ECOSYSTEM MODELLING TO PROVIDE EARLY WARNING OF PEST INFESTATION OF STORED GRAIN

Hitoshi KAWAMOTO, Ranendra N. SINHA and [1]William E. MUIR

Agriculture Canada Research Station
195 Dafoe Road, Winnipeg, Manitoba, Canada R3T 2M9
and
[1]Agricultural Engineering Dept., University of Manitoba
Winnipeg, Manitoba, Canada R3T 2N2

Abstract

Construction of composite stored-grain ecosystem models that will predict pest infestation and its dynamics in stored grain in a granary and in an agricultural region of Canada are being attempted. The granary model consists of a physical model to predict temperature and moisture content of a grain bulk, biological models to predict the dynamics of pest populations, and a bio-energetic model to predict the interaction between pests and stored grain; this requires the input of initial conditions, expected meteorological changes and management actions on stored grain. The granary model would help farmers and granary operators to properly manage stored grain. A regional model would use the granary model with regional estimation of initial conditions of storage using meteorological and other databases. The regional model may help local extension personnel warn farmers of potential infestations and to recommend intensive monitoring of their grain and proper management actions.

We have been developing the physical model, population models of the rusty grain beetle, *Cryptolestes ferrugineus*, and the grain mite, *Acarus siro*, a simple model of fungal deterioration, and a bioenergetic model of *C. ferrugineus* for the granary model. A method has been developed for the regional model to estimate the temperature and moisture content of freshly harvested grain from meteorological database.

INTRODUCTION

Stored grain ecosystem consists of and is influenced by many factors and processes. These factors and processes distribute in a wide spectrum in time and space. For example, metabolic process in cells of grains, micro-organisms and other pests can respond immediately to environmental changes. The heat exchange between a grain kernel and the surrounding air takes less than a hour, while the grain temperature at the center of unventilated granary changes slowly because of the insulation by the surrounding grain bulk (Yaciuk *et al.*, 1975). The moisture exchange takes longer time than the heat exchange between grain and ventilated air (Sanderson *et al.*, 1988a and b). An insect pest population in a bin increases in temporal scale of weeks to months. Grain production and consumption and economic factors affects storage duration and quality requirements of the shipped grain, having the spatial scale of nation to world and temporal scale of months to years.

The research of stored grain ecosystem, therefore, should take into account these various factors and processes which have different temporal and spatial scales. Each research on a single factor at one temporal scale and one spatial scale is essential to understanding the stored grain ecosystem. And only when these factors over the spectrum of time and space are integrated, the stored grain ecosystem is truly understood.

The advantages in the effort in modelling of the stored grain ecosystem are to integrate the current knowledge spread over several research fields and to point out the gaps in the research which is essential for understanding the stored grain ecosystem. In the first half of this paper, granary ecosystem modelling and an expert system for the management of stored grain are discussed. In the second half, a regional modelling to estimate the temperature and moisture content of freshly harvested grain is presented.

GRANARY MODEL AND EXPERT SYSTEM

An expert system for the stored grain management is a computer based consultation program which integrates various data and knowledge and help the user solve problems in stored grain management (Fig. 1). A user should provide specific information such as type of grain, grain temperature and moisture content, size and type of granary, storage amount. In the expert system, these specific data are combined with weather database and

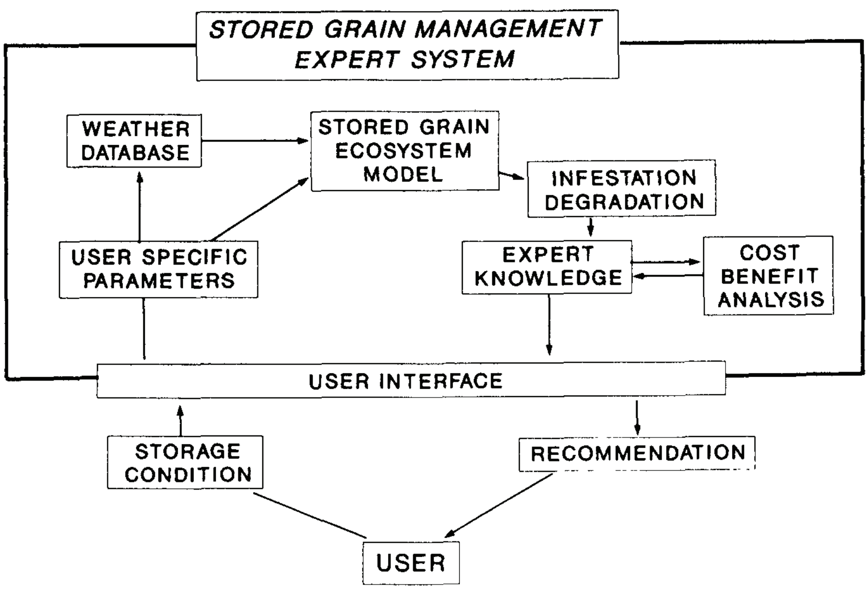

Figure 1. Diagram of expert system for stored grain management.

