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Decision Making in the Practice of Crop Protection

Monograph No. 25

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Preface

The three decades spanning 1950-1980 have seen the introduction of an armoury of effective chemicals for crop protection, better methods for their application, and considerable improvements in the accuracy with which the timing and severity of some pest and disease epidemics can be forecast. While success in farming now requires the use of modern methods of crop protection, evidence is accumulating that farmers are acting on inadequate information, both on the behaviour and the effects of weed, disease and insect pests on their crops and on appropriate control measures. In part, this information gap stems from the complexity of the biological interactions between crops and their pests, and partly from the wide choice of materials and methods for their control.

This Symposium was held because the numerous options now open to farmers do not appear to have been matched by the development of suitable aids to decision making. These aids are essential if farmers are to choose the most appropriate and cost-effective options. By drawing attention to the lack of such aids, it is believed that research and development aimed at providing them will be stimulated.

Of course, many crop protection measures can be planned well in advance, but some pests and diseases, and even weeds can reach epidemic proportions in a short time and require rapid and effective control if substantial crop losses are to be avoided. Using a military analogy, the two types of measures have been called 'strategic' and 'tactical'. Correct decisions, both strategic and tactical, require a range of types of information, effective systems of delivering it and aiding the farmer to use it.

The Symposium considered case studies of farmers' decision making and the role farmers' objectives, perceptions and beliefs had on the decisions made. It also considered sources of information, the value of information and, in this context, some developments in techniques for forecasting epidemics, including those based on computer models. Several papers considered decision making in the protection of particular crops, illustrating the complexity of the problems involved.

An important feature of the Symposium was a Conversazione at which a variety of computer-based aids to decision making were demonstrated. It has not been possible to describe these in detail in the proceedings. Whilst some were games and training aids, several computer-based systems had the potential for providing a means of implementing a cost effective crop protection programme, making best use of all sources of information. Such systems are likely to assume much greater importance in the future.

Thanks are due to all those who contributed to the Symposium. In particular, I wish to thank all the members of the Programme Committee for their help in organising the Symposium, and the session organisers for their assistance in editing the proceedings.

R. B. AUSTIN

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The decision making process

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Decision Making in the Practice of Crop Protection

CROP PROTECTION DECISION MAKING - AN OVERVIEW

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Summary Recent developments in the field of computing and electronic communication, as well as changes in the private and public advisory services, offer considerable potential for improving crop protection decision making. The extent to which this potential may be realised will depend on a number of factors, particularly the context in which information and advice is needed at the farm level. In considering the decision process by which farmers adopt the crop protection measures they do, this paper aims to show the practical value of studying the crop protection decision process. Two concepts that have particular relevance for research and extension activity - information gaps and adoption behaviour - are discussed in detail.

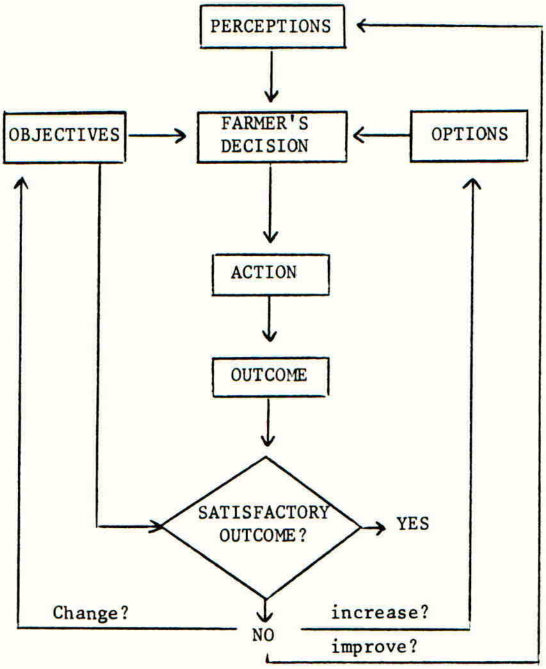
INTRODUCTION

Over the last few years there has been an increasing realisation of the need to focus more attention on the decision making process in crop protection, particularly when the present level of effort is compared with that devoted to chemical, technical, and ecological aspects. That this symposium on decision making has been organised reflects this increasing interest in the subject. However, when studies of decision making are undertaken and reported, there is often a misunderstanding on the part of the pest specialist, and indeed, sometimes on the researcher's part as well, of exactly how such studies can be of practical value in improving pest control decisions. My purpose, in attempting to provide an overview of the crop protection decision making process, is to indicate how the analysis of crop protection decision making can be of practical value.

Since decision making in crop protection is usually made at the farm level, this is the obvious place to start. The diagrammatic representation of how farmers make their crop protection decisions, shown in Fig. 1, is a simple but powerful model of the decision process. Three factors affect the decision that farmers make (Norton, 1976) - their options, their perceptions of pest attack, damage, and of control efficacy (cf. Mumford, 1982), and their objectives (cf. Tait, 1982).

According to this model, farmers, with their own subjective perceptions, try to choose an option, from those available to them, that will achieve an outcome that meets their particular objectives in a satisfactory way. Having made a decision, and adopted a particular pest control action, the outcome that results may or may not be satisfactory (Fig. 1). If the farmer is satisfied, he is likely to continue with the same strategy and is unlikely to be receptive to change. If he is not satisfied, he is likely to search for a means of improving the situation, by searching for other options, by improving his perceptions, or by changing his objectives.

Fig. 1. A model of crop protection decision making.



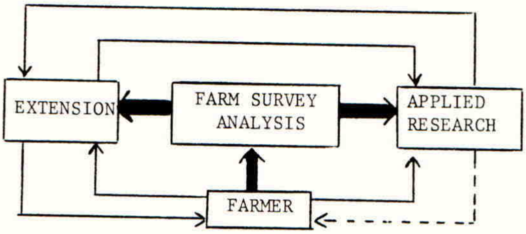
The findings of surveys of sugar beet growers (Mumford, 1981) and oilseed rape growers (Lane, 1981) indicate that this model gives an adequate explanation of why farmers adopt the crop protection measures they do. However, this does not answer the question whether such studies are simply of academic interest or whether they provide information that is valuable in a practical sense.

In attempting to answer this question, consider the situation portrayed in Fig. 2. Extension activities in pest control and, to a lesser extent, applied research carried out by the A.R.C. institutes and by universities, are undertaken in response to problems experienced by farmers. Thus, although there is a general awareness of farmers' problems, what I am arguing here is the case for a more detailed feedback mechanism. Just as industry employs market surveys and monitors product sales as an integral part of their business, so it is argued here that by complementing the existing feedback from the farmer (Fig. 2), appropriate farm surveys can provide information of value to decision making in applied research and in extension. Some of the contributions that farm surveys can make include the following -

(a) Identifying the range of crop protection measures used in practice,
(b) Assessing the feasibility of new techniques,
(c) Assessing the need for information at the farm level,
(d) Forecasting the decisions farmers are likely to take in the future,

(e) Providing realistic criteria for evaluating options.

