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DECISION ANALYSIS IN PEST FORECASTING

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RINGKASAN

Analisa keputusan (decision analysis) ialah suatu pendekatan yang membenarkan seseorang melaksanakan sesuatu penilaian yang mendalam dan logik mengenai strategi-strategi pilihan. Ianya telahpun digunakan dengan agak meluas di dalam bidang sains pengurusan, khususnya di dalam penilaian strategi-strategi perniagaan. Bagi perlindungan tumbuhan, di mana keputusan-keputusan pernah dibuat tanpa kepastian, pendekatan ini mungkin juga diterima. Rencana ini menghuraikan penggunaan analisa keputusan bagi mengendali dan mentafsirkan data pengawalan perosak, dan bagi memilih tektik pengawalan yang paling baik daripada berbagai pilihan yang ada. Dengan menggunakan pendekatan Bayesian ke atas suatu contoh hipothetik, proses pengubahan ramalan-ramalan serangga kepada suatu tindakan yang disyorkan adalah dijelaskan. Pembahagian-pembahagian bangkali dan sistem-sistem penyebaran pengurusan perosak adalah juga dibincangkan.

INTRODUCTION

A farmer contemplating to implement pest control is in essence deciding whether or not to attempt minimising the expected crop loss. To be certain of the outcome of his control decision, he must know how the system will be affected by each of the control alternatives. Otherwise, control decisions would be made under conditions of uncertainty. As climatic, biological and agronomic factors are usually uncertain, the farmer tends to operate under an environment of uncertainty. Thus, pest control may be regarded as decision making under uncertainty (MUMFORD, 1978). One way to handle uncertainty in decision making is by **DECISION ANALYSIS.**

Decision analysis is an approach which allows one to carry out a thorough and logical evaluation of alternative strategies. It has been used in solving complex problems developed in the field of systems analysis and operations research. So far this approach has only been used to consider a few pest management problems. Examples of its use are given by VALENTINE, *et al.*, (1976) for the evaluation of available control alternatives to suppress the gypsy moth in forests; by NORTON (1976) to suggest the appropriate strategies for potato blight control; by CARLSON (1970) to consider crop disease predictions and control, and by CAMMELL and WAY (1977) to evaluate the economics of a forecasting scheme of the black bean aphid on spring-sown field beans. Other examples on the use of decision analysis are found in business decision making (MOORE, *et al.*, 1976; HAUFMAN and THOMAS, 1977; HALTER and DEAN, 1971); the decision to seed hurricanes (HOWARD, *et al.*, 1972) and the judgement for a serious medical problem (BETAQUE and GORRY, 1971).

In using the decision analysis approach, one often goes through a number of stages which help in considering the decision problem in a logical, step-by-step manner (KAUFMAN and THOMAS, 1977). Thus, this procedure helps one to have a better concept of the problem, to identify the nature of the risks and uncertainties. In its more direct role, decision analysis may be used to convert pest data into pest forecasts and to select the 'best' control tactic from among a set of available tactics. This paper aims to show how this may be done and to identify the relevant research areas for a pest forecasting programme.

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PEST MONITORING AND FORECASTING

In most pest forecasting systems, the basic components are, pest monitoring, data processing and conversion to pest predictions, decision on which recommendation and the delivery of this information to the farmers. For the system to be effective, it is important that the information should reach the farmers allowing sufficient time for the recommended action to be taken. Also, the recommendation instructions should be simple, practical and precise. They should be directed to answer the two questions farmers are likely to ask (HEONG, 1981); 'Do I need pest control?' and 'If so, what exactly should I do?' An example of such a delivery system is illustrated in *Figure 1*.

PEST PREDICTIONS AND RELIABILITIES

Pest monitoring data may be collected from the field or monitoring stations. They may be absolute population estimates of

