DEVELOPMENT OF A GRAIN STORAGE INFORMATION SYSTEM FOR CANADIAN FARMERS AND GRAIN STORAGE MANAGERS

BY

DANIEL DELMAR MANN

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DEVELOPMENT OF A GRAIN STORAGE INFORMATION SYSTEM FOR CANADIAN FARMERS AND GRAIN STORAGE MANAGERS

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A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

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ABSTRACT

Once harvested, the quality of grain must be maintained until it is either used or marketed. Grain in storage is susceptible to invasion by pests or infection by fungi, either of which has the potential to cause economic losses. Research is on-going to find ways to minimize such economic losses, but the information needs to be placed in the hands of the farmers and grain storage managers.

Expert system computer technology has been used with some success for this process of technology transfer. Expert systems, which encapsulate human expertise needed for the solution of problems, have been developed in at least four other countries for grain storage management.

The principal objective of this research was to develop a grain storage management expert system for farmers and grain storage managers based on western Canadian conditions. To achieve this objective, several conditions were considered. It had to be feasible to develop such a program. The program had to be practical for distribution and be easy to use. Finally, the program had to make practical recommendations consistent with those made by human experts.

The development of an expert system consists of five parts: identification, conceptualization, formalization, implementation, and testing. Identification means that a suitable problem has been found for an expert system solution. This was achieved by performing a feasibility analysis which concluded the project to be feasible. A conceptual design was formulated to provide a starting point. Formalization consisted of selecting appropriate hardware and software to meet the requirements of the conceptual design and

obtaining the grain storage knowledge in the process known as knowledge acquisition. The implementation stage consisted of putting the acquired knowledge into the computer program. During this phase, my philosophy for the program changed. Rather than having a program which tells the user the appropriate management action, the program should teach the user why certain actions are likely to be more effective than others.

Testing of the system has been limited. A group of agricultural engineering students were given a problem to solve using the program. Although some concerns were raised, 15 out of 17 respondents claimed to have learned something new about grain storage during their consultation. Field testing is required before the program can be trusted completely.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

The management of stored grain is an important part of agriculture. Despite the risks and problems involved with growing a crop, harvest is not the end of all problems. The grain quality must be maintained until it is used.

Farmers and grain storage managers (hereafter "farmer" will refer to anyone who manages stored grain) must be concerned with this storage period because grain is susceptible to invasion by pests or infection by fungi, either of which has the potential to cause economic losses. Unfortunately, there is no simple solution due to the complexity of the stored-grain ecosystem. Researchers have spent much time and effort trying to understand the stored-grain ecosystem with the goal of identifying improved management techniques. Significant gains have been made which address some of the problems faced by all farmers. This new information, however, needs to be placed in the hands of the farmers.

Computers are becoming more prevalent in society and there is a good potential to use a computer program as a tool to transfer information from the researcher to the farmer. One type of computer program which has been used with some success for grain storage management is the expert system. An expert system is a computer program which encapsulates human expertise for the solution of problems.

This thesis discusses the development of the Grain Storage Information System (GSIS) which is an expert system-based program for grain storage management in western Canada with various prediction models based on weather data from Manitoba. Following a review of relevant literature on grain storage, expert system theory, knowledge acquisition, and other expert systems developed for grain storage management; the feasibility of such an expert system for western Canada is discussed. Based on positive findings from the feasibility study, a conceptual design is presented. Specific hardware and software requirements are listed as well as a brief description of the program implementation. In the latter sections of the thesis, some of the most prominent features of GSIS are discussed, followed by the validation and verification which have been done.

2. OBJECTIVES

The general objective of this project was to develop a grain storage management expert system for farmers based on western Canadian conditions.

Specific objectives were:

1. to determine the feasibility of an expert system for grain storage management developed specifically for western Canadian conditions,
2. to develop a computer program which can be distributed to farmers at a reasonable cost (using microcomputer hardware) with a consultation time as short as possible,
3. to develop a computer program which is easy to use, and
4. to develop a computer program which uses the current knowledge of grain storage management to make practical recommendations consistent with those made by human experts in the area of grain storage management.

3. LITERATURE REVIEW

3.1 Grain Storage

3.1.1 Importance of Grain Storage

Grain storage is necessary because harvests occur periodically throughout the year despite a continual demand for food (Bailey 1982). Grain storage management is necessary because grain is a biological material which is susceptible to deterioration. When grain deteriorates, it undergoes a reduction in quality, quantity, or both. These reductions are often referred to as grain storage losses.

There are two ways to view these storage losses. First, since grain is an important source of food, storage losses represent a loss of food. Estimates of grain lost each year due to deterioration during storage range from 9% in the United States to ≤ 50% in some developing countries (Sinha 1995). In a world where hunger and starvation exist, the loss of food reserves is a serious problem which needs to be addressed.

Second, storage losses are economic losses. The producer spends a lot of time and money growing and harvesting a crop. At the time of harvest, the grain will have a certain value. Often, the producer is forced to store the grain until it can be sold. If the grain deteriorates during this period of storage, its economic value declines. Management actions are necessary to prevent these economic losses.

3.1.2 Complexity of the Stored-Grain Ecosystem

Grain kernels are living, respiring biological entities which are influenced by their environment. Although respiration depends on the presence of oxygen in the environment, the rate of respiration can be influenced by factors such as grain temperature, grain moisture content, kernel maturity, and physical damage caused by the moving parts of harvesting and handling machinery. Consequently, grain kernels do not remain inert.

Under ideal circumstances, grain would be alone within the storage structure. Often, however, the grain is infested by other organisms such as stored-product insects, mites, birds, rodents; or infected by fungi. Insects, mites, birds, and rodents are attracted to the grain because it is an ideal supply of food. Fungal growth occurs when the moisture content of the grain is high. Pests and fungi are also affected by the presence of broken kernels, weed seeds, and chaff which often favour deterioration.

There are many interactions that occur within the storage bin. The biotic factors (e.g. grain, insects, mites, and fungi) are influenced by the abiotic factors (e.g. temperature, relative humidity, and intergranular gas composition). The presence of both biotic and abiotic factors suggest that the storage bin and its contents can be described as a stored-grain ecosystem. By definition, an ecosystem consists of producers, consumers, and decomposers within a specified environment. In a stored-grain ecosystem, the grain kernels can be considered the producers; insects, mites, birds, and rodents are consumers; and fungi are the decomposers. The environment is bounded by the walls of the storage structure. The environment within the bin will determine the life of the producers, consumers, and decomposers.

The stored-grain ecosystem can be described as being immature because insects have an unlimited food source and have few natural enemies within the grain bin. Consequently, insect populations can increase to high levels. Similarly, the grain can be decomposed by fungi. The grain, however, has no way to replenish itself the way a growing plant can.

Researchers have tried to isolate individual factors within the stored-grain ecosystem to identify their singular influence, but the complex interactions are not yet completely understood. Consequently, grain storage management is often not a straight-forward task.

3.1.3 Problems Associated with Grain Storage

There are many problems associated with grain storage. Grain quality and quantity losses can be caused by insects, mites, rodents, birds, and fungi.

The severity of a stored-product insect or mite problem depends on the species present and the size of the population. Insects and mites are reproductively prolific under ideal environmental conditions (White 1995a). Although the optimum conditions vary for different species, temperatures near 30°C are favourable for most species. When grain is stored at this temperature, the potential for an insect infestation exists. A large population of grain-feeding insects can cause large grain quantity and quality losses, especially in tropical climates. In colder climates, however, insect populations tend to be smaller than in tropical climates causing quality losses as opposed to quantity losses.

In Canada, for example, it is very unlikely that an insect population will get large enough to cause a significant quantity of damage. Since Canada has a zero-tolerance policy for grain-feeding insects, identification of one live grain-feeding insect in a bin of grain represents a great grain quality problem.

Rodents and birds can also cause quality and quantity losses in grain bulks. A single rodent can consume up to 84.6 g/day (Shepherd and Inglis 1987) and contaminate much more by its feces and urine. Likewise, birds will both eat and contaminate grain with their feces. These pests, however, are usually easier to keep out of stored grain than insects. If storage structures are constructed properly and maintained carefully, rodents and birds should not be able to enter the grain bin.

Fungi, unlike insects, rodents, and birds; do not enter the bin after harvest. They are either present on the grain kernels or present in granaries that have been previously used, but only start to grow under certain conditions. Fungal growth will most likely become a problem in regions of high moisture content within the grain bin such as when wet grain is put into storage (Sinha et al. 1991). Depending on the severity of fungal growth, quality or quantity losses could occur. When fungal growth first starts, only a small amount of grain is contaminated. This is a quality loss. If the fungal growth continues, hot spots develop and a large quantity of grain can be contaminated. At this point, some grain may no longer be suitable for consumption. This becomes a loss of quantity. In some cases, fungi produce mycotoxins which could render the entire grain bulk unsuitable for consumption. Grain should be harvested dry or should be dried soon after harvest to prevent the growth of fungi.

3.1.4 The Need for Help

Insects and fungi have always been major problems for farmers. Throughout history, farmers have been searching for management techniques to solve the problems caused by these pests. Many solutions have been tried with varying degrees of success, but as agricultural practices continue to change, new solutions need to be found.

The way to prevent fungal growth is to dry the grain. Grain can be dried quickly by heated air or slowly using air at ambient temperatures. In either case, energy is required. Some farmers prefer near-ambient drying over heated-air drying because it costs less. Research is on-going to find new ways to control near-ambient grain dryers to make them even more economical (Epp et al. 1994).

Throughout the past few decades, the most popular method for controlling stored-product insects was with chemical pesticides. Due to their toxicity, chemical pesticides worked quickly at relatively low doses. Insect control was fast, easy, and most importantly, inexpensive. At present, however, problems have been identified with the use of chemical pesticides. Since much grain is used for human consumption, there is concern that residues left on the grain may be toxic to humans (Fields 1992; Taylor 1991). Verification of this fact caused the ban of many chemical pesticides. The repeated, and often improper, use of chemical pesticides contributed to the development of insect strains resistant to certain chemicals (Fields 1992; Price and Mills 1988). Once this happens, the pesticide ceases to be useful.

At present, very few chemical pesticides remain for use with grain. There is a good possibility that these last chemicals will soon be banned. New, non-chemical management practices will have to be found that are both practical and cost-effective.

3.2 Expert System Theory

3.2.1 Definition

An expert system is defined as ". . . an intelligent computer program that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution" (Feigenbaum 1982). There are many problems that, despite an incomplete understanding, need to be solved. When a person works in the same area, or on the same problem for a number of years, that person is often said to have become an expert. Due to valuable experience, the human expert is capable of repeatedly finding the "right" answer, even when there is no proven method for solving the problem.

Just like the human expert, an expert system is supposed to find the "right" answer in the absence of a proven algorithmic solution. This can be accomplished by emulating the decision-making ability of the human expert (Holt 1989). In other words, the computer program should use the same "best guesses" and "rules-of-thumb" as the human expert.

Some people use the terms "knowledge-based system" and "expert system" interchangeably, but technically, this is not correct. A knowledge-based system embodies the knowledge and skill associated with performing a specific task (Evans 1994), but the knowledge is generally known. An expert system is a special class of a knowledge-based system which contains expert knowledge or expertise (Evans 1994).

3.2.2 Advantages

If the best an expert system can do is to emulate a human expert, what are the possible advantages of an expert system? An expert system is a computer program which can be readily and easily distributed to many people. This may be the most important advantage because human experts tend to be somewhat rare. At the same time, they are usually very busy. This combination of factors can make it difficult to gain access to an expert when a problem arises. An expert system, however, offers easy and often more timely exposure to expertise.

A second advantage of expert systems is that they can provide a permanent record of knowledge and expertise. Humans grow old and retire, taking their expertise with them (Giarratano and Riley 1994). If their expertise can be captured in an expert system before they leave, training of new people can be much easier. An associated advantage is that expert systems can be useful tools for technology transfer due to their capability for explanation and instruction (Flinn and Hagstrum 1994). It is also possible for the knowledge and expertise from several experts to be included in one system. Also, computers give steady, unemotional and complete responses at all times, unlike humans who get tired or unwilling to communicate.

3.2.3 Appropriate Domains

Despite the fact that expert systems have many advantages, they are not necessarily a good solution for all problems. In many cases, the problem could be solved effectively using conventional computing techniques. A problem may be suitable for an expert system solution if the problem-solving procedure is mainly heuristic and uncertain (Giarratano and Riley 1994; Flinn and Hagstrum 1994) . In these cases, conventional computing techniques will not work effectively. An appropriate domain, however, cannot be identified by these conditions alone. It is important to consider whether there is a need or desire for an expert system. If so, there should be at least one human expert who will cooperate and who is able to communicate his or her expertise. If these conditions can be satisfied, an expert system may be the right solution.

3.2.4 Control Strategies

The term control strategy refers to the way an expert system searches a set of rules to solve a problem. The two most commonly used control strategies are called forward chaining and backward chaining.

Forward chaining can be described as a data-driven approach. In an expert system, problem solving involves searching a set of rules to determine how to solve a given problem. In a data-driven approach, the expert system first collects all necessary information. A list of *IF... THEN...* rules is searched with the objective of finding a solution. A solution can be defined as any set of conditions which matches one of the *IF... THEN...* rules. Since forward chaining responds to changes in initial data, it is often used for tasks such as monitoring, configuration, and process control. A potential disadvantage of forward chaining is that it can yield multiple solutions to a single problem.

Backward chaining can be described as a goal-directed approach. The expert system is given a list of goals or possible solutions, which it then attempts to verify or disprove. Search would start from the first goal. *IF... THEN...* rules with *THEN...* clauses matching the goal would be identified. The knowledge base would then be searched for conditions to satisfy the *IF...* clause of the rule. When a set of conditions has been found to match the rule, the goal has been satisfied. The solution is simply the goal which was satisfied. A search by backward chaining is most efficient when a list of possible solutions can be identified initially. Consequently, backward chaining is useful for tasks such as diagnosis, repair, and planning.

3.2.5 Programming Languages and Environments

The selection of an appropriate programming language or environment is an important decision. The development language or tool should be suited to the application, however, there is no single language or tool that is perfectly suited to all applications (Evans 1994). As a developer, one has several choices:

a. Functional languages (e.g. Lisp),

b. Object-oriented languages (e.g. C++),

c. Logic-based languages (e.g. Prolog), or

d. Knowledge engineering tools.

Each of the tools listed above has its own strengths and weaknesses. The expert system developer must decide whether he or she will try to program an inference engine himself or herself using one of the programming languages, or simply use a knowledge engineering tool or expert system shell which already has a functional inference engine. Building an inference engine is much more flexible, but also requires more effort and programmer experience. For someone who is not comfortable with computer programming, it may be wise to simply use an expert system shell.

3.2.6 Development Procedure

To ensure success, the development of an expert system should follow a pre-determined plan. The five stages of the development procedure are: identification, conceptualization, formalization, implementation, and testing. The first four stages will be discussed in this section with testing being discussed in the following section.

The identification stage is straight forward. The problem and its major characteristics must be identified. It may be useful to perform a feasibility study which would consider factors such as the objectives, the criteria for identifying a successful application, the target environment, and a risk analysis. Before a program can be started, it is also necessary to determine whether an expert system is the best solution for the problem. A suitable source of expertise must be located. Finally, once all of the people involved in the project have been identified, the purpose and scope of the project must be agreed upon.

Once a suitable problem has been identified, a suitable conceptual design must be prepared. Based on the purpose and scope, the project must be planned. At this stage, system developers should have a well-defined overall view of the final program. It is not expected that the final program will be exactly the same as the conceptual design, but the conceptual design does offer a starting point or point of reference. A well-defined conceptual design will help to keep the project focussed, especially in times of difficulty.

When the development team is satisfied with the conceptual design, the next stage is a formalization of the program. At this stage, it is necessary to select appropriate hardware and software for the project. The hardware and software should meet the requirements of the project. It is important to consider factors such as software compatibility, response time, user interface and reporting facilities, portability to multiple platforms, user support and manuals, and cost of development and run-time software. A second important part of formalization is the acquisition of knowledge and expertise from the sources identified earlier. Knowledge acquisition will be discussed in detail in section 3.3.

The fourth step in the development procedure involves implementation of the program. This stage involves the programming of knowledge into the computer. Although implementation sounds easy, it is often a very difficult stage. It is at this stage when limitations of the software first become evident. The conceptual design may have to be modified to accommodate these limitations. It may also become evident that problems exist with the conceptual design, forcing further modifications. Also, gaps in the knowledge may be exposed requiring further knowledge acquisition to fill in the missing information. The output of the implementation stage should be a working prototype.

3.2.7 Validation and Verification

The testing of an expert system consists of two parts: validation and verification. Validation refers to the process of determining whether a chain of correct inferences leads to the correct conclusion. Verification refers to the process of determining whether the information contained within the expert system is correct. In other words, validation is concerned with building the right product, whereas verification is concerned with building the product right (Giarratano and Riley 1994).

Validation may be viewed as taking an overall view of the program. Is the program being built according to the conceptual design? Does the program meet the needs of the intended users? Questions such as these must be answered to validate the program.

Verification requires a more detailed inspection of the program. Is the information within the program correct? Are the recommendations correct? Verification is necessary because it ensures that the information provided for the user by the program is the same as would be given by the human expert.

3.3 The Importance of Knowledge Acquisition

3.3.1 Definition

According to Buchanan and Shortliffe (1984), knowledge acquisition is defined as "the transfer and transformation of problem-solving expertise from some knowledge source to a program." In other words, knowledge acquisition is the process of extracting information from human problem-solvers with the goal of creating artificial problem-solvers (expert system computer programs) designed to assist in the making of expert decisions. In general, the knowledge acquisition process can be broken into two parts: the extraction of the knowledge and the subsequent transformation of that knowledge into a form suitable for a computer.

3.3.2 Knowledge Extraction

Knowledge is defined as "direct perception; understanding; acquaintance with; practical skill; information; learning" (Webster's Dictionary 1987). Based on this definition, it is apparent that knowledge is something that only humans can possess. Knowledge, therefore, must be extracted from humans or alternately, books written by humans. For the final computer program to be called an expert system, the knowledge must be extracted from experts in the field under consideration.

The first constraint on the knowledge acquisition process is the presence of a human expert (or experts) from whom the expertise can be extracted. Since the quality of the expert system is dependent upon the domain expert(s) (Tuthill 1990), the expert(s) should be selected very carefully. The four most important characteristics of a good domain expert are

(Tuthill 1990):

1. knowledge that fits the demands of the project,
2. an ability to communicate that knowledge,
3. commitment to the success of the project, and
4. time to dedicate to the project.

According to Tuthill (1990), the fourth characteristic is often the most difficult to achieve. The reason for this is that the true expert will always be in demand. The expert system project will always be competing for the expert's time. In some cases, the project may benefit from a secondary expert who has more time to devote to the project.

In cases where it is difficult to gain access to an expert directly, it is still possible to develop an expert system, provided there is an adequate literature base from which to work. It may be difficult, however, to gain an understanding of the underlying factors because questions cannot be asked.

3.3.3 Knowledge Transformation

The other half of knowledge acquisition is known as knowledge transformation. The successful completion of the knowledge extraction phase yields a large body of knowledge. The goal of the knowledge transformation phase is to turn the large body of knowledge into a useable form. This is somewhat analogous to a pile of lumber, nails, reinforcing steel, gravel, and cement that can be transformed into a building, with appropriate engineering. The term "knowledge engineering" would seem to apply to this transformation process since a raw material (e.g. knowledge) is being engineered into a precise set of facts and rules (Graham and Jones 1988).

Knowledge engineering can be a difficult task for a couple of reasons. A first reason is that some of the necessary knowledge may be missing. The missing knowledge may be known by the domain expert, but was forgotten or overlooked at the knowledge extraction stage. The knowledge engineer is now trying to put a puzzle together without all of the pieces. Although frustrating, this is solvable with the help and cooperation of the domain expert.

A second reason which can make knowledge engineering a difficult task is that domains suited to expert systems are often scientifically weak (Sell 1985). At present, there may be no verified scientific laws capable of dealing with the knowledge. Some very basic principles may be known, but the entire system cannot be described by any laws or mathematical models. The knowledge engineer is forced to use heuristic rules based on the experience of the domain expert. Though these heuristics may yield the right answers in some or even most cases, they may not work in all cases. The knowledge engineer must determine when specific heuristics apply, and when alternatives must be found.

3.3.4 Sources of Knowledge

As mentioned previously, the main source of knowledge for an expert system is the domain expert. If the domain expert is to develop the system himself or herself, other knowledge sources may not be necessary. However, in cases where a separate knowledge engineer is to develop the system, it can be very beneficial to make use of other available knowledge sources. The first task of a knowledge engineer is to familiarize himself or herself with the domain as much as possible. The domain expert may not have time to personally tutor the knowledge engineer, so alternate sources must be found. These could be informal notes of a novice, books, case studies, empirical studies, databases, records, professional research papers, and computer databases (Tuthill 1990).

For the knowledge engineer who is completely unfamiliar with the domain, the first place to start is with books (specifically, textbooks). Textbooks are written with the goal of teaching the subject matter to students unfamiliar with the subject. General concepts are described, but the book generally does not contain the latest developments in the field. This is, however, a good starting point. Another very useful source, where available, is to take a course in the field of the domain. Instructors or teachers in the particular domain will also provide general information, with the added advantage that discussions can take place. Questions can be answered by personal communication.

After gaining an understanding of the general concepts, the most current knowledge can be obtained from periodicals and professional journals. The latest research developments will be described in detail in these types of publications. At this point, the knowledge engineer should understand the domain well enough that he or she can effectively communicate with the domain expert. Knowledge acquisition can now begin.

3.3.5 Manual Knowledge Acquisition Techniques

Given the importance of knowledge acquisition, some of the most common techniques will now be discussed.

According to Tuthill (1990), manual knowledge acquisition techniques would include interviews, protocols, neurolinguistic programming, traits, and analysis. The interview is the most common knowledge acquisition technique. It has probably been used to some extent in every expert system that has been developed. In this review, therefore, emphasis will be placed only on the first technique, the interview. The reader is directed to Tuthill (1990) for information regarding the other techniques listed.

The purpose of the interview is simple: knowledge is transferred from the domain expert to the knowledge engineer. The effectiveness of the interview, however, is not so straightforward. During some interviews, much knowledge is transferred. Other meetings or interviews can be very frustrating as only fragments of assorted information are obtained. Some argue that this is to be expected because knowledge acquisition by interviewing is a misuse of the expert's capabilities (Sell 1985). The argument goes that an expert is not good at defining his or her knowledge in terms of definitions, hypotheses, or laws because this knowledge or expertise exists at a subconscious level. Therefore, forcing the expert to turn this knowledge into a set of rules can be very inefficient and very frustrating for the expert and the knowledge engineer. The solution given for this problem is to use the experts only to generate and scrutinize examples.

The usefulness of a meeting or interview depends largely on its structure and organization. Each meeting must have a direction with a specific goal in mind. Failure to reach that specific goal is not an indication of an ineffective meeting since there may be too much information for one session. On the other hand, a meeting with no direction can be a waste of time. The information may be fragmented and it will be difficult to visualize how it all fits together.

A meeting should be planned with an agenda and goals. It is the task of the knowledge engineer to set the agenda, which should then be reviewed by the expert before the meeting. This will allow the expert some time to think about what he or she needs to say. Preparation should also include the collection of any necessary props. This could be as simple as checking the supply of pen and paper, or may include things such as computers, white boards, tape recorders, and other such items.

An additional consideration should be the location of the meeting. It is vital that the location be quiet and comfortable. If possible, the meeting should take place away from the offices of both the expert and the knowledge engineer. This can eliminate interruptions from phone calls or normal office business. If this is not possible, every effort should be made to finish other business before the meeting and leave instructions not to be disturbed during the meeting.

In the event that there is no control over the environment, an agenda can keep the meeting on target. Even after an unplanned interruption, the agenda can offer a starting point to get the conversation back on target.

Suppose you are a knowledge engineer and you are in the middle of an interview. You have made some relatively good progress, but are only part-way through the agenda. How do you decide when to end the interview? This question warrants some careful consideration. The agenda was made with the purpose of giving the interview a focus in case the discussion started to get off track. Ideally, all items on the agenda would be related in some way. For this reason, it would be nice to cover all of the items at one time, especially if the discussion has been going well. Ultimately, the end of the interview is determined by a judgement call by the knowledge engineer. Usually short (1 h) meetings work well. If the interview has been going well and there are only one or two more small points left on the agenda, it may be advisable to continue until finished. However, if there are too many items left to cover, it would be advisable to find a logical place to stop and leave the rest for the next meeting. In cases where the interview is not going well, it is not necessary to force the duration to an hour. Everyone has days when things do not go as planned. Simply stop the meeting early before anyone gets frustrated.

Knowing when a meeting is over is more than waiting for a timer to go off. A judgement must be made whether the meeting is still being fruitful or whether it has turned stale. Stopping the meeting at the right time will likely benefit future meetings.

3.3.6 Computer-Aided Knowledge Acquisition Techniques

For much of the history of expert systems, the difficulties involved with the process of knowledge acquisition have been known. In many cases, although the problems and limitations of using manual knowledge acquisition are well-understood, there are no available alternatives which are better. In recent years, this problem has been receiving much more attention and researchers have been attempting to find ways to use the computer to either assist or replace the knowledge engineer. In this section, the issues relevant to computer-aided knowledge acquisition will be discussed.

By tradition, knowledge engineering follows the **expert → knowledge engineer → knowledge base** paradigm (Harandi and Lange 1990). The knowledge engineer is responsible for extracting the domain knowledge from the expert(s) or other knowledge sources and translating this knowledge into a form that the inference engine of the expert system can understand and use. The knowledge engineer forms an integral part in the flow of knowledge from the domain expert to the final expert system. It is imperative, therefore, that the knowledge engineer be able to communicate with both the domain expert and the computer. The ability to communicate with both computers and domain experts is a skill that may take time and practice to learn.

