Decision support systems for integrated management of stored commodities

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Abstract

Grain producers and storers are facing rapidly changing market demands for grain because of current trade negotiations and agricultural policy reforms, particularly in Europe and the USA. There are downward pressures on prices, upward pressures on quality and reduced profit margins for both groups. Costs and pesticide inputs must be kept low, and to achieve this there is a need for help in interpreting and supplying technical information about the effects of insects and other problems on grain quality as well as the options and economic implications of taking remedial actions. The value of decision support systems in assessing current storage strategies and predicting future strategies is discussed, with examples of decision support systems, what they do and how they work.

Trends in Grain Storage

Grain is a very suitable commodity when considering the role of decision support systems in storage pest management. It forms a key part of many diets and has a relatively short harvest period so must be stored between harvests. In addition to being a staple, locally produced food, grain is also a commodity of international trade and as such is expected to conform to certain well-defined standards. Major exporting countries have developed sophisticated systems of storage and grading that channel surplus supplies towards export terminals. However, demand for these exports can be erratic and parcels of grain may have to be stored for many years. As a result, the storage requirements of small farmers, cooperative stores, exporters and shippers may be rather different, although all stocks are at risk from broadly similar problems of biodeterioration. Attack by insects, mites, mould, rodents and birds all contribute to losses of quality and quantity during storage and can have a significant affect on the profitability of grain production as well as influencing local availability.

Despite the need to maintain quality, pest management is rarely a priority in the design and construction of stores. The costs per tonne of construction and operation of a store are of greater importance than the quality of the storage environment provided. Conversations with European manufacturers confirm that, whilst the technology to improve rodent proofing and facilitate pest control and prevention is readily available, few if any customers are prepared to accept a cost penalty for incorporating such features in a new store. As a result, pest management is required to work in spite of the storage infrastructure rather than because of it.

At the moment, grain production and storage in industrial countries is being subjected to several pressures which may result in changes in approaches to storage and pest management. These changes are likely to increase the need for effective decision support systems, particularly if such systems incorporate a cost–benefit function.

The finite world market for grain and the need to dispose of surpluses, has created a very price-competitive market. The world price for grain is often below the costs of production in many parts of the world and this has led to the widespread use of subsidies to protect local producers. The world trade talks (GATT) are likely to result in a reduction in subsidies and lower prices to producers in many countries which will, in turn, reduce profit margins. This is already impinging on pest management in some unlikely ways. For example, research and development inputs into grain production are considered by GATT to constitute market support, and reducing levels of centrally funded research and development and extension effort is an acceptable way of reducing subsidies. This is certain to accelerate the current trend in Europe to move away from central government support for postharvest science. For example, in the U.K. the central government funding for research on grain storage is likely to be halved this year and the input on extension reduced to almost zero. Only four advisors now supply almost all of the independent advice at a farmer or storekeeper level in the whole of the U.K. and then only on a fee-paying basis.

Unfortunately for the producers, this reduction in support is unlikely to be accompanied by any relaxation of quality requirements. General oversupply, both nationally and internationally, means that the market is driven by the customers. This is often particularly relevant in the field of pest control where there are strong pressures to reduce or even eliminate pesticide residues, whilst maintaining a zero tolerance for pests. The problem is exacerbated by the steady decline in the number of insecticides and fumigants available for the control of pests in stored grain.

In Europe there is a move towards Total Quality Management where producers and storers of grain are required to provide documentation proving that they have exercised due diligence during all stages of production and storage. This is an onerous task, particularly when there is a lack of supporting research and development and independent advice. The squeeze on profit margins caused by falling grain prices adds to the problem and means that, in future, high quality pest management will have to be achieved on a reduced budget.

All the above suggests that in the future the majority of pest management decisions will be made by farmers and storekeepers, rather than professional entomologists and that costs will be of paramount importance. In this environment, an effective decision support system becomes an essential and cost effective tool.

