Decision support systems for pest management in grain stores

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Abstract

A decision-support system (PestMan) for the management of insect pests of grains in central storage systems has been developed. The development strategy required the construction of an initial proof-of-concept prototype, followed by a pilot system, based upon the management practices and infrastructure of one state bulk grain handling organisation in Australia and, finally, the production of customised versions for each of the other Australian states. Examples of input and output screens are given. A separate program for accessing mainframe databases, PestMan Link, has also been developed. The use of Windows® as the development environment offers the potential for application of the technology to non-English-speaking countries.

Introduction

Australia produces about 20 million t of grains, grain legumes, and oilseeds annually. At a time when world commodity prices are depressed and global production probably in excess of capacity, the grain industry is being confronted with several challenges: increased competition from within and outside Australia, storage of an increasingly diverse range of commodities with differing properties, and increased antipathy toward the traditional pest control strategy of admixing residual protectants. There is thus a perceived need to refine pest and commodity management procedures to improve the return to the grower in both the short and long term, and to minimise adverse effects on the environment.

In most countries, whether they be producers or consumers of grains, grain storage staff responsible for pest management face a number of problems:

- scarcity of appropriate expertise;
- need for more rapid and consistent decision-making;
- need for reducing costs;
- need to actively conserve existing treatment measures for the future;
- need to make better use of available scientific information;
- need to access corporate databases containing information about the store and its contents.

Such complexities make the decision-making process very difficult and the costs associated with a less than perfect decision may be considerable.

Decision Support Systems (DSS) offer a way to deal with such complexities, and their use in pest management is becoming widespread (Heong 1990). Their functions may include pest diagnosis, pest prediction, executive decision support and training. In terms of pests of grain in storage, however, the achievements have been rather modest, with very few groups developing systems.

The first DSS for stored-grain pest management, Grain Pest Adviser, was developed by Denne (1988), initially as a training device. In the first phase of its development, commercially-available 'shells' were used for rapid prototyping but, as the project developed, the system was re-implemented in PROLOG. It was used to provide decision support for grain store managers in the U.K. (Wilkin et al. 1990a, b). A second decision support for the management of bagged maize stored in the tropics (Compton et al. 1992; Jones et al. 1992) was implemented in yet another package, 'Knowledge Pro', which facilitated the development of a hypertext-based help system. These changes in implementation tool reflect the rapidly changing software environment of knowledge-based programming and highlight the basic need to produce a well-engineered knowledge base independent of the implementation tool.

The knowledge base of the second system was created from decision trees derived from numerous interviews with domain experts. In these discussions, the interviewer asked the domain expert(s) how they would respond to particular pest management problems and why. By contrast, the primary methodology adopted by Flinn and Hagstrum (1990a, b) was to derive rules from the results of several hundred simulations conducted with sophisticated computer models of insect population growth. The system, 'Stored Grain Advisor', was designed to provide the user with a prediction of insect population growth in commodities with particular properties, stored under different seasonal conditions and the consequences for this of various management practices. This system was developed using the frame-based BruceShell, in an Apple Macintosh environment, and made considerable use of a graphical user interface. The only other system of which I am aware, Kawamoto et al. (1990), is in the early stages of its development.

The decision-making process depends, to varying degrees, upon information derived from both experience and experiment. Decision support systems seek to combine such information to allow users to make optimum management decisions to resolve particular problems. Such a system offers the potential to offset many of the problems listed above, although it must be realised that such systems can only make recommendations, with users retaining the responsibility for making the final decisions.

A project to develop a DSS for management of stored-grain pests in the Australian central grain handling system was initiated by CSIRO in 1990 (Longstaff and Cornish 1994). The objective of the project was to combine principles and methods derived from various research programs with the expertise of personnel within the grain industry. The proposed system was seen as having three important functions: to facilitate rational pest management, to aid the training of management and pest control staff, and to help in identifying

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weaknesses in existing knowledge. The overall development strategy adopted was as follows:
- development of a stand-alone proof-of-concept prototype, based on one state bulk-grain handling system;
- evaluation of this prototype;
- development of a pilot system with provision for integration with the corporate database;
- trialing of the pilot system by the user;
- refinement and customising of the system for other states.