Knowledge engineering, in general, is a very difficult task. Harandi and Lange (1990) list five major reasons, in order of increasing complexity:

(1). *Vocabulary*: To communicate with a domain expert, a knowledge engineer has to become conversant with the basic vocabulary of a domain (e.g. the names of basic components, structures, standard problem-solving strategies.).

(2). *Completeness*: A knowledge engineer has to be able to identify pieces of information that are missing from the knowledge base. Being able to do so requires an understanding of the domain as well as a good overview of the contents of the current knowledge base.

(3). *Integration*: As new information becomes available, it has to be determined how this fits into the current knowledge base. Because new information can interact with already available information in undesirable ways, it may be difficult to find the appropriate way to encode new information.

(4). *Analysis*: Experts often find it difficult to explain exactly how and why they arrived at certain conclusions. Consequently, knowledge engineers may have to conduct lengthy interviews with experts. In addition to analytical skills, this requires considerable social skills on the part of the knowledge engineer.

(5). *Transparency*: A major factor in the evaluation of a knowledge base concerns the extent to which it leads to problem-solving behaviour that agrees with experts' styles of reasoning. A knowledge engineer should incorporate this reasoning style in the knowledge base or, in special cases, in the functioning of the inference engine.

The point that is being made with this evidence is that the traditional process of manual knowledge acquisition is very labour-intensive. To do a good job, the knowledge engineer must know enough about the domain so that he or she can communicate with the domain expert(s). In many cases, this means that the knowledge engineer becomes a mini-expert either through extensive review of literature and textbooks or through direct interaction with the domain experts. For this reason, the people chosen to be knowledge engineers often have backgrounds related to the domain of the proposed expert system (Jackson 1986). In fact, one of the best known and most successful expert systems, MYCIN (Buchanan and Shortliffe 1984), was developed by a knowledge engineer who had a background in medicine.

Based on the description of the traditional role of the knowledge engineer, the reasons for automating the process are two-fold: 1) to make knowledge acquisition easier and 2) to make knowledge acquisition faster.

Knowledge acquisition could become easier if there was a standard method that was shown to be effective. Even if a standard method was known, however, it is unlikely that the interaction between two humans (e.g. knowledge engineer and domain expert) would strictly adhere to that method each time. Human characteristics such as fatigue could easily cause the method to go "off track". Alternatively, the interaction between a human and a computer is much more stable, especially if the computer is controlling the interaction. The computer will not be affected by fatigue. If properly programmed, the computer will function the same all the time.

Although standardizing knowledge acquisition will speed up the process, the largest decrease in time will be achieved by eliminating the requirements that the knowledge engineer learn the domain to the extent that he or she becomes a mini-expert. For many humans, learning is a slow process. The domain expert acquired his or her knowledge over a period of several years. It would not be realistic to expect the knowledge engineer to learn everything in a few days. If the process of knowledge acquisition could be automated using a computer, the knowledge engineer would not have to learn all the knowledge in the domain. Emphasis could be placed on the techniques involved with knowledge acquisition rather than the knowledge itself.

With the use of computer-aided knowledge acquisition tools, the role of the knowledge engineer will change. The traditional **expert → knowledge engineer → knowledge base** paradigm will change to a new **expert → acquisition system → knowledge base** paradigm (Harandi and Lange 1990). In this type of system, the knowledge engineer will not be responsible for performing all of the knowledge acquisition himself or herself. The knowledge engineer will now have an assistant which will do a significant portion of the work. The knowledge engineer can become an expert in operating the knowledge acquisition tool rather than becoming a mini-expert in the domain.

3.3.7 Problems with Knowledge Acquisition

Knowledge acquisition, whether manual or computer-aided, can be difficult for the following reasons: 1) there may be multiple experts involved in the project, 2) these experts may find it difficult to communicate or convey their complete knowledge base to the knowledge engineer, and 3) it is probable that the domain experts are very busy, limiting the amount of time they can devote to any single project.

The presence of multiple domain experts is not necessarily a bad thing. Different people will likely have slightly different areas of expertise. If handled properly, this can lead to a more complete knowledge base, especially if the problem domain is very complex. A problem may arise if the different experts have conflicting ideas. The knowledge engineer may find this very beneficial as it exposes different ways of tackling the same problem, however, the potential for hurt feelings exists if the knowledge engineer chooses one expert's ideas over another expert's ideas. This may cause some of the experts to feel that their input is not valued. As a result, they may become reluctant to offer their expertise at future meetings. If the problem reaches this stage, the project ceases to be a team project; the spirit of cooperation is replaced with a spirit of competition.

The best way to ensure the success of a team with multiple experts is to choose people who frequently work together. From past experiences, they will have come to know their own weaknesses and the other person's strengths. They will not be afraid to express their own opinions or discuss the issues with the others. The key is that they will continue to talk rather than arguing or saying nothing. Therefore, the right choice of multiple experts can be very beneficial to the project. A poor choice of multiple experts could be disastrous.

The second difficulty with knowledge acquisition deals with communication problems between the domain expert and the knowledge engineer. To be effective, the knowledge acquisition process requires knowledge, expertise, or both to be conveyed from the domain expert to the knowledge engineer. For some experts, it may seem relatively easy to convey this information. Others will find it very difficult. Expert systems developed at universities may benefit from the fact that university professors are accustomed to teaching students. The knowledge acquisition process may be analogous to teaching the knowledge engineer how to solve the problem. In other cases, possibly where the domain expert has worked for industry all his or her life, teaching or communicating knowledge to others may be a long, time-consuming task. The domain expert will first have to learn how to teach. This expert may possess the same expertise as the university professor, but he or she has never been forced to describe his or her thought processes before. With patience on the part of the knowledge engineer, the goal can still be achieved.

A different type of communication problem relates to expertise or knowledge that the expert possesses at a subconscious level. This information may be vital to the solution of the problem, but the expert uses this information without even thinking about it. It is likely that these "holes" in the knowledge will become apparent at the knowledge transformation stage. It is the duty of the knowledge engineer to then query the expert how he or she was able to jump from one step to the next. Hopefully, this will trigger the subconscious knowledge.

The most serious communication problem occurs when the domain expert is unwilling to share his or her knowledge with the knowledge engineer. The expert may be afraid to expose his or her thought processes because others will question or possibly ridicule some of his or her ideas. If the knowledge engineer is unable to convince the expert to share his or her knowledge, the only alternative is to find another domain expert.

The third difficulty that can affect the knowledge acquisition process is the limited amount of time that the domain expert can devote to the expert system project. In most cases, the expert will be involved in several projects, each of which is competing for his or her time. The knowledge engineer cannot expect to get more than his or her share of the expert's time. Unfortunately, the knowledge engineer sometimes needs more than the expert is willing to give. At times, especially during the knowledge acquisition stage, the knowledge engineer will need to have a lot of help from the expert. If it is not possible to arrange enough time together, or if meetings are continually interrupted by business from other projects, the expert system project can suffer. The knowledge engineer may be forced to look to other sources of knowledge just to keep the project on schedule. If there are no other human experts readily available, this may mean that alternate knowledge sources such as scientific papers and journals will have to be used. This may eliminate the time constraint problem, but may cause other problems such as inconsistencies or holes in the knowledge.

3.4 Expert Systems for Grain Storage Management

3.4.1 Overview

Every farmer realizes that grain quality can deteriorate during storage if not cared for properly. Each year, however, grain deterioration and insect infestations occur. For many years, researchers have been studying the various aspects of the stored-grain ecosystem. Much progress has been made, but the understanding is still incomplete. The knowledge that has been gained, however, needs to be transferred to farmers because it can help prevent storage losses due to fungal deterioration and insect infestation.

Considering the economic value of the grain that is lost each year ($162 - 475 million) (White 1994), grain storage losses are a serious problem which needs to be addressed. An expert system would appear to be a suitable approach because the stored-grain ecosystem is not completely understood in mathematical terms and the decisions involved with management can be described as uncertain and heuristic. As long as there are people willing to serve as experts, grain storage management would appear to be a suitable domain for an expert system.

In the following sections, previously developed expert systems for grain storage management are discussed.

3.4.2 Great Britain: *"Grain Pest Advisor"*

The expert system which the British have developed (called "*Grain Pest Advisor*") is described as a "decision support system for integrated management of stored commodities" (Wilkin and Mumford 1994). This system has a unique approach in that it considers economic factors to be of equal importance to biological factors. As a result, it is assumed that economic factors are considered alongside the biological factors (Wilkin et al. 1990). The developers of this system used the assumption that a grain storage manager would not perform a given action unless there is economic incentive to do so. Based on this assumption, it does not make sense to develop a system that gives advice and makes recommendations unless the cost of each action is included. A potential concern with this approach is that the least expensive recommendation may not always be the most effective recommendation. In other cases, the short term solution may end up causing problems in the future. System developers must be aware of potential conflicts.

3.4.3 Australia: *"PestMan"*

The expert system developed in Australia (called "*PestMan*") is described as a "decision-support system for the management of insect pests of grains in central storage systems" (Longstaff 1994). Australia, like other grain-producing countries, realizes that changes in grain storage practices are beginning to take place. In the past, Australia relied heavily on contact insecticides for insect control. Insecticide resistance (Fields 1992) and public opposition to the use of chemicals which leave toxic residues on the grain (Wilkin and Mumford 1994) have forced the consideration of non-chemical insect control procedures. The main purpose of this expert system, therefore, was to combine principles and methods derived from various research programs with the expertise of personnel within the grain industry (Longstaff 1994). A successful project was to facilitate rational pest management, aid the training of management and pest control staff, and help in identifying weaknesses in the existing knowledge. Although this program is reported as an expert system for grain storage management, it may be more accurately described as an expert system for pest management in grain stores.

3.4.4 United States: *"Stored Grain Advisor"*

The American system, (called "*Stored Grain Advisor*"), is described as a "knowledge-based system for the management of insect pests of stored grain" (Flinn and Hagstrum 1990a). Much of the grain in the central U.S. is harvested warm or hot, conditions which are ideal for the development of stored-product insects. Despite this fact, much grain is stored unprotected because of the difficulty involved with predicting the need for treatment or calculating the economic benefits of treatment. The main purpose of this program, therefore, was to help the farmer identify insects or other problems, predict the likelihood of insect infestation, and select the most appropriate prophylactic or remedial action (Flinn and Hagstrum 1990b). This expert system only considers the grain storage problems related to stored-product insects, however, based on usual Kansas harvest conditions, it is likely that insects will be the most important concern.

3.4.5 France:

The French are also developing an expert system for grain storage management. Unlike the three systems described previously which deal with the "pest control" problem, the French have decided to integrate nutritional and processing qualities of grain as well as its sanitary condition (Ndiaye and Fleurat-Lessard 1994). The proposed system will emphasize prevention of problems rather that simply considering pest control.

3.4.6 Similarities

The first three expert systems discussed appear to be similar. All three place emphasis on the management of stored-product pests in stored grain. This is not a coincidence since all three projects were initiated by entomologists. The fourth system, though not yet complete, proposes to emphasize prevention of deterioration, although pest management will also be considered.

Without seeing and using each of these programs, it is difficult to determine the intricate details of their operation. Grain temperature and moisture content appear to be the two most important parameters, as well as past and present insect infestations and available remedial actions. All three completed systems have incorporated some type of an on-line help system which provides information on stored-product insects, sampling techniques, and other pest and quality control measures.

A further similarity of these systems is that they all seem to have made use of simulation models which supplement the recommendations with information that is based on algorithmic predictions of the future. Each of the development groups has recognized that previously developed simulation models are a good source of knowledge for expert systems.

Another similarity is the use of these programs as educational tools. This makes expert systems valuable for the on-going process of technology transfer.

3.4.7 Differences

Despite their many similarities, these programs have some differences. Although all systems are concerned with stored-product pests and their control, the systems differ in their tolerance level for insects. The Australians, for example, have a zero tolerance for live grain-feeding insects while the Americans allow insects in the grain, as long as the density is less than the pre-determined level of 2 insects/kg. This difference exists as a result of different political (or regulatory) policies in the country where the system was developed. These constraints cannot be controlled by researchers.

A second significant difference exists because the countries of origin and development are from different parts of the world. For example, the growing conditions, harvest conditions, and storage conditions are different in Britain than they are in Australia. Much like political policies, researchers cannot control the climate. An expert system should make use of any climatic advantages, but must also consider the climatic disadvantages.

A further difference that exists is the inclusion or non-inclusion of economic considerations. Ultimately, grain storage management or pest management is an economic decision. A farmer would like to be able to compare possible actions both in terms of effectiveness and cost. Despite its importance, cost may be considered last when developing an expert system. System developers may feel that the system should first solve the problem under ideal conditions and then consider constraints such as cost. Since the expert systems are at different stages of development, this final difference is expected.

3.4.8 The Need for a Western Canadian System

Even though other expert systems for grain storage management have been developed for other grain-producing countries, it was felt that one must also be developed for western Canada. The need for a Canadian expert system is a result of the significant differences that exist between grain storage in western Canada and grain storage elsewhere.

One difference relates to the Canadian winter climate. The cold temperatures experienced on the Canadian prairies make stored-product insect development and survival difficult, although some can still survive inside large grain bulks which take a long time to cool (Muir et al. 1989). With short periods of aeration, the grain bulk can be cooled to temperatures lethal to insects (Chang and Steele 1994). The previously described expert systems did not consider this type of insect control because cold ambient temperatures do not occur in warmer climates.

A further climatic difference is the cool and wet weather that often accompanies harvest in many regions of the Canadian prairies. This weather forces farmers to harvest their crop tough (e.g. elevated moisture contents above the dry limit). Grain in this condition, unless dried, is susceptible to fungal deterioration. This scenario is not common in Australia or mid-west states such as Kansas. Expert systems developed for warm climates would seem to have serious limitations for western Canadian farmers.

Besides differences due to geography and climate, differences exist because different countries have different regulatory bodies. Grain policies are made to favour each individual country. For example, Canada has a zero-tolerance policy for live grain-feeding insects in grain (Canada Grain Act 1970), largely because the presence of insects in Canadian grain is a small problem in an average year (White and Demianyk 1994) which is often solved by the cold winter climate. It is not too difficult to achieve zero-tolerance, and it is economically favourable to do so because it adds value to Canadian grain on world markets. In the United States, however, insect problems are much more common (Cuperus et al. 1986). As a result, they have set allowable tolerance levels or thresholds. As long as the insect density remains below the threshold, the grain is acceptable. In effect, they are saying that it will cost more to deliver insect-free grain than the added value of grain free of insects is worth. The American expert system, therefore, runs simulations to show the user when the insect population is below the allowable density. An allowable density has no meaning in Canada due to the zero-tolerance for insects.

A further regulatory issue is the list of pesticides that can be legally used on stored grain. Although Canada does not have a large insect problem, the zero-tolerance policy means that even one live grain-feeding insect is a problem. Farmers often want to use a quick chemical solution so that they can sell their grain as soon as possible. Regulatory agencies play the role of deciding which chemicals can be used. If the day comes when none will be allowed, farmers will have to look to other options.

Another regulatory issue is that of subsidies. Government subsidies make agriculture more economically rewarding by covering costs that are common to all producers or by artificially inflating grain prices. All governments seem to subsidize agriculture, but some do more than others. Consequently, farmers in one country may not be able to afford management strategies which are commonly used in other countries. These differences must be remembered when developing an expert system.

4. FEASIBILITY OF A GRAIN STORAGE MANAGEMENT EXPERT SYSTEM FOR WESTERN CANADA

4.1 Importance of the Feasibility Study

Although there seems to be a need for a grain storage management expert system for farmers in western Canada, it must be determined whether it is feasible to develop one. The feasibility is discussed in the following paragraphs.

4.2 Scope

The factor that will distinguish this system from others that have been developed is the uniqueness of grain storage in Canada. For example, Canada, unlike many countries, has a zero-tolerance policy for insects in stored grain (Canada Grain Act 1970). This means that any grain bought or sold in Canada must be free of live insects. An unusual aspect of Canadian grain storage is our cold winter climate. Aeration with cold winter air can be used as a method for non-chemical insect control. Cold air is also useful for cooling the grain, which reduces its rate of respiration. Canadian grain export customers have come to expect Canadian grain to be free of insects and chemical residues. Thus, the scope of this system covered the maintenance of grain quality and prevention of insect infestations without the use of chemical pesticides.

4.3 Criteria for a Successful System

In general, an expert system is judged to be successful if it reaches conclusions similar to those reached by human experts within a reasonable amount of time. For grain storage management, this advice should help to reduce both quality and quantity losses from both insects and fungi.

Additionally, the program should be practical for distribution to grain storage managers. It must be able to run on a personal computer, be easy to install and run, and be accompanied by a user's manual.

4.4 Participants

The development of this system was undertaken as a joint project between Agriculture and Agri-Food Canada Winnipeg Research Centre and the Department of Agricultural Engineering, University of Manitoba. Experts from both organizations were involved in the development. It is expected that potential users (e.g. local farmers) will become involved with the testing of the system.

4.5 Target Environment

The development of this system can be beneficial to many people. Researchers may benefit because the development of the expert system can identify the areas where more research is required. It may also help researchers keep their research focussed on practical issues rather than on purely theoretical ideas. The expert system can help instructors by providing an important educational tool for students taking courses in grain storage.

Despite these benefits to researchers and instructors, the system has been targeted towards farmers, grain elevator agents, and agricultural representatives in western Canada. It is important that this knowledge be transferred to where it can be used. It is especially important now with all the changes that are taking place in agriculture. Farmers need cost-effective management techniques to remain competitive.

4.6 Risk of Acceptance

The risk of acceptance refers to the willingness of the target environment (e.g. intended users) to make use of the final product. Some sectors of the agricultural community will be apprehensive about trusting a computer to manage their stored commodity, but, in general, the agricultural community seems to be willing to try new ideas with the hope of becoming more competitive and enhancing their profit margin.

Acceptance of the system will be good as long as the system has been properly tested. It is imperative that the system be easy to use by people unfamiliar with computers. The system should also provide adequate explanation of any recommendations given.

Through consultation with the grain industry, it has been learned that one grain company may be willing to market the expert system once it is completed. This would suggest that there is some support for this project by the target environment.

4.7 Technical Risk

The idea of developing expert systems for the management of grain storage is not a new idea. Expert systems have been developed by the British (Denne 1988, Wilkin et al. 1990), the Americans (Flinn and Hagstrum 1990a; 1990b), the Australians (Longstaff 1994); and one is currently under development by the French (Ndiaye and Fleurat-Lessard 1994). Although the focus of this system was different than the others that have been developed, it was possible to make it work because many aspects were similar.

To reduce the technical risk as much as possible, deviations from the original conceptual design had to be tolerated. The exploration of various options extended the development time, however, this resulted in the development of a more efficient expert system.

4.8 Recommendation of the Feasibility Study

It has previously been established that there is a need for a grain storage management expert system for farmers in western Canada (section 3.1). In the preceding paragraphs, the feasibility of developing such a system has been discussed. Although there was no guarantee that the program would be a success, it seemed feasible. Careful consideration was given to ensuring that the objectives and scope of the project coincide with the needs of the identified target environment. The project had support from experts in two agencies and there was a large base of literature from which to work. The risk involved with the project did not seem to be too great since similar programs had already been developed and it is believed that the target users are willing to try new ideas.

5. CONCEPTUALIZATION OF THE PROGRAM

5.1 Overview

With a positive recommendation from the feasibility study, it was then necessary to develop a conceptual design for the program. A conceptual design is important because it offers a starting point from which changes can be made.

An expert system capable of making recommendations for the safe storage of grain is extremely complex. The most practical way of developing such a system was to divide it into small pieces, each of which could be linked together with a central controller. It was proposed that the flow of the complete system would be as shown in Figure 1. The conceptual design will be discussed in more detail in the following sections. It should be noted that this is a discussion of the initial conceptual design, not the final program.

5.2 Collecting Initial Grain Conditions Data

A consultation can begin in one of two ways: 1. enter the initial information into the system directly using the graphical user interface (hereafter called a GUI), or 2. retrieve previously saved information from the "Consultation Database". Data would usually be entered by using the GUI unless one wanted to retrieve a previous consultation to update or make changes to it. When the GUI is used, the user is guided through a series of screen displays designed to retrieve all of the data necessary for the system to determine the "grain storage status". The GUI is very important to this application because the majority of end users will be farmers. The GUI must collect all of the necessary information, allow for editing, and be simple to understand and use. If the GUI is not easy to use, it becomes more likely that an error will occur. Since farmers have a tendency not to trust computers (Pleban 1989), it is important that all problems be eliminated.

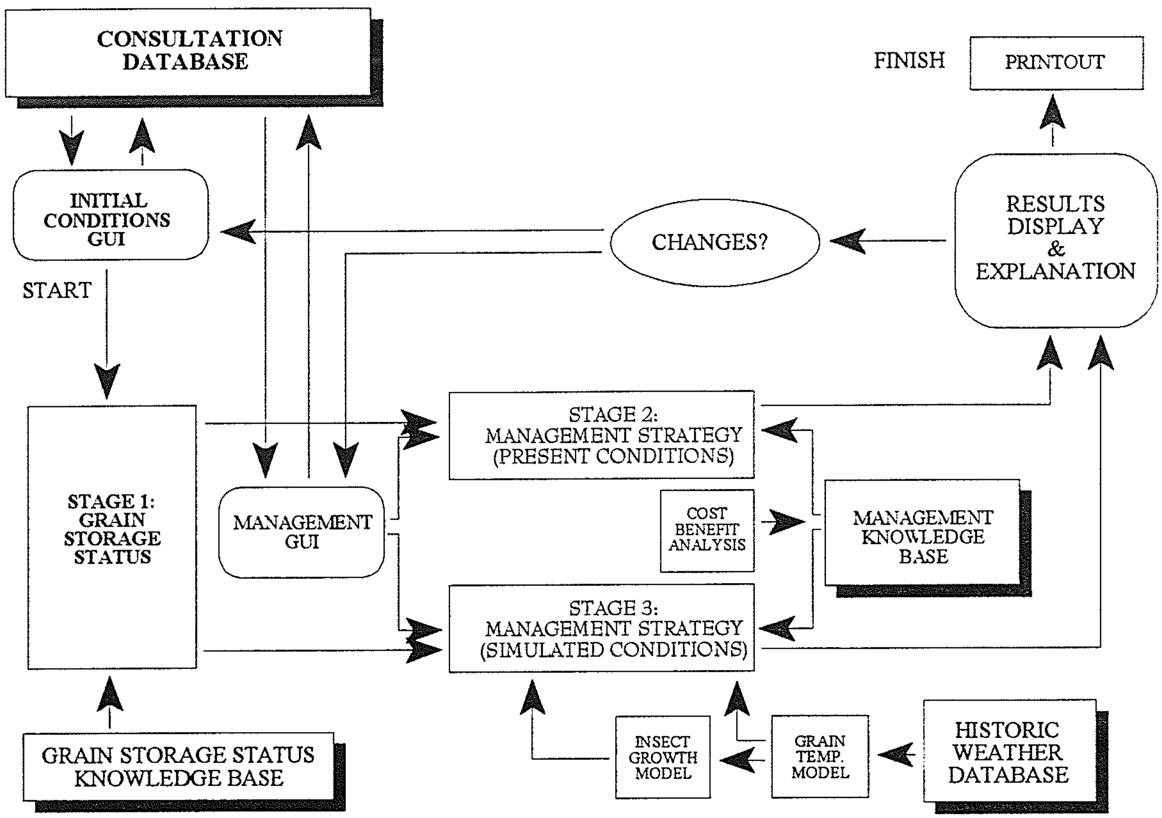

Fig. 1. Conceptual Design of the Post-Harvest Grain Storage Management System (GUI stands for Graphical User Interface).

5.3 Determining the Grain Storage Status

The first stage of the conceptual design is the determination of the "grain storage status". Based on the information collected in the previous step, the inference engine will forward chain through the rules in the "Grain Storage Status Knowledge Base". In addition to the forward chaining rules, the knowledge base also contains information that describes the proper techniques of grain sampling and information on the identification of stored-product insects. The goal of this sub-section is to determine the status of the stored grain at the time of the most recent sampling. Some of the possible "Grain Storage Status" states are: 1) tough or damp, 2) insect infested, and 3) no obvious problems.

A forward chaining mechanism has been chosen for this application because the nature of the problem is such that it is data-driven.

5.4 Collecting Management Options and Objectives

Before proceeding to the next stage, information must be obtained from the user regarding the types of grain handling and storage equipment that he or she has (or can easily obtain by renting or borrowing), and the future objectives he or she has for the stored grain. This task was accomplished with the use of another GUI. It was designed in much the same way as the initial grain conditions GUI.

This section is important to the overall system because individual farmers have different types of equipment and different intended uses for their grain. Even though a standard recommendation may work for 90% of the users, allowances must also be made for the other 10% of users who have unique conditions. The system will only seem knowledgeable if it makes recommendations that can be implemented for most situations.

5.5 Determining Management Strategies

Based on the grain storage status and the management options and objectives input by the user, the system now must identify the best management strategy.

In one scenario, a management strategy is obtained based on the conditions as they are at present. This will work best for short-term storage in which the system speculates about what will happen in the near future. In the second scenario, the management strategy is based on the predictions of insect growth models and grain temperature and moisture content models. The system consults more resources to determine what the conditions will be after a specified amount of time has elapsed. For both scenarios, the management strategy will be based on management rules.

The basic difference between the two scenarios is the time required to arrive at a management strategy. Management strategies based on predictive models may provide a better understanding of the situation, but the computer time requirements are greater. If the objective is for a long storage period, the extra computer time may be well spent. On the other hand, if there is no problem at the time of sampling and the intended storage period is relatively short, the extra computer time may not be necessary. It may be more appropriate to sample again after a specified time interval and re-consult the expert system.