There is also another role for such systems: to provide guidance on the most cost-effective avenues of research and development. The construction of a decision support system

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requires the collation of large amounts of information on pest status, commercial views of damage and loss, rates of pest development and various control options. These data are then interpreted to predict changes and risks and to advise on management actions. Developing such a system and using it under practical conditions will quickly expose gaps in knowledge. For example, in the U.K. there are very limited data on the development of common fungus beetles in grain and there are almost no data to estimate population growth of mites in bulks of grain as opposed to laboratory cultures. However, once a system has been constructed, the effects of using 'soft data' for fungus beetles and mites on the quality of prediction will be apparent. This, in turn will allow an estimate to be made of the need for 'harder data' and allow cost–benefit analysis to be used in setting research priorities.

Role of Decision Support Systems

Store managers face several tasks that can be made easier or more reliable with the help of computerised decision support systems (Wilkin et al. 1990b). Managers need to predict future conditions in the store, then select management actions available to ensure that the grain will meet their marketing objectives, and finally they must record both the condition of the commodity and their management actions to assure buyers that the product has been properly kept (Fig. 1). All these tasks must be accomplished at minimum cost. The managers task is made more onourus by a lack of independent advice and the need to become 'an expert' in areas which fall outside his or her normal areas of expertise. Such a situation is precisely one where decision support systems are at their most valualuable.

Prediction

Decision support systems operate by predicting events and the impact of management inputs, and then assessing the risks involved in various courses of action or inaction. Grain storage offers a relatively confined environment which is well suited to this approach as day-to-day changes in weather, for example, have little instant effect on the conditions within a store.

Pest and mould development is controlled by the physical conditions within the grain (temperature and moisture content), the initial population or risk of contamination and the effects of management inputs. Large amounts of data are available, at least in some geographic areas, to predict and model physical and biological changes within bulk grain (Armitage et al. 1991; Burrell and Laundon 1967; Sinha and Lee 1970; Howe 1965). For example, simple insect growth models which take account of grain temperature and moisture content when calculating insect numbers have been produced for a wide range of pest species (Howe 1965; Evans 1983). Two serious problems arise from this approach. Firstly, non-uniform conditions are not readily accommodated and, secondly, these models rely on accurate sampling and monitoring to determine the initial population and grain temperature and moisture.

A sophisticated decision support system can largely overcome these problems by concentrating on risk assessment rather than precise prediction of insect numbers. It is also possible to interpose the effects of control treatments on the models and this would appear to be an essential future development. However, to be of real value a decision support system must also include a large element of cost–benefit analysis. This latter point may be complicated by the need to consider relative market values, the costs of meeting the quality requirements of such markets and the risks and