Proof-of-Concept Prototype

This prototype, subsequently known as 'PestMan 1.0', was developed for the Grain Elevators Board of Victoria (GEB). The knowledge base for the system was restricted in size (about 50 rules) and derived through interrogation of experts from CSIRO and the GEB. Two simple PC-based databases were incorporated, containing information about the facilities at every store in the system, which consisted of five regions, almost 250 sites and about 1800 storage structures. The information used consisted of storage contents, treatment and infestation histories of every store, treatment options, and market requirements. These were accessed by the system as needed. The prototype was also required to include a simple textual and graphical Help system, to demonstrate both the user-friendliness of the package, and its potential as an instructional aid. In addition, it was deemed necessary to demonstrate the potential for accessing external simulation routines, which may be in the form of a Fortran or C program or some sort of spreadsheet.

The prototype was developed using Level 5 Object Release 2.2. The intention of this phase of the development strategy was to demonstrate the potential of this approach to the Australian grain storage industry and, as such, it was well-received by the GEB. This led to the approval of work to build a more advanced pilot version. The extremely positive reactions of the industry managers to this prototype illustrated the value of using a Windows-based graphical user-interface in creating a good first impression.

Prototype Evaluation

The proposed decision support system relied heavily on access to detailed information contained in databases to drive the decision-making process. Thus the problem is inherently forward-chaining in nature. Unfortunately, Level 5 Object is primarily a backward-chaining inferencing program, with aspects of a forward-chaining inference algorithm. This difficulty was surmountable in this simple prototype but the knowledge base structure necessary to allow full forward-chaining was rather more convoluted than would have been ideal. A much larger knowledge base could prove intractable.

Other software-related constraints were: database integration was limited to dBase files, absence of support for Dynamic Data Exchange (DDE), and limited capabilities for GUI construction. The restriction on DDE meant that it was not possible to access an external routine transparently. The system had to drop out into the external routine (an Excel program) and then return to the main program afterwards. Other limitations of this prototype include the restricted knowledge-base and the lack of any ranking or costing of recommendations.

The evaluation suggested that the following points needed to be addressed in developing the pilot system:
- *Forward-chaining inference engine* —being essentially data driven, backward chaining was not appropriate for this project;
- *Faster performance*—the prototype was taking around 60–90 seconds to make decisions on a 386 computer and even longer to retract facts; this was considered to be too long for a production system;
- *Simple and easy reporting* —the results of an assessment need to be printed in an easily understood and presentable format;
- *Seamless access to the mainframe database* —requiring dBase files for storage bin details was too restrictive;
- *Access to on-line help* —users need support for both the operations of PestMan and background information on pests and management techniques; and,
- *Extensions to knowledge base* —include knowledge on fumigation practice, SIROFLO, preference ranking and treatment costings.

Pilot System Development

Design methodology

Although a new and more powerful version of Level 5 Object was released shortly after the completion of PestMan 1.0, most of the constraints noted above still existed and it remained a predominantly backward-chaining package. With this in mind, it was decided to develop the next version of the system, 'PestMan 2.0', using a true forward-chaining software package, 'ART-IM'.

Given the inputs from the user, it was decided that the best way to build the knowledge base was to propose treatments first then check all the suggested treatments for any constraints. The advantages of proposing first then constraining the results are:
- the user is given a complete picture of all ideas considered, even if they were rejected;
- there is a complete audit trail of all reasons why a plan can or cannot be used; and,
- the logic is simpler to design and, importantly, maintain.

The alternative approach of checking for constraints first, then looking at what was left to propose, proved to be problematic. If all the treatments considered were not included in the results, the potential existed for the user to try an unlisted plan under the impression that it was not considered. If the reasons for rejecting a treatment were not shown, then PestMan would not lend itself easily for use as a training tool.

Visual Basic (VB) was chosen for the development of the user interface. VB provides a much more flexible and extensible solution for the user interface. VB gives the user a 'comfortable' feeling about PestMan because PestMan then looks like a simple Windows program. Whilst the underlying technology is complex, it should not appear that way to users, particularly new and inexperienced users.

The data capture screens were designed to capture only information relevant to making decisions, nothing else. By reducing the amount of data captured, the user is more productive and less intimidated.

The design called for three (3) major input screens to capture the necessary information about:
- the store's physical attributes and infestation history;
- the commodity, intended market and storage period as well as any previous treatments the commodity had received;
- the pest infestation details and history.

Additionally, some specialised input screens for SIROFLO, a novel fumigation method, and malting barley, the storage of which requires additional data, were also included.

As the user completes each form, VB passes the resulting knowledge to ART-IM, via Dynamic Link Library (DLL) calls. ART-IM will make any necessary decisions and VB can request the results from ART-IM. The constant interaction between ART-IM and VB prevents the user from entering invalid data as the knowledge base is constantly checking the results.