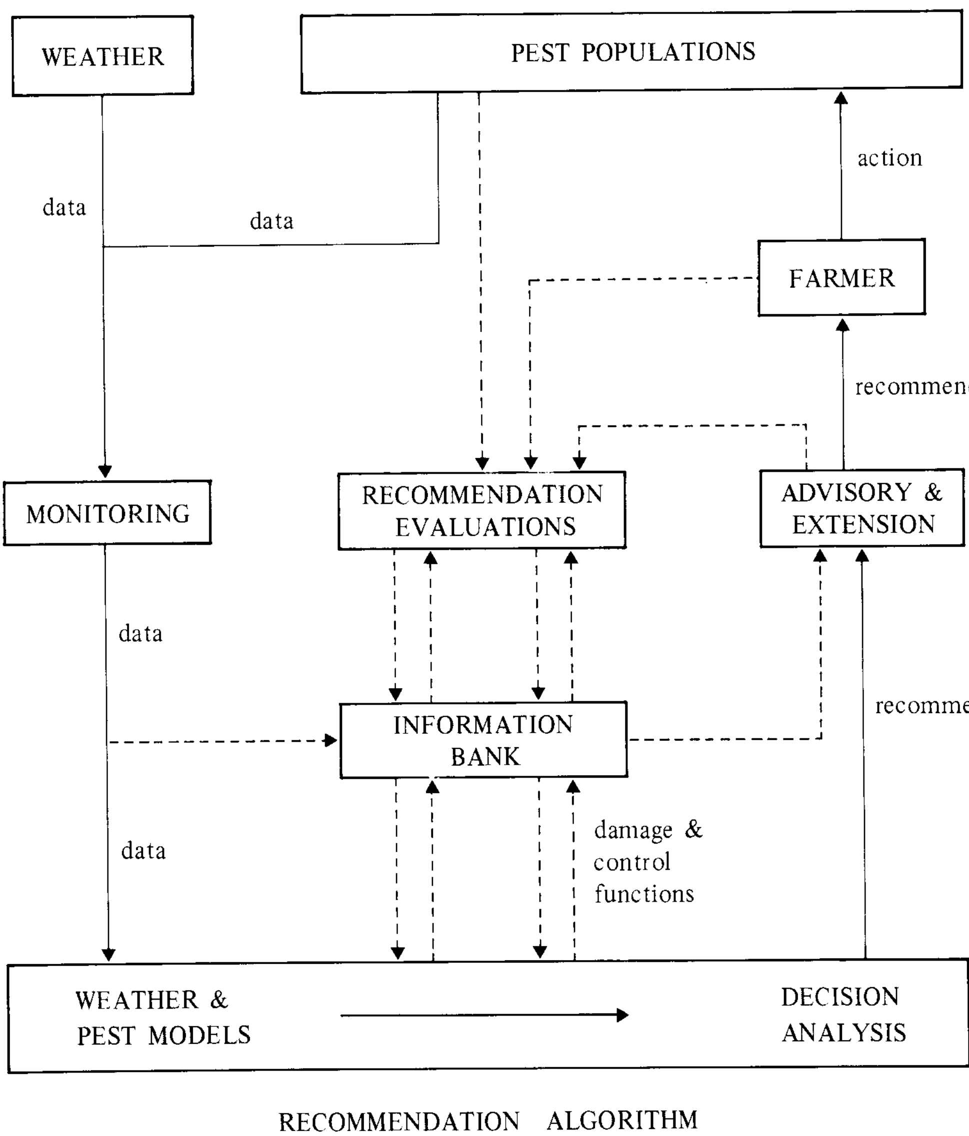

Figure 1: A representation of a pest management operation at farmer's level.

relative population indices. By the use of the appropriate population models, these data may be converted into population predictions. Some of these models are now available in the literature (see RUESINK, 1976). If the situation requires models for the specific environment, such models may be constructed accordingly. The important thing to note here is that the data collected should bear some relationships to the model variables.

Population predictions may then be generated from these models. The future state(s) of the pest population is predicted using the data which is collected from the field. However, it is important to note that such predictions are only as accurate as the data input and the model(s) itself. In order to obtain the reliability of the model predictions, series of model simulations from the initial field data and the actual field records may be compared. Results of such experiments are best presented in a reliability matrix *(Table 1)*.

DECISION MAKING WITH PEST INFORMATION

A decision making situation in which pest information are available may be illustrated in a decision tree *(Figure 2)*. Here the field data is converted into predicted pest infestations, Z_i, with known probabilities of accuracy, $P(Z_i/\theta_j)$. Assuming that there are six alternative actions available, one of which is 'no action' (A_0) the task then is to decide which action will give the best payoff. In order to do this the payoffs of each action under the four categories of pest infestations must be known. These may be in expected yields or profits. Also necessary for the analysis are the *a priori* probabilities of pest infestations $P(\theta_j)$ and the probabilities that the pest predictions will indicate the particular infestation category, $P(Z_i)$. The set of *a priori* probabilities of a given locality describes the chance that pest infestation will occur at the different levels, such that $\sum_{j=1}^{J} \theta_j = 1$. Quite often, such information can be computed from historical data (see NORTON, 1976; MUMFORD, 1978). The other set of probabilities $[P(Z_i)]$ may be obtained by combining the *a priori* probabilities and the reliability probabilities. This is shown in *Table 2*.