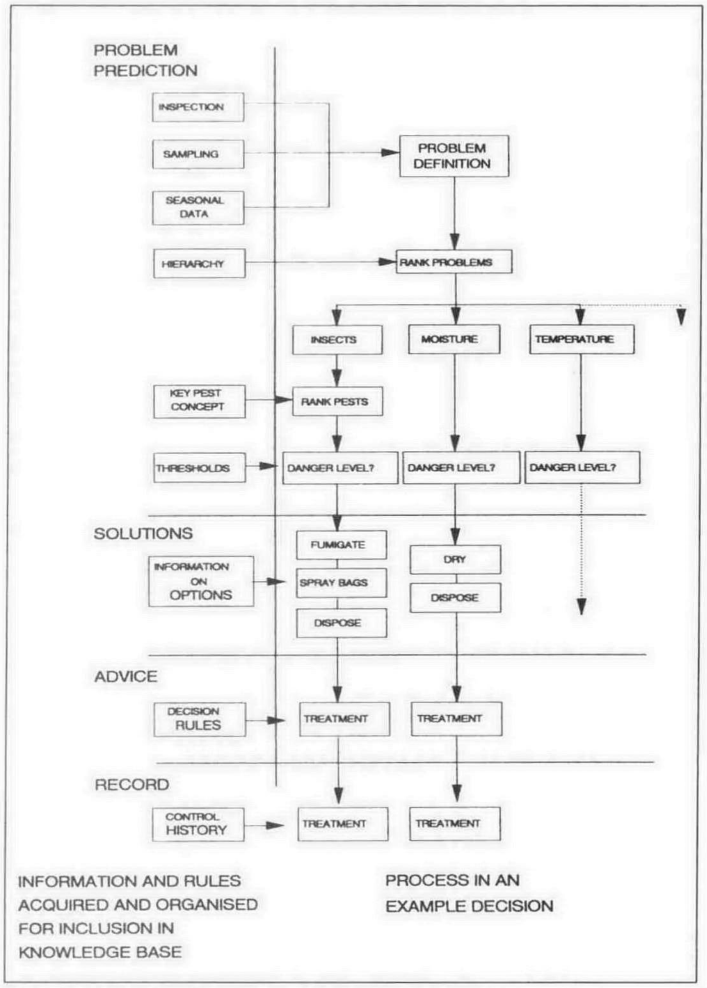

Fig.1. The role of a decision support system, with examples of the processes involved (modified following Jones et al. 1993).

benefits associated with following specific management options.

An example of this approach can be summarised as follows. Firstly, the market requirements can be reduced to a series of superimposed windows, where the borders represent the extreme tolerance of the specific markets (Fig. 2). Normal grain storage practice should produce data on temperature, moisture content, pest numbers, etc. which can be used by the system to indicate if the grain is within tolerance for a specific market (Fig. 2). At the same time the models built into the system can be used to develop predictions over time to show if and when market tolerances will be exceeded (Fig. 2). If monitoring of conditions and pest numbers is continued, actual and predicted figures can be compared. Where pest numbers, for example, already exceed or are predicted to exceed market tolerances, various pest management options can be superimposed on the model and the costs of these options can be balanced against the financial benefits of attaining a specific markets.

At its most simple, a decision support system must be able to predict or model changes in three key components: commodity conditions, pest numbers and the value of the commodity. However, each of these components may be subject to complex forces which may affect direction and rate of change. The condition of the commodity (principally temperature) will be affected by ambient conditions which, in turn will be subject to day-to-day variation and to general seasonal changes, as well as the production of metabolic heat. Seasonal

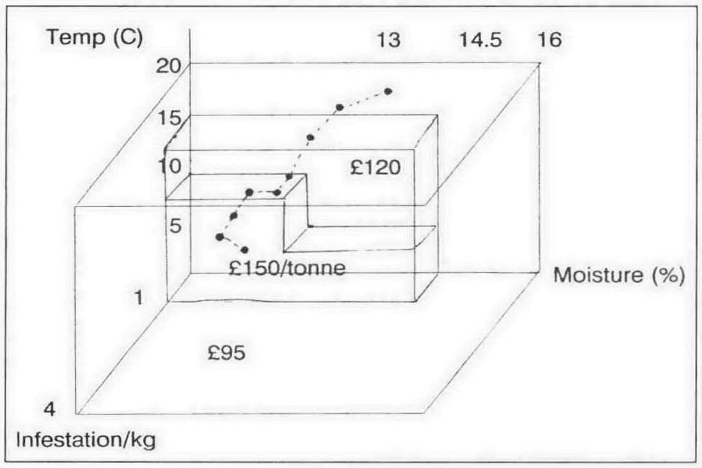

Fig. 2. Pest development and commodity condition plotted against market boundaries.

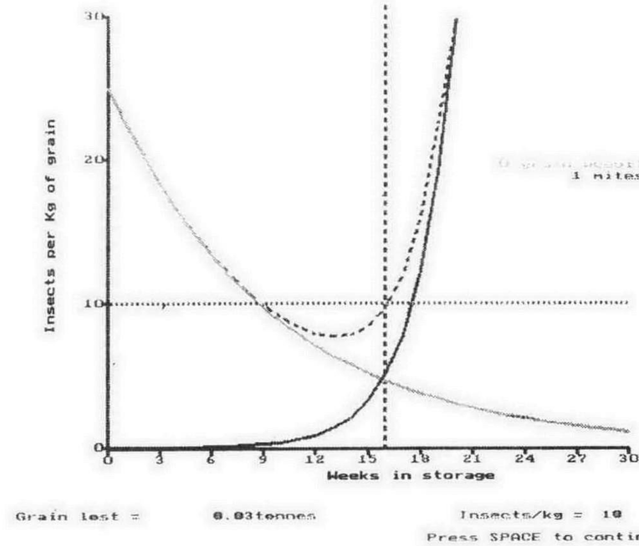

Fig. 3. Prediction output from GPA-2 decision support system, with 'crosshairs' to indicate market boundaries and expected sale dates superimposed on pest growth curves.

variations may also limit management options so that ambient aeration is not an available option in mid-summer. The other two components may be equally complex and all the components may interact. Therefore, the design and integration of the predictive model or models is the most important feature of a decision support system.