Regardless of which method is used, the end result of this stage of the expert system is a management strategy best suited to solve the identified problem.

5.6 Predictive Models

The insect growth model and grain temperature and moisture content models would be consulted only if the end user specifies for them to be consulted. They increase the length of the consultation because it takes time for the simulations to run. The model predicting the temperature within the storage bin would be based on historic weather data.

The temperature simulation model would predict future grain temperatures based on the initial temperature of the grain and historic weather data for a given year (e.g. good, bad, or average year). The insect growth model would predict the number of insects at some future point in time based on the initial number of insects in the grain and the grain temperatures simulated by the temperature model. Based on these "future" values of grain temperature and insect numbers, the "Management Rule Base" would select a best management strategy.

5.7 Display of Management Strategy and Explanation

After the expert system has completed the entire process and arrived at a management strategy, it must then display the recommendation(s) to the user. A GUI will be employed to perform this task. The management strategies will be displayed and the user will be able to ask for further explanation if he or she so desires. The explanation facility is necessary to provide the user with the reasons behind the chosen management strategy. This is important because the user wants to know the reasoning used to reach a conclusion. If no explanation is provided, the user may not trust the advice.

5.8 Changing Options

If the user does not like the management strategy given or simply would like to test other alternatives, he or she would be given an opportunity to change some of the inputs. This can be performed by a GUI which determines the area of interest and takes the user to that section. Once the changes have been made, the expert system will proceed to find the best management strategy in the same process as described earlier.

5.9 Saving Consultation Information

Much of the initial information will remain unchanged from consultation to consultation (e.g. initial grain conditions) or even from year to year (e.g. bin specifications). To eliminate the re-entering of information, the system will have a feature to allow consultation information to be saved and retrieved.

6. FORMALIZATION OF THE PROGRAM

6.1 Selection of Hardware

One of the criteria for a successful system listed previously was that the program be practical for distribution to farmers. This means that the program must be developed using hardware to which farmers have access. Though the percentage of farmers who have personal computers is not known, it was determined that the personal computer was the only logical choice. This program requires a 486 cpu microcomputer with 7Mb of disk space and 4MB of RAM.

6.2 Selection of Software

6.2.1 Knowledge Engineering Tool Requirements

Based on the conceptual design, an appropriate knowledge engineering tool should:

a. support a forward chaining rule-based representation,

b. support object-oriented representations,

c. support the integration of these two representations,

d. have good graphical user interface capabilities,

e. be capable of providing explanations to users,

f. be capable of communicating with database applications,

g. be capable of displaying graphic images (e.g. pictures of insects for identification purposes),

h. be reasonably priced (both development and run-time versions),

i. allow integration with existing simulation programs (written in FORTRAN),

j. be easy to extend or modify as the scope of the project increases or changes, and

k. be relatively efficient to keep consultation time as short as possible.

6.2.2 Knowledge Engineering Tool Selection

Based on consultation with others working on expert system development in the Department of Agricultural Engineering at the University of Manitoba, LEVEL5 OBJECT (Information Builders Inc., New York, NY.) was chosen as the development tool. Review of literature (Tellzen 1992) also identified LEVEL5 OBJECT as the software used by the Australians in the development of their grain storage management expert system. Since the cost of the development software was quite reasonable (approximately $1400 Cdn), the software was investigated more closely for its suitability to the application.

This development tool satisfies a number of the requirements listed in the previous section. The inference engine supports both forward and backward chaining through rule-bases. Although forward chaining has been identified as the most likely method to be used, the presence of both inferencing strategies allows more options as the scope of the project is broadened. LEVEL5 OBJECT also allows the combination of rules and frames, as is required for this system.

The design of graphical input and output displays is one of the strengths of LEVEL5 OBJECT. There are many different display items (or tools) that are available to the developer.

The explanation facility provided with LEVEL5 OBJECT has some limitations. It is useful at development time for debugging, but some work has to be done to obtain clear explanations for the user at runtime.

There are several ways in which access can be gained to a database. LEVEL5 OBJECT supports object-oriented database interfaces to dBASE and FOCUS. An alternative to this method is to use client-server architectures between the database and LEVEL5 OBJECT.

It is also possible to integrate simulation programs into the expert system through the use of function calls to external programs. Variable passing is allowed between applications.

Review of literature on LEVEL5 OBJECT suggested that it would allow the program to be developed as it has been conceptually designed. The fact that other developers are using this tool suggested that it was a capable and reliable package. A further advantage to be gained by the use of this tool was the presence of people using it at the University of Manitoba. Consultation with these developers enhanced syntax problem-solving.

6.3 Knowledge Acquisition

6.3.1 Sources of Knowledge

After completion of the conceptual design and selection of appropriate hardware and software, the process of knowledge acquisition began. The first step was to identify the sources of knowledge and expertise to be used in the development of the program.

The initiative for this project came jointly from the Agriculture and Agri-Food Canada Winnipeg Research Centre and the Department of Agricultural Engineering, University of Manitoba. The domain expertise was extracted largely from researchers working in these two organizations: Dr. D.S. Jayas, Dr. W.E. Muir, and Dr. N.D.G. White. For many years, research has been conducted, both in Canada and around the world, in the fields of grain storage and grain storage management. Consequently, there is a large base of scientific literature from which knowledge can be extracted.

Over the past number of years, various computer models have been developed to model certain processes within grain storage bulks. Simulation models are available which predict heat transfer (Yaciuk et al. 1975, Metzger and Muir 1983, Muir et al. 1980, Alagusundaram et al. 1990a, Alagusundaram et al. 1990b); moisture migration (Metzger and Muir 1983); and CO_2 movement (Alagusundaram et al. 1994a, Alagusundaram et al. 1994b) within grain bulks. Researchers have also developed models to predict the population dynamics of various stored-product pests such as the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Kawamoto et al. 1989). Since much knowledge and expertise has gone into the development of these models, it was decided to incorporate these models into the expert system.

Another source of knowledge for the expert system was my own farm background. It is difficult to quantify the extent to which a practical understanding of grain storage contributed to the final program, but it did contribute in some way.

6.3.2 Methods of Knowledge Acquisition

When this project first started, the people directly involved in the development of the expert system could be divided into two very distinct groups. One group consisted of the three domain experts identified previously. These people had a good understanding of grain storage, both practical and scientific. The other group consisted of myself as the knowledge engineer. Although a farm background provided me with a practical understanding of grain storage, my scientific knowledge of grain storage was minimal compared with that of the domain experts. As a result, the first stage of knowledge acquisition consisted of reading and reviewing the scientific literature available on grain storage. This was a required first step to ensure that I was able to communicate with the domain experts.

After an initial reading and learning period, a more structured knowledge acquisition phase began. Written questionnaires were prepared for distribution to the domain experts. A meeting was scheduled, at which time the questions and answers were discussed. The questionnaire and meeting process worked quite well, although it had to be modified slightly. The initial plan had been to allow each of the experts to answer the questionnaire. The answers would then be compared and discussed at the meeting. This plan was modified slightly to make more efficient use of the experts' time. The questionnaires were distributed with preliminary answers based on my review of the literature. The domain experts were then only required to decide whether the answers were right or wrong.

I also attended a university course taught by one of the domain experts, as well as a course offered by the university on the theory of expert systems. This structured format worked well for educating me about grain storage. Throughout the knowledge acquisition stage, very little use of the interview process was made. Rather, I assembled the knowledge base from published literature which was then verified by the experts.

6.3.3 Problems Encountered

The process of knowledge acquisition has long been regarded as the bottleneck in the development of expert systems (Feigenbaum 1978, cited by Harandi and Lange 1990). Knowledge acquisition is known to be a slow and difficult process, often accompanied by various problems. In that sense, the development of this expert system was similar to many others that have been developed in the past. Problems were encountered, but in most cases, solutions were found.

Multiple experts can be a great benefit to a project, but certain problems or difficulties must first be overcome. In this project, it became obvious at a very early stage that it would be difficult to schedule meetings to fit the schedules of three experts. To find an appropriate meeting time, it was often necessary to plan several days in advance. Unfortunately, it is sometimes difficult to foresee the need for a meeting several days in advance. Problems have a tendency to occur suddenly. It would be very beneficial if a meeting could be organized just as quickly. From my experience, the best way to ensure "spur of the moment" meetings was to meet with only one of the experts on an individual basis. The chance of finding one person with some spare time was better than the chance of all three being available at the same time.

A second problem associated with multiple experts is knowing which expert is the most appropriate person to talk with in specific situations. Even though all three people are experts in grain storage, each of them has slightly different areas of expertise. For this reason, each expert may give a different perspective to the same question. It is up to the knowledge engineer to decide how the different perspectives can be combined or which one should be chosen as the most "correct".

Another major problem that was faced in the development of this expert system was a limitation on the amount of time each expert was able to devote to the project. This was especially critical during the knowledge acquisition phase. With the traditional interview method of knowledge acquisition, the experts were required to devote quite a large amount of time to the project. Due to busy schedules, this was not always easy to do. A solution to this problem was for the knowledge engineer to look to other sources of knowledge. Many research papers have been published by the three domain experts and their colleagues. This large literature base was used extensively in the development of this expert system. I compiled the knowledge base from the literature. The domain experts were then consulted to verify the knowledge base. Although the overall time required to assemble the knowledge base may have been greater, the amount of time required of the experts was less than with the traditional interview approach. In some applications this may not be desirable, but I found it to be an acceptable trade-off.

A further problem that I encountered was an incomplete understanding of the grain storage problem. Based on a farmer's perspective, grain storage is quite simple. The granary is used to hold the grain until it can be sold. If the grain was harvested tough, it needs to be dried. Alternately, based on the scientific research on grain storage, it seemed that grain storage was much too complex for an expert system to solve. As time passed and my understanding of grain storage became more complete, the complexity of the problem seemed to decrease somewhat. It is possible that this confusion or misunderstanding occurs in many expert system projects. It may not be evident to the domain expert because he or she already has a reasonably complete understanding of the problem under consideration. In cases where the knowledge engineer is not an expert in the domain, it will take some time for him or her to gain sufficient understanding for the confusion to go away.

Another problem encountered in this project is one which may not be common for many expert systems. Since grain storage deals with living seeds within an ecosystem, biological variability can be a factor. A simple example is the question of how to define the optimal environmental conditions for a stored-product pest, such as the rusty grain beetle. Every source seems to quote slightly different numbers. There may be several reasons for these differences. It is possible that experimental differences exist (e.g. experimental procedure, instrument precision, and other such factors) or simply that strains of insects in different regions have slightly different characteristics. Regardless of where the differences come from, it is important to recognize that they exist. In some cases, choosing one number over another can be a very arbitrary decision, but one that has to be made.

7. IMPLEMENTATION OF THE PROGRAM

7.1 Overview

Based on the definition that implementation is the programming of knowledge into the computer, it may seem that this stage would be quite easy. In fact, this conclusion is wrong. It was only at the implementation stage that I began to realize the limitations of and problems with my conceptual design in relation to the formalization of the problem. Until this stage, the conceptual design was on paper only. As I began to construct the initial prototype, new ideas came to mind and the conceptual design was continually changing.

It is impossible to describe all of the ideas that were tried and all of the prototypes that were developed. A cyclic process began where a problem arose with the implementation of a specific part of the conceptual design. A new idea or solution was considered which altered the conceptual design. Further problems were encountered with the altered conceptual design, and the cycle started over. This cycle repeated itself hundreds of times before the current version of the program was obtained. It is expected that this cycle would continue if further work is done on the program.

7.2 Difficulties Encountered

The implementation of the program was made challenging by the expert system development shell software. There were many times when the conceptual design had to be altered because I was unable to manipulate the software in the desired way. Part of this difficulty could be attributed to my incomplete knowledge of the software, but in some cases there was no apparent method to accomplish the desired task.

It would be unfair, however, to blame the software for all of the implementation problems. The addition of new knowledge and new ideas also caused changes to the conceptual design. This in itself is not the problem. The problem is that there is so much information about grain storage that it was difficult to decide what to include and what to leave out. Basically, the problem was that I was not convinced that I had found the "right" conceptual design. Consequently, I was continually searching for new ideas.

7.3 Prototype Testing

During implementation, many prototypes were created. Some were similar, while others were quite different. For many of these prototypes, I was the only person to see and evaluate them. Occasionally, however, I found it necessary to get feedback from others. This prototype testing was informal. The domain experts or other students used the program and offered suggestions and made comments. I was present to observe and offer help when needed. Notes were made of user's comments and areas of difficulty. These sessions were useful for identifying problems which were not apparent to me because of my familiarity with the program.

7.4 Changes to the Program Philosophy

During the lengthy implementation stage, my philosophy for the program began to change. In the previously discussed feasibility study, the objective for the program was "to develop an expert or knowledge-based system that can be used to assist farmers with the post-harvest management of stored grains." At that time, my idea was that the program would collect all of the necessary information from the user and then tell the user what to do to protect his or her grain. I now believe that to be a poor approach. Rather than telling the user what to do, the program should teach the user why certain actions are likely to be more effective than others.

There are several factors which contributed to my change in philosophy. The first and most significant factor was an observation that I made one evening when my father was reading some of my notes. He had been reading about convection currents in grain and how they deposit moisture at the top near the centre of the grain bulk. He had known the top centre was the most likely location for the development of a hot spot, but did not know why. After reading a scientific explanation, he understood. I decided that it may be better to teach farmers why certain management actions work rather than simply telling them what management action should be done.

A second factor was the realization that farmers have a lot of valuable experience with grain storage. I did not want to insult their intelligence by telling them what to do with only a limited explanation. A related factor is the fact that some farmers do not trust computers. It is necessary for the expert system to earn their respect before they will begin to trust it. This will not happen by dictating instructions. The program must be designed in such a way that the farmer feels completely comfortable with the program.

In my opinion, this change in philosophy will increase the potential usefulness of the program.

8. DESCRIPTION OF THE GRAIN STORAGE INFORMATION SYSTEM

8.1 Main Purpose

In my opinion, the Grain Storage Information System (GSIS) will be the most useful if it is viewed as an educational tool. The management of stored grain has become a challenging task. To remain in business, farmers cannot afford to make grain management decisions which result in reduced grain quality. Farmers need help to deal with the rapidly changing agricultural industry. University and government researchers have recognized this need. The main purpose of GSIS, therefore, is to teach farmers the current knowledge of grain storage to enable them to become better grain storage managers.

8.2 An Overview of GSIS

The procedure followed by GSIS is basically the same from consultation to consultation with the changes being the result of different initial conditions. The program can be described as follows:

1. The initial grain conditions are input by the user.
2. The grain storage life is calculated. The storage life of the grain is based on a mathematical equation developed by researchers. The safe storage life is described as the period of time before germination drops 5% or visible mould appears. The storage life is based on the grain temperature and moisture content.
3. The storage life is compared with the intended storage period.
4. If the storage life is less than the intended storage period, either the grain moisture content or grain temperature should be reduced.

If the grain condition is tough (having a moisture content above the limit for dry grain), appropriate drying actions will be explored. A near-ambient drying simulation program is available. If the grain condition is dry, appropriate cooling actions will be explored. An aeration simulation program is available.

5. If the storage life is greater than the intended storage period, the grain should be safe from fungal deterioration, however, insects must still be considered.

   If insects are currently present, possible control measures will be indicated. An insect identification module is available. Even if insects are not currently present, the risk of a future insect infestation always remains. A risk factor is presented.

6. Changes can be made to the initial grain conditions so that the user can consider possible effects of several storage options.

7. Information screens are available throughout the consultation.

8.3 Features of GSIS

8.3.1 Calculation of Storage Life

The storage life of grain is the predicted length of time which the grain will remain in good condition. Different researchers have used different criteria for deciding when the end of the safe storage period occurs. Fraser (1979) decided that the safe storage life would be the number of days before germination drops 5% or visible mould appears on the grain. Kreyger (1972) set the safe storage life as the time to appearance of visible mould in barley stored at different combinations of temperature and moisture content.

Researchers agree that the storage life is dependent upon the grain temperature and grain moisture content. This implies that the storage life of a bulk of grain will be altered if either the temperature or moisture content changes. Theoretically, it should be possible to lengthen the storage life of grain by drying, cooling, or both.

The predicted storage life is a very important component of GSIS. The need to dry (or cool) the grain occurs when the predicted storage life is shorter than the intended storage period. It should be noted, however, that the storage life equations assume constant values of temperature and moisture content. If either parameter changes, the prediction may no longer be accurate. The storage life equations provide a good starting point. It must be remembered, however, that the storage life equations do not consider damage caused by insects.

The storage life equations used in GSIS are:

wheat: (Fraser 1979)

$$W = 12 \text{ to } 19\% \qquad \log\theta = 6.234 - 0.212\,W - 0.053\,T \qquad (1)$$

$$W = 19 \text{ to } 24\% \qquad \log\theta = 4.129 - 0.0997\,W - 0.057\,T \qquad (2)$$

canola: (Muir and Sinha 1986)

$$W < 11\% \qquad \log\theta = 6.224 - 0.302\,W - 0.069\,T \qquad (3)$$

$$W \geq 11\% \qquad \log\theta = 5.278 - 0.206\,W - 0.063\,T \qquad (4)$$

barley: (Kreyger 1972)

$$W = 12 \text{ to } 16\% \qquad T = 5 \text{ to } 25^{\circ}C$$

$$t_m = 67 + \exp\{5.124 + (39.6 - 0.8107\ T)[1/(W - 12) - 0.0315 \exp 0.0579\ T]\} \quad (5)$$

where: W = moisture content, wet mass basis, (%)

T = grain temperature, (°C)

θ= storage life before germination drops 5% or visible mould occurs, (days)

t_m = time for mould to appear, (h)

8.3.2 Determination of Unventilated Cooling Times

If the grain is dry and the storage life is still less than the storage period, the grain should be cooled. Some cooling inside the bin near the wall and top surface occurs when the outside air turns cold. In western Canada, this occurs each winter. Unfortunately, this conductive cooling may not be sufficient to cool the entire grain bulk because grain kernels have low thermal diffusivity (Muir et al. 1989). Consequently, it can take a long time for a temperature gradient to move through a grain bulk by conduction. Unless the grain is stored in a bin with a small diameter, it is unlikely that conductive cooling will be of sufficient help.

Yaciuk et al. (1975) ran a series of computer simulations to determine the length of time required to cool a bin of warm grain below 20°C in Winnipeg without aeration. His results indicated that grain stored in large bins (> 4 m diameter) should be cooled by some external means.

The data shown in Table 1 (from Yaciuk et al. 1975) were used in GSIS to predict an approximate cooling time if aeration was not used.

Table 1. Simulated number of days for wheat at the centre of a bin located in Winnipeg to drop below 20°C for bins of different diameter.

	Initial Temperature (°C)	
Diameter (m)	25	35
2	45	49
4	90	112
6	150	192
8	225	323
10	329	652
12	553	978
16	1026	1726
20	1637	*

* Indicates that the bin centre does not drop below 20°C during the first 5 years of storage.
Source: Yaciuk et al. (1975)

8.3.3 Aeration Simulation Model

Since grain cooling by natural conduction is a slow process if grain is stored in a large bin, farmers often decide to cool their grain by aeration. Aeration refers to the process of forcing cool ambient air through the bulk of grain with a fan. As long as this operation is done when the ambient air temperature is lower than the grain temperature, cooling will take place.

Grain cooling by forced convection is a relatively fast process. Consequently, it is not necessary to run aeration fans at high airflows. Normal aeration rates are 1-2 (L/s)/m^3 of grain (Friesen and Huminicki 1987). At 1 (L/s)/m^3, it may take 150 - 200 h to change the temperature throughout the bin. If the airflow rate is doubled, it will take only half as long (Friesen and Huminicki 1987).

When it is determined that the grain should be cooled and the storage bin is equipped with aeration equipment, GSIS will present the user with an opportunity to run an aeration simulation model. The aeration model is the equilibrium drying model by Thompson (1972) contained within the GRAIN89 program (Huminicki et al. 1986). The simulation runs with an airflow of 1.5 (L/s)/m^3. It is assumed that the initial temperature is constant throughout the bin. The temperatures within the bin are simulated from the specified harvest date until November 15 for three years of historic weather data (1965, 1968, and 1969). When the simulations have stopped, the temperature 1 m below the surface in the centre of the bin is presented to the user for each of the three separate simulation years. This location was selected because it is the most likely location of the maximum temperature in fall and winter (Muir et al. 1989).

8.3.4 Near-ambient Drying Simulation Model

When grain is not dry, it tends to be susceptible to fungal growth and deterioration. To ensure quality, the grain should be dried as soon as possible. The quickest way to dry grain is with a heated-air grain dryer, but it can be quite expensive. Many farmers choose to use near-ambient drying as opposed to heated-air drying.

Near-ambient drying uses the drying potential of unheated ambient air to remove moisture from the grain (Friesen and Huminicki 1987). Similar to aeration, air is forced through the grain bulk by a fan, but at much higher airflows. The high airflows are required because the drying front must be moved through the grain bulk before spoilage occurs.

If GSIS determines that the grain needs to be dried and the bin is equipped with an aeration floor, the user will have an opportunity to run the simulation model. GSIS selects an appropriate airflow value based on the recommended minimum airflow requirements for Manitoba using a perforated floor and a level grain surface (Friesen and Huminicki 1987). The user can view these recommended airflow charts and change the value if desired. The near-ambient drying model is the equilibrium drying model by Thompson (1972) contained within the GRAIN89 program (Huminicki et al. 1986).

The drying simulation program predicts drying based on 10 randomly selected years of historic weather data. The simulation program stops either when the grain bulk is dried or when the date reaches November 15. The simulation is run for all 10 years of weather data. The user is then presented with the results. For each simulation year, GSIS determines whether the grain has dried before November 15. The years are ranked from best to worst. If the simulation model predicts the grain to be dried by November 15 in an average year, GSIS will recommend near-ambient drying. Otherwise, GSIS will recommend heated-air drying.

It should be noted that the equilibrium drying simulation model as included in the GSIS is valid only for grain stored in circular steel granaries equipped with forced ventilation equipment and a fully perforated floor near Winnipeg. If the bin is either filled to the peak or if a less than fully perforated floor is used, the results of the drying simulation will not be accurate. The program can easily be used for other western Canadian locations with the addition of weather files and minor modifications.

It should also be noted that no changes were made to the simulation models. The GSIS has simply accessed the models within the GRAIN89 program. This was done so that it should not be necessary to validate the simulation models. This validation has been done previously (Sanderson et al. 1989).

8.3.5 Drying Recommendations

As discussed in the previous section, grain often needs to be dried to prevent fungal growth. Farmers can choose between heated-air drying and near-ambient drying. The choice of one type of drying over the other depends on several factors.

The first consideration must be given to the equipment which the farmer owns. It would be pointless to suggest near-ambient drying if the farmer had no equipment for near-ambient drying.

If there is no limitation due to lack of equipment, consideration must be given to the time constraints involved with drying. Heated-air drying is relatively quick and does not present any time constraints. Near-ambient drying, on the other hand, is a lengthy process. It is important that the entire grain bulk be dried before the grain spoils. If the grain will not get dried before spoilage starts then it may be advisable to use heated-air drying.

When neither equipment nor time causes any constraints, the selection should be based on cost and convenience. Near-ambient drying is usually more convenient because it requires very little labour. Near-ambient drying can be less expensive if only the energy cost is considered. However, if the overdrying cost is also included, it is difficult to predict which type of drying will be less expensive.

8.3.6 Insect Control Recommendations

In the previous sections, discussion was made of ways to increase the storage life of the grain either by cooling or drying. As a farmer, it is also necessary to consider the problems associated with the presence of stored-product insects. Since it is illegal in Canada to knowingly sell grain infested with live grain-feeding insects, one must consider possible ways of controlling insects once they have been identified as a problem.

If insects are identified as being present, GSIS suggests some possible actions. From a list of all possible control methods, the most probable ones are selected. It is up to the user to decide which method to use. There are limitations on all of the possible control methods.

High temperature thermal disinfestation may be practical if the grain is tough and a grain dryer is available. Low temperature thermal disinfestation may be practical during the winter if aeration equipment is available. If a pneumatic grain conveyor is available and the grain needs to be moved, it may be possible to kill the insects as the grain goes through the pneumatic grain conveyor. Fumigation with carbon dioxide is only practical if the grain is dry and the bin is airtight. Fumigation with phosphine should not be attempted if the grain temperature is less than 5°C. Finally, though not recommended for use on any type of grain in this program, malathion should never be used in empty bins where canola is to be stored.

Though not yet mandatory, non-chemical control of insects is recommended.

8.3.7 Calculation of Potential Infestation Factor

Even when insects are not currently present in the grain sample, there is no guarantee that the grain will always remain free of insects. The likelihood of an insect infestation depends on many factors. These factors interact with one another, making it difficult to determine the overall risk of future infestation. A possible solution is given by Eq. 6 below.

$$PI = \{ F_{mc}\, F_T\, F_{MD}\, F_{SD}\, F_{LP}\, F_{SP}\, F_{GS}\, F_P\, F_{HD}\, F_B \} \times 100 \qquad (6)$$

where:

PI = potential infestation factor

F_{mc} = moisture content factor

F_T = grain temperature factor

F_{MD} = mechanical damage factor

F_{SD} = sprouting damage factor

F_{LP} = large dockage particles factor

F_{SP} = small dockage particles factor

F_{GS} = granary sanitation factor

F_P = previous insect infestation factor

F_{HD} = harvest date factor

F_B = bin size factor

Each factor is given a decimal value less than or equal to one. The value assigned to each factor depends on the initial grain conditions specified by the user. A summary of the assigned factor values is given in Table 2.

Table 2. Insect infestation factors for various grain conditions.