As an example of the interaction between the front-end and knowledge base; if the user indicates that the commodity is intended for a market that will not accept it, for reasons of previous treatment or commodity type, the knowledge base will propose a list of acceptable markets. The user will not be permitted to continue until an acceptable market has been selected.

The knowledge base was restructured, to eliminate the problems referred to above, and almost trebled in size, to encompass more of the management practices used by the GEB. The rule base for PestMan 2.0 addresses the following major areas:

- treatment agent effectiveness;
- pest resistance to pesticides;
- storage type;
- malting barley quality;
- fumigation issues, including fumigant sorption and SIROFLO;
- industrial relations issues;
- market bans and acceptable residue levels;
- withholding periods;
- treatment costs; and
- ranking of the proposed treatments.

To improve the reporting aspect of PestMan, a Windows word processor was chosen as the report engine. Reproducing the capabilities of a word processor within PestMan was not cost effective and would not be nearly as flexible. The GEB use Word for Windows as their word processor, so PestMan was designed to transfer the results of the assessment to Word via DDE.

Access to remote databases

The pilot version of PestMan requires a connection to the users' mainframe database, to enable the downloading of store details. It was decided that, since PestMan will ultimately need connections to a range of mainframes throughout the country, the download process should be detached from the main expert system. A separate program, 'PestMan Link', was created to facilitate this access. This program can be re-engineered easily to allow access to the mainframe databases of different authorities. A standard file format was chosen to receive all the data from the mainframe, which the expert system component can read. The GEB use an IBM AS/400 for their corporate database, so PestMan Link, via a proprietary access program, reads the AS/400 bin database and produces the standard PestMan bin details file. The relationships between the various components of the system are shown in Figure 1.

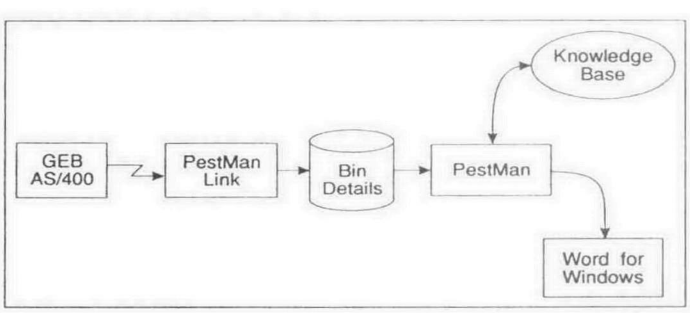

Fig. 1. A diagrammatic representation of the links between the components of PestMan

PestMan Link will:

- access a database detailing the facilities at each storage within the grain handling system. These include storage type, capacity, sealing status, availability of aeration and turning facilities;
- access a database detailing the contents of each storage within the grain handling system. This includes information on the type, grade, and volume of the commodity in storage, and the type and rate of any treatment in place. This database also includes information on the likely market and expected outloading date;
- access a database detailing the infestation history of each storage within the grain handling system. This includes information on the date, type and extent of previous infestations, the original treatments applied to the commodity before infestation, and all subsequent retreatments;
- store the retrieved details in the PestMan Bin Details file.

For the sake of efficiency in data transfer, the user can select to retrieve only stores with known infestations.

PestMan operation

The data file created by PestMan Link is read by PestMan when the user selects to open a file. The user is presented with a list of stores retrieved, from which a selection can be made. PestMan will load all input screens with all the information retrieved. The user can accept the information as retrieved or overwrite it with new information (Fig. 2).

PestMan responds to the data presented to it and generates a set of recommendations, using the set of rules within the knowledge-base, taking into account market requirements (Fig. 3). The recommendation(s) will be costed and ranked (Fig. 4) and accompanied by an explanation of the reasoning involved. By using the graphs the user can quickly identify the preferred treatment.

In addition to ease of use in a commercial environment, PestMan must also be easy to use as a training tool. PestMan will allow users to create any pest management scenario they desire and get the results for proposed treatments. The user can, having seen the list of proposed treatments, go back and alter any of the details to see what effect that variation has on the treatments. This interaction makes PestMan an ideal training tool for new pest and quality control managers.

An on-line help system provides instruction in using the package and a range of tutorial and reference material about insect identification and biology (Fig. 5), fumigation practice, and other pest and quality control measures. This was developed using the Windows 3.1 Help system.

