to determine if the grain could become severely reinfested before it is either sold, aerated, or cooled naturally. For example, if the user says that he has sampled for insects, he is asked to enter the number of *R. dominica, S. oryzae, C. ferrugineus, C. castaneum* and *O. surinamensis* caught in the traps or found in the grain probe samples. The first two species are given more weight than the other species. SGA will recommend fumigation if a total of five or more of the first two species are caught in probe traps over a five day period, or if more than 20 of the other species are caught. SGA also asks the length of time until fall aeration or until the grain is sold. The following is an example recommendation that would be shown to the user.

> "You have caught enough primary stored-grain insects in you traps to warrant fumigation. We advise:
> 1) Fumigating now and selling the grain within 50 days.
> 2) Fumigating now and resampling the grain in one month, and then reconsulting the expert system for advice."

The following explanation would be provided to the user if the user selected "explain" from the menu.

> "The fact that you have caught high numbers of primary insect pests in your traps indicates that your bin is infested and that your risk for monetary losses is high unless you do something to reduce insect population growth.
>
> The fact that it is going to be more than 60 days until you either sell the grain, or cool it means that there is a good chance that insects in the grain will increase in density, even if the grain is fumigated. This is why we recommend resampling the grain 30 days from now."

We've only shown you two possible scenarios within the management submodule in SGA. Obviously, there are many other possible scenarios. However, it should be evident how valuable this system could be to a grain manager. Its powerful predictive capability comes from the simulation models, which are able to predict future insect densities based on grain temperature and moisture during storage. SGA is able to remember its logical chain of reasoning, so the user may ask the system to explain why it wants information or why it gave a particular recommendation. In addition, it provides a user-friendly environment that requires little previous computer skills.

Discussion

The ability of SGA to forecast population trends and provide prophylactic and remedial advice should make it a powerful tool for stored-grain managers. In addition, it should also prove to be a useful educational tool for extension specialists and county agents. The frequency of use of the expert system will be proportional to the number of grain bins being managed. With small facilities, it is more likely that it will be used at key times of the year when decisions in stored grain management are made. For example, at the time the grain is stored (June to September) or, when insects usually begin to be found in grain (October to December). The expert system is used both at the time of storage to forecast problems and suggest alternative management schemes, and later for diagnosis and treatment recommendations for insect infestations that the manager has found.

To date, extension manuals are one of the primary sources of information for managers. These only supply general information on management techniques—it is up to the manager to determine the best tactics for their region and storage condition. Our expert system has several advantages over current U.S. extension manuals for stored grain management. Perhaps the most important are its abilities to customize recommendations specifically to the user's situation, and to predict population growth of stored-grain insect pests for specific storage conditions. These abilities are critical to making rational pest management decisions. Use of this expert system should result in better quality grain, and a more judicious use of chemical controls. For example, in many cases unnecessary protectants are used, because insecticides are applied at binning without knowing whether insects will become a problem. This expert system can predict the likelihood of the grain becoming heavily infested, and gives advice for ways to prevent damaging insect infestations. Currently, there is little variation in treatment recommendations for stored grain insect problems. This expert system should allow recommendations to be customized based on geographic region and storage conditions. The quality of the recommendations should be higher than current extension manuals because the rules in this expert system are based on simulation models that are able to forecast population trends and the effects of management practices.

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LE GUIDE DU GRAIN STOCKE : UN SYSTEME BASE SUR LA CONNAISSANCE POUR LA GESTION DES RAVAGEURS DU GRAIN

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Résumé

La gestion des ravageurs de blé stocké est complexe et met en oeuvre plusieurs facteurs interactifs comme la température et le degré d'humidité, la dégradation des insecticides, la ventilation et la fumigation. Savoir évaluer si oui ou non les insectes vont devenir une nuisance dans un stock est un problème de prédiction de croissance d'une population dans un milieu environnemental donné. Nous avons conçu un modèle informatique pour les cinq principaux ravageurs du blé stocké. Ces modèles prédisent aussi bien la croissance des populations d'insectes que la dégradation des insecticides et les effets de la fumigation ou de la ventilation du grain en rapport avec la température de stockage et la teneur en eau. Les résultats provenant de simulations ont été incorporés dans la logique du système expert "Stored Grain Adviser". Celui-ci assiste le gérant lorsqu'il veut identifier des insectes ou pour d'autres problèmes, prédit la possibilité d'une infestation et aide à choisir les actions prophylactiques ou les meilleurs remèdes.

Le "Guide du Grain Stocké" (SGA) a été conçu sur ordinateur Apple McIntosh, en utilisant le BruceShell^{TM} (Université d'Etat de Pennsylvanie). C'est une infrastructure basée sur une forme s'utilisant en conjonction avec un commutateur de langage C. L'infrastructure possède une interface d'utilitaire graphique en avant et en arrière de la chaîne et des capacités d'aide et d'explication. Le SGA fonctionne sur micro-ordinateurs compatibles en langage MS-DOS^{R}. Ce système expert sera utile aux producteurs, au personnel des silos, aux spécialistes en poste et toutes les autres personnes que le stockage du grain concerne, et il devrait aider à conserver le grain en toute sécurité.