Fig. 2. The role of farm surveys.



To illustrate how some, if not all, of these contributions can be made in practice, the remainder of this paper focusses on two major aspects of crop protection decision making - information gaps and adoption behaviour.

INFORMATION GAPS

The problem of improving crop protection decision making can, in many instances, be regarded as one of identifying and attempting to close an information gap that exists at the farm level: that is, a gap that exists between the information that is needed by the farmer to make good decisions and that of which he is aware (Norton and Mumford, 1982). To investigate this concept in more detail, we first need to consider three aspects - the types of information we are dealing with, the need for this information by the farmer, and how this information gets to the farm.

Types of Information

Information relevant to crop protection decision making can be classified under four headings:

1. Fundamental information, which is concerned with the basic technical, biological, and ecological processes that affect the damage caused by pests and the effectiveness of control actions.

2. Historical information, in the form of a record of past levels of attack and damage, which can be used to indicate trends in pest development and allow some probability of forthcoming attacks to be assessed.

3. Real-time information, that is collected by on-farm monitoring schemes or by regional surveillance, and concerns information on current pest status. Real-time information on pest attack and pest damage can be obtained by direct assessment or indirectly, through meteorological measurements.

4. Forecast information involving estimates of future levels of attack and damage, can be gained by combining the previous categories of information, often by means of a regression or more complex model.

The Need for Information

The extent to which farmers need these four types of information will largely depend on two factors - the decisions to be made and the objectives to be satisfied (Fig. 1). The type of information a farmer needs ideally, when making a particular crop protection decision, will depend on the specific options he is considering. For instance, in the decision tree portrayed in Fig. 3, the total need for information will be determined by the options considered, while the specific need for information will depend on the particular decision point under consideration. Similarly, the type of information, and the precision with which it is needed, will depend on the farmer's particular objectives. If he is averse to taking risks, for example, his main concern may be with estimating the lowest yield (or net revenue) outcome that each option could conceivably produce. A more detailed discussion of the value of information in crop protection decision making is given by Webster (1982).

Information Flow

Although farmers can often provide for their own information needs, by monitoring pest attack themselves for instance, our concern in this paper is with the role that research and extension agencies can play in helping to meet farmers' information needs. Clearly, once relevant information has been obtained, the extent to which this actually meets an information need depends on the flow of information from research and extension to the farmer (Fig. 2). This process of information flow can be considered as consisting of four stages:-

1. Information generation: the product of empirical and experimental research and extension activity, including field observations.
2. Information synthesis: this involves the collation and analysis of generated information and its interpretation for decision making purposes.
3. Information dissemination: the process whereby information is relayed to the farmer. It typically involves a number of channels, including pesticide labels, brochures, the farming press, personal advice, television and radio, demonstration plots, training courses, etc.
4. Information reception: although information may reach the farmer, it may not be received if it is in a form that is unclear, not particularly relevant to his problem, or not easy to use.

This concept of information flow, and its constituent stages, provides the context for identifying information gaps. To illustrate the idea, consider two pest problems where the information gap (that is, the shortfall of information between that needed by the farmer and that available to him) is the same. As shown in Fig. 4, the major cause of the final information gap for situation 1 (the open histograms) is a research gap and a synthesis gap: whereas for situation 2 (the closed histograms), the problem is due to a dissemination and a reception gap. Before attempting to close information gaps, it clearly is essential to determine which type of situation exists (Fig. 4) and which particular stage contributes most to the final gap.

An attempt to identify information gaps associated with pest control in winter oilseed rape is described by Lawson (1982). In this case, he concludes that a major cause of information not being available to growers is simply a lack of relevant information and not poor dissemination or poor

Fig. 3. Part of a decision tree for Black-grass control (after Moss, 1980).

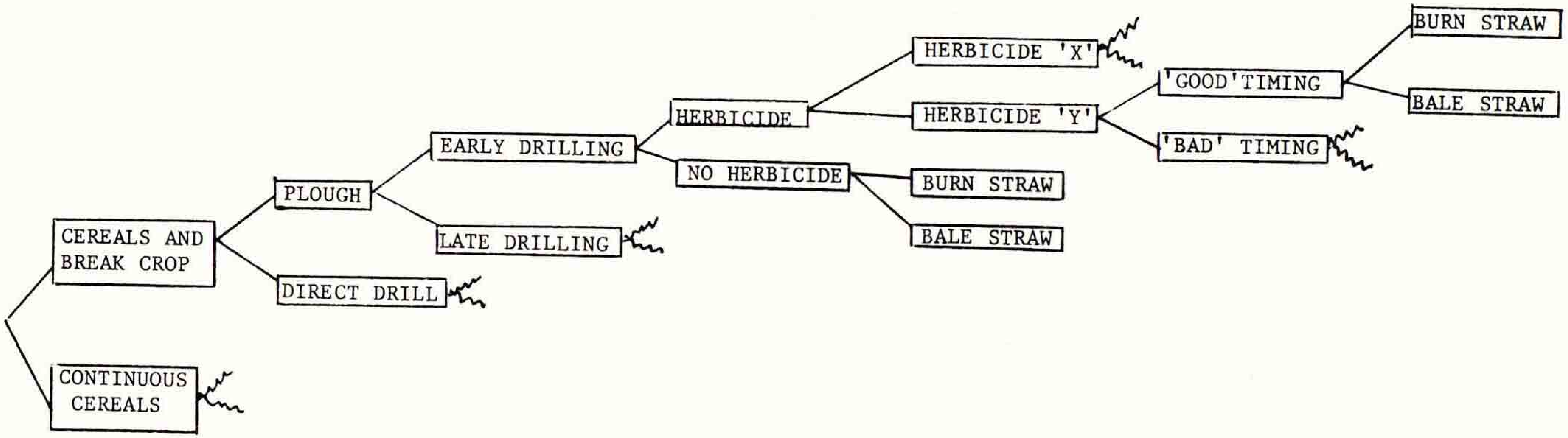
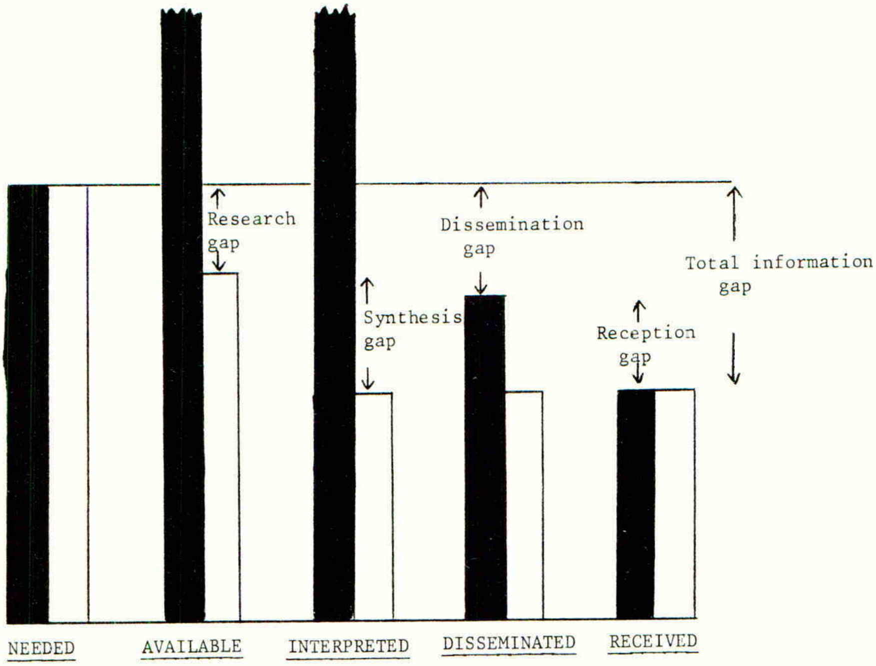