Pest numbers and damage have been predicted using fairly simple exponential growth models (Wilkin et al. 1990a; Howe 1965) and feeding rates derived from experimental observation at a few temperature and moisture conditions (Bekon and Fleurat-Lessard 1992). As already stated, however, two serious problems arise: non-uniform conditions and the quality of sampling.

The latter problem can be reduced if a decision support system can offer advice on a sampling procedure which gives adequate basis for prediction, through encyclopaedic reference screens (Wilkin et al. 1990a; Subramanyam et al. 1993; Reed et al. 1991), or through statistical analyses for sequential sampling. With automated pest sampling, such as acoustical sampling (Hagstrum and Flinn 1993), computerised interpretation in a decision support system is natural complement.

With some difficulty, non-uniform temperature and moisture conditions can also be included in a model of pest growth, if they are adequately sampled (Flinn et al. 1992; Obaldo et al. 1991). However, the value of additional sampling to determine the distribution of grain condition is limited by the relatively poor quality of data used to calculate growth rates under the different conditions. A major factor to consider in deciding on the precision of the predicted numbers of pests within the grain is the likelihood of detection at the time of sale. This will increase as pest numbers increase, as the distribution of pests within the grain becomes more uniform, or, less predictably, if the buyer is more careful or lucky (Flemming et al. 1990).

Figure 3 shows an example of the type of prediction output from GPA-2, developed from the original decision support system of Wilkin et al. (1990). Growth curves show insect populations developing or declining over time, with movable 'cross hairs' establishing target market quality and expected sale date. By adjusting the quality and sale date lines the manager can see whether pests will need to be controlled for that target, and if so he can go on to decide whether to take control action or to adjust his target, either in terms of quality or sale date.

The value of the grain will be determined by four factors: overall quality, condition, pests and market forces at the time of sale. The first is generally determined before the crop enters storage. The second two can be predicted, as described above, but market circumstances will vary considerably depending on the product and the market into which it is being sold. In many cases, with government purchases at fixed cost, the market is totally predictable. In other cases, there is considerable volatility. In changeable markets two approaches can be used to estimate future values. Futures prices can be used to give a 'best guess' indication of value at a given time in the future. Alternatively, a range of potential prices can be used to see if the value of losses from pests or grain deterioration are likely to be significant. A computerised decision support system can allow fast, easy calculation of future values using either method. Figure 4 shows a mockup of a spreadsheet-like calculator for future commodity values.

Selection of management actions

After predicting future grain quality and value, a decision can be made about what actions to take. This can be based on whatever objectives the manager has, such as economic profitability or minimising pesticide use (Compton et al. 1993; Mumford and Norton 1990).

A further useful function of a decision support system could be in the management and interpretation of pest detection. This requires a graduated response that depends on assessments of the variability within the grain bulk, market demands, the cost of sampling and the likelihood of being caught. The use of an intelligent link between sample and predicted data would clearly enhance this aspect of the system.

Non-active options

Sampling/monitoring: collection and assessment of samples. The value of this increases as the number and size of samples is increased, and as a series of sequential samples are drawn over time. The key limitations of this process are that sampling will only detect insects at relatively high population densities, and its ability to predict changes in populations is also limited.

Trapping provides a more sophisticated estimate of population density, as would an acoustic system (Hagstrum and Flinn 1993). However, this is an area where there are limited data to

Quantity in store (tonnes)	1,360					
Weeks	Temperature (°C pred)	Moisture (% mc)	Insects (per kg)	Futures price ($)	Price +20% ($)	Price -20% ($)
4	12	13	.1	50	60	40
8	14	13	.1	100	120	80
12	19	14	.2	120	134	96
16	25	14	2	120	134	96
20	27	14	20	120	134	96

Fig. 4. Example predictor of future value under various conditions.

interpret trap catches in terms that can be used in a population growth model (Wilkin 1990).