fed into a granary ecosystem model. Then the probability of pest infestation and degradation are estimated. Using expert knowledge of the management practice stored in the computer, suitable several actions will be suggested to the user.

Granary ecosystem model

The central part of the expert system is a granary ecosystem model, which simulates the physical and biological changes in the granary ecosystem during the storage (Fig. 2). In the annual cycle of grain storage on farm, freshly harvested grain is filled into farm granaries in late summer and autumn. Occasionally, new grain is mixed with old grain carried over from previous crop year, increasing the risk of pest infestation. The amount of carry over is determined by world-wide economic factor and farmer's financial factor. Weather factor affects production amount, timing of harvest, temperature and moisture content of freshly harvested grain, gradual change of unventilated stored grain temperature, efficacy of aeration, and consequently metabolic activity and population dynamics of grain pests inside the granary. Weather factor also affects the population dynamics of stored grain pests outside the granary, their long- and short-range movements,

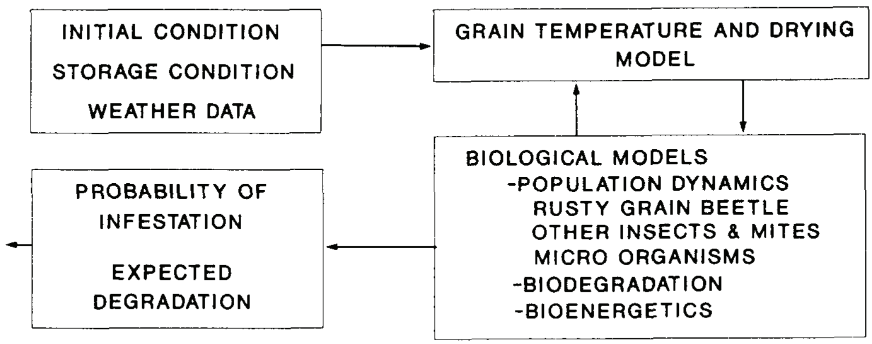

Figure 2. Diagram of granary ecosystem model.

and therefore, their rates of immigration into granary. The granary ecosystem model simulates physical and biological change in the stored grain for a given period in the annual cycle. The expert system organizes the data provided by the user and stored in the computer, and call the granary ecosystem model.

The granary ecosystem model receives initial grain temperature and moisture content, date the granary is filled, the period of simulation, storage amount, presence or absence of aeration equipments, sanitation prior to storage, updated and cumulated weather data to start simulations and estimate the change of grain temperature and moisture content and the probability of pest infestation and spoilage.

The granary ecosystem model consists of physical and biological models. The physical model simulates the change of temperature and moisture content of grain stored in a given type of granary with or without aeration for a set of meteorological data. The biological models simulate the population dynamics of grain pests, the biodegradation of grain, the production of heat, moisture, carbon dioxide, mycotoxin, and other metabolites of the grain pests. We have been developing the physical models for grain temperature and moisture content with and without aeration (Metzger and Muir, 1983), and biological models for population dynamics of the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera, Cucujidae) (Kawamoto *et al.*, 1989), the grain mite, *Acarus siro* (Acari: Acaridae) (Kawamoto *et al.*, unpublished), and bioenergetics of the rusty grain beetle (Campbell and Sinha, 1990).

As an example of a biological model, the basic structure of simulation model is briefly mentioned here for population dynamics of the rusty grain beetle (Kawamoto *et al.*, 1989). The daily grain temperature and relative humidity of inter-granular air which is in equilibrium with grain moisture content are calculated by a physical model for grain temperature and moisture content. Using these temperatures and relative humidities, the biological model calculates the development rate, mortality and oviposition rate to estimate the age structure and overall population growth. In a hypothetical simulation, the initial density was set to approximately one pair of young adult per kilo gram of wheat, and three temperatures of 20, 25 and 30 °C and three relative humidities of 50, 70 and 90% were used. Among these conditions, 30 °C and 90% relative humidity had the highest initial growth rate. After 18 weeks, the population reached a peak density. The model is capable to simulate population dynamics under changing temperature and relative humidity as well as the constant environments as shown in this example.