Parameter	Parameter Value	Numerical Factor
Moisture Content	very dry	1.0
	dry	0.9
	tough	0.7
	damp	0.5
	wet	0.6
Grain Temperature	cold	1.0
	cool	1.0
	warm	0.7
	hot	0.5
Mechanical Damage	yes	0.7
	no	1.0
Sprouting Damage	yes	0.9
	no	1.0
Large Dockage Particles	significant numbers	1.0
	none	1.0
Small Dockage Particles	significant numbers	0.8
	none	1.0
Granary Sanitation	yes	1.0
	no	0.6
Previous Infestations	yes	0.9
	no	1.0
Harvest Date	early	0.9
	normal	0.9
	late	1.0
Bin Size	small	0.9
	intermediate	0.7
	large	0.5

In an ideal case, each factor would have a value of one. This would yield a PI value of 100. This means there is a negligible risk of a future insect infestation. When some of the factors have values less than one, the PI value decreases below 100. The lower the number, the greater the risk of a future insect infestation. Any PI value less than 10 defines a high risk. A value between 10 and 25 defines an intermediate risk and values greater than 25 define a low risk of a future insect infestation.

The values given to the factors were selected arbitrarily. There is no justification for these values, other than the fact that they were chosen by the domain experts.

The particular format of Eq. 6 was chosen because it represents the type of interactions that occur among the factors. When two factors interact with each other it is a multiplicative effect, not an additive effect.

8.3.8 Insect Population Growth Simulation

When a high risk of an insect infestation exists, it may be beneficial to be able to predict the size of an insect population. Kawamoto et al. (1989) developed a computer simulation program for the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), which could predict the size of an insect population based on the initial population and the conditions within the grain bulk.

This simulation program has not been directly incorporated into GSIS for a couple of reasons. The first reason is that there is some concern for the ability of the program to produce realistic results. In a laboratory experiment it may be possible to produce a population density of 50 000 insects per kg of grain, but densities of this magnitude are not realistic for farm bins (White 1995b).

The second reason for not using the program is that it would further increase the length of a consultation with very little advantage to be gained. Kawamoto et al. (1989)

observed that insect populations peaked at approximately the same density regardless of the initial density. The only difference was that the peak tended to occur sooner at higher initial densities. The most important observation was that the rate of increase and peak density were predominantly controlled by temperature and affected by relative humidity.

For Canadian farmers, predicting the size of an insect population is a purely academic exercise. When it is illegal to sell grain that has even one live grain-feeding insect, why would the farmer care how big the problem could get? The farmer should take actions to eliminate the insects long before the population peaks. The data of Kawamoto et al. (1989) imply that insect populations can be reduced significantly by cooling the grain. This is the information which the farmer should get from the simulation model.

8.3.9 Insect Identification Module

The purpose of the insect identification module is to teach farmers about the different species of insects most commonly found in western Canada. Although each species is different and has different habits, it is most important to differentiate between grain-feeding and fungus-feeding insects because the type of management action depends on the type of insect present. Grain-feeding insects feed on the grain. They are usually found in warm, dry grain. Since it is illegal to knowingly sell grain in Canada which is infested with these insects, an appropriate management action is one which eliminates the insects. Fungus-feeding insects, however, feed on fungi rather than the grain kernels. The presence of fungus-feeding insects usually suggests that the grain is tough. In this situation, the appropriate management action is to dry the grain. Once it has been dried, the insect problem will also be solved.

The insect identification module consists of a series of computer display screens containing information about and pictures of some common insect species. The user must read through the screens to determine whether a match has been made with the insects found in the grain. Even if one is not trying to identify an insect found in the grain, reading through the information screens can be educational. Print-outs of the screens in GSIS are included in Appendix A.

8.3.10 Grain Sampling Module

The accuracy of the information collected from a grain bin depends on where the samples were taken. Grain sampling, therefore, is very important.

The purpose of this module is to provide the user with information on proper sampling techniques and preferred sampling locations. The information is mainly for insect sampling. This information is not used in the main program, but rather is included as a source of additional information for the user. The sampling information screens are included in Appendix B.

8.3.11 Sanitation Module

One of the best ways to prevent an insect infestation is to make use of good sanitation in and around the storage bin. Stored-product insects infest freshly harvested grain from outside of the bin or from old grain and dust within the bin. If bins are swept out as soon as the grain is removed and the outside of the bin is kept clean, there is a better chance that the freshly harvested grain will not become infested.

The importance of good sanitation cannot be stressed enough. It is hoped that farmers will read and follow the advice given in this module. The sanitation information screens are included in Appendix C.

8.3.12 General Information Module

Since the purpose of the expert system is to teach farmers as much as possible about grain storage, a module containing general information about various aspects of grain storage was useful. A lot of information is made available to the user throughout a consultation, but it is impossible to include all relevant information within the main framework of the program. The information contained in this module is not vital to the use of GSIS nor is it necessary that it be read by all users. It is included for those who are interested and who are willing to take the time to learn more about grain storage. The information contained in the general information module is included in Appendix D.

8.3.13 Conclusions

Once the consultation is complete, there must be an end or a conclusion. At this point, GSIS briefly summarizes the most important information that was given throughout the consultation. GSIS does not tell the user what to do. Rather, the situation is explained and some possible courses of action are discussed. The user must then decide what will be done.

8.4 User's Manual

A computer program is not complete without an accompanying user's manual. A user's manual is necessary because potential users are less familiar with the program than the program developer. It is inevitable that questions will arise as the program gets used. A user's manual which can be distributed along with the program is a good way to address this need.

One of the most important purposes of the user's manual is to make people feel comfortable and confident with the program. It gives the impression that the program developers are trying to make the program suit the user. If a program is distributed without a manual, the user may get the impression that the developers are not interested in customer support. This impression will not enhance confidence in the program.

A second purpose of a user's manual is to provide help. Every program is unique in certain ways. These differences may cause problems for users. Solutions to these types of problems should be included in the manual. The user's manual written for GSIS is included in Appendix E.

9. VALIDATION AND VERIFICATION

9.1 Criteria

Before a computer program can be judged suitable for distribution, it must be tested. A computer program can be tested in many different ways depending on what test results are required. The computer program should be tested according to the constraints imposed by the problem. In other words, the first step of testing should be to select the criteria by which the program will be judged.

GSIS was designed to be an educational tool for farmers in western Canada. A prime objective of the testing procedure should be to determine the adequacy of the program as an educational tool. To be effective, GSIS should be easy to use and easy from which to learn. Information should be presented in a logical manner so that it is as understandable as possible. It is also important that the information be presented in a way that will make sense to farmers. It may not be suitable to present the information as it would be presented in a scientific paper. This testing may be described as validation of the program.

A second important function of testing is to verify the accuracy of the information contained in the program. Assuming the program functions well as an educational tool, it is also advisable for the program to contain accurate information. It is imperative, therefore, that the program be carefully scrutinized to ensure that any information or recommendations are accurate.

9.2 Procedures Used

By its nature, validation of a program is somewhat subjective. In this case, it was necessary to determine whether the program was useful as an educational tool. There is no mathematical formula which will calculate this characteristic. It must be based on the user friendliness of the program and its ability to convey information. There are two methods which have been used to determine these characteristics. The user friendliness of the program was judged by responses to a questionnaire (Appendix F) completed after use of the program. This questionnaire consisted of ten questions which provided an overview of the program and allowed for specific comments to be made.

The ability to convey information was based on responses to a sample problem given to a class of agricultural engineering students. The sample problem (Appendix G), was intended to force students to thoroughly search GSIS for the information needed to give an accurate solution to the problem. It is hoped that close scrutinization of the responses given by the students will be an indication of the program's ability to convey information.

Although verification is less subjective than validation, other difficulties exist. Verification requires that the information be accurate, but accurate according to what standard? Since the knowledge for the expert system has come from several sources, verification should also be based on several sources. Ideally, the program should contain information consistent with all grain storage experts, not only the experts involved in the development of GSIS. Unfortunately, it is difficult if not impossible to determine what information is consistent with all grain storage experts. A possible solution to this problem is to test the program in actual situations. Field testing will show whether the recommendations given by GSIS result in safe storage or whether they result in fungal deterioration or insect infestation. The constraint on this testing procedure is time. To be useful, field testing must occur in the fall when freshly harvested grain is placed into storage. The program would then be consulted and recommendations followed. During the winter storage period, the grain would be monitored to see whether the recommendation given by GSIS was good or bad. Due to the time constraints of this research project, field testing has not been done. Until this testing is done, verification of GSIS must be based on the judgement of the human experts involved in the project.

9.3 Results

I have received 18 completed surveys from people who have used GSIS. In many cases, all of the questions were answered, although some people did not provide answers for all questions. Many useful comments were given which will benefit future changes to the program, however, these comments will not be included in this section of results.

The following figures illustrate a summary of the responses on the 18 questionnaires. It should be noted that the majority of survey respondents were agricultural engineering students who had just completed a class on grain storage. Their background of education and computer usage is different than the majority of farmers. It should also be noted that questions 2 and 9 only asked for comments.

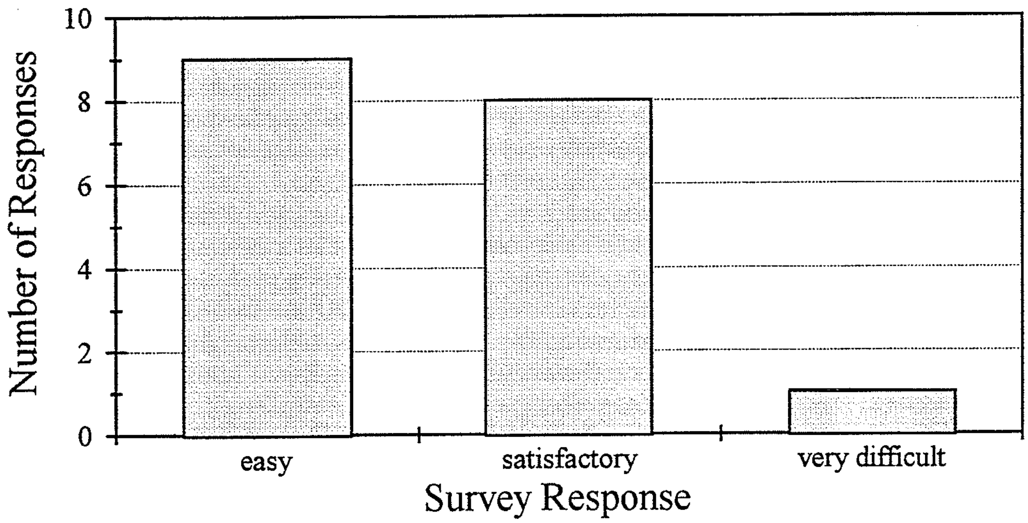

Fig. 2. Response to question 1 from GSIS user survey, "*How would you describe the ease of use of the program?*"

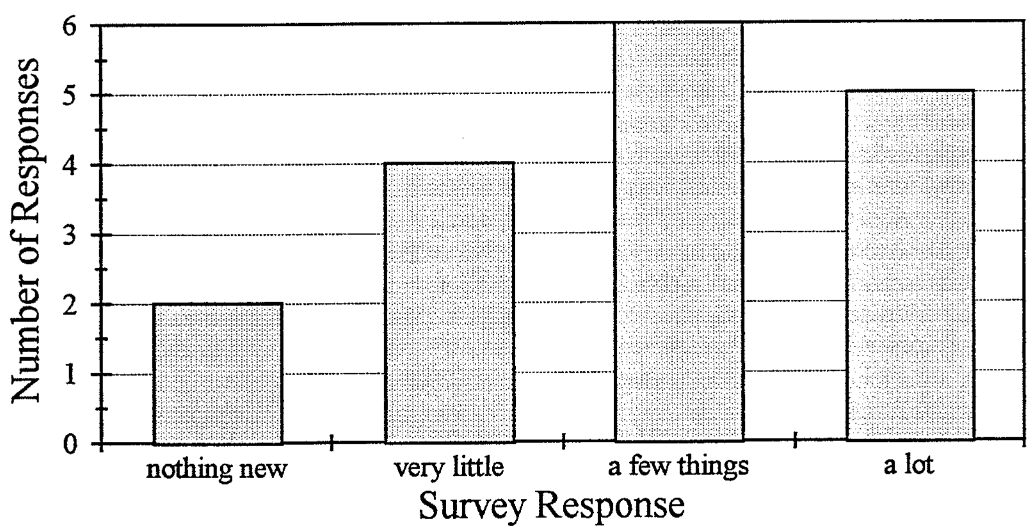

Fig. 3. Response to question 3 from GSIS user survey, "*Did you learn anything about grain storage during your consultation?*"

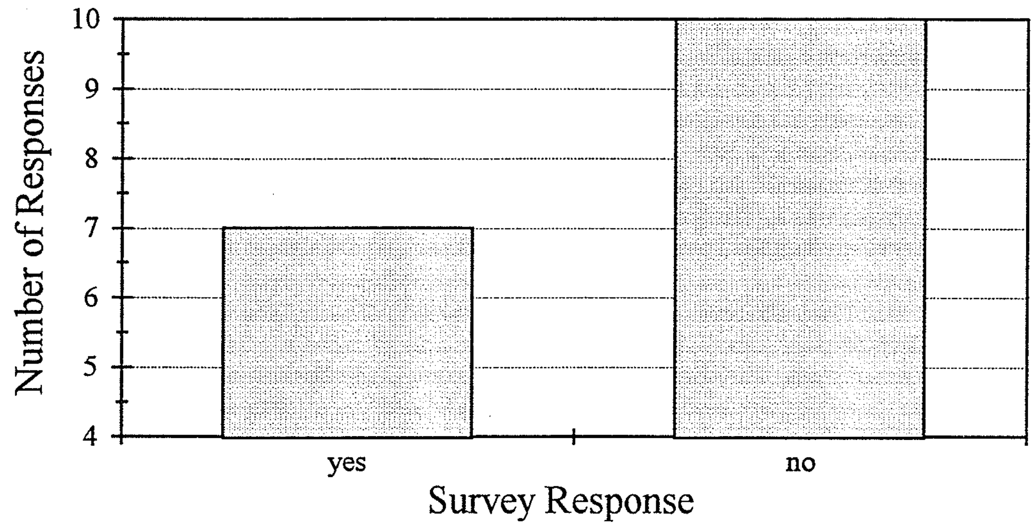

Fig. 4. Response to question 4 from GSIS user survey, *"Did the consultation raise questions which were left unanswered?"*

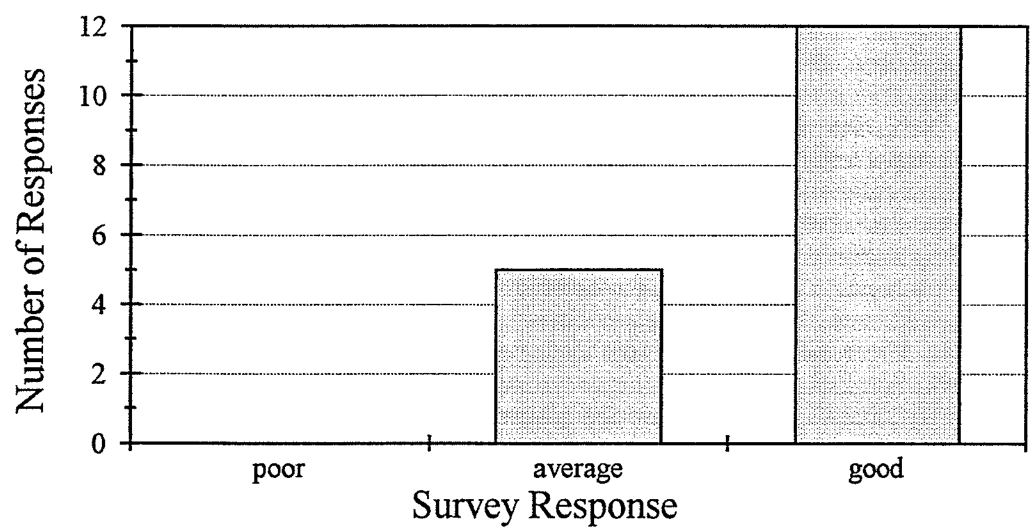

Fig. 5. Response to question 5 from GSIS user survey, *"How would you judge the potential of this program for teaching the fundamentals of grain storage to university students, farmers, or both?"*

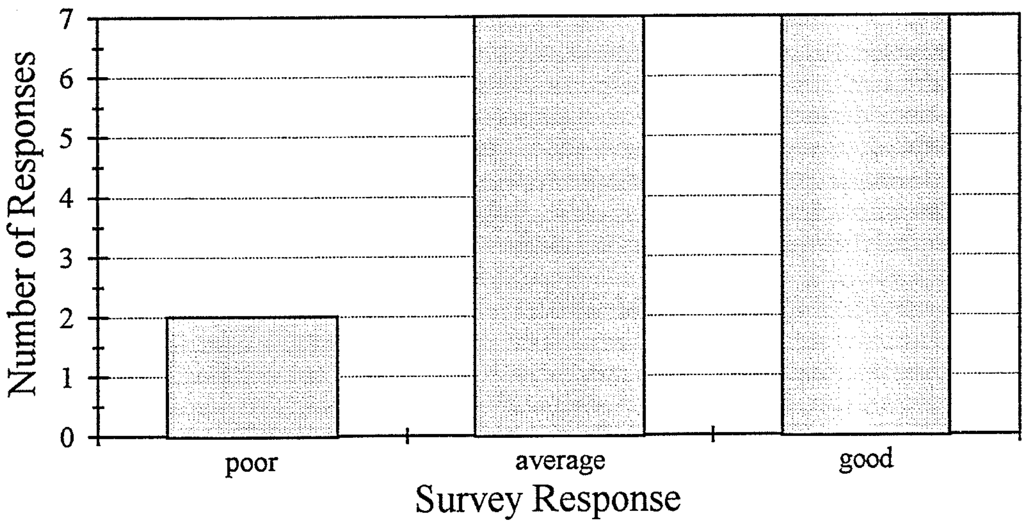

Fig. 6. Response to question 6 from GSIS user survey, "*How would you judge the potential of this program as a practical tool for a farmer or grain storage manager?*"

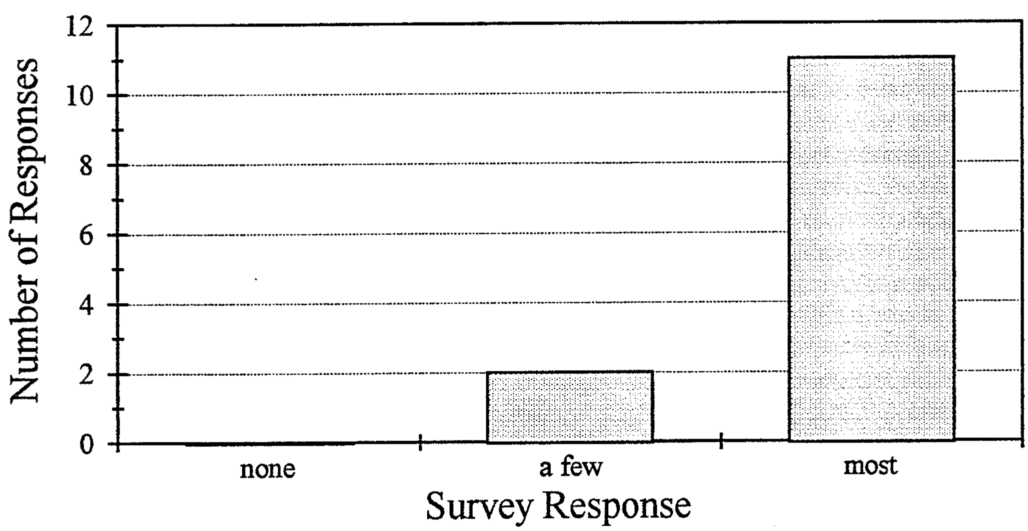

Fig. 7. Response to question 7 from GSIS user survey, "*Were the suggestions and recommendations reasonable based on your experience?*"

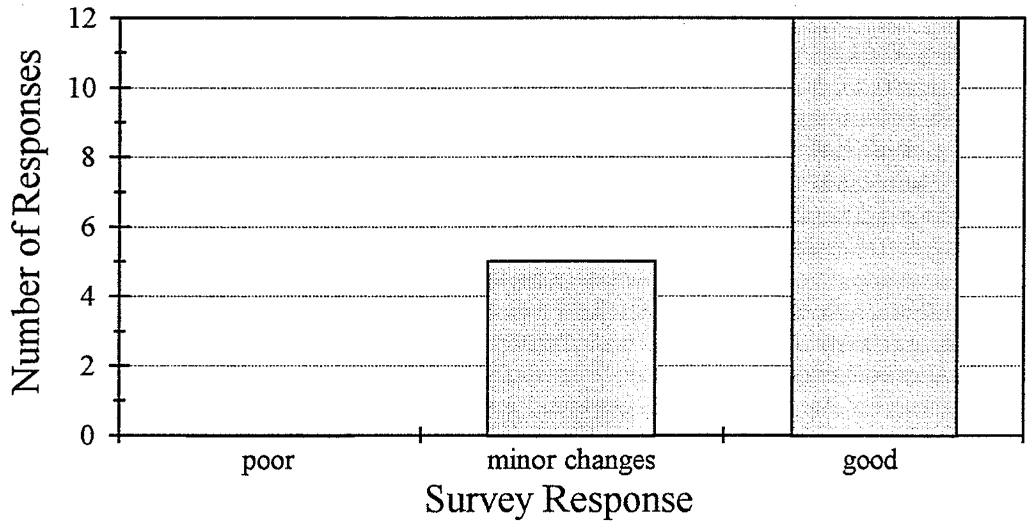

Fig. 8. Response to question 8 from GSIS user survey, "*What is your overall impression of the program?*"

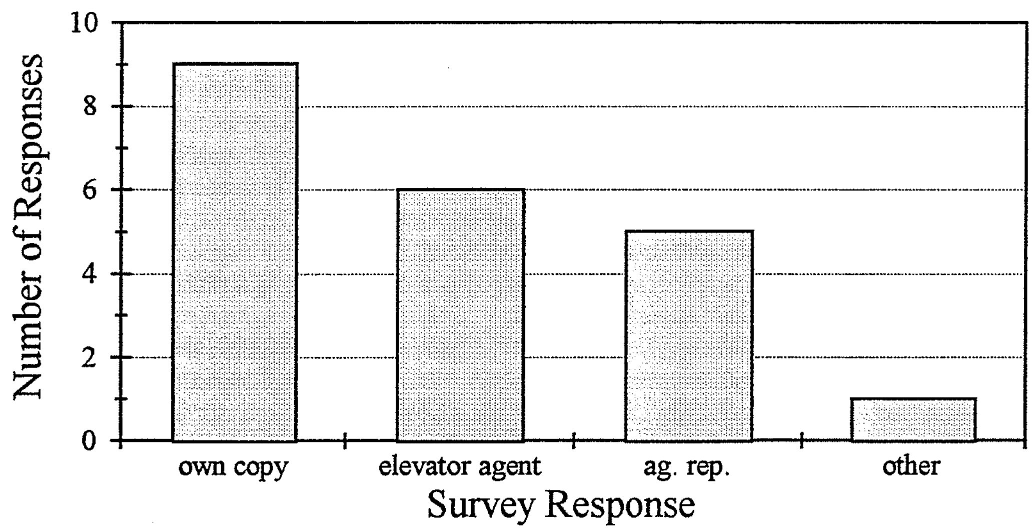

Fig. 9. Response to question 10 from GSIS user survey, "*As a potential future user, what do you feel is the best way to gain access to such a program?*"

The results from the sample problem given to the class of agricultural engineering students are difficult to summarize. The students were required to make various assumptions to answer the question. Due to different assumptions and answers that did not have to meet a standard format, the problem was answered in different ways.

In their answers, 15 out of 16 students included the safe storage life in days (Fig. 10). The storage life of grain is based on temperature and moisture content. The moisture content was given, but the students had to assume a grain temperature.

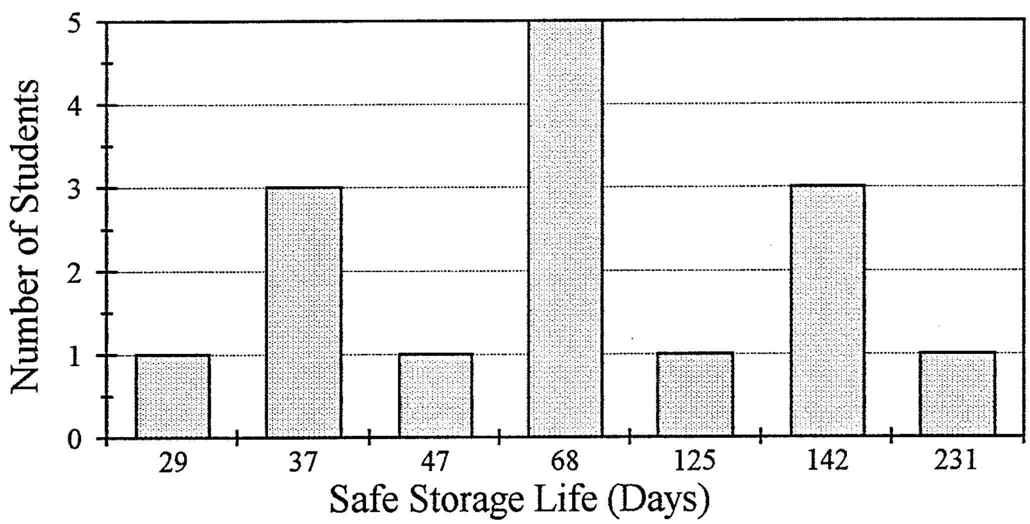

Fig. 10. Values of *Safe Storage Life* (in days) used by a class of agricultural engineering students to solve a sample problem using GSIS. The different values are the result of assumed grain temperatures.