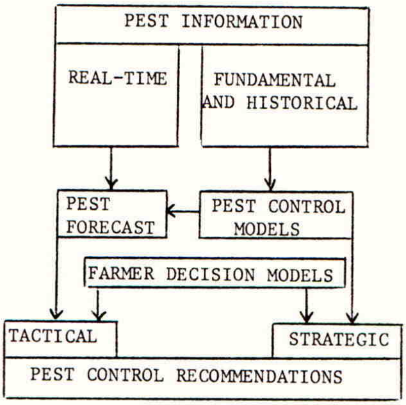
Fig. 4. The cause of information gaps for two, hypothetical pest situations. For further explanation, see text.



reception. The implication here then is that research on specific aspects is required. In other situations, perhaps where the pest problem is more established, a lack of synthesis may contribute most to the information gap. Here, computer models have a role to play, as indicated in Fig. 5. As well as providing information on which tactical pest control recommendations can be made (Rijsdijk, 1982), computer models can also be employed to make strategic recommendations (Sutherst, Norton and Maywald, 1981; Cussans, 1982).

Finally, in those situations where information dissemination and reception are the major cause of information gaps, improvements can be attempted by modifying the way in which the information is transferred. In this context, two recent developments are of interest, the establishment of the Association of Independent Crop Consultants in the U.K., and the development of Prestel, the British Telecom Teletext system. Judging by the success of independent crop consultants in the U.S.A., the developments of this private advisory service may well have a considerable impact on crop protection decision making in the U.K. in the future. As for Prestel, the role that it has to play in future crop protection decision making is by no means as clear, at least at this stage.

Fig. 5. The role of models in synthesising pest information



While the concept of an information gap provides a basis and rationale for at least some research and extension activity, the fact that information gaps are continually changing, as farmers adopt new production and pest control practices, means that appropriate changes are also required in research and extension. For instance, in the case of oilseed rape, the need for information on crop protection has changed over time and space as the area of crop has spread northwards over the past ten years, following Britain's entry into the E.E.C. (Lane, 1981).

ADOPTION BEHAVIOUR

While the adoption process of a new crop, such as oilseed rape in the U.K., has implications for crop protection research and extension activity, our attention is focussed here on the adoption process of crop protection practices themselves, and the implications this has for the likely implementation of new approaches. Although a number of factors affect this adoption process (Norton 1982), three main conditions under which adoption takes place can be identified:

(i) "Big Bang" implementation, where adoption is stimulated by the occurrence of trigger events that produce actual or potential outcomes that are unsatisfactory (Fig. 1). These trigger events may involve - (a) an increase in potential crop loss, (b) increased pest attack, (c) revolutionary technology becoming available or (d) the failure of existing control measures. As a rule, the adoption of resistant varieties and pesticides occur in response to trigger events (a), (b), and (c) (Norton and Conway, 1977), whereas integrated pest control programmes usually seem to require (d) (Way, 1977; Brader, 1979).

(ii) Incremental implementation, in contrast to the previous situation, involving a gradual shift from one control strategy to another, such as the gradual reduction in calendar spraying towards an integrated pest control strategy. From our understanding of farmers' behaviour (Fig. 1), an intensive promotional campaign is likely to be required to achieve this form of implementation, concentrating in particular on increasing farmers' perceptions of the benefits of integrated pest control.

(iii) Off-farm implementation, where government or private agencies, such as consultants, undertake pest control decisions on behalf of the farmer and, in some cases, may apply the control measures as well. Since incremental implementation of integrated pest control is likely to be difficult to achieve in the U.K., perhaps off-farm implementation, through private consultants, and possibly on a regional scale, offers most potential for the future.

CONCLUSION

This paper has been concerned with the relationship between applied research and extension activity in crop protection and the farmer. If improved crop protection decision making is to be implemented on the farm, techniques and information made available to the farmer must be appropriate to his problem and help him meet his objectives more effectively. In this context, the analysis of crop protection decision making has a valuable role to play in providing the feedback necessary for designing appropriate research and extension programmes.

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Decision Making in the Practice of Crop Protection

FARMERS' PERCEPTIONS AND CROP PROTECTION DECISION MAKING

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Summary This paper states the importance of farmers' perceptions, and their formation, in crop protection decision making. Several studies of such perceptions are discussed with emphasis on associations in the perception and control of pests that are not always biologically related. Possible reasons for such associations are presented, including experience with other pest-crop problems, and awareness of their solution through pest control practices. The idea of a key pest problem that influences crop protection decisions on the farm is put forth. Finally, some suggestions for improving decisions are made.

INTRODUCTION

Experience and information combine to give an individual a perception of a problem. This perception is not always a good representation of the real problem, however. The individual's preconceived attitudes to that class of problem, or to sources of information, may bias his interpretation of these inputs, or may limit or enhance the type of information he will seek, accept, and believe (Lawson, 1982). Each of these influences ultimately affects the decisions made through their effects on perceptions. This is true of crop protection decision making as in all other decisions.

Perceptions of the outcomes likely from possible actions are clearly of great importance in making choices, and even in framing the problem the decision maker is trying to solve. It is, therefore, essential for those interested in crop protection decisions to recognise what these perceptions are and how they are formed. The advisor, sales representative, or researcher must be aware of perceived farm problems and solutions before trying to influence the choices farmers make. As Norton (1982) states, surveys of farmers are a very useful way of providing this information to these groups.

This paper discusses several such studies of farmers' perceptions of pests and pest control, and offers some hypotheses on the development of these perceptions. In particular, emphasis is placed on possible reasons for associations between the perceptions of pests, and between control of various pests, many of which are unrelated biologically. Some implications of these associations and their possible causes are presented, along with some suggestions for improvement in crop protection decision making.

METHODS AND MATERIALS

Several surveys covering farmers' perceptions of a range of pests and/or their actions to control pests have been reported in the literature and will be discussed below. Tait (1977, 1978a, b) gives information on personal interview surveys of 42 vegetable growers and 54 fruit growers in England in which their use of insecticides and fungicides on different crops is compared. Mumford (1982) presents data from two postal surveys on perceptions of weeds, insects, and diseases of arable crops and their control by 258 responding farmers in New Zealand and 111 in England. The methods of these surveys are given in detail in the works quoted.

