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ANALYSIS OF DECISION MAKING IN CROP PROTECTION

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ABSTRACT

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The crop protection decisions taken by a farmer are determined by four main factors: the farmer's objectives, his perception of pest attack and the damage it can cause, the control measures available to him, and the decision rules by which he operates. In analysing the way in which these factors interact, the purpose of this paper is to increase our understanding of the crop protection decision problem and to show how an appreciation of the farmer's situation is important in designing successful research and extension programs.

The paper is divided into two parts. In the first part, two classes of decision model are illustrated by means of case studies. For the economic threshold model, requiring specific information on pest attack and using conventional economic analysis, the potato cyst eelworm problem is used as an example. The prophylactic decision model, which uses information on the probability distribution of attack and relies more on decision theory techniques, is illustrated by reference to the problem of potato blight.

It is recognised, however, that in many real life situations these decision models are not appropriate, the result of inadequate information, limited managerial ability, or extreme risk constraints. In this situation, farmers do not attempt to optimise but search for a crop protection strategy that is satisfactory, one that meets their objectives as well as their operational constraints.

With this view of the farmer's situation, the second part of the paper concentrates on the way in which research and extension programs can improve it. Attention is focussed on the three methods of achieving this; by widening the range of control measures available, increasing the perception of relevant information, and by improving decision rules. In concluding, it is stressed that a successful reduction in a particular constraint to better decision making is only likely to be achieved where the measures taken are designed in the context of those constraints that remain.

INTRODUCTION

Agro-ecosystems are designed and managed to produce particular crops in the quantities required to meet the personal needs of farmers. The decisions they make are constrained by the state of such resources as capital and labour, that lie within their control, and take account of other resources, such as climate and pest attack, that are outside it. Consequently, when a farmer anticipates

or observes pest attack of damaging proportions, he attempts to protect against potential losses either by modifying agro-ecosystem design or by adopting explicit, crop protection measures.

Since the decisions taken by farmers on the form and level of crop protection to adopt are determined by a range of factors (Fig. 1), research and extension programmes can attempt to improve decision making in crop protection by modifying the state of these factors. For instance, by developing new methods of control and improving the way in which existing techniques are applied,

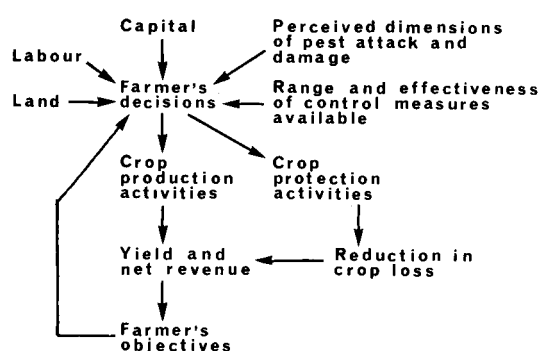


Fig. 1. Factors affecting crop protection decision making.

research effort can increase the range and effectiveness of control measures available to farmers and so improve their decisions. Whether such developments have any impact on real-life decision making however, will also depend on the state of other factors, particularly the farmer's objectives and the constraints set by his farming system. The success of applied research therefore, will depend as much on the effort made to appreciate the problem from the farmers' standpoint, and direct research effort accordingly, as on the quality of the research itself.

By analysing the process of decision making in crop protection, the aim of this paper is to show how research and extension programs might best improve it. The paper is divided into two parts. The first is concerned with analysing decision making in crop protection to illustrate the theoretical and practical considerations involved. Within this framework, the second part describes the methods of improving it.

PART I: DECISION MAKING IN CROP PROTECTION

The need for crop protection arises from the damage caused to valued resources by pest organisms. Through their effect on the various components of a crop, weeds, diseases and animal pests can reduce both the yield of the crop and its quality. Weed attack, for instance, can reduce yield by impairing the availability to the crop of such environmental resources as solar radiation,

nutrients and water. Diseases, on the other hand, can directly impair the physiological system of the plant, as can insects and other pests that feed and lay eggs on crop plants, or which introduce other pathogens. A loss in crop quality can result from reduced nutritive status, from visible damage to the crop product or from the presence of pest organisms in the harvested crop.