Using the elements from this matrix, the probabilties of the pest infestation levels given the model predictions may be calculated. Bayes' Theorem is then used to evaluate these probabilities. Thus if the prediction is Z_1 and the level of infestation is θ_1, the probability of infestation level, θ_1, occurring given Z_1 is $P(\theta_1/Z_1)$ calculated from

$$P(\theta_1/Z_1) = \frac{P(\theta_1).P(Z_1/\theta_1)}{P(Z_1)} \quad (1)$$

TABLE 1: POPULATION PREDICTION RELIABILITY MATRIX

Pest Infestation Levels	Predictions from model			
	Z_1	Z_2	Z_3	Z_4
θ_1	$P(Z_1/\theta_1)$	$P(Z_2/\theta_1)$	$P(Z_3/\theta_1)$	$P(Z_4/\theta_1)$
θ_2	$P(Z_1/\theta_2)$	$P(Z_2/\theta_2)$	$P(Z_3/\theta_2)$	$P(Z_4/\theta_2)$
θ_3	$P(Z_1/\theta_3)$	$P(Z_2/\theta_3)$	$P(Z_3/\theta_3)$	$P(Z_4/\theta_3)$
θ_4	$P(Z_1/\theta_4)$	$P(Z_2/\theta_4)$	$P(Z_3/\theta_4)$	$P(Z_4/\theta_4)$

$P(Z_i/\theta_j)$ where i = 1,2,3,4; j = 1,2,3,4 is the probability that the prediction category, Z_i, is correctly predicting the level of infestation, θ_j. Thus,

$$\sum_{i=1}^{4} P(Z_i/\theta_1) = 1$$

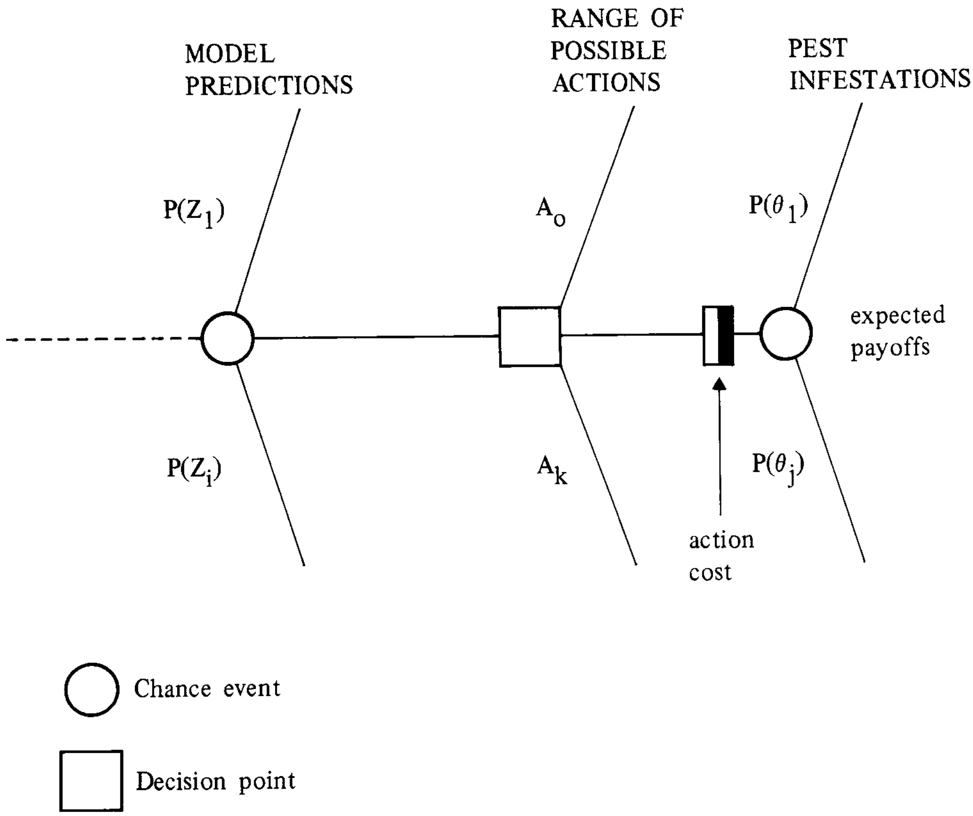

Figure 2: Decision tree of pest control with pest information available.