RESULTS AND DISCUSSION

In her surveys, Tait (1977) found that insecticide and fungicide use by her respondents varied much more between farmers than between crops on the same farm. This occurred despite differences in actual pest problems in these crops. Also, in the case of potatoes, she found that the use of insecticides and fungicides was generally associated, despite the conditions promoting aphids (hot dry weather) and potato blight (cool wet weather) being in direct contrast.

Mumford (1982) also found that the use of different groups of pesticides on farms was associated. Participants in two surveys were asked if they had used herbicides, insecticides, or fungicides on each of their crops during the previous season(s). Table 1 shows some of the associations found between the use of herbicides and other pesticides. In the New Zealand survey approximately 80% of the responding farmers had used some herbicides on their farms during the previous season. Among those using herbicides, 40% also used insecticides and/or fungicides on some crops, while among those not using herbicides only 9% used insecticides or fungicides. This general relationship was also seen for individual crops. In the English survey, herbicides were used by almost all farmers on each of their crops except potatoes, so it was not possible to make a valid general comparison between herbicide users and non-users. On potatoes, however, one third of the growers did not use herbicides during the previous three years. Of the herbicide users, all but one used insecticides or fungicides on potatoes as well, while 30% of the non-users of herbicides did not use insecticides or fungicides on potatoes.

Table 1.

The use of herbicides and insecticides and/or fungicides; during the previous season on any crops on farms in New Zealand survey, and during a three year period on potatoes only in English survey

New Zealand

	Insecticides and/or Fungicides	Herbicides	
		Used	Not used
Any crop on farm	Used	84	4
	Not used	128	42
		$X^2 = 16.1$	$p<.001$

England

		Used	Not used
Potatoes only	Used	44	16
	Not used	1	7
		Fisher's exact test	$p = .0015$

There are thus two types of associations that have been found with pesticide application. First, different crops on the same farm tend to be treated similarly (that is, pesticide applications tend to be uniformly high or low among the different crops). And second, individual crops are often treated similarly for weeds, insects, and diseases (ie, if a crop is treated with one type of pesticide, for instance a herbicide, it is more likely to be treated with another, either insecticide or fungicide).

Several factors have been presented to help explain these associations. Tait (1977) mentions the use of standard operating procedures as one such factor. By adopting standard treatment programmes a farmer can greatly reduce the decision making time allotted to crop protection. This may be quite sensible, considering the relative value of devoting limited managerial resources to crop protection compared to other, sometimes more critical, farm management decisions. Another factor that may be important in respect to these associations is the risk attitude of the farmer, discussed by Mumford (1981a) and Tait (1978b, 1982).

A third factor that may contribute to such associations of chemical use (or, on the other hand, may simply arise from them) is that the relative perceived hazards the various pests pose to each crop are also positively associated. Results from several surveys suggest that there are, in fact, such associations.

In both the New Zealand and English surveys noted earlier, respondents were asked to give estimates of the worst and normal losses they expected from weeds, insects, and diseases on each of their crops. Normal losses in all cases were estimated to be quite low, while estimated worst losses had a wide range for most crops (Mumford, 1982). Most farmers responded positively to a separate question that it was more important to consider the worst possible losses than normal losses when deciding on a spray operation.

For each geographical region in which the surveys were conducted, two provinces in New Zealand and two counties in England, the median estimate for worst losses from weeds, insects, and diseases on each crop was determined. Each respondent's estimate for each pest-crop combination was then classified as above or equal/below this median. The estimates were then compared using Chi-square analysis to see if the positions of the respondents' various estimates with respect to the regional medians were, in fact, associated.

Table 2 (adapted from Mumford, 1982) shows positive associations found between estimates of losses (relative to regional medians) from different pest types on almost all crops. So, for example, among respondents to the survey in England who grew winter wheat there was a significant tendency to estimate both weed and insect losses either above or below their respective regional medians, and similarly for weeds and diseases, and insects and diseases. In the English survey the losses from diseases caused by viruses in sugar beet are included with insects since they are vector borne and control can only be aimed at the vectors.

Table 3 (adapted from Mumford, 1982) shows similar positive associations between losses estimated for weeds, insects, and diseases in the most commonly grown crop in each area surveyed (winter wheat in England, spring barley in New Zealand) and losses for those respective pest groups in each of the other crops grown. So, for example, respondents in England who estimated losses from weeds in winter wheat to be greater than their regional median were significantly more likely to estimate weed losses in their other crops higher than the median, and *vice versa*. In general, if pest losses were estimated higher than the regional median in the main crop, then there was a significant tendency to

Table 2

Positive associations of worst loss estimates (relative to regional medians) as determined by Chi-square analysis ($p<.05$)

	Weeds-Insects	Weeds-Diseases	Insects-Diseases
England 1980			
Winter Wheat	X	X	X
Winter Barley	X	X	X
Spring Barley	X	X	X
Sugar Beet	X	-	-
Potatoes	X	X	X
New Zealand 1979			
Winter Wheat	X	X	X
Spring Wheat			X
Spring Barley	X	X	X
Ryegrass Seed	X	X	X
Clover Seed	X	X	
Peas		X	X

Table 3

Positive associations between worst loss estimates (relative to regional medians) in main crops and other crops grown, as determined by Chi-square analysis ($p<.05$).

	Winter Wheat - England		
	Weeds	Insects	Diseases
Winter Barley	X	X	X
Spring Barley	X	X	X
Sugar Beet	X	X	X
Potatoes	X	X	X

	Spring Barley - New Zealand		
	Weeds	Insects	Diseases
Winter Wheat	X	X	X
Spring Wheat	X	X	X
Ryegrass Seed	X	X	X
Clover Seed	X	X	X
Peas	X	X	X

estimate pest losses in each of the other crops as higher than the regional median for that crop.

It has already been mentioned that standard operating procedures arise to save time and managerial effort. Attitudes to risk are intrinsic components of individuals' psychological makeup, arising from complex interactions of personal and social influences. Perceptions arise from direct experience and indirect information on a subject, often filtered in the mind to produce a consistent view of the subject.

There are several possible ways in which perceptions of pest hazards could be formed, some of which could contribute to the associations previously noted. These could include:

1. 'Experience' (either direct or indirect, and not necessarily correctly interpreted or remembered) of a pest on a crop.
2. 'Experience' of the same or similar pests on another crop.
3. 'Experience' of different pests on the same crop.
4. Awareness of solutions to pest problems on crops.

Where an individual has had direct experience of a pest problem his estimate of losses is likely to be quite good, as in the case of estimating normal losses from insect pests in sugar beet (Mumford, 1981b). To estimate worst losses, however, an individual can not always rely on direct experience, since worst losses are, by their nature, rare events often not yet experienced. An individual may have to use some indirect means of estimating such losses, possibly a channel from a body of wider experience, such as the farm press or advertising. Unfortunately, the necessary use of such indirect information can introduce perceptions of problems that are not actually relevant to the individual's specific circumstances (Leeks and Mumford, 1982).