The extent and form of the losses caused in a crop depend upon the dimensions of the pest attack that occurs. This is determined by: (a) the numbers initially present, (b) the numbers entering the crop and their time of entry, and (c) the development of the attack over time. The state of the crop when attacked is also important. In many crops, critical periods have been identified when attack is particularly deleterious. In sugar-beet, for instance, Scott and Wilcockson (1974) have shown that there is a critical period between 4 and 8 weeks after emergence when yield is seriously affected if weeds are not removed (Fig. 2). Before and after this critical period, weed infestation has negligible effect on yield. The critical period associated with cabbage root fly appears to be the first few weeks after transplanting, when attacked plants may be killed. After this critical period, cauliflower crops have been shown to have considerable tolerance to attack (Coaker, 1970). A similar situation

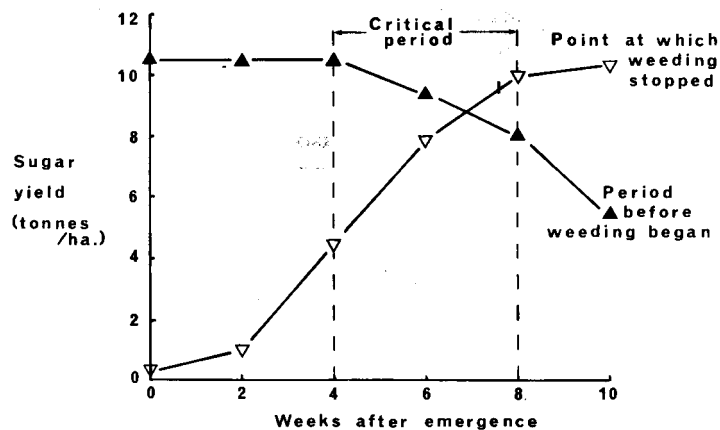


Fig. 2. Critical period for weed control in sugar beet (after Scott and Wilcockson, 1974).

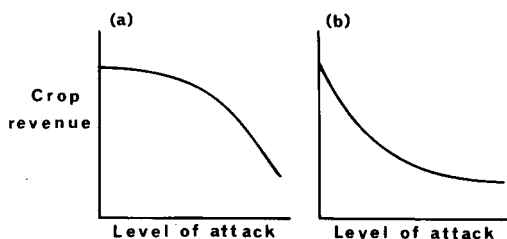


Fig. 3. Two forms of damage function.

appears to occur in barley mildew, where early infection is particularly damaging (Brooks, 1972; Jenkyn, 1974).

The farmer's interest in pest attack is mainly focussed on the effect of various levels of attack on crop revenue. He will be particularly interested in the form of this damage function, of which two extreme types have been distinguished (Southwood and Norton, 1973). The first (Fig. 3a), is associated with crops that are tolerant of low levels of attack or which are able to compensate for it. The second (Fig. 3b), occurs where pest attack is at a critical period, where the crop is attacked by insect vectors, or where attack reduces the quality of a crop whose price is sensitive to such changes.

Crop protection measures

The protective actions adopted by a farmer against pest attack may be embodied in the cropping system itself, through diversification and rotation, or may involve the use of specific control agents. Since these actions are applied at different times, the farmer will have to make crop protection decisions at various stages in the crop season. This sequence of decisions can be illustrated in the form of a decision tree (Fig. 4), the number of branches being determined by a variety of constraints. For instance, particular control methods will be unavailable where there is no suitable machinery, where labour is unavailable at the time required, or where there are legal restrictions on the use of particular chemicals.

It will be clear from Fig. 4 that the later in the season a farmer makes his crop protection decision, the narrower will be the range of choice. At the same time, with many pest problems, the farmer's perception of the dimensions

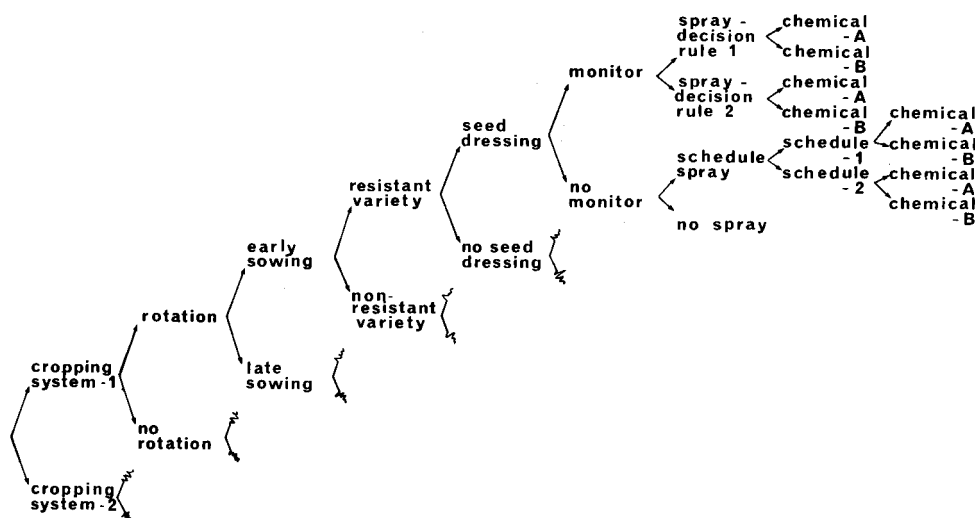


Fig. 4. A decision tree for crop protection.

of attack increases over the season. Hence, the range of choice and the information available to a farmer in considering crop protection measures will frequently depend upon the time at which the decision is being made. In this context, two categories of crop protection can be identified. The first, consisting of prophylactic measures, is taken without specific information on the level of attack that occurs, whereas the second category, involving economic threshold measures, is adopted in response to such information.