Expert system for granary management

One of the advantage in using expert system comes from its friendly user interface to obtain information necessary to carry out simulations (Fig. 1). To run the above mentioned granary ecosystem model, the user must provide appropriate data to the computer. It is often time-consuming process to modify a complex simulation model without a friendly user interface. An expert system enables for unexperienced users to input their specific information and run the computer program. The expert system asks the user several questions about user specific storage condition. Unlike non-intelligent computer programs, imprecise answers are allowed to use. However, the user should give the information as precisely as possible, because the uncertainty of the results increases depending on the uncertainty of the information provided by the user.

Based on the information given by a user, the expert system organizes the data in an appropriate way for the granary ecosystem model to simulate the dynamics of the stored grain ecosystem (Fig. 1). For example, a simulation using an average climate in the past provides an estimation of the expected change in stored grain ecosystem from the initial condition. The variation of the change in the ecosystem is obtained by repeated simulations using hypothetical weather data randomly chosen from weather data in the past. The expert system selects the necessary weather data based on the granary location given by a user.

The expert system provides the summary of simulation of granary ecosystem. When a risk of spoilage is expected, the expert system suggests several actions such as the use of aeration system, turning over the grain, fumigation, change of end use, with estimated costs and resultant storage condition. Based on the summary of simulation and suggested actions, the user can decide which action to take.

REGIONAL MODEL

The role of regional model in stored grain ecosystem is to estimate the potential risk of pest infestation in an area. Based on the estimation by the regional model, an advisory or warning can be issued to the farmers and managers of grain elevators in the area, recommending close investigation of stored grain and taking necessary actions. The regional model may also help the analysis of pest outbreaks in the past and factors leading to the outbreaks.

The regional simulation model consists of various databases and sub models. To carry out regional simulation, the sub models require current and cumulated data of weather, harvest date and amount, carried over amount, etc. The sub models are granary ecosystem model and regional harvest condition model, which is being developed (Kawamoto *et al.*, unpublished).

Various sources of data support the modelling of regional stored grain ecosystem for Canadian prairie (Fig. 3). Cumulated and updated meteorological data are provided

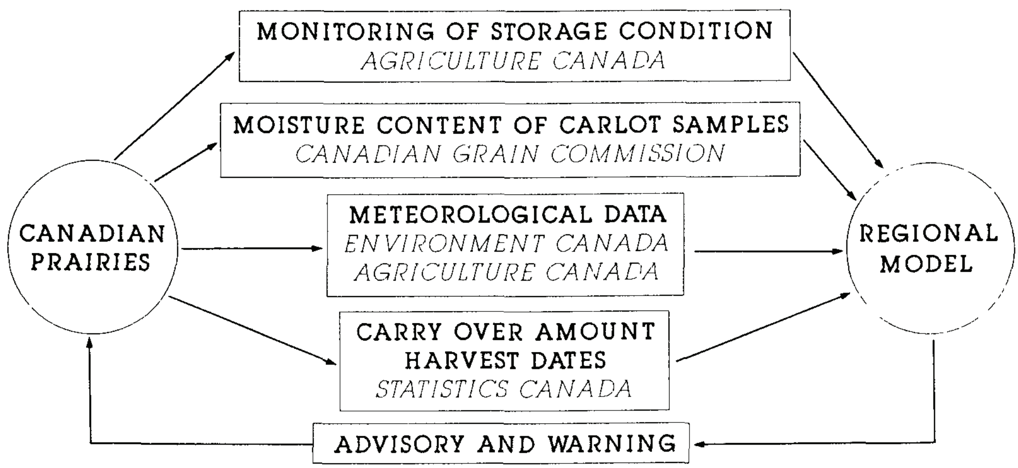

Figure 3. Flow diagram of data supporting the regional modelling. The type of data is shown by bold letters and the institution responsible for the data is shown by italics in boxes.

by Environment Canada and Agriculture Canada; carlot data in the past are provided by Canadian Grain Commission; carried over amount and harvest dates are provided by Statistics Canada (1952-1987 and 1989); and direct monitoring on the storage condition is carried out by the Agriculture Canada Research Station.