In many cases, certain pests or groups of pests, for instance the family of aphids, attack many different crops. It is possible that the perception of the threat to one crop will be affected by the perception of the threat to other crops, as it is natural to imagine the same sort of pest causing rather similar damage in all cases. Similarly, if a crop is perceived to be under threat from one type of pest, an individual's consciousness of the need to protect that crop from other pests may be heightened.

Finally, the awareness of the range of available solutions to pest problems, particularly pesticides, may contribute to different pests being perceived similarly. The current widespread use of tank mixes of pesticides, for instance, gives the farmer the chance to deal with biologically unrelated weed, insect, and disease problems simultaneously with a common solution, a mixture of farm chemicals. Even without tank mixes, however, the possibility of controlling most pest problems with the same spray rig, and with chemicals that are bought, handled, and used very similarly, may contribute to a generalised perception of pests that does not differentiate between their relative threats very well.

If pests are often perceived in general terms, it is not surprising to see results such as those in Table 3, in which perceived pest hazards in the secondary crops are all positively associated with those in the main crop. Coupled with the associations seen in Table 2 between different types of pests, it is possible to postulate that there is a key pest problem in the minds of farmers in a region, for instance weeds in winter wheat in England. It is possible that an individual's perception of, or concern for, that key pest problem will be reflected in his view of almost all other pest problems on the farm.

CONCLUSION

In conclusion, some of the implications of these factors that affect crop protection decisions should be recognised by researchers, advisors, and commercial interests. This is particularly so if they wish to influence crop protection decisions to promote more economical and more ecologically based pesticide use.

Crop protection decisions need to be made easier, to lessen the adoption of standard operating procedures for pest control. This could include the development of simple monitoring and economic threshold rules, or forecasting systems. Alternatively, the greater use of commercially provided advice (as from crop consultants) could put the complex pest problem in the hands of specialists, leaving the farmer to concentrate on other management problems.

Alternative ways of satisfying individuals' risk attitudes may need to be developed. For the risk averse individual, insurance schemes, or again specialist crop protection advice, may allow the farmer to have peace of mind without so much chemical treatment, and at lower cost. On the other hand, in cases where regional control is beneficial it may be advisable to penalise or control the risk taker who doesn't spray when he should.

To reduce possible undesirable treatments (or encourage those that may be lacking arising from associated perceptions of pest problems, it may be useful to undertake greater efforts to provide information that clearly differentiates pest problems. More localised and specific information could reduce the uniformity that arises if all information on pests that a farmer receives is from aggregated regional or national data. Care may also be needed in promoting the application of mixtures of chemicals, which may inadvertently result in unnecessary applications of some products, based on their perceived ease of use rather than real need.

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Decision Making in the Practice of Crop Protection

INFORMATION FLOW AND CROP PROTECTION DECISION MAKING

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Summary The flow of pest control information from the various dissemination channels through to its use by farmers is investigated for the specific case of insect control decision making in UK winter oilseed rape. The farmers' perception of the trust, clarity and relevance of the various information channels appear to affect where they go for insect control advice. Farmers either make their own spray decisions, or rely on pesticide dealers and oilseed rape contracting companies. Both groups of farmers have the same insecticide usage. In general, farmers' knowledge of key items of insect control information is related to the number of channels disseminating that information. However, certain categories of information, particularly information on economic thresholds, are not well known despite being widely disseminated. In terms of insecticide usage, it is suggested that the uncertainty resulting from the lack of basic information on insect/crop interactions is relatively more important than the channels through which pest control information reaches the farmer. Ecological information on the possible harm to bees by spraying during flowering is the only key item of insect control information known by all the farmers

INTRODUCTION

The pest control decision made by a farmer is influenced by a crop protection industry which involves not only a variety of technologies but also public and private investment, regulatory authorities and the media. The complexity of this background, coupled with the dynamic and variable nature of pest infestations, places heavy reliance on the efficient flow of information.

The value of information to the farmer lies in reducing the uncertainty surrounding his pest control decision. Ideally, information on the costs and benefits of any control option would be available, and the farmer could select that option most suited to his objectives and constraints. In practice, inadequacies in the generation and flow of information mean that such an economic analysis is usually not possible (Norton, 1976).

Few studies have been made of the channels through which farmers receive their information. Sheppard (1965) investigated which communication methods were considered by government advisers to be most effective, while Gibbons and Sheppard (1965) reviewed the effectiveness of different information channels in reaching farmers. Since the information content and presentation of the various channels are likely to differ, it might be expected that which channel a farmer used could also influence his pest control decision. For instance, Turpin and Maxwell (1976) concluded that corn farmers in Indiana, who used pesticide dealers as the primary information source, tended to use pesticides more than those who used the county agent. In contrast, Tait (1978) found that with fruit and vegetable growers in the UK there was no evidence that commercial sources of advice (including manufacturer's representatives) were acting to increase pesticide usage by farmers.

The nature of the information can change at each stage in its flow due to the processing biases of the recipient, whether scientist, adviser or farmer. In the context of business planning and forecasting, Hogarth and Makridakis (1981) have extensively reviewed the various biases that can occur. Some of the biases most relevant to the present study include:

- selective perception of information which is in agreement with the recipient's experience and anticipations.
- ease of recall of information
- frequency, mode (written or verbal) and clarity of the presentation.

To these should be added the perceived relevance of the information to the recipient's objectives, and the perceived competence, values and aims (i.e. trustworthiness) of the source from which the information comes.

The present study is concerned not only with the channels of information flow, their information content and their possible influence on the farmer's pest control decision, but also with the farmers' perception of the clarity, trust and relevance of the different channels. The information flow for insect control in winter oilseed rape (swede rape - Brassica napus) is used as a case study. This crop has now achieved an important position in the arable farm rotation, following a rapid expansion after the mid 1970's (Lane, 1981). The speed of this expansion has left comparatively little time for research work on the pests and their control. The resulting uncertainty has perhaps been compounded by the switch from spring oilseed rape, for which some of the earlier pest control recommendations were developed.

MATERIALS AND METHODS

The following surveys were conducted during Summer 1981 to identify the pest control information content of the main channels of information used by oilseed rape farmers (Lane, 1981)

- collection of all relevant booklets, pamphlets etc. produced by ADAS.
- written requests to all pesticide manufacturers for leaflets on insecticide application recommendations and pest control in oilseed rape.
- collection of pesticide labels.
- interview survey of 6 B.A.S.I.S. registered pesticide dealers and oilseed contracting companies in Northants for verbal and written information which they provided to farmers.
- collection of pamphlets produced by the major oilseed rape companies for whom farmers may choose to grow their crop under contract.

The reception of information by the farmer was covered in an interview survey of 15 randomly selected farmers in Northamptonshire who grew oilseed rape during 1980/81. The farmers were interviewed on their farms. The farms ranged in size from 57 ha to 810 ha, with a range of oilseed rape areas from 4 ha to 92 ha, and the farmers had from 1 to 17 years experience in growing rape. Full details of the surveys are given in Lawson (1981).