The economics of crop protection

Faced with a range of crop protection measures such as those shown in Fig. 4, on what basis does the farmer decide to adopt a particular method of control? Since the overall farming objective may consist of a mixture of economic, social, and other goals (Gasson, 1973), decisions in crop protection are also likely to be assessed in terms of a number of criteria. First, however, let us concentrate on the economic factors involved and consider a particular example: the control of potato cyst eelworm by DD, a pre-sowing, soil fumigant.

If soil samples are taken from the field in which potatoes are to be grown, the level of eelworm attack that will occur can be estimated from egg numbers per gram of soil. Having obtained this information, the farmer then has to decide whether it will be profitable to apply the soil fumigant against the estimated level of attack. To make this decision, additional information is required on the following.

- (i) Details of the damage function, relating yield losses to pest attack. Brown (1969) has shown that this relationship can be represented by a linear function, each egg per gram of soil reducing tuber yield by 0.1 tonne/ha.
- (ii) The estimated price of the crop. For the time being this is taken as £40/tonne.
- (iii) Details of the control function, determining the reduction in pest attack associated with application of the control measure. It appears that DD achieves a reduction in attack of about 80% (Jones, 1973).
- (iv) The cost of the chemical and its application. This is assumed to be £100/ha.

Hence, where

θ = the level of pest attack in terms of eggs/g of soil,

d = the damage coefficient, expressed as tonnes/ha lost for each egg/g of soil,

p = the price of potatoes/tonne,

k = the proportional reduction in attack associated with the application of DD,

c = the cost of applying DD/ha.

The loss in revenue associated with eelworm attack is given by the expression:

$$pd\theta$$

and the reduction in loss can be expressed as

$$pd\theta k$$

Consequently it will be profitable to apply DD when

$$pd\theta k > c$$

that is, when the reduction in lost revenue is greater than the cost of the control measure.

Hence, the level of attack at which it becomes profitable to apply DD

$$(\theta^*) = \frac{c}{pdk}$$

Using the information given above, this economic threshold will be

$$\frac{100}{40 \times 0.1 \times 0.8} = 31 \text{ eggs/g of soil.}$$

This is shown in Fig. 5 as the point at which the net revenue lines for a treated and untreated crop intersect. Clearly, as the price of potatoes and the cost of DD application change, the economic threshold will increase and decrease accordingly, as shown in Fig. 6. The economic threshold level will also be modified by changes in the damage function, associated with new potato varieties, for example, or by changes in the control function, associated with alternative control agents, new chemicals or novel methods of application.

It will be evident that decisions based on this type of analysis can only be made where an estimate of the level of attack is available. As we have already seen, this information may well be unavailable at the time when crop protection decisions are made, in which case prophylactic measures have to be taken. Since this information on attack may be unavailable for two reasons, it is useful to identify two forms of prophylactic treatment. Pre-emptive measures, of which resistant varieties and seed dressings may be examples,

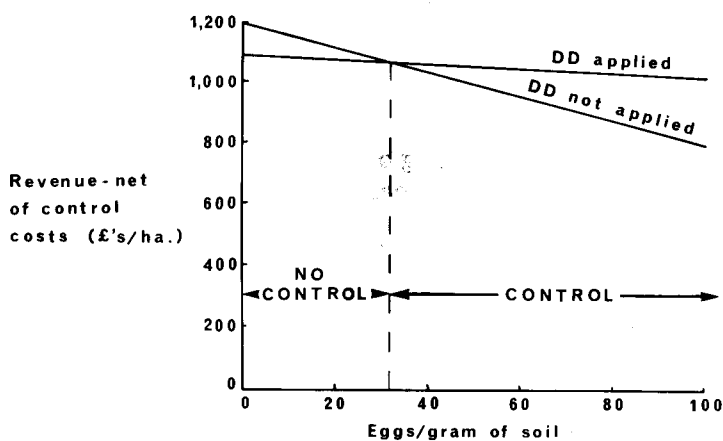


Fig. 5. Economic threshold for potato cyst eelworm and DD.