Three types of estimations are created by the regional model. The estimation of the stored grain status in the past is used for the validation of the model, and will be used to analyze the importance and relations of factors which cause the region wide outbreak of stored grain pests. The estimation of current status covers the lack of data on the conditions of grain stored in granaries distributed in the prairie provinces. Only limited number of granaries can be directly monitored depending on the available resources. The probability of pest outbreak is forecasted using the estimated current status and meteorological data for the past 30 to 40 years. Simulations can be carried out using either average climate or actual weather data for selected years.

An eight-year field study (Sinha *et al.*, unpublished) was combined with historical weather data and crop harvest data. Regression models have been developed to estimate the temperature and moisture content of freshly harvested wheat and barley using the daily precipitation and the daily maximum temperature from 3 days before the harvest to the harvest day. Detail of the model development and estimations will be published elsewhere (Kawamoto *et al.*, unpublished). The regression equation for moisture content of freshly harvested wheat in wet mass basis percentage, W, is

$$W = 19.0 - 0.10\,H - 0.13\,M + 0.24\,P,$$

where H is the maximum temperature of the harvest day in °C, M is the mean of the maximum temperatures of the first to third day before harvest in °C, and P is the total precipitation of the first to the third days before harvest in mm.

The regression equation was applied for the cumulated weather data for Canadian prairies to estimate the provincial mean moisture contents of freshly harvested spring wheat. The estimated mean moisture content was shown for the province of Saskatchewan from 1952 to 1987 (Fig. 4). The provincial mean moisture contents of carlot arriving at shipping port were also calculated for Saskatchewan from 1964 to 1984. The condition at the harvest is indirectly reflected in the carlot mean moisture content because of several

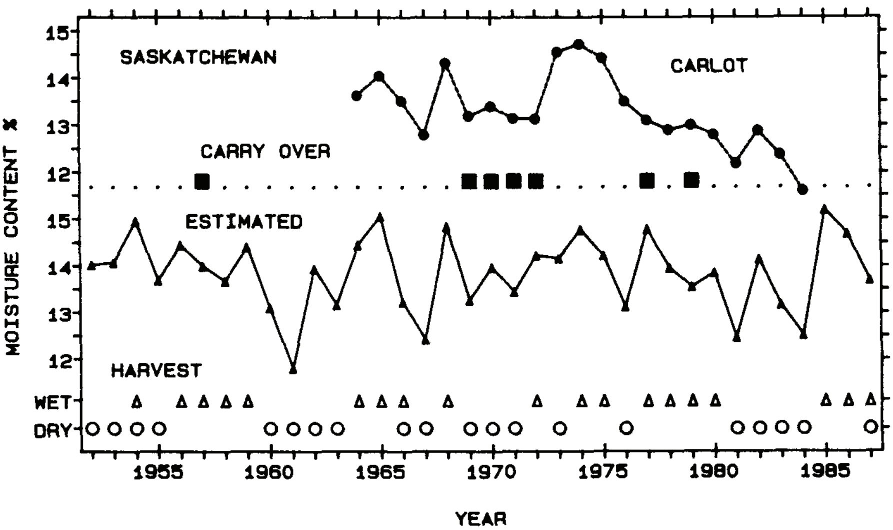

Figure 4. Mean moisture content of spring wheat in province of Saskatchewan. The estimated moisture content of freshly harvested wheat is shown by solid line. The mean moisture content of carlot arriving at shipping port is shown by broken line. Years with large amount of carry over are shown by solid squares. Wet harvest years designated by Tipples (personal communication) or Martens and Hlynka (1969) are shown by open triangles. Dry or normal harvest years designated by any of them are shown by open circles.

factors such as drying the grain and mixing the new crop with old grain carried over from previous crop years. However, the model estimation and the carlot mean moisture content showed a reasonable agreement. The moisture contents at the time of harvest were estimated higher in 1965, 1968, 1974, and 1982 than in previous several years. The carlot means showed peak moisture contents in those years except in 1977, when the large amount of carry over masked the wet harvest. The model estimation also reasonably agreed with the wet or not wet harvest years designated by Tipples (personal communication) and Martens and Hlynka (1969).

CONCLUSION

The above mentioned modelling approach will be able to provide early warnings of pest infestation of stored grain in two different spatial magnitude. The expert system for the stored grain management will work in scope of individual granary, requiring granary specific information. Detailed simulation will be carried out, and suggestions will be produced to help a user solving granary specific problems.