The PestMan package also provides the user access to a range of simulation routines. For example, a recommendation to fumigate a storage will need to be accompanied by a proposed treatment regime, including time and dose. These are dependent upon a number of factors peculiar to the storage and its contents. PestMan is able to perform the simulation to calculate these parameters, for all types of fumigation, without the user needing to understand the complexities of the underlying model. Other models, that are included, are those describing loss of germination in malting barley, and temperature-dependent breakdown of residual pesticides. Inclusion of the malting barley model will, for the first time, provide managers with a tool to enable them to assess the storability of this commodity. This is important because, for malting barley to retain its commercial value, it must retain at least a 95% germination capability. This declines with time in proportion to temperature and grain moisture content. The model is able to assess variety-specific deterioration rates and calculate the expected storage period of the lot in question. If this is less

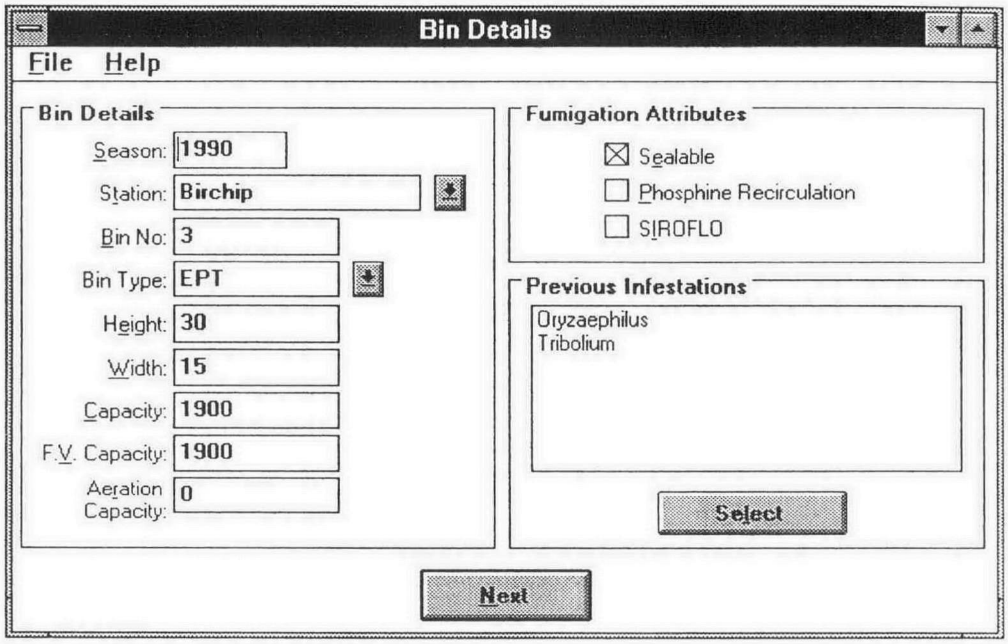

Fig. 2. An example of the bin details screen of PestMan, showing the data fields to be filled via the keyboard or accessed from a database.