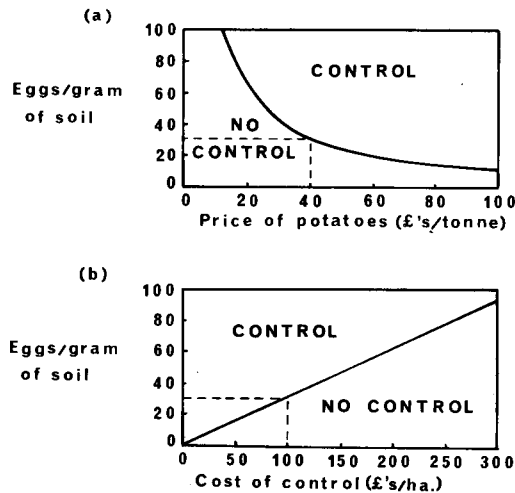


Fig. 6. Effect of (a) price of potatoes and (b) cost of applying DD on the economic threshold.

are prophylactic since the nature of the control measure requires a decision to be made before pest attack occurs. Schedule measures, on the other hand, involve the use of pesticides or other control agents that are applied directly against the pest. In this case, accurate monitoring is too difficult or too expensive to carry out and so the protection measures are applied according to a pre-determined program.

Decision theory

Although the actual level of pest attack cannot be assessed, it may be possible to estimate the probability distribution of attack, using historical evidence, for example. Here, as with other natural hazards, decision theory provides a means of analysing the problem (Slovic et al., 1974).

To illustrate the methodology, let us consider the case of potato blight (Large, 1958) and assume that the control measure taken against this disease consists of three schedule sprays. To derive the probability distribution of attack, we must first determine the range to be considered. Expressing the level of attack in terms of the time at which 75% of the haulm is blighted, four categories of attack are identified. Using historical evidence, the probability of each level of attack occurring in the four main potato regions of the U.K. is given in Table I.

As well as the probability distribution of attack, the outcome associated with each strategy (no spray/spray) at each level of attack has to be determined. A physical pay-off matrix, that expresses these outcomes in terms of tuber yield is shown in Table II. Taking the price of potatoes as £40/tonne and

TABLE I

Probability distribution of blight attack (based on Large, 1958)

Region	Level of attack			
	θ_1 (Mid-August)	θ_2 (End of August)	θ_3 (Mid-September)	θ_4 (End of September)
South-west	0.5	0.5	0	0
Fens	0.4	0.2	0.1	0.3
Southern	0	0.5	0.2	0.3
Northern	0	0	0.5	0.5

TABLE II

Physical pay-off matrix (tonnes/ha)

Level of attack	Strategy	
	Unsprayed	Sprayed
θ_1	22	26
θ_2	26	28
θ_3	29	29*
θ_4	30	29*

* 3% loss by wheel damage.

TABLE III

Monetary pay-off matrix (£/ha)

Level of attack	Strategy	
	Unsprayed	Sprayed
θ_1	880	1,010
θ_2	1,040	1,090
θ_3	1,160	1,130
θ_4	1,200	1,130

spraying costs as £30/ha, this can be converted to a monetary pay-off matrix (Table III).

The average, long run profitability, or expected monetary outcome, of consistently adopting a no spraying or spraying strategy can now be calculated for each region (Table IV). It is found by summing, for each strategy, the product of the monetary outcome associated with each level of attack and the

TABLE IV

Expected monetary values (£/ha)

	Strategy	
	Unsprayed	Sprayed
South-west	960	1,050*
Fens	1,036	1,074*
Southern	1,112*	1,110
Northern	1,180*	1,130

* best strategy.

probability of this level of attack occurring. For instance, the expected monetary outcome of not spraying in the south-west will be

$$£[(880 \times 0.5) + (1040 \times 0.5)] = £960/\text{ha. (see Tables I and III)}$$

If farmers do opt for a particular strategy on the basis of its expected monetary value, Table IV suggests that it is rational to spray in the south-west and the Fens but not in the southern or the northern region. This will be true for all combinations of price and cost above the break-even line for each region, shown in Fig. 7. Since only θ_3 and θ_4 occur in the north, it would appear (from Table II) always unprofitable to apply control measures in this region.

Provided similar information can be obtained, the technique of decision analysis can also be used where there is a wider range of choice in protecting

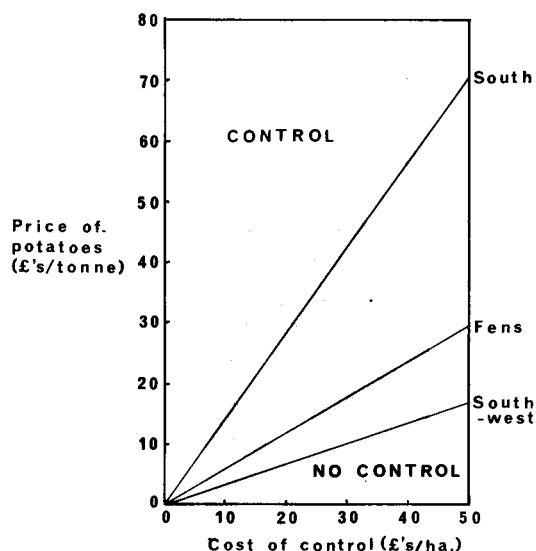


Fig. 7. "Break-even" lines for potato blight control.

against pest attack. For example, to choose a particular course of action from the decision tree shown in Fig. 4, one can attempt to determine the expected monetary value associated with each complete branch of the tree, and adopt that with the highest value.