Similarly, 10 out of 16 students reported the risk of a future insect infestation (Fig. 11). This value was based on several assumptions as well.

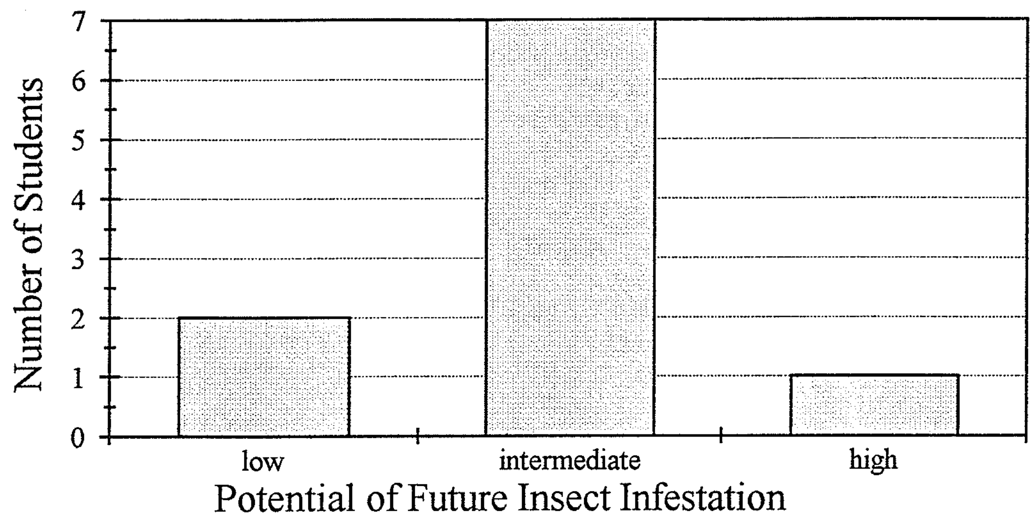

Fig. 11. Values of *Potential for a Future Insect Infestation* reported by the class of agricultural engineering students as part of their solution to a sample problem.

9.4 Discussion

As mentioned previously, validation of GSIS will be based on user friendliness and the ability to convey information. Figure 2 suggests that GSIS is reasonably easy to use, however, the large number of people who answered "*satisfactory*" indicate the need for further improvements. Figure 8 confirms the fact that the majority of people feel the program requires only minor changes.

Even though GSIS can be described as being user friendly, it must be able to convey information to the user to be successful. While 12 out of 17 people judged the program to have good potential for teaching the fundamentals of grain storage, a significant number of people felt that questions were left unanswered (Fig. 4). Fifteen out of 17 (Fig. 3) claim to have learned something new about grain storage during their consultation. I interpret this as a measure of success. The majority of these people have used GSIS only once. If they even learn only one piece of information each time they use the program, they will soon have learned a lot.

The responses to the sample problem offered insight to the way in which GSIS is used. To answer the question, the students were required to make several assumptions. Review of the assumptions made by the students seems to indicate a good understanding of grain storage, however, it is difficult to determine whether the understanding is because of GSIS or because of other sources. In my opinion, many of the assumptions could be based on information found in GSIS. If that is the case, GSIS can be considered to function well as an educational tool.

Only 2 out of 16 people felt the program would have poor potential as a practical tool for farmers and grain storage managers (Fig. 6). Despite this result, an observation was made which will have to be addressed. Many farmers do not directly measure the grain temperature at the time of harvest. To run a consultation with GSIS, they will have to assume a grain temperature. Based on the sample problem given to the students, a hot, sunny September day can be interpreted in different ways. People from different regions of the province would choose different temperatures. The regional impact of ambient temperature must be examined carefully in the future.

The sample problem answered by the students reinforced my belief that GSIS is best used as an educational tool. One would not expect such a wide range of values for safe storage life (Fig. 10) given constant grain conditions. The students should be able to observe the impact of different temperature assumptions.

10. CONCLUSIONS

The following conclusions can be drawn from this thesis work:

1. Successful expert systems for grain storage management have been developed in at least four countries around the world. Climatic and regulatory differences between countries make these programs unsuitable for Canadian farmers. The presence of experts willing to be part of the project and an abundant source of published knowledge, in conjunction with the need for an expert system, make the project feasible.

2. The Grain Storage Information System has been developed to run on a personal computer. Many farmers either have a personal computer or can gain access to one through an agricultural representative or elevator agent. The system, therefore, is practical for distribution.

3. Half of the survey respondents described the program as being easy to use. This is a positive first step, but more work should be done to satisfy the other survey respondents.

4. The Grain Storage Information System must gain the trust of farmers and grain storage managers before it will be widely accepted. Dictating a recommendation with little explanation will not create trust. Rather, the program should teach the user why certain management actions are more likely to be successful than others. Field testing is required to ensure that suggested management actions are consistent with those made by human experts and that the program is trustworthy.

11. RECOMMENDATIONS FOR FUTURE WORK

The number of comments and suggestions received from survey respondents indicates that GSIS needs some improvement and refinement. Before a large number of changes are made, however, I believe it is imperative to get more feed-back from users. This will help to identify the areas of greatest concern.

It would be useful to get feedback from users about the graphical user interface. This could help to identify potential problems (e.g. things done poorly) and potential solutions (e.g. things done well).

Since GSIS functions well as a teaching tool, it may be useful to consider the possibility of applying computer-aided instruction technology to the existing program. This could make GSIS an intelligent tutor.

At present, the practical use of GSIS is unclear. GSIS appears to function satisfactorily as an educational tool, but further field testing is required before it can be determined that it makes the correct suggestion in all cases.

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APPENDIX A

Print-outs of the Insect Identification

Module Screens from GSIS

INSECT INFORMATION MODULE

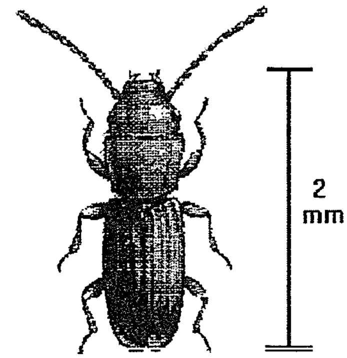
Pick Insect Species

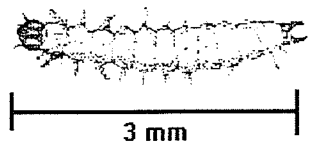
RUSTY GRAIN BEETLE

Cryptolestes ferrugineus

COLOR:	reddish-brown
SHAPE:	flat, rectangular
SIZE:	1.5 - 2.5 mm long
FLYING:	Yes
FOODS:	The germ of cereals; will feed on some fungi.

RANGE FOR DEVELOPMENT:	20 - 40 °C 40 - 95% R.H.
OPTIMUM CONDITIONS:	33 °C 70 - 80% R.H.





It is the most common and serious pest of stored grain on farms and elevators in western Canada. When grain is harvested warm, large populations can build up quickly, causing grain heating and spoilage. Insect-infested grain is likely to cake, to become moldy and musty, to sprout and to undergo loss in germination and in milling and baking quality. The rusty grain beetle is very cold-hardy. It can survive short exposures of -25 °C, although prolonged exposure to -5 °C will kill them. Typical damage to a grain kernel can be recognized by the presence of a distinct burrowing hole in the germ area made by the emerging adult. Large populations can generate enough heat and moisture to create hot spots in bulk grain in cold weather under favorable conditions. This species tends to move downward in bins. It will also move towards areas of high moisture content or high carbon dioxide concentration .

INSECT INFORMATION MODULE

Pick Insect Species

RED FLOUR BEETLE

Tribolium castaneum

COLOR: reddish-brown to blackish

SHAPE: cylindrical, clubbed antennae

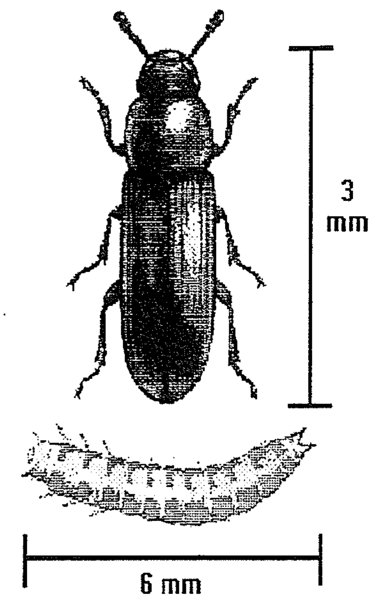
SIZE: 2.3 - 4.5 mm long

FLYING: Yes

FOODS: broken and ground kernels, dust, fungi.

RANGE FOR DEVELOPMENT: 20 - 40 °C
10 - 95% R.H.

OPTIMUM CONDITIONS: 32 - 35 °C
70 - 75% R.H.



This species cannot feed on undamaged, dry seed with less than 12% moisture content. It prefers grain dust, broken grain and milled stocks. Adults and larvae are also cannibalistic, particularly in crowded situations, where they will feed on the eggs and pupae of their own species. Food stocks infested by the red flour beetle show many reddish brown beetles moving over the material when they are disturbed. Heavily infested flour turns grayish and contains cast skins, fecal pellets and frass. In some cases, the flour may turn pink, giving out a disagreeable taste and odor caused by a secretion of the adults. Infested wheat undergoes rapid germination loss. The red flour beetle is a strong flier. It has an unusual tolerance for low relative humidity and can survive in very dry environments. It shows a distinct dispersal behavior unlike some other stored-grain beetles, which stay inside the grain mass. It often occurs on the surface of stored grain.

INSECT INFORMATION MODULE

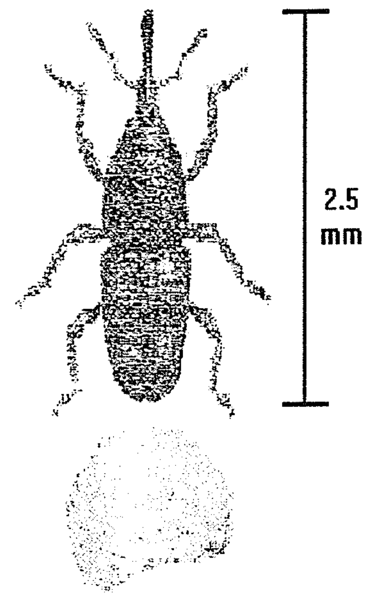
Pick Insect Species

RICE WEEVIL

Sitophilus oryzae

COLOR:	reddish-brown or dark brown
SHAPE:	long, narrow snout; chewing mouth parts
SIZE:	2.5 - 4.0 mm long
FLYING:	rarely
FOODS:	whole cereal grains

RANGE FOR DEVELOPMENT:	17 - 34 °C 45 - 100% R.H.
OPTIMUM CONDITIONS:	26 - 31 °C 70% R.H.



The rice weevil is universally regarded as one of the most destructive primary pests of stored cereals. It can completely destroy stored grain. Invasion by this primary pest may cause grain heating and may facilitate the establishment of fungal colonies, secondary insect pests and mites. It is moderately cold-hardy, but requires relatively high relative humidity to develop. The larvae feed and develop inside the grain kernel undetected from outside. Irregularly shaped holes on seeds characterize a rice weevil infestation. A single insect can destroy about 30% of a wheat kernel in the development from egg to adult. In a heavy infestation, the only part of the grain that remains is the shell of the kernel perforated by adult feeding and emergence holes. Infested kernels contain a gelatinous plug (usually in the end of a kernel) where a single egg was laid. The adults disperse quickly at high temperatures. Loosely packed grain facilitates insect movement.

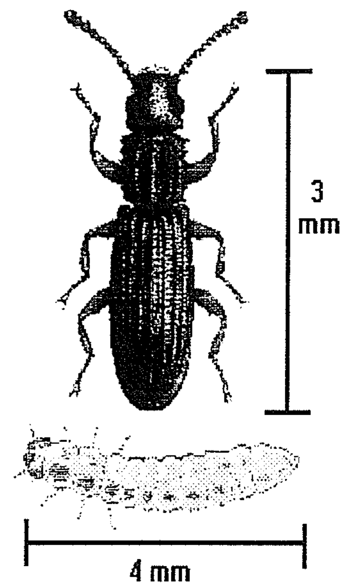
INSECT INFORMATION MODULE

Pick Insect Species

SAW-TOOTHED GRAIN BEETLE

Oryzaephilus surinamensis

COLOR:	dark brown
SHAPE:	slim, neck shield with 2 deep grooves
SIZE:	2.5 - 3.5 mm long
FLYING:	
FOODS:	grain and grain products
RANGE FOR DEVELOPMENT:	18 - 37.5 °C 10 - 90% R.H.
OPTIMUM CONDITIONS:	31 - 34°C 90% R.H.



This species is often associated with heating of dry bulk cereals such as oats. It is both cold-hardy and tolerant of low relative humidity. Scarring and roughing of the surface of the food are indications of feeding by saw-toothed grain beetles. When found on a mass of whole grain, its presence indicates that either the grain was invaded earlier by other granivorous insects or the grain mass contains broken grain, weed seeds, dust, or other types of dockage, because this insect species does not feed on undamaged grain. Heavy infestation of farm-stored grain, particularly oats, may cause heating. Masses of beetles may migrate to the bulk surface above the hot spot. The adult tends to be very active, but rarely flies. Their activity tends to be greatest in the evening.

INSECT INFORMATION MODULE

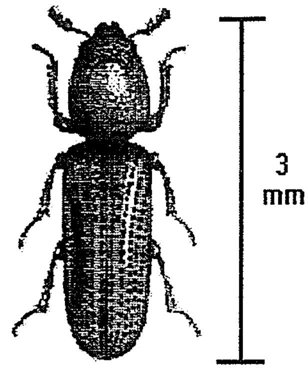
Pick Insect Species

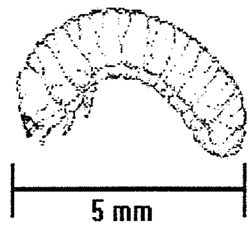
LESSER GRAIN BORER

Rhyzopertha dominica

COLOR:	red-brown to black-brown
SHAPE:	slim, cylindrical body; neck shield extends beyond head
SIZE:	2.0 - 3.0 mm long
FLYING:	Yes
FOODS:	whole kernels

RANGE FOR DEVELOPMENT:	18 - 39 °C 25 - 70% R.H.
OPTIMUM CONDITIONS:	32 - 34°C 50 - 60% R.H.





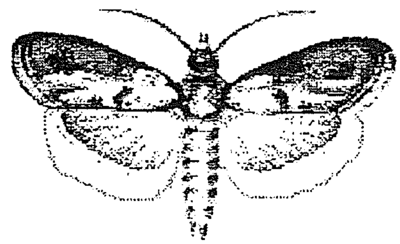
Although the lesser grain borer is rarely found in stored-grain in Canada, it has been found in flight traps. Since it is a good flier, there is a danger that Canadian grain could be infested by insects migrating from the United States. It is important to detect these insects because they are among the most voracious of pests attacking stored product. Both the adult and larvae will eat through a kernel, leaving only the skeleton of the kernel behind. They are also able to survive on wheat as low as 7.5% mc, so they cannot be controlled by simply having dry grain.

INSECT INFORMATION MODULE

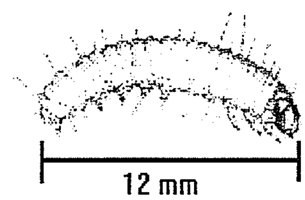
Pick Insect Species

INDIAN MEAL MOTH

Plodia interpunctella



COLOR:	outer forewings: bronzy; inner wings: grey to yellow
SHAPE:	
SIZE:	closed wing: 8 - 10 mm; wing span: 14 - 20 mm
FLYING:	Yes
FOODS:	adults do not feed



RANGE FOR DEVELOPMENT:	18 - 33 °C 25 - 95% R.H.
OPTIMUM CONDITIONS:	26 - 29°C 70% R.H.

The adults do not cause damage to the stored-grain because they do not feed and are short-lived. However, severe damage can be done by the larvae. The larvae will move through cereals contaminating them with webbing and frass; in cereals they feed preferentially on the embryo. Just before pupation, larvae pass through a 'wandering' phase, spinning more silk threads which in heavy infestations can form webbing completely covering produce surface. Some strains under certain temperature conditions can go through a pre-pupal diapause phase which is particularly difficult to control with insecticides and, more so, fumigants.

INSECT INFORMATION MODULE

Pick Insect Species

FOREIGN GRAIN BEETLE

Ahasverus advena

COLOR: brown

SHAPE:

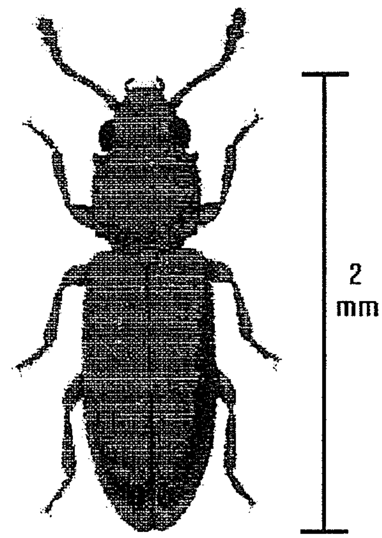
SIZE: 2.0 - 3.0 mm long

FLYING: Yes

FOODS: damp and moldy grains, several fungi

RANGE FOR DEVELOPMENT: 25 - 30 °C
60 - 100% R.H.

OPTIMUM CONDITIONS: 27 - 30 °C
85 - 92% R.H.



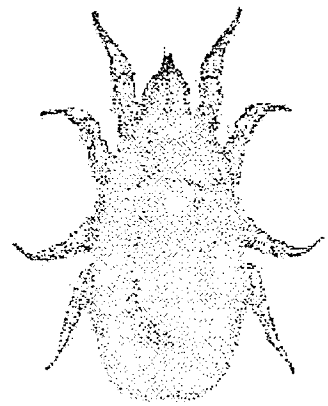
The presence of this insect in farm-stored grain is taken as a warning that the grain is beginning to spoil and become moldy. It is frequently associated with hot spots in farm-stored grain. Although primarily a fungivorous species, it also feeds on various other foods, especially if they are damp and moldy. The foreign grain beetle can be separated from the rusty grain beetle, with which it is frequently associated, by its larger size, less flattened body, and the presence of a single blunt tooth on each apical corner of the prothorax. A quick and easy method for identifying the foreign grain beetle from the rusty grain beetle is to place the insects in a glass container. Foreign grain beetles are able to climb the walls of glass containers, while rusty grain beetles cannot. The foreign grain beetle is also a strong flier, which enables it to move freely from granary to granary.

INSECT INFORMATION MODULE

Pick Insect Species

GRAIN MITE

Acarus siro



COLOR:	white
SHAPE:	globular, short legs
SIZE:	< 1000 microns
FLYING:	No
FOODS:	damaged seed germ, also fungi

RANGE FOR DEVELOPMENT: 25 - 32 °C
> 62% R.H.

OPTIMUM CONDITIONS:
80 - 85% R.H.

Mites are whitish and about the size of a pinhead. They feed on stored foods such as flour, grain, seeds or bulbs or on the fungi that develop on these products. Because of their soft skin, they are very sensitive to the moisture content of the grain. Therefore, it is most likely to find mites on grain that is tough or damp. A mite infestation will kill seeds, reduce germination and reduce the milling quality of grains. The product will often acquire a minty odor. Fumigation may be ineffective because of the unusual ability of some species of mites to survive under adverse conditions by going into a hypopal stage. An infestation can be controlled either by turning the grain several times or by drying the grain. In winter, mites can be controlled by cooling the grain to -7 °C.

INSECT INFORMATION MODULE

Pick Insect Species

GROUND BEETLE

Calosoma scrutator

COLOR: black and shiny

SHAPE: long and slender

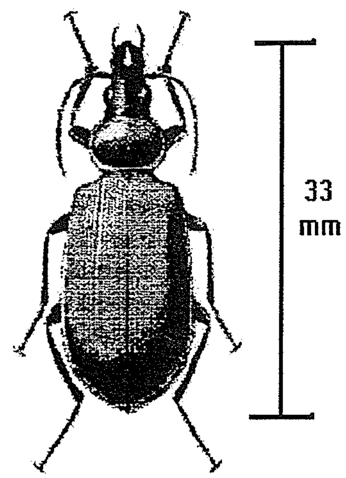
SIZE: up to 30 mm long

FLYING: Yes

FOODS: do not feed on stored grain

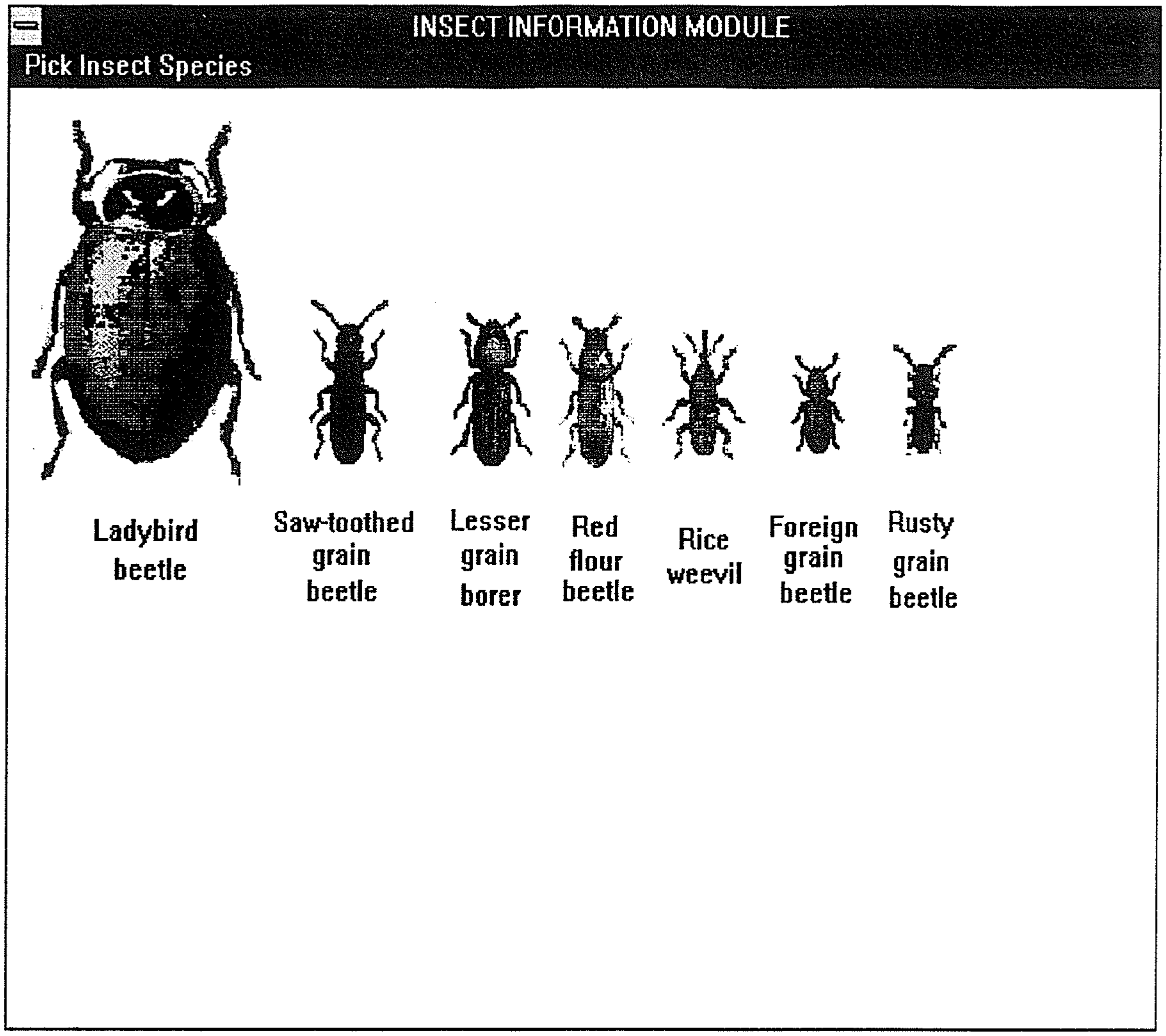
RANGE FOR DEVELOPMENT:

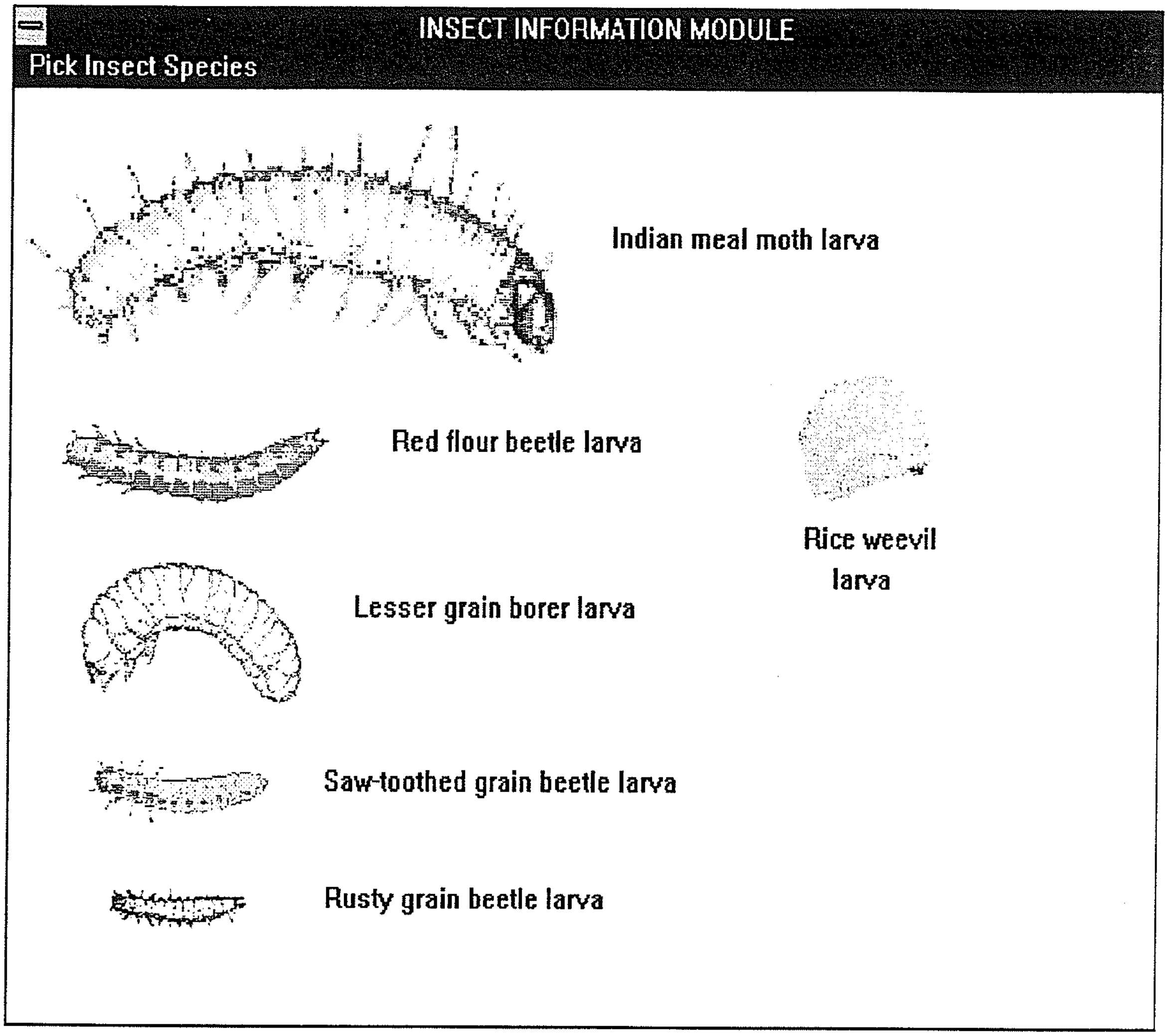
OPTIMUM CONDITIONS:



This beetle is usually black and shiny or dark, but sometimes is brightly colored. Carabids are generally found on the ground beneath objects; some are found on vegetation and flowers. They are able to fly and commonly fly towards light.