With any pest control problem there is likely to be a set of key questions on which farmers need information if they are to make a rational control decision. The following key items of information about the pests of oilseed rape were selected after a review of the literature (Alford, 1977, 1979; Alford *et al*, 1979; Free and Williams, 1978; 1979 a,b; Gould, 1975; Graham, 1981; MAFF, 1981; Tatchell, 1977; Williams and Free, 1978, 1979; Winfield, 1961)

- names of the four most important insect pests (cabbage stem flea beetle *Psylliodes chrysocephala* (L), pollen beetle *Meligethes aeneus* Fab., seed weevil *Castorhynchus assimilis* Payk., pod midge *Dasineura brassicae* Winn.)
- recognition of the two insect pests most prevalent at flowering (pollen beetle, seed weevil).
- appreciation that pod midge is mainly a headland pest.
- appreciation that the exit hole bored in the pod by the emerging seed weevil larva can be used by the pod midge for laying eggs inside the pod
- knowledge of the ADAS recommended economic thresholds for cabbage stem flea beetle, pollen beetle and seed weevil.
- appreciation of the ability of the rape plant to compensate for pollen beetle damage early in flowering.
- appreciation of the possible yield losses that could be caused by the four main insect pests.
- knowledge of possible harm to bees by spraying during flowering.

RESULTS

Information disseminated by information channels

The extent of dissemination of different key items of information by various categories of organisations is shown in Table 1. Within each category, the number of organisations that disseminated a particular item of information is expressed as a percentage of the total number of organisations in that category. ADAS was put in a group by itself and so scored either 0% or 100%. Variations in information disseminated could result, for example, from differences in interpretation or from differences in objectives.

The written information from ADAS covered all the key information items, although not all in a single pamphlet. The contracting companies provided a wider range of information than the chemical companies. In particular, they provided more information on economic thresholds and the relative unimportance of pollen beetle. However, in common with the chemical companies, they tended not to mention the seed weevil/pod midge relationship, or that pod midge damage was mainly at the headlands. When this was discussed with the contracting companies, it was found that they dropped this information due to field experience to the contrary.

Verbal information on nearly all items was provided by most dealers, although it could not be assessed how much emphasis was placed on each item.

Information was disseminated by all sources on the possible harm to bees caused by spraying during flowering.

Information received by the farmers

The 15 farmers in the Northants survey were asked how frequently they received written or verbal information from different sources. Table 2a shows that the most frequently received written information was once a month from ADAS, contracting companies and the press. ADAS produce a monthly newsletter for Northants farmers, covering many subjects in addition to oilseed rape.

Table 1

Percentage dissemination of information by various categories of organisations

Information		Written			Verbal
		ADAS	Contracting companies	Chemical companies	Dealers
Names	CSFB[1]	100	100	100	100
	PB[2]	100	100	100	100
	SW[3]	100	100	100	100
	PM[4]	100	100	100	100
Recognise	PB	100	100	33	100
	SW	100	100	100	100
Headlands	PM	100	0	33	80
Relation	SW/PM	100	67	33	100
Economic thresholds	CSFB	100	33	0	N/A[5]
	PB	100	100	33	N/A
	SW	100	67	33	N/A
Least sig.	PB	100	67	0	100
Harm to bees		100	100	100	100
Plant compensation		100	0	0	60

Note:
1. Cabbage stem flea beetle
2. Pollen beetle
3. Seed weevil
4. Pod midge
5. Dealers not asked

Items on oilseed rape pests were generally warnings to look for particular pests. Eighty percent of farmers interviewed said that dealers did not provide written information. However, the distinction between some dealers and contracting companies was confused, since the larger dealers contracted to buy seed after harvest, and may have been regarded as contracting companies by some farmers. No written information reached the farmers as frequently as once a week. This shortcoming may be alleviated with the current development of Prestel services by ADAS (Craig, 1979) and the pesticide industry (Anon, 1981).

Verbal information (Table 2b) was most frequently received from other farmers, dealers and contracting companies. Nearly 50% of farmers received weekly information from their neighbours, mainly real-time information on current pest infestation levels in the area. Although farmers were found to have a low level of trust in this information, they did use it as a warning to scout in their own fields. Verbal information from dealers and contracting companies came mainly during visits by fieldmen. ADAS reached only 13% of farmers with verbal information, in contrast with their comprehensive coverage with written information. Verbal and written information from the chemical

Table 2a

Percentage of farmers receiving written information

Source	once/week	once/month	once/season	once/year	Never
ADAS	0	74	13	0	13
Other farmers	0	0	0	0	100
Dealers	0	7	7	7	79
Chem. companies	0	0	27	13	60
Contracting companies	0	40	20	0	40
Press	0	46	40	7	7

Table 2b

Percentage of farmers receiving verbal information

Source	once/week	once/month	once/season	once/year	Never
ADAS	0	7	7	0	86
Other farmers	47	13	13	7	20
Dealers	13	27	27	0	33
Chem. companies	0	13	13	0	74
Contracting companies	0	40	13	0	47
Press	0	0	0	0	100

companies was received by 26% and 40% of farmers respectively, the lowest combined total of any of the information sources.

Weighting of information received by the farmers

The clarity, trust and relevance of information on pest control in oilseed rape received from various sources was scored by farmers on a scale from 1 - 5. The responses from farmers who made their own spray decisions were separated from those who were advised by dealers or contracting companies. Using the mean scores achieved, the information channels were ranked for clarity, trust and relevance (Table 3), and the significance of differences within ranks and between ranks assessed using the Mann-Whitney test.

The clarity of information from the various channels was ranked rather uniformly by both categories of farmers. Only the top and bottom ranked channels

Table 3

Ranking of Information Sources for Clarity, Trust and Relevance, According to the Source of Spray Advice

			Source of Spray Advice			
	Rank		Self		Dealer/Contractor	
Clarity	1	A[1]	ADAS		Contractors	B[1]
	2	A	Contractors		Dealers	
	3		Farmers		ADAS	
	4		Dealers		Farmers	
	5		Chemical Cos.		Chemical Cos.	
	6	a	Press		Press	b
Trust	1	A	ADAS	*[2]	Dealers	B
	2		Contractors		ADAS	B
	3		Chemical Cos.		Contractors	
	4	a	Farmers		Press	b
	5	a	Press		Chemical Cos.	b
	6	a	Dealers		Farmers	b
Relevance	1		Contractors		Dealers	B C
	2		Farmers		Contractors	b C
	3		ADAS		Farmers	b
	4		Dealers		ADAS	b
	5		Chemical Cos.		Chemical Cos.	b
	6		Press		Press	b c

Notes: 1. Channels marked with upper-case letters scored significantly ($P<0.10$) higher than those with lower-case letters in the same rank.

2. Channel marked * was scored significantly ($p<0.10$) higher by farmers advised by dealers or contracting companies than by self-advised farmers.

had significantly different scores, with the press regarded as less clear than the contracting companies by both categories.