Risk considerations

In selecting control strategies on the basis of their expected monetary value, however, it is necessary to assume that the decision maker is risk neutral as well as being a profit maximiser. In other words, he is assumed to be indifferent to the range of outcomes associated with each strategy, and his utility — which can be regarded as a quantitative measure of satisfaction — increases linearly with income. For many farmers this assumption is quite invalid. More often, they value initial increases in income far higher than later increases, and are said to be risk averse. For instance, if a farmer has just started farming and has little capital available, his primary goal is likely to be the achievement of a certain minimum level of income. Under these circumstances, he will assess crop protection strategies mainly in terms of their ability to meet this particular goal.

To illustrate the importance of risk, consider a risk averse farmer who grows potatoes in the southern region. We have already seen that the best strategy, having the highest expected monetary value, will be not to schedule spray (Table IV). However, if variable costs (excluding spraying costs) amount to £900/ha, the probability distribution of the gross margin obtained in any 1 year (gross margin = revenue – variable costs) can be estimated for each strategy. It can be seen from Fig. 8 that a wider range of variance is associated with the no spraying strategy compared with that for schedule spraying. Indeed, if the farmer also has to meet fixed costs of £160/ha, he has a 0.5 probability of making a loss of £20/ha, when sprays are not applied, compared with an equal chance of making £30 or £70/ha with schedule spraying. Since a loss could mean financial ruin, our risk averse decision maker will not hesitate to spray.

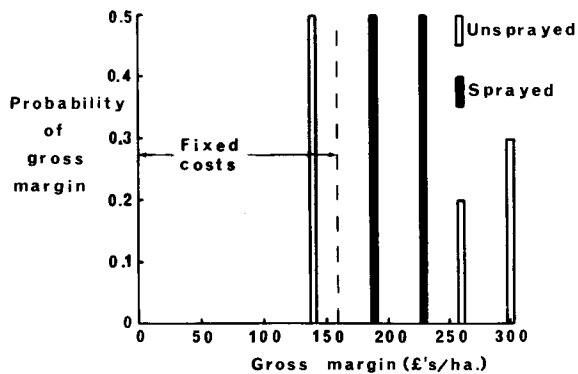


Fig. 8. Probability distribution of the gross margin for potatoes with and without blight control.

The satisficing approach

A decision is said to be subject to risk when the resulting outcome is not determinate but one of a range of possible outcomes. Consequently, risk associated with crop protection decisions can arise from other sources apart from an inability to determine the level of pest attack. Even where pest attack is monitored, as in the potato eelworm example, uncertain outcomes can arise from sampling errors in estimating the level of attack. Similarly, uncertainty can occur where there is inadequate information on the damage and control function, where the effect of agronomic and climatic variables on these functions is unknown, and where future prices and costs are difficult to estimate.

In many real life situations therefore, farmers will have only the vaguest idea of the probability distribution of outcomes associated with various control strategies. Under these circumstances, crop protection decision making will not be based on economic or decision theory analysis but will be more likely to occur through a process of trial and error, satisfactory control decisions being achieved through the rejection of those that were unsatisfactory in the past (Cyert and March, 1963). From this standpoint, a more descriptive analysis of crop protection decision making can be made. It consists of four components:

- (i) the farmer's goals,
- (ii) the range of crop protection measures he is to choose from,
- (iii) his perception of relevant information, and
- (iv) the inferences he draws from (i), (ii), and (iii) in deriving expectations and making appropriate decision rules.

From this viewpoint, the farmer first sets his goals and constraints and then searches for a satisfactory solution.

In some cases, a satisficing approach to decision making will obtain the same result as an optimal solution. This can occur where there are severe risk constraints, where the protective measure involves an all-or-nothing decision, where the optimal solution is insensitive to change, due to low insecticide costs, for example, or where the cost of obtaining data for optimisation is prohibitive (Strickland, 1966). In many other cases, however, there is likely to be considerable room for improvement, where research and extension services can make a contribution towards improved decision making.