Most other species of ground beetles are nocturnal, and hide during the day. They will run rapidly when disturbed, but seldom fly. These beetles are predators and feed on other pests such as Gypsy Moth larvae, cankerworms and cutworms. Therefore, they are no danger to stored grain. They are sometimes found in freshly harvested grain because they come with the grain from the field. No action needs to be taken if these beetles are found in the grain.


INSECT INFORMATION MODULE
Pick Insect Species
Ladybird beetle
Saw-toothed grain beetle
Lesser grain borer
Red flour beetle
Rice weevil
Foreign grain beetle
Rusty grain beetle


INSECT INFORMATION MODULE
Pick Insect Species
Indian meal moth larva
Red flour beetle larva
Rice weevil larva
Lesser grain borer larva
Saw-toothed grain beetle larva
Rusty grain beetle larva

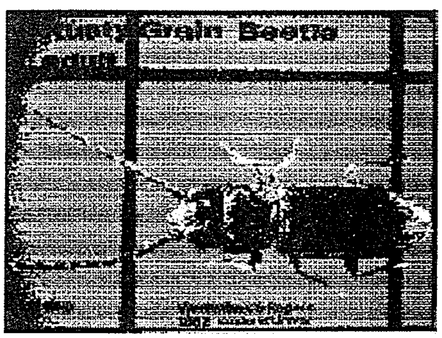
RUSTY or FOREIGN Grain Beetle?

These two insects look much the same, but their presence usually indicates very different problems. The Rusty grain beetle is a grain feeder. Both the larvae and the adults attack kernels of grain and cause damage. It is a common pest in farm granaries and storage elevators in Canada, and on the prairies it is rated as the most troublesome of the pests that attack stored grain. When this insect is present, you have a problem that must be controlled.

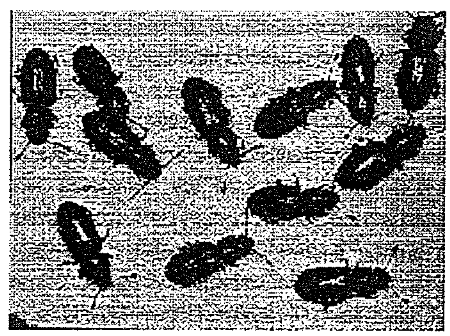
The Foreign grain beetle is a fungus feeder. The insect feeds on molds on damp grain. It is usually found in moist, moldy grain. Although it can damage the germ of kernels if the relative humidity is over 65%, grain injury by this pest is not severe enough to cause economic loss. When this insect is present, you have a moisture problem as opposed to an insect problem.

Distinguishing the Two:

To an entomologist, the Foreign grain beetle can be distinguished from the Rusty grain beetle by its club-shaped antennae. A more practical method for deciding which insect you have is to place the insects into a glass jar. The Foreign grain beetle can climb the sides of a glass jar, but the Rusty grain beetle cannot.



Rusty Grain Beetle



Foreign Grain Beetle

Damage caused by Rusty grain beetles:

Note that the insects physically damage the wheat kernels by chewing holes. Also note that the wheat kernels are free of damage from molds.

Damage caused by Foreign grain beetles:

Note that the wheat kernels are covered by mold growth. The insects feed on the mold rather than the kernels.

APPENDIX B

Print-outs of the Grain Sampling

Module Screens from GSIS

GRAIN SAMPLING MODULE

Sampling Information

INSECT SAMPLING LOCATION

The most likely location for an insect infestation to occur is in the center of the bin, near the surface. This is due to the insects congregating in the warmest region within the grain bulk. If the grain has been in storage for as much as two months or longer, the most critical location to sample is the center of the bin, at the surface and 1 m below the surface.

However, if the grain has only recently been placed into storage, it is unlikely to have formed a pocket of warm grain. If the grain has recently been placed into storage, take samples across the entire bin at the surface and 1 m below the surface of the grain.

If the bin has been filled to the peak, take samples from the top center of the bin (surface and 1 m deep) and from the auger hole.

GRAIN SAMPLING MODULE

Sampling Information

There are two relatively fast, easy and economical sampling methods which can be used to detect live insects:

1. Grain Trier

The first method, known as the grain trier method, consists of forcing a sampling tube into the grain bulk and removing a sample of the grain. The grain sample is then carefully examined for the presence of insects. The insects can be separated from the grain either by sieving the sample or using the Berlese funnel method.

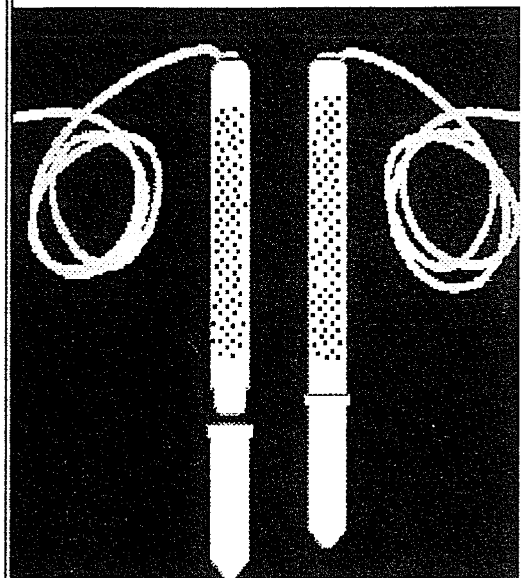
2. Probe Trap

The second sampling method, known as the probe trap method, consists of placing a hollow, cylindrical tube into the grain bulk. The tube has holes to allow insects to crawl in, but prevents them from getting out. The trap is left in the grain for several days, then taken out and the insects counted. Grain does not usually get into the trap, so it is not necessary to separate insects from grain as in the method described above.

GRAIN SAMPLING MODULE

Sampling Information

GRAIN PROBE TRAP



A probe, as shown to the left, is pushed into the grain. The probe is a hollow, plastic tube with downward -sloped holes. The tube is approximately 2.5 cm in diameter with approximately 2.8 mm diameter holes. Insects move through the grain, enter the perforations in the trap, and fall into a collecting vial at the bottom of the trap.

Probe traps are useful for detecting insect infestations because they can be left in the grain for several days, catching insects from a larger area than other sampling methods.

For cylindrical bins, one trap placed 1 m deep in the top center of the bin will be sufficient.

Probe traps are mainly used for cereal grains. It is not useful for canola because the small canola seeds plug the holes. The holes may also become plugged if there are a lot of small weed seeds in the grain.

GRAIN SAMPLING MODULE

Sampling Information

INSECT DETECTION -- SIEVING METHOD

Detecting insects in cereals:

Screen surface samples using a No. 10 sieve (2.0-mm aperture). Use a sampling probe to obtain deep samples. Warm the siftings for a few minutes under a light bulb and then examine them for insect movement.

Detecting insects in oilseeds:

Screen surface samples using a No. 20 sieve (0.85-mm aperture). Use a sampling probe to obtain deep samples. Warm the siftings for a few minutes under a light bulb and then examine them for insect movement.

Detecting mites:

Sift grain or oilseed samples through a No. 20 or 30 mesh sieve (0.595-mm aperture). Warm the dust and screenings to room temperature and examine them through a magnifying glass. Large numbers of mites in siftings look like clumps of moving dust. Smaller numbers that look like specks of dust are hard to see.

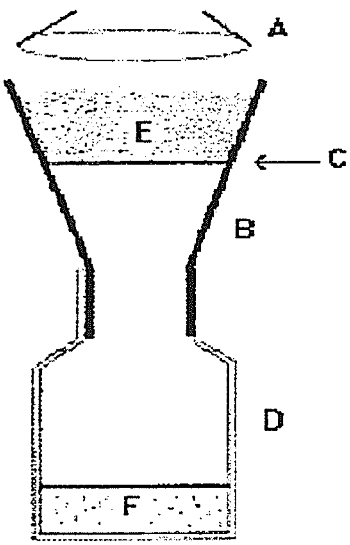
GRAIN SAMPLING MODULE

Sampling Information

BERLESE FUNNEL

The Berlese funnel method of separating insects from grain is based on the fact that insects move away from extreme heat.

A simple apparatus like the one shown can be used. It consists of the following:



A. Heat Source - a 60 watt bulb can be used. The grain temperature should reach 70 - 75 °C. Complete extraction of insects will often take 5 - 6 hours.

B. Funnel - holds the grain and forces the insects to fall into a holding container.

C. Sieve - a four-mesh or 1680-micron screen is placed in the funnel to hold the grain but let the insects through. For smaller seeds such as canola, the four-mesh screen is too large. Place a layer of clean wheat in the bottom of the funnel before adding the canola.

D. Glass Container - this is used to hold the insects when they come out of the grain.

E. Grain Sample - grain sample with insects.

F. Rubbing Alcohol - kills the insects, preventing their escape. Use a mixture of 1/2 water and 1/2 alcohol to prevent rapid evaporation.

GRAIN SAMPLING MODULE

Sampling Information

To complete the consultation, you will need to sample the grain to obtain the following information. To obtain a printed copy of this screen, select the menu item labelled 'Print Current Information...'.

Grain Type: [ ] Grain Temperature: [°C] Harvest Date: [ ]

Moisture Content: [%] [°F] Selling Date: [ ]

Foreign material
- small particles
- large particles

Grain damage
- frost
- mechanical
- sprouting

granary sanitation
- yes
- no

previous infestations
- yes
- no

Insect species
- Rusty grain beetle
- Red flour beetle
- Rice weevil
- Saw-toothed grain beetle
- Lesser grain borer
- Foreign grain beetle
- Indian meal moth
- Grain mite
- Ground beetle

bin diameter [ ]

bin height [ ]

presence of insects
- yes
- no
- were not sampled for

heated-air dryer
- yes
- no

aeration or near-ambient drying equipment
- yes
- no

pneumatic grain conveyor
- yes
- no

APPENDIX C

Print-outs of the Sanitation Module

Screens from GSIS

SANITATION INFORMATION MODULE

Sanitation Information...

BIN SANITATION:

Bin sanitation techniques are only useful if the bin is empty. If your grain is already in the bin, the information below can be used for future storage years.

The main purpose of bin sanitation is to eliminate the possibility of contamination from a previous years' grain residues. A thorough cleaning of the walls, ceiling and floor will remove most existing infestations. All cracks, crevices and corners should be carefully examined and cleaned. A broom and shovel will do the job, however, you may want to use a shop-vac.

In cases where there is an existing infestation in the grain residues, it may be advisable to treat the walls, ceiling and floor with a contact insecticide such as malathion.

To view information, select the topic of your choice from the menu at the top of the screen.

SANITATION INFORMATION MODULE

Sanitation Information...

BIN MAINTENANCE:

Bin maintenance can be very beneficial for preventing both moisture entry and insect entry into the storage bin.

Holes in the roof should be fixed to prevent moisture entry into the bin. Corners and crevices should be eliminated if possible because these are ideal spots for residue build-up.

Small, visible openings in bin walls can be closed with silicon caulking.

To view information, select the topic of your choice from the menu at the top of the screen.

SANITATION INFORMATION MODULE

Sanitation Information...

GENERAL SANITATION:

Proper sanitation is also important outside of the storage bin. Long grass and other debris offer harborages for insects. Grass should be cut and debris cleaned up.

The most important insect harborage is spilled grain. Therefore, it is vital that all spilled grain be cleaned up. If it is difficult to clean up, spilled grain should be either buried or treated with insecticide.

To view information, select the topic of your choice from the menu at the top of the screen.

SANITATION INFORMATION MODULE

Sanitation Information...

MALATHION USE:

Malathion is used either as a preventive insecticide or for controlling established infestations. Malathion can be applied to the walls, ceiling and floor of empty bins. 1% malathion remains active for only a couple days on concrete and and up to 6 months on wood and steel.

The following example shows how to mix 5L of 1% malathion:

Malathion = 5L x 1% desired / 50 (% active ingredient of emulsion)
= 0.1 L concentrate

Water = 5L - 0.1 (L of emulsion)
= 4.9 L

As a general rule for covering floors or walls, apply the spray at 5L/100 sq. meter (1 gal/ 1000 sq. ft)

Observe these safety precautions:

- use a protective mask with approved filters when applying insecticide inside enclosed areas
- wear protective clothing, hard hat, goggles, rubber work boots and gloves during preparation and spraying
- application should be done on calm days. Leave the granary closed for a couple of days.

To view information, select the topic of your choice from the menu at the top of the screen.

APPENDIX D

Information Contained Within the

General Information Module from GSIS

Convection Currents

Temperature differences can cause moisture to move from warmer to colder areas of the bin. As autumn turns to winter, the ambient air temperature drops, causing the edges of the grain bulk to cool. As shown in Figure 1, the cool air travels downward along the edges of the bin and turns inward. As it approaches the centre of the grain bulk, it warms and starts to rise. As the warm air approaches the cold grain near the surface, it cools producing a region of increased moisture content near the surface where rapid spoilage can occur. Crusting on the surface of stored grain is a common symptom of moisture migration. In summer, it is possible to get moisture migration in the opposite direction if the outside temperature is warmer than the grain (Figure 2).

Figure 1

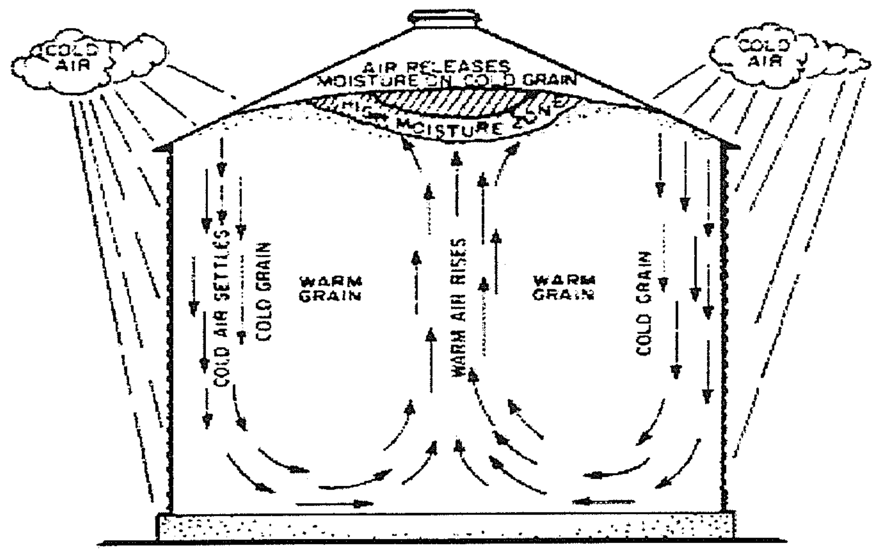
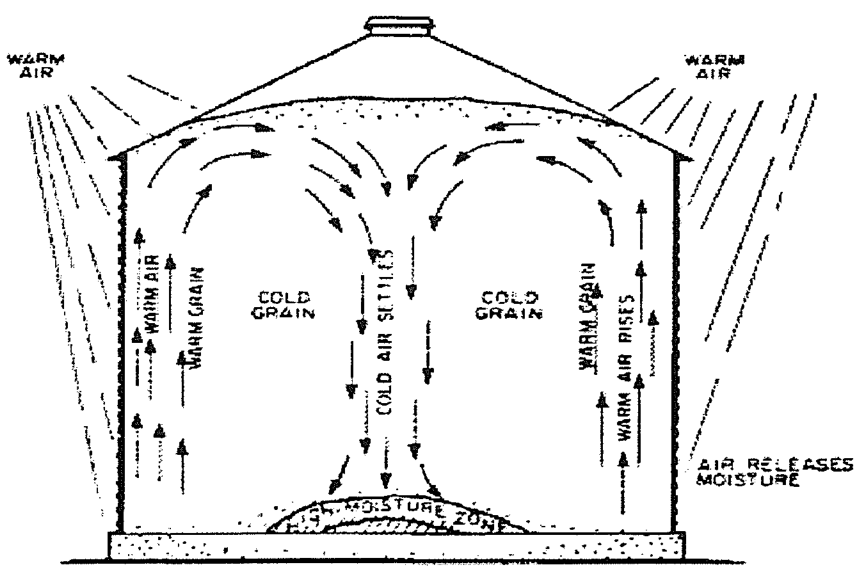


Figure 2



Significant migration can occur in cereal grains at moisture contents as low as 12 per cent or oilseeds as low as 8 per cent if they are placed into storage at a high temperature and not cooled.

Larger storage bins and greater differences between grain and ambient temperature cause more moisture migration. In western Canada, wide ambient air temperature variations necessitate the use of aeration systems, particularly for large storage bins (100 m^3 or larger). Large bins provide more opportunity for the development of the convection currents which cause moisture migration.

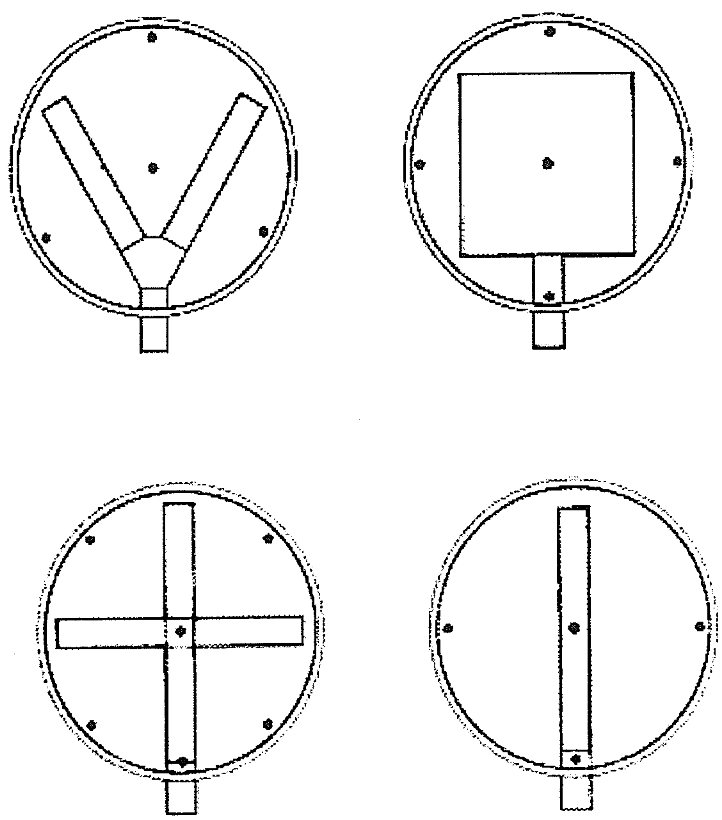
Difference Between Aeration and Near-Ambient Drying

The purpose of aeration is to produce the lowest practical temperature and the least temperature variation within the stored grain. The amount of air required to change the temperature of the grain will produce very little change in moisture content. Aeration is not a grain drying system and should not be considered as such.

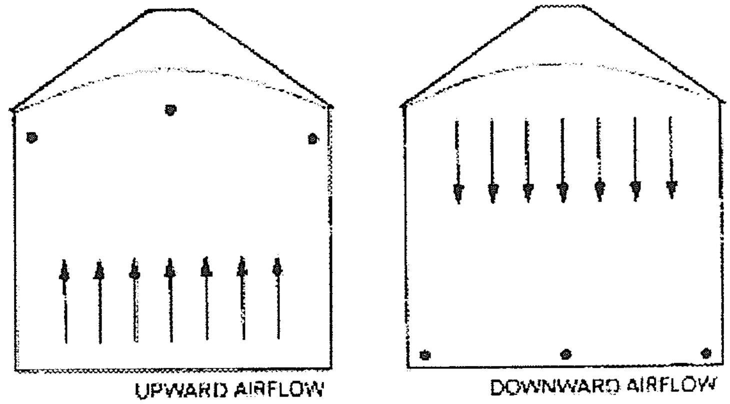
Near-ambient drying, on the other hand, uses the drying potential of surrounding air to remove moisture from the grain. Some of the moisture in the grain evaporates and is removed by the air. Near-ambient drying is a race to get the grain dried before it spoils. The key to success is to move the drying zone through the top of the grain mass within the allowable storage time.

AIRFLOW RATES

The airflow rates for aeration are normally one to two litres of air per second per cubic metre [1-2 (L/s)/m^3]. With an airflow rate of 1 (L/s)/m^3 about 150 - 200 hours of fan operation are needed to change the temperature throughout the bin. With an airflow rate of 2 (L/s)/m^3, it takes only half as long. It is essential for the fan to be operated long enough to equalize the temperature throughout the entire bin. The temperature of the grain must be checked to see when cooling is completed. Recommended monitoring points are shown below.



a) PLAN VIEW



b) ELEVATION VIEW

The airflow rates for near-ambient drying are usually much higher than 1 or 2 (L/s)/m^3. At higher moisture contents and temperatures, the allowable time for drying is reduced. Wetter grain, therefore, requires higher airflow rates to accomplish drying within the allowable storage time. At higher temperatures, the grain deteriorates faster so higher airflow rates are required to complete drying before the grain spoils. The required airflow rates for various moisture contents and harvest dates are given below.

AIRFLOW RATES...

Grain which is located at the top of the bin is likely to spoil first since it is the last to dry. The more air that is delivered, the quicker the drying zone moves through the grain and the shorter the time that the top layer is at risk. The fan should be operated continuously until the drying zone moves through the top of the grain or the temperature drops low enough for safe storage. The bottom layer of grain overdries in dry weather and re-wets in damp weather. However, as re-wetting occurs at the bottom, the drying zone continues to move upward. The rate of re-wetting is slower than the drying rate so a few days of fan operation in wet weather will not seriously affect the overall drying rate. Also, the grain is kept cool by the air moving through it, which increases the allowable storage time.

Near-Ambient Drying Considerations

Near-ambient drying involves moving large quantities of air at moderately high pressures, so the selection and matching of equipment is extremely important. Minimizing air losses and pressure drops in the components is a prime consideration.

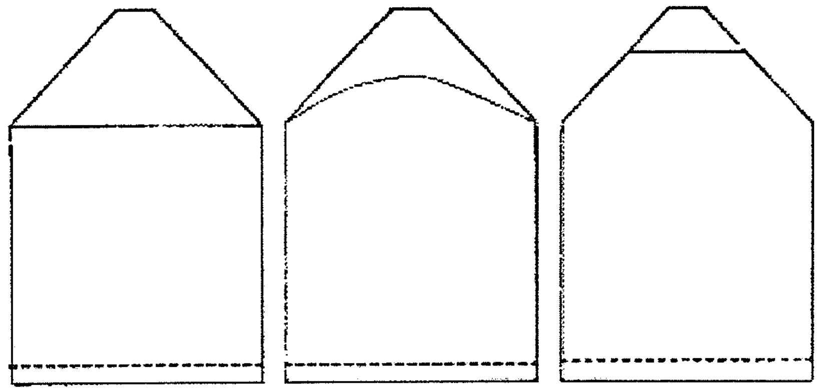
PERFORATED FLOORING

There are two main types of perforated flooring material available. They are commonly referred to as cereal and canola flooring. The cereal flooring has larger openings and is able to pass more air without a significant pressure drop.