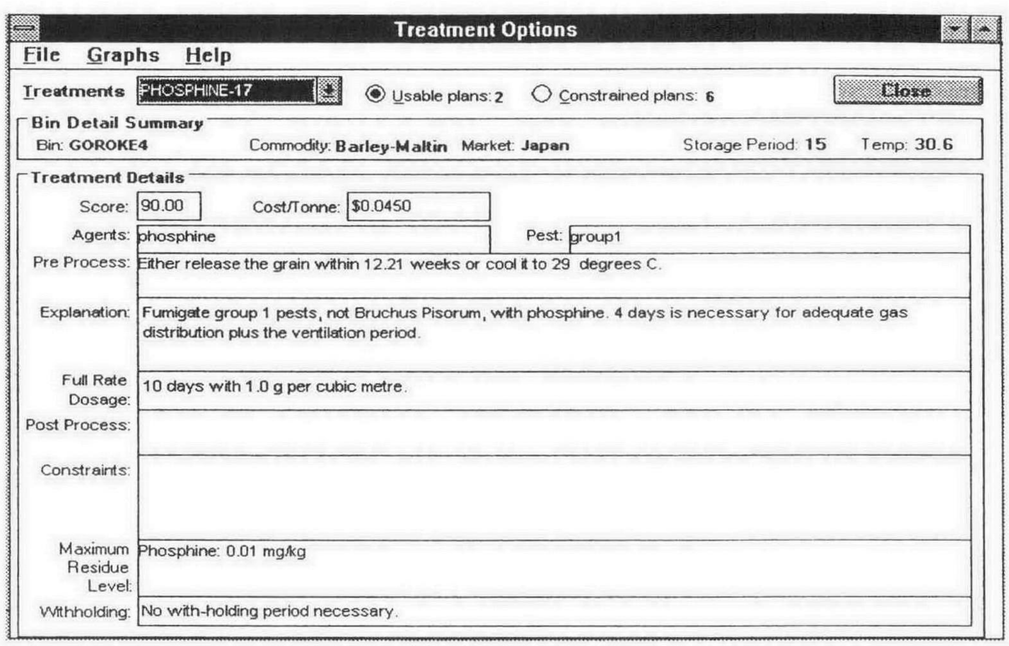

Fig. 3. An example of the output screen PestMan, showing the recommendations and associated explanatory notes.

than is desired, the model calculates the temperature to which the grain must be cooled to permit this.

PestMan 2.0 is currently being connected to the GEB database system for trial purposes. The other state bulk handling authorities are evaluating the Victorian system as a prelude to the development of systems tailored to their own needs. This project should be completed by mid-1994.

Discussion

Whilst many of the finer details of PestMan are uniquely Australian, it is essentially a generic package that has global application. In addition to its intrinsic attractiveness to the user, the use of a Windows-based GUI means that, although the underlying programming has to be in English, the GUI can be in any language (Fig. 6). CSIRO is already involved with the Chinese Ministry of Commerce in applying the technology to their grain handling system. Another cooperative project has begun with Indonesia in which a range of decision support and training tools will be developed. The PestMan system will serve as the basis for the development of a hybrid system that will combine the existing rule-based component with a case-based reasoning component. Whilst rules can handle the majority of the management problems, they are not as effective in less well-defined areas. Case-based reasoning can complement the rule-based component by interpreting these grey areas from a suite of past experiences or cases. The

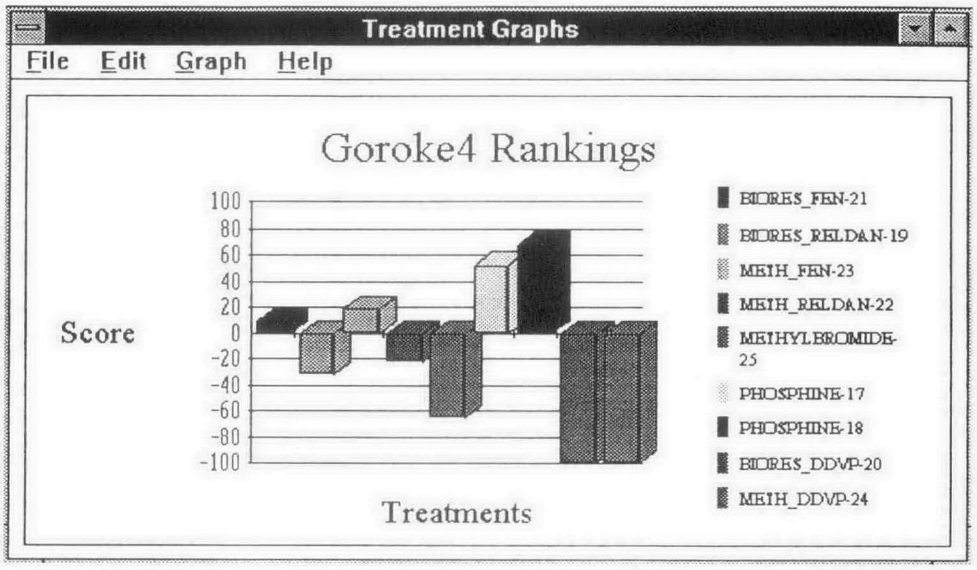

Fig. 4. An example of the graph showing the relative rankings of treatments. Treatment costs are included in the ranking process.