PART II: THE IMPROVEMENT OF DECISION MAKING IN CROP PROTECTION

Satisfactory decisions are defined in terms of the initial aspirations of decision makers. When crop protection outcomes are thought to be unsatisfactory therefore, the first problem is to decide whether the goals to be achieved by crop protection are realistic. If they are, the next stage is to search for a means of improving decision making in the variables that affect the decision process. It is here that research and advisory programs can help. As

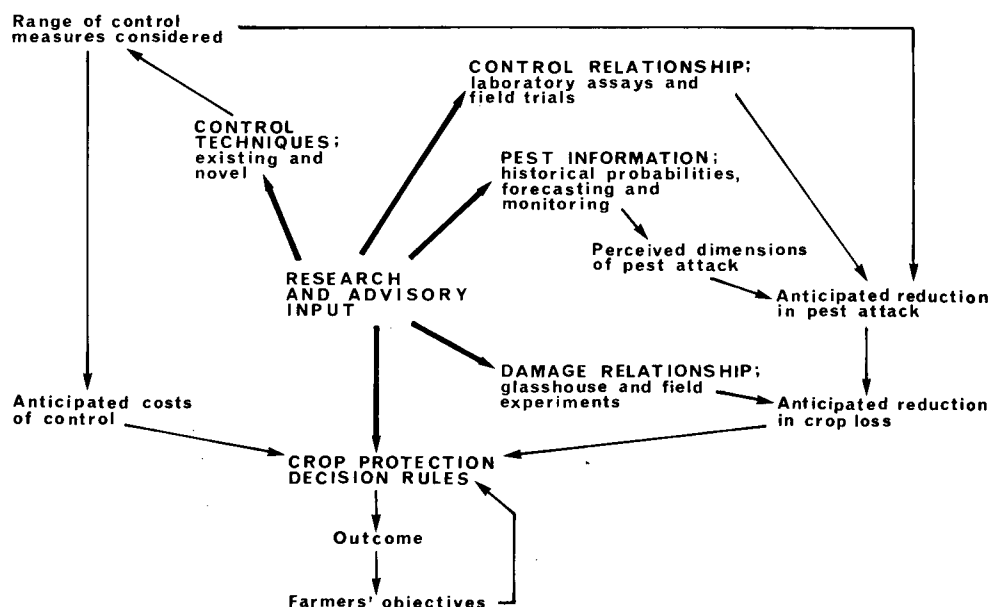


Fig. 9. The role of research and advisory programs in crop protection.

shown in Fig. 9, they can improve decision making in crop protection in three ways: they can (i) widen the range of crop protection measures available, (ii) increase the perception of relevant information, and (iii) improve the decision rules by which farmers operate.

(i) *Widen the range of choice.* — By encouraging the development of novel methods of control, new chemical products and formulations, and improved methods of application, government intervention can increase the overall range of crop protection measures that exist. To widen the range of choice available to a particular farmer, however, these measures must not only be brought to his attention but must also meet the constraints set by his farming system, his managerial ability and by other, external factors. Apart from increasing and advertising the number of alternatives therefore, the range of feasible choice can be augmented by reducing constraints and adapting new techniques to fit into existing cropping systems. Alternatively, where a farmer's goals act as constraints, choice can be increased by finding alternative means of achieving these goals. For instance, where pest attack is infrequent, public insurance schemes that reduce the risk element may obviate the need for regular, prophylactic treatment.

(ii) *Increase perception of relevant information.* — Information that is relevant to crop protection decision models falls into two categories: information on the component damage and control functions of the decision model, and

information concerning its variables — crop price, control costs and pest attack. We will concentrate here on the improvement of information on pest attack.

As already seen, pest attack can be defined in terms of initial numbers, numbers entering the crop at particular times, and the development of attack over the season. The importance of each of these variables in decision making depends upon the ease with which each can be measured and their importance in the decision model. This, in turn, will be determined by the nature of the damage function, the type of decision to be made, and the goals the farmer is aiming to achieve. Hence, different types of information are likely to be required at different times, depending on whether pre-emptive, schedule or economic threshold measures are to be taken. Similarly, where control measures are used to maintain gross margins above a minimum level, only sufficient information to determine if a particular strategy will meet this goal is required.

An increase in information on pest attack can be obtained by research and extension services from three sources: historical evidence, forecasting models and monitoring schemes. Historical evidence of pest attack can be obtained at a regional level (cf. Table I), as can forecasts of pest attack, based on such information as mean winter temperatures, spore numbers, and the size of over-wintering populations. Although the operation of monitoring schemes is usually the prerogative of individual farmers, extension services may also be involved in monitoring using field checks, trap counts, or climatic information to estimate the overall level of attack at a regional level. In addition, research effort can contribute to monitoring schemes in developing novel and more effective monitoring techniques. It has recently been demonstrated, for instance, that the potential level of slug attack on potatoes can be assessed by planting 'decoy' potatoes before the main planting (Symonds, 1973).