Temperature monitoring is also an essential component and is one area where accurate high value data are likely to be collected. Once again the value of the data is enhanced by regular, sequential monitoring. The relationship between temperature and insect numbers can be combined in model output, to indicate suitable sale options (Fig. 5).

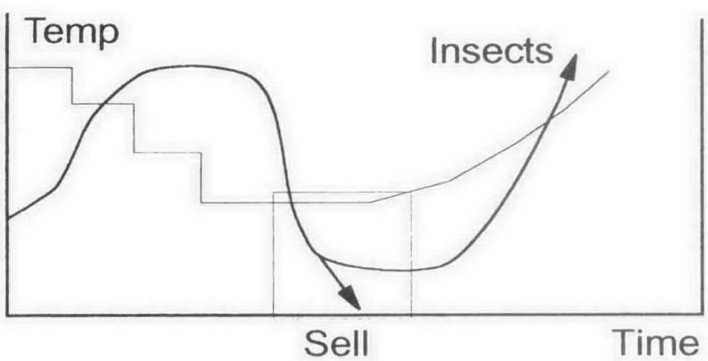

Fig. 5. Example output for a grain cooling model with a 'sale' window of low temperature and insect conditions. The model shows two scenarios for insect development, either extinction or resurgence as temperatures rise with warmer ambient air.

Moisture measurement is important but may not be needed on a regular basis, unless temperature changes indicate that moisture changes are likely.

Collation of cost and price data. This involves collection of data on current prices and the development of simple models to predict future price movements. It also can be supplemented with both fixed and variable costs incurred during storage and pest management.

Active options

Changing physical conditions in grain bulks. Cooling (ambient aeration and refrigeration), drying, exclusion of oxygen, physical removal of pests will all have varying efficacy and costs (depending on the condition of the grain, time of year, and the nature of the problem). Cooling, in particular, is a long-term measure and will reduce pest densities only slowly.

Fumigation. This is an expensive but effective option. It gives good disinfestation on a one-shot basis but offers no long-term protection. Timing is therefore critical. Fumigated grain cannot be called organic but phosphine leaves undetectable residues. Fumigation can only be used by registered pest control companies, which may also make it expensive. Furthermore, the future registration of many fumigants is in doubt.

Contact pesticides. This is a relatively low cost option that is very flexible. It can be used by farmers or store operatives; however, it results in detectable residues which can be unacceptable to some customers, and is susceptible to the development of resistance.

Before a final decision is made on the appropriate management option, the system must calculate the costs of these actions and balance them against changes in the value of the grain. In the present economic climate, this latter function may be the most important feature of a decision support system.

Recording commodity condition and management

As discussed earlier, it is becoming increasingly important in many markets to not only deliver commodities in good condition after storage but to be able to guarantee that the commodity has been stored under appropriate management. Keeping records can be tedious and prone to error, but the process can be semi-automated using a database within a decision support system to record and print information such as grain temperature, moisture, pest sampling results, pesticide inputs, etc. throughout the storage period. Actions recommended by the decision support system should comply with market conditions. Sampling records can be shown graphically (as in Figure 2).

Conclusion

So far, decision support systems have either been developed in prototype form (Wilkin et al. 1990; Flinn and Hagstrum 1990; Jones et al. 1993; Compton et al. 1993) or are only planned (Kawamoto et al. 1992). However, the economic and institutional pressures outlined here are making their need even greater, while technical developments in computing capabilities and wider availability of computers makes them more feasible. The major obstacles to their successful development remain the lack of suitable biological data on pest population growth and damage and efficient sampling techniques for their detection. The prototype decision support programs developed so far have contributed to the specification of data required for management decisions, and this has been their principal value to date.

As always, the major problem of funding the development of such systems remains. The multiple approaches that are currently underway on a worldwide basis can only be a healthy sign and should ensure that many alternative routes are followed. However, perhaps this conference offers the opportunity for pooling of ideas and cooperation on a international decision support system for stored grain. Certainly, the groups with whom we are associated are prepared to consider cooperative ventures or pooling of ideas with any other group.

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