TABLE 2: MATRIX OF JOINT PROBABILITIES

Pest Infestation Levels	Predictions from model Z_1	Z_2	Z_3	Z_4
θ_1	$P(\theta_1).P(Z_1/\theta_1)$	…	…	…
θ_2	…	$P(\theta_2).P(Z_2/\theta_2)$	…	…
θ_3	…	…	$P(\theta_3).P(Z_3/\theta_3)$	…
θ_4	…	…	…	$P(\theta_4).P(Z_4/\theta_4)$
$P(Z_i)$	$P(Z_1)$	$P(Z_2)$	$P(Z_3)$	$P(Z_4)$

The Bayesian probability matrix may then the calculated *(Table 3),* from which the expected outcomes can be calculated.

An Example

To illustrate how decision analysis works, let us consider a hypothetical example. **P** is an insect pest which attacks the crop C. For convenience, the pest attacks can be classified into four categories, viz., θ_1, θ_2, θ_3 and θ_4. Based on the historical data obtained over several years, the *a priori* probabilities of pest attack was found to be $P(\theta_1) = 0.4$; $P(\theta_2) = 0.2$; $P(\theta_3) = 0.3$; $P(\theta_4) = 0.1$. There are six control options available, A_O .... A_5, where A_O is do

TABLE 3: BAYESIAN PROBABILITY MATRIX

Pest Infestation Levels	Predictions from model			
	Z_1	Z_2	Z_3	Z_4
θ_1	$P(\theta_1/Z_1)$	$P(\theta_1/Z_2)$	$P(\theta_1/Z_3)$	$P(\theta_1/Z_4)$
θ_2	$P(\theta_2/Z_1)$	$P(\theta_2/Z_2)$	$P(\theta_2/Z_3)$	$P(\theta_2/Z_4)$
θ_3	$P(\theta_3/Z_1)$	$P(\theta_3/Z_2)$	$P(\theta_3/Z_3)$	$P(\theta_3/Z_4)$
θ_4	$P(\theta_4/Z_1)$	$P(\theta_4/Z_2)$	$P(\theta_4/Z_3)$	$P(\theta_4/Z_4)$

Each element in the matrix describes the probability of the pest infestation level occurring given the particular model prediction.

nothing. From a separate experiment, the monetary payoffs of each control option under each state of pest attack are available. Also available is the reliability of the forecast information on **p** provided by the agricultural authorities.

The relevant matrices of this numerical example is given in *Table 4* and illustrated in *Figure 3*. The values in the boxes are the expected monetary values (EMV's) of the actions taken under the different conditions. Thus, when the pest forecast is Z_1, action A_1 yields the best payoff. Action A_2 is chosen when the forecasts are Z_2 and Z_3, and action A_3 is chosen when Z_4 is forecasted.

PROBABILITY ASSIGNMENTS

One of the main advantages of decision analysis is to be able to quantify uncertainty. As illustrated, the analysis and decisions arrived at are all dependent on these probabilities. Probability assignment is thus an important aspect of decision making.

Probabilities may be determined through subjective or objective means. Where data is not available or insufficient, probabilities have to be assigned using the subjective approach. Several methods of assessing these values have been described by MOORE and THOMAS (1975). Although most of these values are more applicable to managers or businessman who have a better understanding of the risk environment, some of them may be adapted for use in agricultural research.

Wherever data is available, objective probabilities may be calculated. Data on pest infestations collected annually may be summarised and the *a priori* probabilities of infestations can be expressed as percentages of occurrences (NORTON, 1976; MUMFORD, 1978). Assigning probabilities on the forecast reliability has been discussed earlier. These may be obtained from simulations and the construction of the reliability matrix.