(iii) *Improve decision rules.* — With the protection measures and information available to him, a farmer has to decide on a strategy of crop protection. In making his choice, the farmer first has to consider what type of crop protection, if any, is to be applied, and then has to consider the time at which to apply it. In discussing decision models, and their improvement, it is useful to consider these two questions separately.

(a) What type of crop protection, if any, is to be applied this year?

When faced with a range of protection measures, as in Fig. 4, a farmer will assess their merits in terms of their ability to meet his particular constraints. He will consider the ease with which each control measure can be applied, its toxicological properties, the time at which it has to be applied and the extent to which it fits into his farming system. In addition, of course, the farmer will also consider the performance of each protection measure in relation to his goals, particularly in terms of the expected profit and risk associated with its use.

In attempting to assess the performance of a particular protection measure, the farmer is faced with a two-stage problem. The first stage is to identify the 'best' strategy to adopt against a particular level of attack. It involves making

an estimate of net revenue as a function of pest attack for each crop protection measure (cf. Fig. 5). With the available information on pest attack, the second problem is to decide on the 'best' strategy to adopt for a particular season. Clearly, the type of decision model a farmer can use in reaching this decision will depend on the information available. If a single estimate of attack is available, strategies can be chosen on the basis of their efficiency, using economic threshold models. Where the farmer can only estimate the probability of attack however, he has to rely on decision models similar to that described earlier for potato blight control. In this case his choice of strategy will be made on the basis of its contribution to expected profit and probability of loss.

In many cases, the decisions associated with this second model are unlikely to be much better than those derived from a satisficing model, based on the farmer's intuition and experience. Indeed, a significant improvement may only be achieved by obtaining a single estimate of pest attack, allowing an economic threshold decision model to be used. In determining whether it is worth it, an estimate of the potential value of such information can be obtained using decision theory analysis. To illustrate, consider the potential value of a potato blight forecast in deciding whether to schedule spray or not. From the monetary pay-off matrix (Table III) we have seen that it is profitable to spray when the level of attack is θ_1 or θ_2 but not when it is θ_3 or θ_4 . Since only θ_1 and θ_2 occur in the south-west and only θ_3 and θ_4 in the north (Table I), a forecast appears to be of no use in these regions for making this decision.

In the Fens and the southern region, however, there are years when sprays should be applied — when θ_1 and θ_2 occur — and years when they should not — when θ_3 and θ_4 occur. If a forecast were available, it would predict the level of attack and so enable the correct decision to be made each year. Since we have estimates of the probability distribution of attack in these two regions (Table I), we can calculate the value of having information in the form of a forecast of pest attack rather than as a probability distribution. Table V shows that the

TABLE V

Potential value of a forecast

Level of attack	Strategy	Outcome (£/ha) (from Table III)		Fens Probability (from Table I)	Southern Probability (from Table I)
θ_1	spray	1,010	X	0.4	0
θ_2	spray	1,090	X	0.2	0.5
θ_3	no spray	1,160	X	0.1	0.2
θ_4	no spray	1,200	X	0.3	0.3
Expected monetary value with forecast (£/ha)				1,098	1,137
Expected monetary value without forecast (£/ha) (from Table IV)				1,074	1,112
Potential value of forecast (£/ha)				24	25

potential value of a forecast in both the Fens and the southern region is estimated at approximately £25/ha/annum.

Apart from deciding whether to adopt crop protection or not, a single estimate of pest attack can also be of value in choosing between different methods and strategies of control. The extent to which this potential is realised however will largely depend upon the accuracy of the information obtained. If the estimation procedure is fallible, at least in the farmer's view, he will probably ignore the information and apply prophylactic measures each year. When a predictive or monitoring system is first introduced therefore, farmers are likely to continue with regular, prophylactic treatment until they are satisfied with its performance. This probably explains why bean growers have only recently begun to follow the recommendations of the forecasting scheme for black bean aphid, despite the fact that it accurately predicted when spraying was unnecessary over the first 5 years of its operation (Way and Cammell, 1973).

(b) When should protection measures be applied?

Where pre-emptive measures, such as a seed dressing, are to be adopted, the time at which they are applied is determined by other farm activities. For schedule measures and those adopted according to an economic threshold, however, farmers are likely to have a considerably wider choice of application times. Their decision on the time of application will depend upon the importance of temporal constraints, such as those set by the farming system, as well as the effect of time on the degree of control obtained.

Nevertheless, the application of schedule measures, particularly by risk averse farmers, will probably be the same each year, being timed according to the temporal dimensions of the worst possible attack. It is only where information on pest attack is available in the form of a single estimate therefore, that the time of application can be varied accordingly. In the forecasting scheme for black bean aphid, for instance, not only are overwintering eggs sampled in December and January but a second estimate is made in May, to assess the numbers of alatae on spindle prior to the migration on to field beans. If the winter forecast indicates that insecticide application will be necessary, this second forecast indicates the best time to apply it (Way and Cammell, 1973).