Partially perforated floors are sometimes used in near-ambient drying facilities. There are several disadvantages to using anything less than a fully perforated floor. There is a higher pressure requirement with a partial floor, which means a larger fan size is needed. Field tests have shown that if 40 per cent of the total area is perforated flooring, 10 per cent more fan power is required; if 25 per cent of the total area is perforated flooring, 30 per cent more fan power is required. The time required to complete drying is substantially increased if a partially perforated floor is used. Depending on the layout and the amount of perforated flooring, a partial floor may require 25 to 100 per cent more fan operating time because of the non-uniform airflow produced. This means that a higher airflow rate needs to be used to compensate for the non-uniformity of the airflow patterns, which in turn means a higher fan power requirement. In most cases the money spent on the extra purchase and operating costs of the fan would be better spent on providing a fully perforated floor. If a partially perforated floor is used for near-ambient drying, the perforated floor area should be at least 40 per cent of the total, and the airflow rates must be increased.

BIN FILLING

There is a great temptation to leave the grain peaked up in the centre of the bin because of the extra work involved in levelling, and to gain the additional storage space under the roof cone. This does, however, substantially extend the time required to finish drying, and in some cases may result in grain spoilage near the top of the cone. The figure below shows the increased volume of grain and the increased drying times required as determined in one field test. A seven per cent increase in grain volume increased the drying time by 50 per cent, and a 10 per cent increase in grain volume increased the required drying time by 80 per cent.



STORAGE VOLUME	1.0	1.07	1.10
REQUIRED DRYING TIME	1.0	1.5	1.8

GRAIN SPREADERS AND FINES

Fine material and broken grain increases airflow resistance, which reduces total airflow. Screening this material out will speed up the drying process. Since the fines tend to accumulate in the centre of the bin, unloading some grain from the centre when the bin is full will make the airflow more uniform.

Keeping the grain level will also help to promote uniform airflow. Grain spreading devices can be used to distribute the grain, but some additional hand levelling may still be needed. The use of a grain spreader helps to distribute the fines throughout the bin but also packs the grain, thus increasing the resistance to airflow and increasing drying time.

If a spreader is not used, some grain should be removed from the centre of the bin after filling. This reduces the amount of grain to be moved while levelling, and removes some of the fine material.

Selecting a Near-Ambient Drying System

If you do not have a near-ambient drying system, there is a program which can help you choose the right size of fan for your specific bin. Although this program is not part of the expert system, it has been included because it is a useful tool for the design of near-ambient drying systems. The program is called 'GRAIN89'.

We recognize that 'GRAIN89' lacks user-friendliness. There is a brief description of the program in the manual for GSIS. However, if this brief description is inadequate, a complete manual has been written for GRAIN89. Contact Dr. Bill Muir [(204) 474-9660] at the Department of Biosystems Engineering, University of Manitoba for a copy of the GRAIN89 manual.

GRAIN89

Resistance of Insects to Insecticides

A major factor limiting the successful use of chemicals for insect control is the emergence of insect strains that possess the ability to detoxify or counter insecticides. The intensive and widespread use of insecticides is one of the main factors contributing to insecticide resistance. Furthermore, misuse of insecticides and failure to apply them in conjunction with other control measures such as sanitation has intensified the problem.

Insects have developed resistance to contact insecticides more rapidly and to a greater extent than to fumigants. Perhaps this is because contact insecticides, being less expensive and easier to apply than fumigants, are more widely used.

The transport of infested foods in infested vehicles and ships has undoubtedly contributed to the spread of insecticide-resistant strains throughout the world.

The survival of insects following an insecticide treatment may be the first indication of a resistance problem.

When a problem of insect resistance has been identified, an alternative pest-control method must be applied.

Mycotoxins

Mycotoxins are fungal products that are poisonous to most farm animals and humans. Aspergillus and Penicillium growing on stored grains and oilseeds produce mycotoxins under favourable conditions of temperature and moisture. Mycotoxins have occasionally been found in areas of Canada where high humidity prevails.

When they occur, highly toxic mycotoxins are usually present at low concentrations detectable only by lengthy and complex chemical analyses. The health of farm animals can be affected at the parts per million level, or less. Animals feeding on moldy grain and feeds may show reduced mobility and productivity or, in extreme cases, may die. Farmers suspecting mycotoxin poisoning should their local veterinarian.

Stored grains and oilseeds often become contaminated with blue-green Penicillium molds and Aspergillus versicolor through accidental dampening or faulty storage, and mycotoxin-producing strains of these fungi may develop. Contamination by the mycotoxins ochratoxin A, citrinin, and sterigmatocystin has been observed in crops stored damp and, from limited experimental information, appears to follow a specific risk pattern:

low risk: oats, HY320 wheat, hard red spring wheat, 2-row barley
moderate risk: corn, 6-row barley
high risk: amber durum wheat

During periods of high rainfall, field fungi of the Fusarium type have infected standing wheat, giving rise to the development of a disease called fusarium head blight, which can produce low levels of trichothecene mycotoxins. It is not advisable to feed grain that is suspected of being contaminated by mycotoxins to animals, especially swine and poultry.

The Toxicity of Pesticides to Man

With few exceptions, pesticides must be toxic to living organisms to be effective. They are specifically designed to be toxic to those organisms man considers pests. In many respects, however, living organisms are not all that different; they share many basic common features. A substance that is toxic to one species may also be harmful to another, including man. Pesticides are poisons; they are poisonous to pests and they may be poisonous to man.

There are two ways in which exposure to pesticides may cause illness or even death. A person may be exposed to a single large dose of a pesticide. This is an acute exposure; the degree to which a pesticide is poisonous as a result of acute exposure to it is referred to as its acute toxicity. A person may also be exposed to smaller doses of a pesticide repeatedly over a period of time, which may be weeks, months, or even years. This is called chronic exposure, and the corresponding ability of the pesticide to cause harmful effects is its chronic toxicity.

INSECTICIDES

Approved insecticides are selected largely on the basis of the following:

- low toxicity to mammals and high toxicity to insects
- freedom from taint or odour on food
- nonpersistent environmental effects
- safe, economical, and easy use
- presence of negligible residues or toxic products in food

Some insecticides do not meet all of these requirements in all circumstances. For example, oilseeds absorb contact insecticides from treated granary surfaces. Therefore, avoid treating granaries in which oilseeds are to be stored.

Grain treatment with malathion is not recommended, however, premium-grade malathion can be used for long-term protection. There are certain precautions which emphasize the fact that contact insecticides are poisons:

- chemical odours may be produced if insecticides are applied at rates in excess of those recommended
- insecticide-treated grain should not be sold for 7 days
- insecticide-treated grain should not be used for feed for 60 days after treatment

The Canadian Grain Commission does not recommend the use of grain protectants for the following reasons:
- insect problems may not arise
- alternative control measures, such as aeration or grain movement, are available
- chemical residues remain in the grain

FUMIGANTS

Fumigants generate toxic gases that are used to control insects in stored grain. They are available for farm use only as solid formulations. Fumigants are also toxic to humans and farm animals and, therefore, should be applied only by trained people. Avoid inhaling the vapours, and follow the directions on the container.

Cautions for fumigators

When using fumigants, follow the directions on the label closely and especially take the following precautions:

- Always wear a full-face gas mask either when applying fumigant to binned grain or to grain during augering or when entering a fumigated bin. Respirators are ineffective on bearded men because a tight seal cannot be made around the face.
- Always fit a new canister in your gas mask before starting fumigation. Use the type of canister recommended for phosphine gas. A canister does not protect people exposed to heavy concentrations inside buildings (for gas levels above 2% in air) and does not supply oxygen.
- Always work with at least one other person.
- Wear rubber gloves, coveralls, and a hard hat.
- If an individual shows symptoms of overexposure to a fumigant, move that person to fresh air and call a doctor immediately. Symptoms of fumigant poisoning are dizziness, blurring of vision, vomiting, and abdominal pain.
- After applying the fumigant to a granary, nail or lock the doors, seal ventilators, and post warning signs on the door.
- After 1 week, open the ventilators, but do not enter until the granary has been checked for fumigant with a gas detector tube. Because fumigated grain can take several weeks to aerate during cold weather, check for residual gas with gas detector tubes from outside the bin before entry and inside during any prolonged period of work in the bin.
- Do not feed fumigated grain to livestock unless the grain has been shown to be gas free by detector tubes or other analyses.
- Always consider wind direction. If there is a dwelling or livestock close to and downwind from the structure to be fumigated, postpone fumigation until the wind subsides or changes direction.
- Do not fumigate when winds are strong.
- For your safety, position yourself upwind during application of fumigant to grain being augered into a bin. Avoid standing downwind from a bin under fumigation.
- Phosphine gas may react with certain metals, especially copper, brass, silver, and gold to cause corrosion at high temperatures and humidity. Take precautions to remove or protect equipment containing these metals, such as electric motors, wiring, and electronic systems.

Prevention of Infestations

INSECTS

To prevent and control infestations we need to know where and when insects occur. Surveys have shown that most empty granaries are infested with low numbers of insects and mites. Animal feeds, trucks, and farm machinery are other sources of insect infestations. Some insects can fly as well as walk, which increases their ability to infest stored crops. Take the following measures before the crop is harvested to prevent infestation and spoilage during storage.

- Keep dockage to a minimum by controlling weeds in the growing crop; insects do not multiply extensively in stored crops that contain low amounts of dockage.
- Clean granaries preferably with a vacuum cleaner; burn or bury the sweepings.
- Repair and weatherproof granaries before filling with grains or oilseeds.
- Do not allow waste grain or feed to accumulate either inside or outside storage structures.
- Eliminate grass and weeds around granaries.
- Do not store crops in bins next to animal feeds that are likely to be infested.
- Spray the walls and floor of empty granaries with an approved insecticide about 1 week before crop storage.
- Examine grains and oilseeds that have been binned tough every 2 weeks: (1) push your hand into the surface at various points to feel for warmth or crusts; and (2) insert a metal rod into the bulk to test for heating at various depths; after at least 15 min, preferably 60 min, withdraw the metal rod and test for warmth on the wrist or palm of the hand.
- Store new grains or oilseeds only in clean, empty bins; bins that contain old grain might be infested.
- Try and sell for feed your high-moisture grains first.
- Remember that cool, dry grains or oilseeds seldom spoil.

MITES

Mite infestations can be prevented and or controlled by the following procedures:

- Keep the moisture content of cereal grain below 12% and that of canola below 8%.
- Transfer the grain or oilseed to an empty bin to break up moist pockets, or chill cereal grain of 15 - 16% moisture content with forced air movement during winter.

STORAGE FUNGI

To prevent storage mold activity, give particular attention to the moisture and temperature of the bulk at binning, especially in unaerated bins. Monitor bulk temperatures at 1- or 2-week intervals. Dry high-moisture and cool high-temperature grains or oilseeds by aeration. Use spreaders to disperse throughout the bulk: small, broken, and shrivelled kernels; weed seeds; chaff; and straw. Remember that the increased bulk density in the bin much reduces the rate of forced airflow through the bulk. Remove windblown snow before it melts and provides a focus for mold development. To control heating or spoilage in progress, move the bulk to cool it and break up high-moisture pockets. Alternatively, aerate or dry the bulk. Have someone with you when climbing into or onto granaries. Wear a protective mask to prevent inhalation of mold spores either when breaking up a moldy crust within a bin or when handling spoiled grains or oilseeds.

Why Are Insects Not Tolerated?

The Canadian climate is far from ideal for the survival of stored-product insects. If it were not for large warm grain bulks, insects would find it very difficult to survive the cold winters. In this respect, therefore, insects are not as serious a threat in Canada as they are in many other countries. At the same time, Canada is one of the few countries which has a zero-tolerance policy towards insects. This means that grain cannot be sold or delivered to an elevator if 1 live grain-feeding insect is found. If a live grain-feeding insect is found, the grain must first be fumigated.

Canada has implemented and enforced this law largely because it gives Canadian grain an advantage on world commodity markets. Canadian grain is renown world-wide for its high quality and because it is usually free of insects and insecticide residues. Export customers expect that Canadian grain will always be insect-free. It would only take 1 or 2 infested shipments to tarnish the reputation of Canadian grain. We would then lose our special status on world markets. To prevent this from happening, we must all work together to ensure that insects do not enter the Canadian grain system.

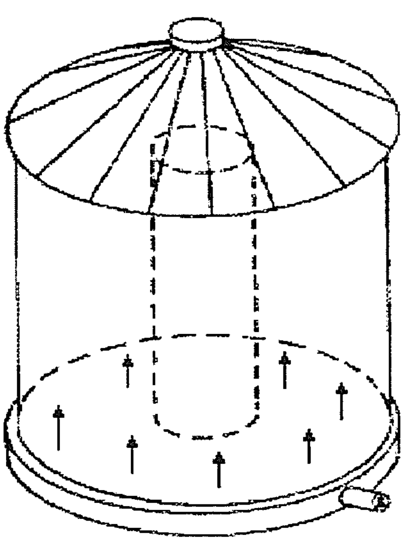
SPOUTLINES

You may find that small dockage particles such as weed seeds and broken parts of kernels are in your grain. When grain bins are loaded by dropping the grain from the top centre of the grain bin, these small particles or fines tend to accumulate in the centre of the bin, forming a core from top to bottom. Because the fines are smaller than whole grain kernels, they pack together more closely, forming a region of high bulk density. The presence of a spoutline of small dockage particles can be a contributing factor to the development of both fungal and insect infestations.

Fungal Infestation: Where grain goes into storage above its safe storage limit, fungi will usually develop at some time in the future. A common technique used to correct this problem is near-ambient drying. A spoutline, however, decreases the effectiveness of near-ambient drying. The drying air will flow around the densely packed core through the more loosely packed clean grain. As a result, the core may not dry properly, leaving a region that is ideal for the development of fungi.

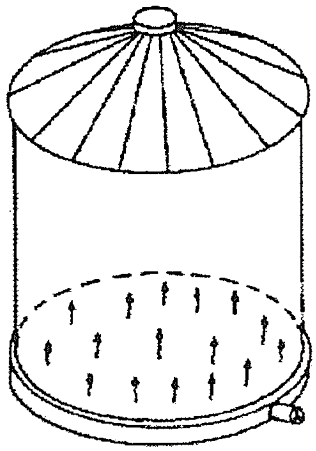
Insect Infestation: Even when grain goes into storage dry, spoutlines can still contribute to problems. Spoutlines are attractive to several species of stored-product insects for two reasons: 1) small weed seeds and broken kernels are a good food source and 2) small weed seeds usually have elevated moisture contents which are good for the development of insects and mites. As a result, insects and mites may populate the spoutlines. As the population increases, heat is produced and the temperature will begin to rise. It is difficult to reduce the temperature by aeration because the cooling air has a hard time penetrating the densely packed core. As a result, insect populations can flourish.

How do you solve the problem?

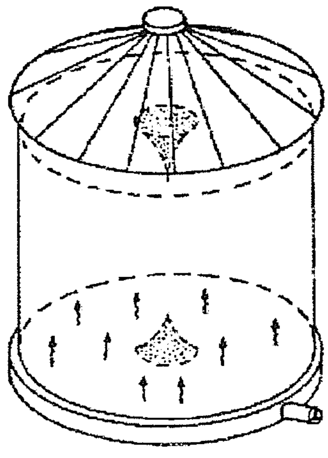


Core of Foreign Material

One way to prevent this core of fine foreign material from forming is to use a spreader when filling the bin. In theory, the spreader will distribute the fines throughout the grain bulk.



Aeration System Using
Perforated Floor



Storage Location Where
Spoilage Generally Occurs
With Inadequate Aeration
When Using Perforated Floor

In cases where a spreader was not used, there are ways to deal with the existing problem. The first action should be to determine whether a spoutline is a problem in your bin. This can be done by probing the centre of the bin. If it is much more difficult to push the probe into the grain in the centre of the bin, it is likely that a core of fines is present. This may be confirmed by examining the contents of the sample removed.

The best way to eliminate a spoutline problem is to remove the grain from the storage bin and clean it.
An alternative method is to remove the centre material by unloading the bin with a centre draw unloading auger. The core material could be handled in several ways: 1) fed to livestock, 2) sold, or 3) uniformly spread over the top surface of the grain after levelling.

* A good method of determining when the central core has been removed is to place tissue paper on the grain surface and observe when it passes through the unloading auger.

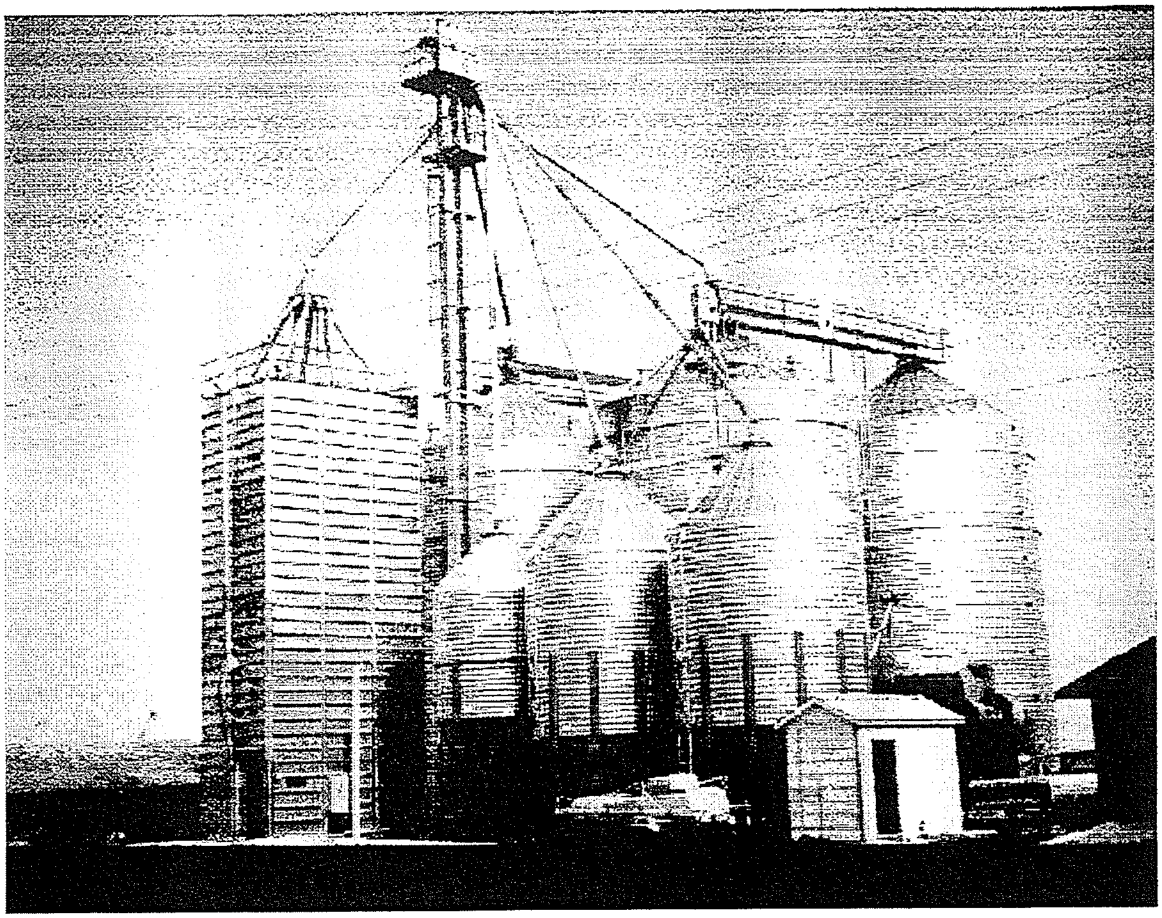
WARNING! Core removal may involve some risk to workers so be extremely careful that no one is caught inside the bin when it is being unloaded.

APPENDIX E

User's Manual Written for GSIS

GRAIN STORAGE INFORMATION SYSTEM

FOR FARMERS AND GRAIN STORAGE MANAGERS



Agriculture & Agri-Food Canada, Winnipeg Research Centre
Department of Biosystems Engineering, University of Manitoba

Programmer: Danny Mann

GSIS Version 1.0
March 1995

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GRAIN STORAGE INFORMATION SYSTEM

The **Grain Storage Information System** (GSIS) is a computer program (i.e. an expert system) developed specifically for farmers and grain storage managers in western Canada. The program has been designed to help farmers make wise grain management decisions by explaining grain management principles and techniques rather than simply dictating instructions.

1. LIMITATIONS OF THE PROGRAM

This program is designed primarily to be a source of information for grain storage managers. The statements given should be interpreted as suggestions rather than instructions. *RESPONSIBILITY RESTS WITH THE USER.*

2. PROGRAM OVERVIEW

The program works as follows:

1. You must provide the initial grain conditions.
2. The grain storage life is calculated. The storage life of the grain is based on a mathematical equation developed by researchers. The safe storage life is described as the period of time before germination drops 5% or visible mould appears. The storage life is based on the grain temperature and moisture content.
3. The storage life is compared with the intended storage period.
4. If the storage life is less than the intended storage period, either the grain moisture content or grain temperature should be altered.

   If the grain condition is tough, appropriate drying actions will be explored.
   Note: A near-ambient drying simulation program is available.

   If the grain condition is dry, appropriate cooling actions will be explored.
   Note: An aeration simulation program is available.

5. If the storage life is greater than the intended storage period, the grain should be safe from fungal infestation, however, insects must still be considered.

   If insects are currently present, possible control measures will be indicated.
   Note: An insect identification module is available.

   Even if insects are not currently present, the risk of a future insect infestation always remains. A risk factor will be presented.

6. Changes can be made to the initial grain conditions so that the user can consider the possible effects of following several storage options.
7. Information screens are available to you throughout the consultation.

3. SYSTEM REQUIREMENTS

This program requires Microsoft Windows version 3.1, and at least a 386 cpu with 7Mb of disk space and 4MB of RAM. A math coprocessor is required to run the simulation models.

4. INSTALLATION INSTRUCTIONS

GSIS is installed from DOS. Insert Disk #1 GSIS into either drive A or B. From the DOS prompt, type a:ainstall (or b:binstall) depending on which drive you are using. Follow the instructions on the screen. You will be asked to insert the second and third disks at the appropriate time.

5. SETTING UP A WINDOWS ICON

1. Highlight the LEVEL5 AGENT icon.
2. Select the 'File' menu from Program Manager.
3. Select the 'New' menu item. Choose 'Program Item'. Click on 'OK'.
4. Type the following for 'Description': **GSIS 1.0**
5. Type the following for 'Command Line': **C:\L5AGENT\L5RO.EXE C:\GSIS\GSIS10.APP**
6. Click 'OK'.

6. START-UP INSTRUCTIONS (if a Windows icon was set up)

You can start GSIS simply by double clicking the icon labelled **GSIS 1.0** found in the LEVEL5 AGENT Group.

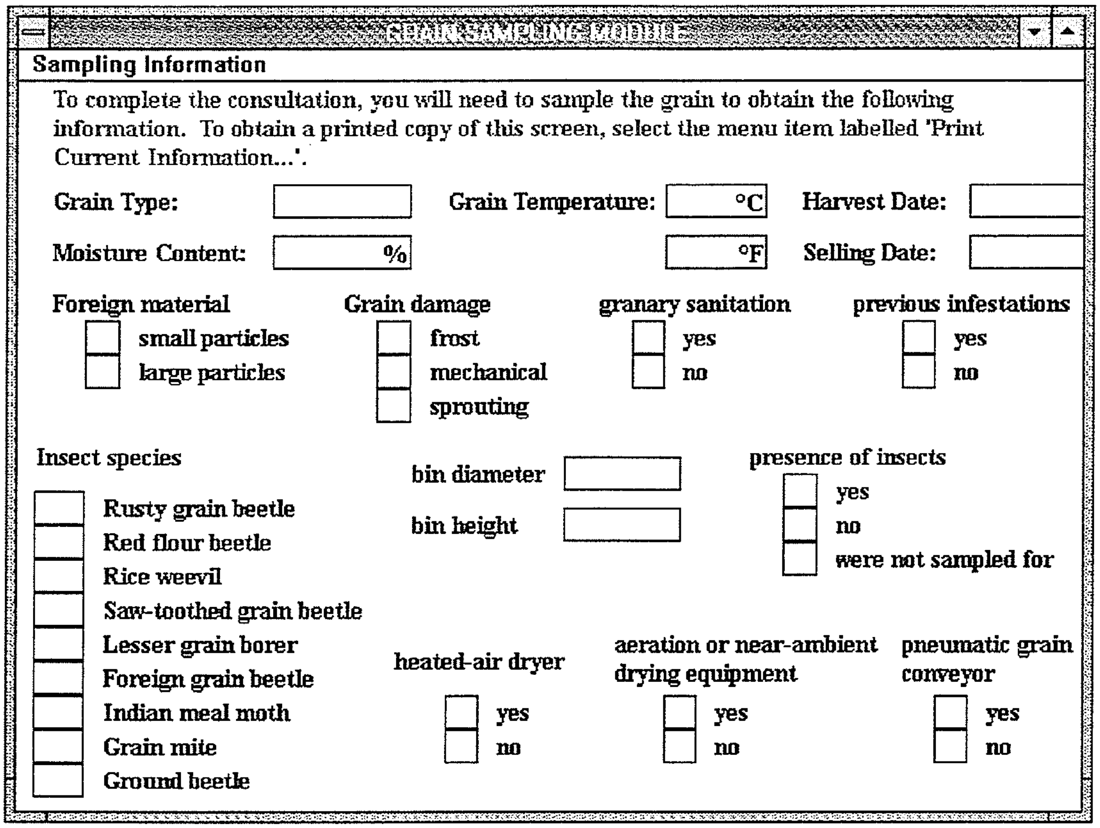
7. START-UP INSTRUCTIONS (if no Windows icon was set up)

If you did not set up an icon for GSIS, follow the start-up instructions given below.

1. Start Windows.
2. Open the LEVEL5 AGENT file group by double clicking your mouse.
3. Double click the icon labelled "LEVEL5 AGENT".
4. To start GSIS, you must select the "gsis" directory by double clicking on it.
5. Select the file "gsis10.app" and click "ok". Sit back and wait for the program to start.