Probability assignment can be a diffi-

TABLE 4: MATRICES OF THE NUMERICAL EXAMPLE

A: Payoff Matrix (x $ 1000 per ha)

States	Actions					
	A_0	A_1	A_2	A_3	A_4	A_5
θ_1	12.0	11.0	10.0	9.0	8.0	7.0
θ_2	9.5	10.5	10.0	9.0	8.0	7.0
θ_3	2.5	5.0	7.0	7.5	7.5	7.0
θ_4	– 1.0	2.0	4.0	6.0	7.0	6.5

B: Forecast Reliability Matrix

States	W	Forecasts			
		Z_1	Z_2	Z_3	Z_4
θ_1	0.4	0.40	0.30	0.20	0.10
θ_2	0.2	0.25	0.35	0.25	0.15
θ_3	0.3	0.15	0.25	0.35	0.25
θ_4	0.1	0.10	0.20	0.30	0.40

W = probability of state of nature.

C: Joint Probability Matrix

States	Forecasts			
	Z_1	Z_2	Z_3	Z_4
θ_1	0.16	0.12	0.08	0.04
θ_2	0.05	0.07	0.05	0.03
θ_3	0.05	0.08	0.11	0.08
θ_4	0.01	0.02	0.03	0.04
P(Z)	0.26	0.29	0.27	0.19

D: Bayesian Probabilities

States	Forecasts			
	Z_1	Z_2	Z_3	Z_4
θ_1	0.60	0.42	0.30	0.22
θ_2	0.19	0.23	0.19	0.16
θ_3	0.17	0.26	0.40	0.41
θ_4	0.04	0.07	0.11	0.22

E: Expected Outcomes (x $ 1000 per ha)

Forecasts	Actions					
	A_0	A_1	A_2	A_3	A_4	A_5
Z_1	9.42	9.55*	9.26	8.63	7.88	6.98
Z_2	9.97	8.67	8.79*	8.39	7.80	6.96
Z_3	6.29	7.51	8.13*	8.07	7.69	6.94
Z_4	4.73	6.54	7.49	7.74*	7.51	6.89

* These values are the expected monetary values (EMV).