For trust, ADAS scored significantly higher with self-advised farmers than the three bottom ranked channels, although not significantly higher than the contracting companies and chemical companies. For farmers advised by dealers or contracting companies, both the dealers and ADAS scored significantly higher than the three bottom ranked channels. Dealers, who were ranked bottom for trust by self-advised farmers, were ranked top by those advised by dealers or contracting companies. This difference in trust was significant ($p<0.10$), and provided the main contrast between the two categories of farmers. When the mean number of insecticide applications for the two categories of farmers were compared, it was found there was no significant difference between those farmers who relied on the dealers or contracting companies for advice (0.71 applications/farmer) and those who made their own decisions (0.75 applications/farmer).

Self-advised farmers scored all channels of information as equally relevant to their pest control problems (no significant differences between scores). This contrasts with farmers advised by dealers or contracting companies who scored dealers as significantly more relevant than all other sources ($p<0.10$). These farmers also scored contracting companies as significantly more relevant than the press.

Farmers' knowledge of key information received

Table 4 shows the percentage of farmers who were aware of the individual key items of information. The results indicate that except for seed weevil, the names of the pests were relatively well known. However, more farmers could name the pests than could recognise their photographs, particularly for seed weevil, where only 1 in 3 farmers could identify it successfully. Knowledge of economic thresholds was also poor, particularly for cabbage stem flea beetle. In contrast, the possible harm caused by insecticides to bees was known to all the farmers.

Virtually no information was disseminated by any of the information channels on the possible yield losses caused by the different pests. Accordingly, knowledge of yield losses was restricted to whether the farmers knew that pollen beetle was the least important of the four main pests. Although 27% of the farmers interviewed were unaware of this, none of them actually sprayed against pollen beetle. This absence of spraying against pollen beetle was confirmed by a larger survey (Lawson, 1981) where only 4% of insecticide sprays were against pollen beetle, compared with 66% against seed weevil/pod midge and 30% against cabbage stem flea beetle.

Plant compensation is an important feature that reduces pollen beetle damage, and it is perhaps not surprising that 53% of farmers appeared aware of this feature (Table 4). However, this result needs explanation. When farmers were questioned further, it was clear that very few had considered plant compensation from the point of view of insect damage. After consideration of the plant's response to other forms of damage, several farmers concluded that some compensation for early insect damage could occur.

None of the individual key items of information was significantly ($p<0.10$) better known by farmers who made their own spray decisions than by those who relied on dealers or contracting companies for advice. This result is unexpected, particularly for information about economic thresholds and pest recognition.

Table 4

Comparison of farmers' knowledge with information disseminated

Information		Farmers knowledge (%)	Dissemination index (%)
Names	CSFB[1]	73	100
	PB[2]	87	100
	SW[3]	60	100
	PM[4]	93	100
Recognise	PB	73	75
	SW	33	100
Headlands	PM	27	50
Relation	SW/PM	73	75
Economic thresholds	CSFB	0	33
	PB	27	71
	SW	20	57
Least sig.	PB	73	53
Harm to bees		100	100
Plant compensation		53	33

Note: 1. Cabbage stem flea beetle 3. Seed weevil
2. Pollen beetle 4. Pod midge

Comparison of knowledge with information disseminated

It might be expected that farmers' knowledge of particular items of information relates, in part, to the number of organisations providing the information, the mode of delivery (verbal or written) and the nature of the the information (entomological, chemical, ecological, financial etc.). An initial attempt to correlate information disseminated with farmers' knowledge is made in Table 4 by calculating a 'dissemination index' for each item of information. This index is the number of sources providing any particular item, expressed as a percentage of the total number of sources that would be expected to provide that information (Lawson, 1981).

In general, high values for farmers' knowledge of a particular item coincide with a high dissemination index. The extreme case is the ecological information on the threat to bees. Not only is this mentioned by all sources, but farmers' appear to remember it more readily than even the names of the major pests. This knowledge carried over into the pest control action since all farmers who intended to spray waited until flowering was nearly complete.

The inability of farmers to recognise the seed weevil cannot be attributed to a lack of disseminated information (Table 4). One explanation may be that at flowering, the infestation of pollen beetles is generally much higher than that of seed weevils. Unless a deliberate search is made for seed weevils, they can easily be overlooked. Sixty seven percent of farmers who made their own spray decision could recognise seed weevil, compared with 14% who were advised by dealers or contracting companies. Pollen beetle was recognised equally well by both categories.

The tendancy of pod midge damage to occur mainly at the headlands was not well known, and this may be partly attributed to the lack of written information. However, some farmers and dealers said that they had experienced pod midge damage away from headlands. This uncertainty may mean that the information is not disseminated as positively as it could be. The seed weevil/pod midge relation was also questioned by some farmers who said that pod midge eggs could be laid in the flower or in wind damaged pods, as well as through the seed weevil exit holes.

Knowledge of economic thresholds was relatively poor. During informal discussion with the farmers it appeared that spray decisions were made more on their perception of previous experience than on the ADAS recommendations.

Additional factors related to farmers' knowledge

Apart from the information disseminated, other factors are likely to affect farmers' knowledge. Some of the more important factors covered in the survey are discussed below.

Source of spray advice   Farmers who made their own spray decisions had a higher mean knowledge of the 14 key items of information than those who received advice- 9.50 ± 0.76 S.E. compared with 7.43 ± 0.95 S.E. Although in the expected direction, this difference is significant only at $p<0.13$.

Experience growing oilseed rape   The number of years' experience in growing oilseed rape was positively correlated with knowledge of key information items (linear correlation significant at $p<0.05$). The fact that 73% of farmers started growing oilseed rape within 3 years of each other prevented a more detailed study being made. This uneven distribution results from the rapid expansion of rape growing in Northants following the UK entry into the EEC (Lane, 1981).

Size of farm   Farmers' knowledge was positively correlated with the size of their farms (linear correlation significant at $p<0.02$)

DISCUSSION

Farmers fell into one or two categories regarding their attitudes towards information. The first category covered those farmers who made their own spray decisions. They regarded all information sources as relevant to their decision problem, but tended to place more trust in the information they received from the larger organisations (ADAS, contracting companies and chemical companies). They had a higher knowledge of the pest problem than the second category of farmers, who relied on dealers and contracting companies to advise them on their pest control decision. Farmers in the second category rated their advisers highly in terms of relevance and trust, implying that they were satisfied with the service they were getting. Since there was no difference in insecticide usage between the two categories, this confidence seems justified.

Both categories came to similar control decisions, but after receiving information through channels suited to their individual preferences. It could be argued that since the channels of information flow did not appear to influence the control decision, the crucial factor was the generation of information. If so, it is the lack of knowledge about the pest/crop interaction which is likely to be the main obstacle to improved pest control. For example, since almost no information was available on yield losses caused by seed weevil and pod midge, farmers either had no idea what the losses were or perceived them as being high (Lawson, 1981). Whether or not these perceptions were reasonable, approximately two-thirds of all insecticide applications were against these two pests. In contrast, sprays were rarely applied against pollen beetle for which a large amount of information is available on its relative lack of economic significance. This is despite the fact that pollen beetle is a widespread and highly visible pest.