Where pest attack is monitored, there is likely to be even greater flexibility in the time of application. Since decision models based on an economic threshold criterion can be used in an iterative manner, protection measures can be applied whenever it is profitable to do so (cf. Stern et al., 1959). It is in considering the particular problems of assessing and improving these threshold criteria that the general need for including dynamic considerations in decision models becomes evident.

Dynamic considerations

Our analysis of decision making in crop protection has so far been implicitly

concerned with the decisions and outcomes occurring in one time period. In many situations however, crop protection decisions taken in one period can affect the level of attack in subsequent periods and can also reduce the measures available to control it. Chemical methods of crop protection, for instance, may not only produce an immediate reduction in the target population but may also influence subsequent levels of attack. This may occur through natural population dynamics or as a result of the chemical's effect on predators and parasites. At the same time, the use of such methods can lead to the development of pesticide resistance, reducing the effectiveness of that chemical in later periods.

To illustrate how dynamic factors can affect crop protection strategies, let us reconsider the case of potato cyst eelworm. Since eelworm attack builds up over time, DD is applied not only to achieve a yield increase in the current year but also to reduce attack in the following year. Using information available on the relationship between eelworm populations in 1 year and the next (Jones, 1973) and assuming that the price of potatoes will be the same in both years, the economic threshold illustrated in Fig. 5 can be modified to include the effect in the subsequent year. It can be seen from Fig. 10 that this 2-year threshold is 1 egg/g of soil, compared with a single-year threshold of 31 eggs/g. However, when egg numbers range from 1 to 15 /g of soil, it is in fact more profitable to delay control until the following year (Fig. 10). Above 15eggs/g of soil, treatment in both years is the most profitable strategy.

To incorporate such dynamic considerations in decision models requires comprehensive research programs, capable of bringing together the relevant biological, technical and economic factors involved. It is in this context that systems analysis may have a role to play. As well as demonstrating how these various elements interact, systems analysis can also determine the key elements affecting the outcomes of crop protection strategies (Conway et al., 1975).

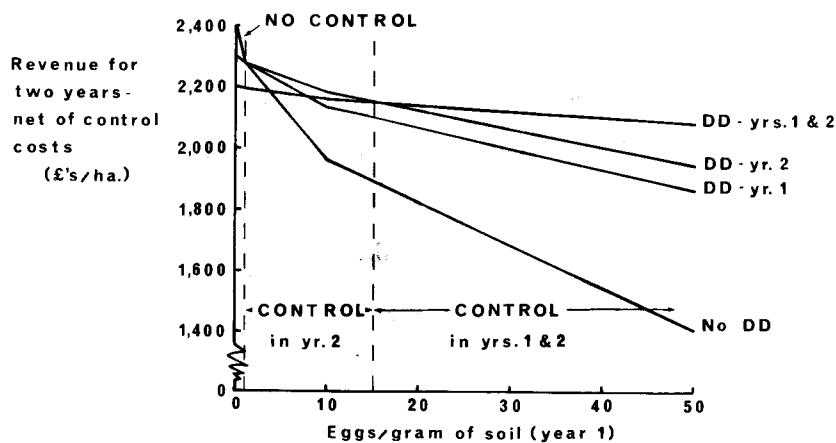


Fig. 10. Two year economic threshold for potato cyst eelworm and DD.

If dynamic factors are to be accounted for in crop protection strategies, however, not only must there be an awareness of the dynamic relationships involved but there must also be an institutional framework that allows appropriate action to be taken. For instance, a farmer who is well aware of the problems that can arise from encouraging pesticide resistance may still adhere to short-run strategies since any effort he makes to delay the development of resistance can be defeated through its development elsewhere. Similarly, control strategies that take account of the effect on subsequent levels of attack are only likely to be taken where future benefits are not dissipated by the short-run strategies of neighbours. In these circumstances, there are two ways in which government intervention can improve crop protection decision making. Either regional control strategies are undertaken by government agencies themselves, or a legal framework is created, through regional legislation or other means, within which individual farmers can expect to reap the benefits of long term strategies.

CONCLUSION

The protection of a crop against pest attack, as with the adaptation taken to other forms of natural hazard, is determined by

- (1) the decision maker's objectives,
- (2) his perception of the hazard,
- (3) the range of available protection measures, their cost and effectiveness, and
- (4) the decision rules employed by the farmer.

The extent to which decision making in crop protection can be improved depends on the particular constraints that operate. The farmer's limited perception of pest hazards and a lack of appropriate control techniques and decision rules can all be stumbling blocks to improved decision making. Programs aimed at rectifying this situation will only be successful where the nature of these constraints is identified and where the measures taken to reduce one constraint are designed within the context of those that remain.

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