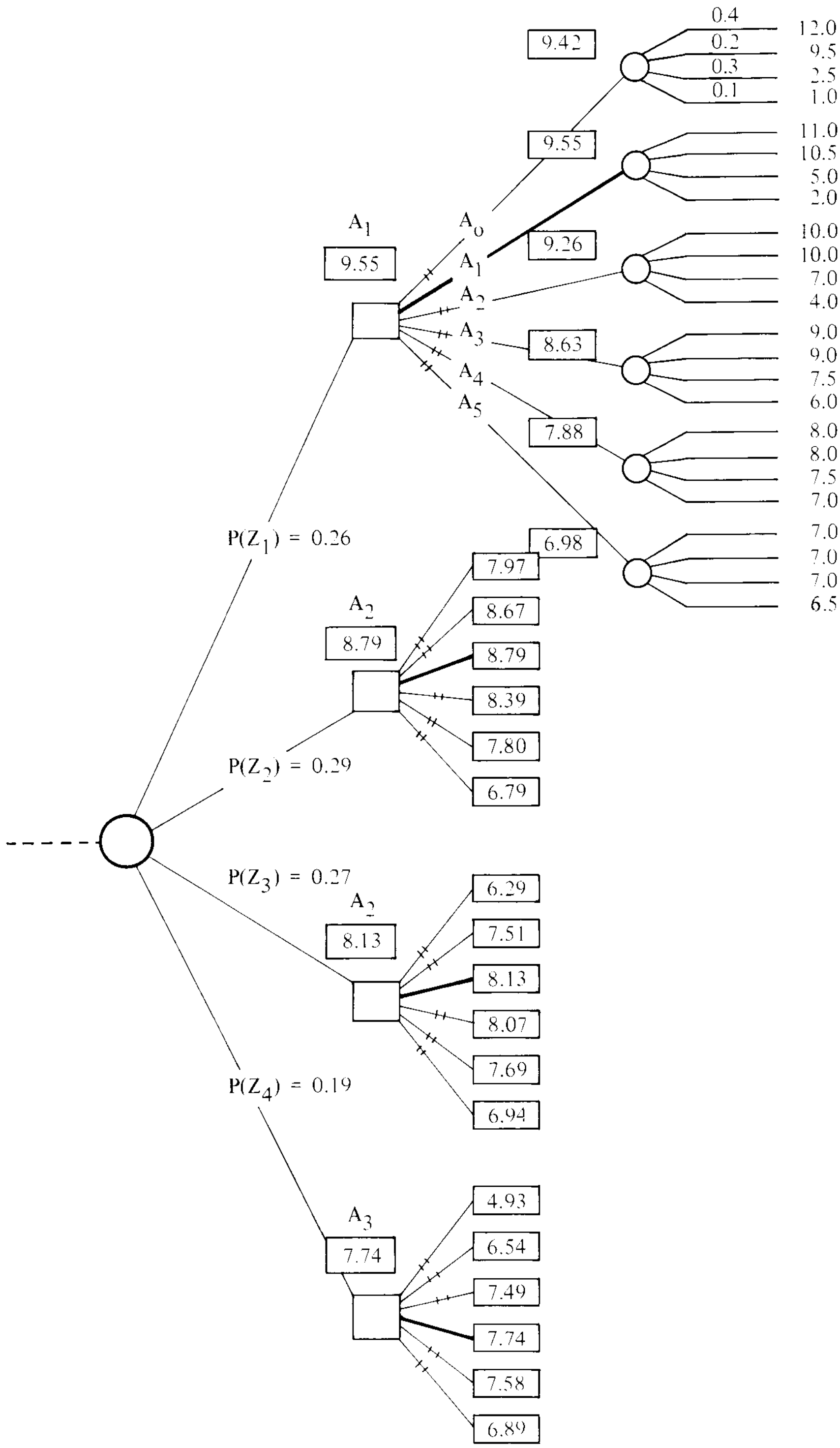

Figure 3: A hypothetical example of pest control decision making with information (see text for details).

cult part of decision analysis. In some cases, the *a priori* probabilities may be obtained from historical data. However, in most cases, subjective probabilities have to be used. In practice, the decision maker must first decide how many and which variables are uncertain. Once this is done, the assessment procedure involves processing a mixture of subjective and objective data for each uncertain quantity into meaningful values. Achieving accurate values may be difficult, but in general, satisfactory values can be obtained. The decision maker's experience with such assessments usually improved the quanlity. Quite often, the *a priori* probabilities are location-specific and in some cases, so are the reliability probabilities. It is thus necessary to repeat such assessment procedures for a number of situations and locations.

PEST MANAGEMENT DELIVERY SYSTEMS

Obtaining an objective pest control decision for the given pest situation is one thing, quite often, the transfer of such recommendations to the farmers is another. In most cases, these recommendations are transfered to the farmers through an extension delivery system. Thus to enable decisions made in this way to have some real-life impact on the crop protection practices at the farm level, an efficient delivery system is essential. This may be achieved by automating information flow along the broad arrows in *Figure 1* as much as possible.

More advanced pest management delivery systems are the on-line pest management systems (HAYNES, *et al.*, 1973) and the use of microcomputer based instruments (JONES and CROFT, 1981). On-line pest management systems are based on models and the continuous reviews of the changing meteorological conditions, ecological states of the ecosystem and the relative effectiveness of previous control tactics. It allows the researcher or agricultural extension personnel to interrogate the management models on the basis of the output and alert farmers to the various control options (HAYNES and TUMMALA, 1978). In some cases, however, due to the high communications costs, the excessive size of the computer and its other limitations, such an on-line system may not be appropriate. A second generation delivery system based on a network of smaller computer processes, is now being developed (CROFT, *et al.*, 1979). For instance, various models integrated into a single microcomputer based instrument is being used to 'advise' extension personnel on apple scab control (FISHER, *et al.*, 1979).

CONCLUDING REMARKS

In conclusion, the author would like to say that decision analysis can play a more significant role in improving pest management practices. Not only can it serve to condense data obtained from pest monitoring into a perceivable pest control decision, it can also serve as a tool for researchers to structure specific pest problems and coordinate research activities. Much of its success will depend on advancements in modelling the pests, ecological processes, actions of control options and decision making processes. But in most cases information pertaining to these aspects are still relatively scarce. Decision analysis is only recently being applied to pest management. With the advancements in computer technology and systems science, it is likely that more emphasis will be placed on using the decision analysis to solve pest problems in the future.

SUMMARY

Decision analysis is an approach which allows one to carry out a thorough and logical evaluation of alternative strategies. It has been used quite extensively in management sciences, particularly in the evaluation of business strategies. In crop protection, where decisions are often made under uncertainty, this approach may also be adopted. The paper describes the use of decision analysis to handle pest surveillance data, and to select the best control tactic from a range of available alternatives. Using the Bayesian approach on a hypothetical example, the process of converting insect forecasts into a recommended action is illustrated. Probability assignments and pest management delivery systems are also discussed.

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