8. DATA REQUIREMENTS FOR GSIS

During the course of a consultation, you will be asked to provide the information illustrated in the following figure. Answer carefully, because the accuracy of suggestions depends on the accuracy of your responses.



9. PROGRAM DESCRIPTION

This program relies on the mouse for selecting appropriate answers and advancing from screen to screen. You can advance from screen to screen either by selecting buttons on the current screen or by selecting appropriate choices from the menus at the top of the screen.

Once the program has started, you will see the title display with the names and telephone numbers of the contact people. Continue by selecting the button labelled 'CONTINUE...'. After viewing the program limitations, the program overview will be presented. You can use the arrow buttons on the right-hand side of the screen to scroll up or down. This allows you to read the entire contents of the screen. At the bottom of the screen are instructions for continuing. Select either 'New...' or 'Retrieve...' from the menu entitled 'Consultation'.

9.1 Initial Parameters

Before the program can give advice, you must provide information on the initial conditions of the grain and storage facility. Answer all questions carefully, then proceed to the next screen. For some of the questions, you are allowed to select an answer of 'unknown'. A default value will then be assigned to that parameter and an explanation will be displayed on the screen.

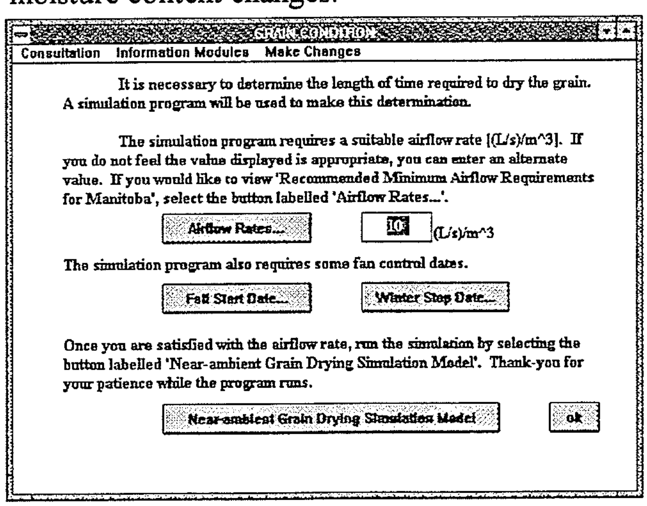
The harvest date and selling date are input using the calendar functions. The currently selected date is shown in the middle of the bottom of the calendar. The month and year can be changed using the arrows in the bottom corners. Change the day by selecting another number with the mouse. (Warning messages will be given if you select inappropriate dates.)

You will have to use the keyboard to enter the bin dimensions. Enter the dimensions in the current units (displayed near the top of the screen).

Once you have answered all of the questions, a summary screen will be displayed. To get an explanation of each parameter, select the button labelled 'explain'. If you want to make changes, select the appropriate choice from the 'Make Changes' menu at the top of the screen. When you have made all the necessary changes, select the 'Finished Making Changes...' menu item under the 'Make Changes' menu. This takes you back to the summary screen. When satisfied with your choices, select the button labelled 'ok'.

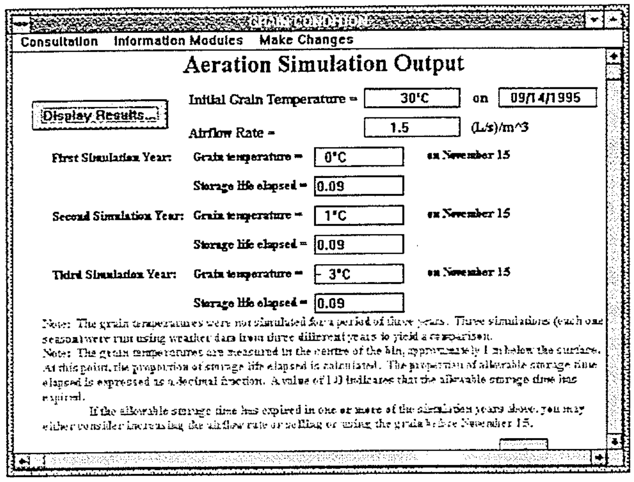
9.2 Storage Life Calculation

Earlier you specified temperature and moisture content ranges. If you know exact values, enter them now. Select the 'Calculate Storage Life...' button. For an explanation, choose 'Explain...', otherwise, select 'Continue'. Based on answers given earlier, the program will take you to one of three possible screens.
Note: The calculated storage life assumes constant conditions. The storage life will not be accurate if the grain temperature or moisture content changes.

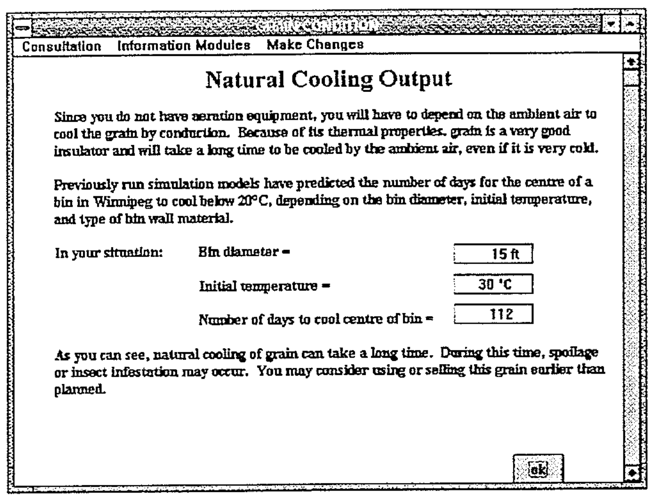


Possibility One: If you are unsure of the airflow rate, you can view the Recommended Minimum Airflow Requirements for Manitoba by selecting the button labelled 'Airflow Rates...'. Fan control dates can also be input by selecting the appropriate buttons. Once this information is input, select the button labelled 'Near-ambient Grain Drying Simulation Model' to run the simulation. (The simulation program takes a few minutes to run so do not be concerned if it appears as though nothing is happening. You do not need to press the button more than once.) When the simulation stops running, select the button labelled 'ok' to see the simulation results.

Possibility Two: When the simulation stops running, select the button labelled 'Display Results...' to view the results. The results displayed on the screen illustrate the effectiveness of aeration under three different sets of fall weather conditions. **Aeration is not simulated for a storage period of three years.**



Possibility Three: When you do not have aeration equipment and the grain needs to be cooled, you must rely on unventilated cooling. During the cold winter months, the bin wall and grain will be cooled by conduction as a result of the cold winter air. This type of cooling takes place in all bins, even if no aeration floor is present.



9.3 Insects

If you specified that insects were present earlier in the consultation, you will now be asked to indicate the species that is present. If you are unsure, select the button labelled 'Insect Identification' to get help. Once you have identified the type of insect present, you will be presented with a list of possible insect control measures. The options selected with a checkmark are your most likely options. You can get an explanation of any option by selecting the appropriate 'Explain...' button.

Even when insects are not currently present, the potential for a future insect infestation always exists. Cooling the grain is usually the best method to prevent an infestation from starting or increasing.

9.4 Conclusions

The consultation is summarized on these final screens. Please interpret these statements as suggestions rather than instructions.

10. INFORMATION MODULES

Although the information modules are not part of the basic program flow, they are a very important component of GSIS. Only a certain amount of information can be contained in the main program, otherwise it would get too cluttered. The extra information is relevant to grain storage and is included in the program.

You can view these information screens by selecting your choice from the menu labelled 'Information Modules'. Follow instructions on the screens or make a selection from the menu at the top of the screen. If you select the menu item entitled 'Print Current Information...', the current screen will be printed to the active printer (if available).

11. SIMULATION MODEL DESCRIPTION (GRAIN89)

GRAIN89 can be accessed through the INFORMATION MODULES.

1. Select 'Information Module...'.
2. Select 'Fan Sizing (GRAIN89)' under 'General Information'.

GRAIN89 was developed previous to GSIS. Only a brief description of the program is included in this manual. The description is taken from Huminicki et al. (1986). If you would like more information about GRAIN89, contact Dr. Bill Muir [(204) 474-9660] at the Department of Biosystems Engineering, University of Manitoba. A complete user's manual has been written for GRAIN89.

Huminicki, D.N., C.I. Kitson, O.H. Friesen, and W.E. Muir. 1986. Computerized design of ventilation systems for stored grain. Paper NCR-86-604. Am. Soc. Agric. Eng., St. Joseph, MI. 9 p.

The design package is controlled from the Main Menu which accesses the programs. The programs start with a screen that contains all the variables that the user can modify along with a prompt asking which variable should be changed. If a variable is to be changed, the corresponding letter is entered and an appropriate request for a new value is made by the program. When all changes have been entered the user can run the program by selecting Z, Run. All input data remains at the top of the screen while program output is displayed at the bottom of the screen. The user then has the choice of printing the input/output information, running the program again or returning to the Main Menu to select another program. All common input variables are transferred from program to program and need to be modified only once.

The Main Menu of GRAIN89 lists all of the programs available in the package. A brief description of each of the programs follows.

1. Airflow Rate Recommendations

This program displays tables of recommended minimum airflow rate requirements for unheated air drying in Manitoba. The required airflow rate depends on harvest date, harvest moisture content, type of grain and weather conditions. The table contains airflow rates that are expected to dry the grain by November 15th 100, 97, 94, or 90 percent of the time without excessive spoilage. It also contains airflow rates that would be sufficient to dry the grain by June 1 of the following year without excessive spoilage. The "% of time dried in fall" indicates the likelihood that the airflow rates would complete the drying by November 15th without excessive spoilage.

2. Fan Selection

Fan Selection searches the database and generates a list of fans that will deliver more than the specified airflow rate for a given combination of crop, bin, and air distribution system. Fans are sorted according to lowest horsepower and then according to highest airflow within each horsepower group.

3. Fan/System Performance

Fan/System Performance generates a table of airflow rates for several depths of grain that would be produced by a specified fan for the given combination of crop and bin.

4. 5. & 6. Drying Simulations

Drying simulation programs for wheat(4.), barley(5.), and canola(6.) are available in the package. They can be run using a specified airflow rate or they can be run using a specific fan. When a specific fan is used, the Fan/System Performance program runs automatically. Fan temperature rise and power consumption data are returned to the simulation from this program. Power consumption is used to calculate fan operating cost. Fan temperature rise is an important input to the drying simulation program. The simulation program is very sensitive to fan temperature rise therefore it is shown on the input screen to permit valid comparisons between systems. The output from Fan/System Performance is appended to the simulation output form after the simulation has run.

Harvest dates between August 15th and November 14th and initial and final moisture contents can be selected. Drying completion is determined by the moisture content in the top layer or by the average moisture content in the bin. Seed grain is considered to have spoiled when there has been a predicted germination drop of 10%. Commercial grain spoilage is based on visible molds and fatty acid content. Grain price is used to determine the overdrying cost. Additional inputs include supplemental heat and humidistat settings to control the fan or heater or both.

Program output includes the number of days to reach the desired final moisture content for the worst, second worst, and third worst years. The number of days is also shown for an average year which uses a simple average of 33 years of weather data. If the grain spoils before drying is completed, the line "Days to reach 14.5%" shows the number of days until excessive deterioration occurs and the number is tagged with asterisks. If the grain is not dry or spoiled by November 15th, the number of days is tagged with minus signs.

12. MENU DESCRIPTION FOR GSIS

Main Menu: **Consultation**

menu item: **New...**

Select this menu item to start a new consultation.

menu item: **Retrieve...**

Select this menu item to retrieve a consultation saved previously.

menu item: **Save...**

Select this menu item to save the current consultation information.

menu item: **Restart...**

Select this menu item if you want to discard the current consultation information and start over from the beginning.

menu item: **Quit...**

Select this menu item when you want to quit the consultation. Remember to save before you quit!

Main Menu: **Information Modules**

menu item: **Insect Information...**

Select this menu item to view information about different insect species.

menu item: **Grain Sampling Information...**

Select this menu item to view information about suggested grain sampling techniques. This information is useful when looking for insects in grain.

menu item: **Sanitation Information...**

Select this menu item to view information about recommended sanitation techniques.

menu item: **General Information...**

Select this menu item to view general grain storage information.

Main Menu: **Make Changes**

Use this menu to make changes to the initial grain parameters. Select the appropriate menu item to make changes to individual parameters. Select the 'Finished Making Changes...' menu item to return to the summary screen.

Main Menu: **Pick Insect Species**

Use this menu to select different insect species to view. The current screen can be printed. 'Return to Main Program' takes you back to the screen in the main program from which you came.

Main Menu: **Sampling Information**
Use this menu to view information relevant to sampling for insects.

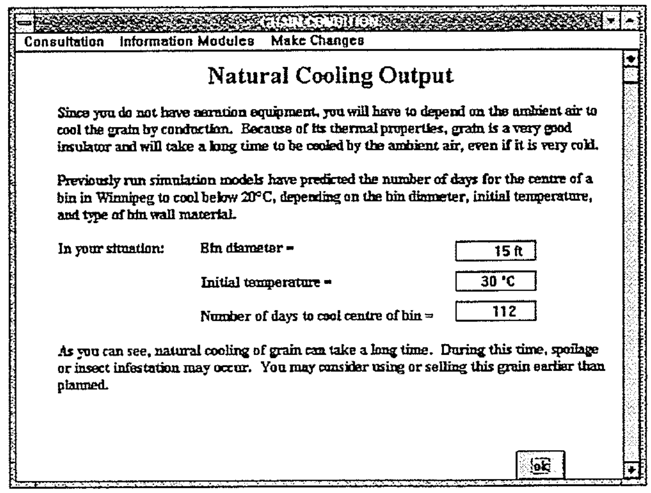
Main Menu: **Sanitation Information...**
Use this menu to view information on recommended sanitation techniques.

13. GSIS SAMPLE PROBLEM (Answer the questions as shown below.)

1. Temperature units	answer:	**°C**
2. Distance units	answer:	**feet**
3. Volume units	answer:	**bushels**
4. Grain type	answer:	**wheat**
5. Moisture content	answer:	**dry**
6. Grain temperature	answer:	**hot**
7. Frost damaged kernels	answer:	**no**
8. Mechanical breakage	answer:	**significant levels**
9. Sprouting or Excessive Weathering	answer:	**no**
10. Small particles	answer:	**none present**
11. Large particles	answer:	**significant numbers present**
12. Granary sanitation	answer:	**yes**
13. Presence of insects	answer:	**were present**
14. Previous infestations	answer:	**yes**
15. Harvest date	answer:	**September 5, 1995**
16. End of storage date	answer:	**December 31, 1995**
17. Bin height	answer:	**15**
18. Bin diameter	answer:	**15**
19. Is the storage bin airtight?	answer:	**no**
20. Aeration equipment?	answer:	**no**
21. Grain dryer?	answer:	**yes**
22. Pneumatic grain conveyor?	answer:	**yes**

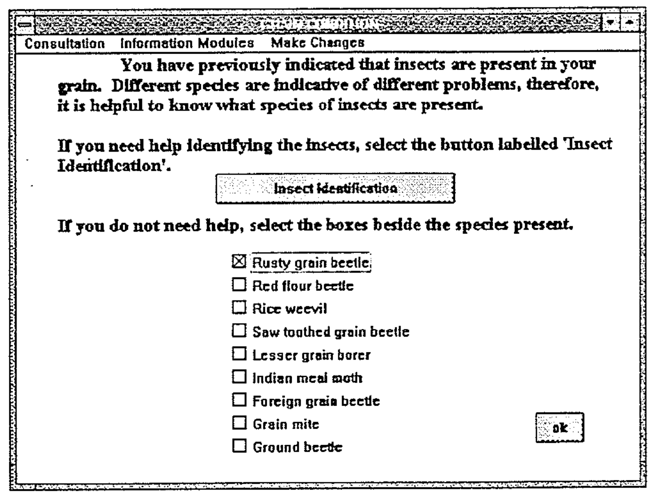
When you get to the Storage Life Display, leave the values for moisture content and grain temperature as shown. The calculated storage life should be 77 days.

When you select 'ok', the following screen should be displayed.

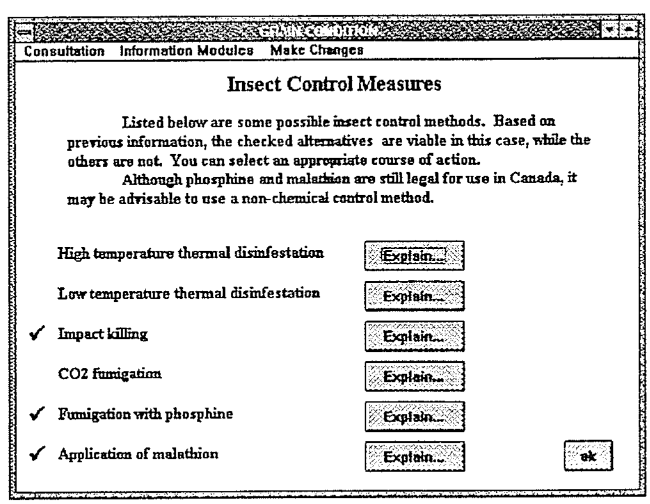


When you select 'ok', you should see the following screen.

Select the Rusty grain beetle.



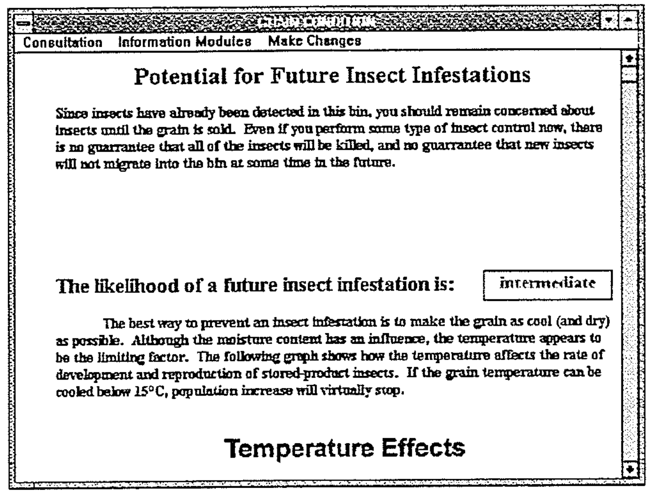
Choose 'ok'. You should see a screen telling you that you have a grain-feeding insect problem which should be dealt with soon. You should then see the screen shown below.

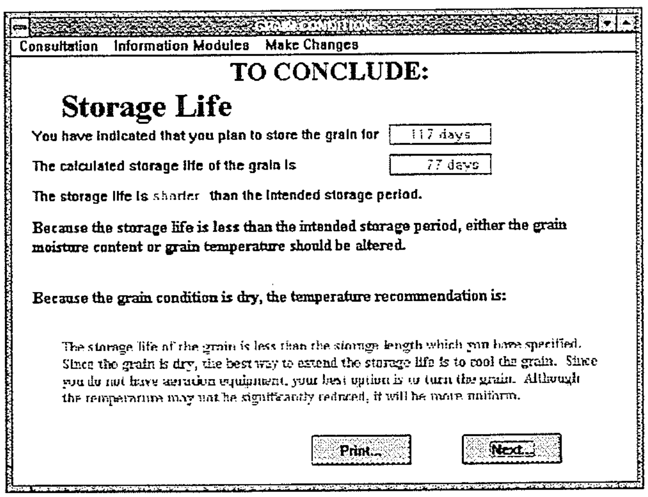


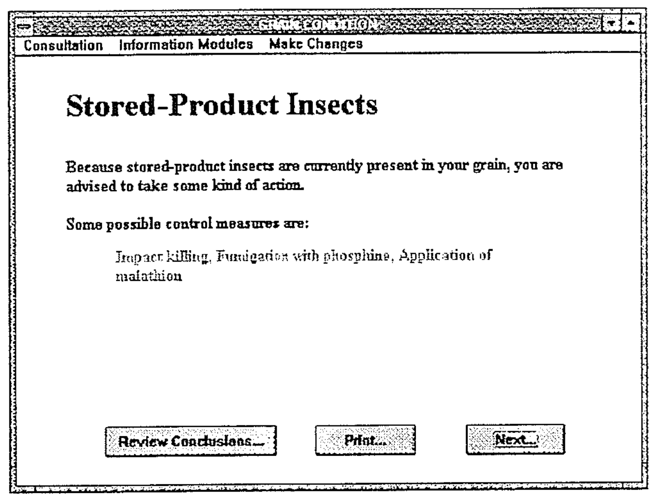
When you have finished exploring the various options, select 'ok' and you should see the screen shown below.

Read this screen carefully. It tells you that the best way to prevent an insect infestation is to cool the grain. When you proceed, you will see the Conclusion displays, as shown below.

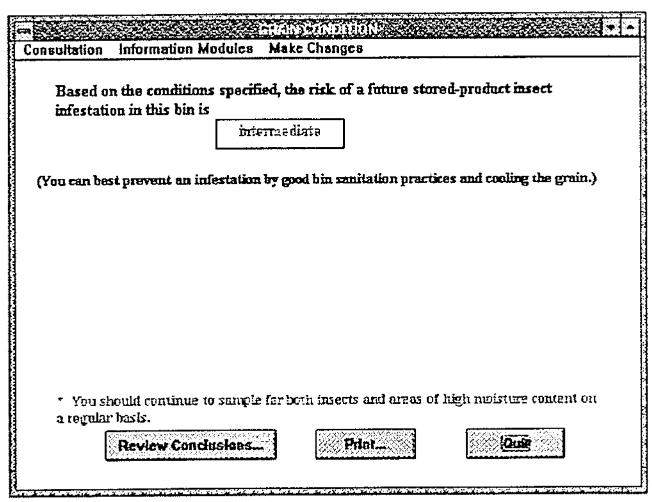
Note: You will have to scroll down using the arrows at the right-hand side to see the entire screen and reach the 'OK' button.







If you would like to try other options, select the menu labelled 'Make Changes' and make the desired changes.



14. CONTACT PEOPLE

N.D.G. White, Research Scientist
Agriculture & Agri-Food Canada, Winnipeg Research Centre
195 Dafoe Rd.
Winnipeg, MB
R3T 2M9
Tel (204) 983-1452
Fax (204) 983-4604

D.S. Jayas, P.Eng., Professor
Department of Biosystems Engineering
438 Engineering Bldg.
Winnipeg, MB
R3T 5V6
Tel (204) 474-6292
Fax (204) 275-0233

W.E. Muir, P.Eng., Professor
Department of Biosystems Engineering
438 Engineering Bldg.
Winnipeg, MB
R3T 5V6
Tel (204) 474-9660
Fax (204) 275-0233

15. ACKNOWLEDGEMENTS

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GSIS version 1.0 was developed using LEVEL5 OBJECT for Windows by Information Builders, Inc.

GSIS User Survey

Name: ______________________________
Address: ______________________________
Phone Number: ______________________________
Occupation: ______________________________

I would be grateful if you could take some time to answer the following questions. Your comments and suggestions will be considered when making improvements to the program.

Thank-you,
Danny Mann (Program Developer)

1. How would you describe the ease of use of the program?
   __ easy
   __ satisfactory
   __ very difficult

   Comments: ______________________________

2. Did you have any specific problems or difficulties during your consultation with the computer? If so, please explain.

3. Did you learn anything about grain storage during your consultation?
   __ nothing new
   __ very little
   __ a few things
   __ a lot

   Comments: ______________________________

4. Did the consultation raise questions which were left unanswered?
__ yes
__ no

If yes, please write your unanswered questions below.

____
____
____
____
____

5. How would you judge the potential of this program for teaching the fundamentals of grain storage to university students and/or farmers?
__ poor
__ average
__ good

Comments:_______________________________________
____
____
____
____

6. How would you judge the potential of this program as a practical tool for a farmer or grain storage manager?
__ poor
__ average
__ good

Comments:_______________________________________
____
____
____

7. Were the suggestions and recommendations reasonable based on your experience?
__ none of them were
__ a few were
__ most of them were

Comments: (which do you not agree with?) ________________
____
____
____

8. What is your overall impression of the program?

__ poor
__ needs a few improvements
__ good (with minor changes)

Comments:____
____
____
____
____

9. Do you have any suggestions? Is anything missing?

____
____
____
____
____

10. As a potential future user, what do you feel is the best way to gain access to such a program?

__ purchase a copy for your own computer
__ have access to the program through a grain elevator agent
__ have access to the program through an agricultural representative
__ other

Comments:____
____
____
____
____

Thank-you for your time. We are hopeful that this computer program will be a useful tool for farmers and grain storage managers. Your input will help us to achieve that goal!

RETURN ADDRESS:

Department of Biosystems Engineering
438 Engineering Bldg.
Winnipeg, MB
R3T 5V6

ATTENTION: D. MANN

APPENDIX G

Sample Problem using GSIS given to a class of Agricultural Engineering Students

Grain Storage Information System

The **Grain Storage Information System (GSIS)** is an expert system for grain storage management under western Canadian conditions. One of the main priorities of this system is that it be able to assist grain storage managers make decisions which will result in safe storage of the grain.

You have recently been hired by a private consulting company who has undertaken the task of marketing and distributing this system to farmers and/or grain storage managers. An interested farmer has contacted your company with a set of grain conditions. He (she) is curious to see what kind of a recommendation will be given by **GSIS**. Your boss has given you the task of writing a response to this interested farmer.

Your report should be based on information contained within **GSIS** (including the information screens). It is likely that you will have to make some assumptions because the farmer has sent you only the following information:

grain type:	*wheat*
harvest date:	*September 3 (hot, sunny day)*
intended selling date:	*January 1*
grain moisture content:	*14.5%*
bin size:	*20 feet in diameter by 20 feet tall (with aeration floor)*
available equipment:	*pneumatic grain conveyor* *aeration fan (only if absolutely necessary)*

There were bugs in my grain last year, but I don't know what kind. I haven't sampled yet this year.

Note: Remember that you are trying to convince this farmer to buy **GSIS**.