The regional model is intended to help extension personnel and primary elevator managers to obtain average risk of grain spoilage in an area and issue an advisory or warning to the farmers in the area. When the advisory or warning are issued, the farmers in the area are encouraged to monitor their own granaries to obtain granary-specific grain conditions.

The regional model would also be a tool to analyze the factors which caused grain spoilage in the past. The records available for the outbreaks of the rusty grain beetle, for example, are fragmental. In addition, the grain temperature and moisture content prior to the outbreak are seldom measured. The regional model would be able to estimate the grain condition which preceded the outbreak.

Ecosystem modelling may be regarded as an activity that integrate the knowledge of related scientific fields. Only the multi-disciplinary approach enables the grain storage ecosystem to be truly understood.

Acknowledgements The authors thank Dr. K. H. Tipples and Mr. J. C. Babb, Grain Research Laboratory, Canadian Grain Commission for providing data on harvest conditions and carlot of red spring wheat, Mr. R. L. Raddatz, Atmospheric Environment Service, Environment Canada for providing information of meteorological data.

REFERENCES

Campbell A. and Sinha R. N. (1990) Analysis and simulation modelling of population dynamics and bioenergetics of *Cryptolestes ferrugineus* (Coleoptera: Cucujidae) in stored wheat. *Res. Popul. Ecol.* **32,** (in press).

Kawamoto H., Woods S. M., Sinha R. N. and Muir W. E. (1989) A simulation model of population dynamics of the rusty grain beetle, *Cryptolestes ferrugineus* in stored wheat. *Ecol. Modelling* **48,** 137-157.

Martens V. and Hlynka I. (1969) *Protein content of Canadian wheat 1927-1968.* Board of Grain Commissioners for Canada, Canada Department of Agriculture, Winnipeg.

Metzger J. F. and Muir W. E. (1983) Computer model for two-dimensional conduction and forced convection in stored grain. *Can. Agric. Eng.* **25,** 119-125.

Sanderson D. B., Muir W. E. and Sinha R. N. (1988a) Intergranular air temperature of ventilated bulks of wheat. *J. agric. Eng. Res.* **40,** 33-43.

Sanderson D. B., Muir W. E. and Sinha R. N. (1988b) Moisture contents within bulks of wheat ventilated with near-ambient air: experimental results. *J. agric. Eng. Res.* **40,** 45-55.

Statistics Canada (1952-1987) On farm stock of spring wheat at July 31. *Field Crop Reporting Series, Cat. No. 22-002.*

Statistics Canada (1989) Reference dates of field crop operations pertaining to spring wheat. In *CANSIM, Statistics Canada's computerized data base,* Matrix nos. 2645-2648.

Yaciuk G., Muir W. E. and Sinha R. N. (1975) A simulation model of temperatures in stored grain. *J. agric. Eng. Res.* **20,** 245-258.

MODELISATION POUR LA DETECTION PRECOCE DE L'INFESTATION DU GRAIN STOCKE PAR LES RAVAGEURS

H. KAWAMOTO; R.N. SINHA et W.E. MUIR (1)

Agriculture Canada Research Station
195 Dafoe Road, Winnipeg, Maniboba, Canada R3T 2M9
(1) Agricultural Engineering Dept.
University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2

Résumé

On essaie de modéliser un écosystème du grain stocké composite pour déduire l'infestation de ravageurs et sa dynamique, dans les magasins de stockage d'une région agricole du Canada. Ce travail incorpore un modèle physique servant à prédire la température et le contenu en humidité du vrac, des modèles biologiques servant à prédire la dynamique des populations d'insectes ravageurs (*Cryptolestes ferrugineus* et *Acarus siro*). Un modèle bio-énergétique sert également à prédire les interactions entre les ravageurs et le grain stocké. Tout ceci demande l'introduction des conditions de départ, des changements météorologiques et des actions de gestion des stocks. La modélisation aidera les fermiers et le personnel des entrepôts à gérer correctement les stocks de grain. Un modèle régional pourra utiliser la simulation de ce grenier avec une évaluation des conditions initiales de stockage par l'emploi de la météorologie et d'autres bases de données. Le modèle régional pourra aider le personnel local en poste à renseigner les fermiers sur les infestations probables et leur recommander une surveillance intensive de leur grain ainsi que les renseigner sur leur propre gestion.