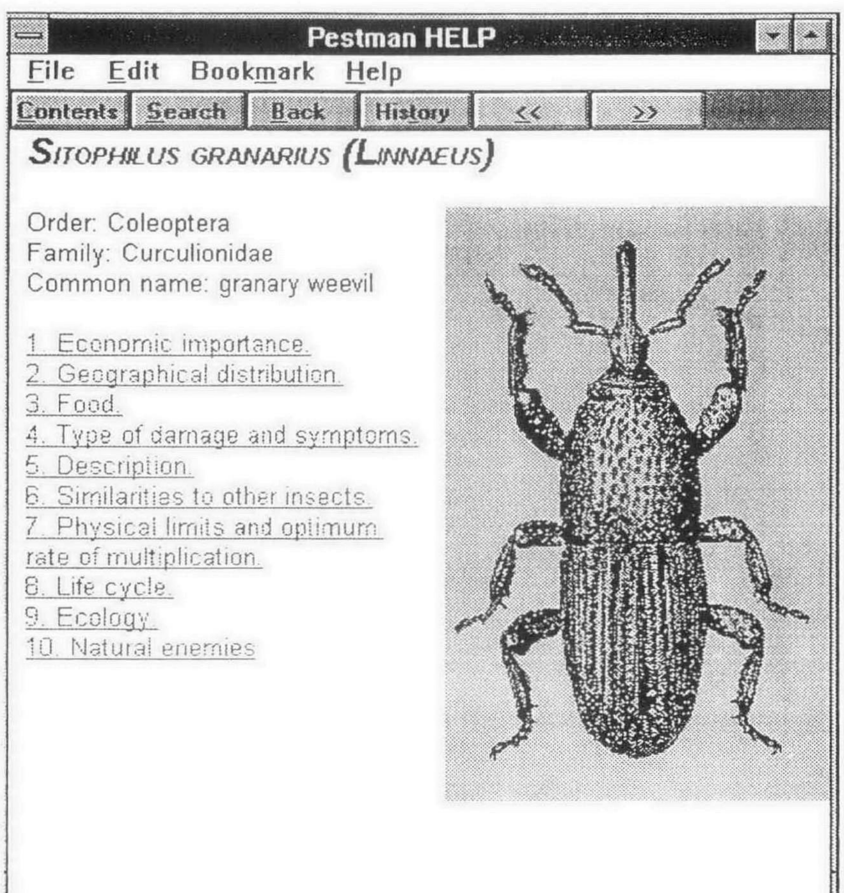

Fig. 5. An example of PestMan on-line Help system, showing the insect and the underlined active fields that will show additional information when clicked upon.

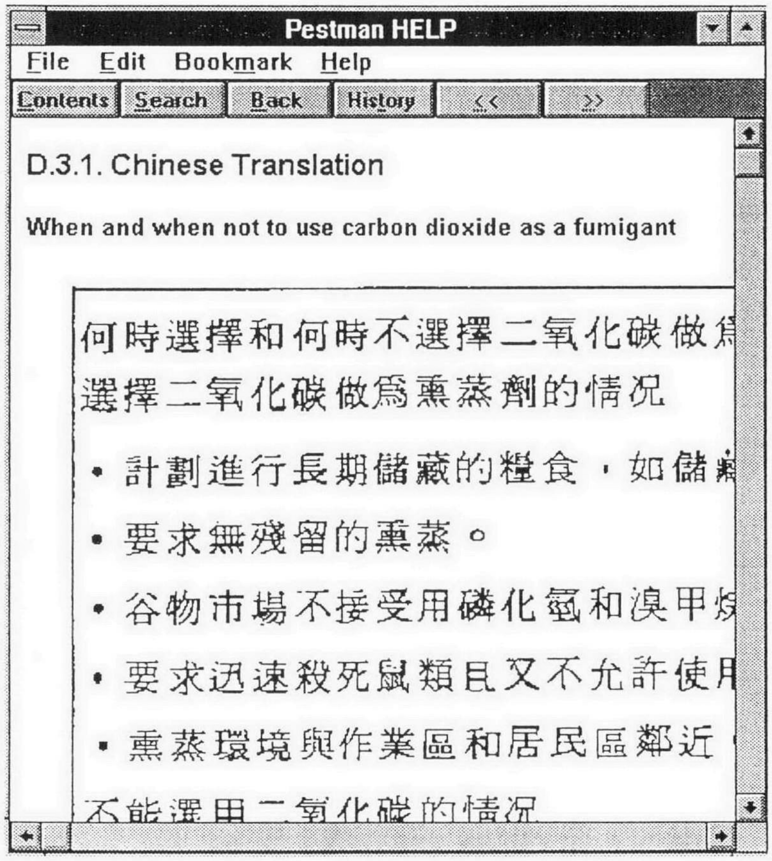

Fig. 6. An example of the potential of Windows-based programs, like PestMan, to display information in languages other than English.

proposed system will exploit, more fully, the extensive CBR and multi-media facilities provided in the ART-Enterprise package, which is the next release of ART-IM. This type of hybrid system offers the exciting possibility of being able to 'learn' from its own mistakes and provide organisations with an important productivity tool.

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