Farmers who relied on dealers and contracting companies tended to have less experience of growing oilseed rape. It might be expected that most farmers would eventually change to making their own decisions, but after differing lengths of experience. As well as their perceptions of the trustworthiness and relevance of the information they received from dealers and contracting companies, the farmers' education and self-confidence were both likely to influence when any changeover might occur.

In this study the information flow in oilseed rape has been studied in isolation. However, this approach may overlook some significant factors. In particular, dealers and farmers appear to value long term relationships (also noted by Brown, 1968), and are involved together in many aspects of farming. Both these factors would tend to strengthen the service function of dealers. This may partly explain why the routes by which information reaches farmers are relatively unimportant in terms of the subsequent pest control action, even in a crop where a high degree of uncertainty surrounds most of the pests, their behaviour and the damage they cause.

In general, information which was widely disseminated was reasonably well understood by the farmers. However, certain categories of information, particularly information on economic thresholds, was poorly understood despite being widely disseminated. It may be that economic thresholds are not relevant to the farmers' decision making processes. This was appreciated by Norton (1976) when he proposed a perceptual approach to pest control decision making, as opposed to strict economic or decision theory analysis. The results of the present study indicate that a perceptual approach may have been followed both by farmers who received advice on their spray decisions, and by those who made their own decisions. Since this second category of farmers said that they scouted for pests, they presumably compared their infestation with some reference level. From informal discussions with the farmers, one possibility appears to be that they compared the infestation with their perceptions of infestations in previous years, and the damage that resulted.

It is noteworthy that the pest control information best understood by farmers, the possible hazard to bees, was not related to the pests, their behaviour or the damage they caused. Farmers were not only well aware of the hazard, but also followed the ADAS recommendations for post-flowering treatments, despite some misgivings as to their effectiveness.

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Decision Making in the Practice of Crop Protection

THE VALUE OF INFORMATION IN CROP PROTECTION DECISION MAKING

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Summary There are many pressures on farmers to make correct crop protection decisions, not the least being economic pressures. After a brief look at the categories of information needed for wise decisions the problem of specifying disease losses is identified. Estimates of disease loss can be made by observation of indicators in the crop, the use of these indicators carrying a value which can be calculated. The methodology is outlined and applied to a scheme put forward in 1977. Individual components of the scheme are valued and it is shown how suggestions for further investigation might be generated. To minimise the cost of decision-making compared with the value of new information, simple on-farm advisory techniques may need to be devised.

INTRODUCTION

Every change in agricultural practice involves the acquisition of information. The introduction and use of crop protection chemicals implies that farmers have become aware of the benefits which these materials can bring. Many studies have shown the increasing economic importance of crop protection, and perhaps nowhere is this shown as dramatically as in cereal production over the last six years. Table 1. presents spray costs as a proportion of total variable costs for typical crop budgets for winter wheat over the last ten years. Up until 1976 sprays represented around 10% of the variable costs. By 1982 they were approaching 40%. This increase is probably most pronounced in winter cereals but similar trends are occuring in other crops.

Table 1

Spray costs as % of total variable costs in winter wheat crop budgets 1973-1982

Year	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
percent	11	10	9	11	19	21	29	32	37	39

Source: (J.S. Nix, 1972-1981)

The adoption of pesticides is explained by their availability and the increasing awareness of their potential benefits by farmers. The decision to spray is made by farmers on the basis of things as they see them. There is little doubt that most farmers would like to maximise their own economic benefits but to what extent they succeed is generally difficult to assess. This paper is concerned with information associated with the spraying decision. In recognising that decisions must often be taken without complete knowledge of what the benefits will be, farmers often rely on advisers for help with crop protection decisions. The second section discusses some of the information which a recommendation to take action implies. The third section then turns to the role of advice in risk reduction and, using a simple example, shows how a value may be placed on this function. Finally, some results are presented showing the application of the method to an advisory scheme developed a few years ago for late fungicide applications to winter cereals (Cook and Webster, 1977).

The examples used in the following discussion are taken from the application of fungicides to winter cereals. The terminology is simplified by using 'spraying' and 'not spraying' as the alternatives in the crop protection decision, but the concepts are general and apply to very many crop protection problems, irrespective of the form of the relevant control measures.

INFORMATION REQUIRED FOR A CROP PROTECTION RECOMMENDATION

Certain information must be known before a recommendation to take action can or should be made. For instance, the recommendation 'to spray' implies that the costs of spraying have been assessed as lower than the costs of 'not spraying'. Table 2 lists some of the more important variables which go into this assessment.

Table 2

Major variables involved in a crop protection decision

'Spray'	units	'Not Spray'	units
Application cost	£/ha	Loss in yield	t/ha
Chemical cost	£/ha	Sale price of crop	£/t
Crop (wheeling) damage	t/ha	Loss of Quality	£/t
Additional harvest and post-harvest costs	£/t		

As far as 'spraying' is concerned the farmer incurs the costs of chemicals and their application plus the value of any damage to the crop when application takes place. The method of application (by farmer's own machinery or by contractors) and the degree of crop damage, depending on whether good tramlines exist or not for instance, may vary considerably from farm to farm but will not necessarily be difficult to estimate in the field. However there may be a significant 'opportunity cost' to the application of materials on farms where there are many other jobs to be done at the time. Only the farmer can estimate this opportunity cost. Furthermore, there may be a significant interaction with the expected disease losses, since delays in application (in order to avoid high opportunity costs) may lead to increased disease losses. Finally there may be an increase in variable costs of harvesting and post-harvest operations (for instance, the drying costs) associated with the extra yield expected from spraying.

On the other side of the equation, a recommendation implies that the expected loss in yield has been assessed, along with the value of the crop. A 'blanket' recommendation to spray or not, over a region or over a number of years in a region, implies that one side of the equation is larger than the other in all situations in that region. However as the money values associated with the two sides of Table 2 become closer it becomes important to take account of the variability on individual farms. Otherwise, wrong decisions will be taken. The indications seem to be that as far as some cereal fungicides are concerned the two sides are often close together.

It is apparent from Table 2 that individually-tailored recommendations need information from the crop protection specialist and the farmer. The process of arriving at a wise decision must integrate data from both sources.

THE VALUE OF A RISKY FORECAST

It can be seen from the previous section that a recommendation requires some forecast of disease loss. Whilst a perfectly reliable forecast is obviously desirable, there are many situations when this is not possible. But even if the forecast still leaves doubt about the actual loss, it may be valuable in reducing the proportion of errors. The calculation of this value can be demonstrated using a simple example (Table 3).

Consider a farmer who must decide whether or not to spray. Assume that he faces disease every other year on average. On the basis of the gross margins shown in Table 3a and with no other information he would maximise his expected return (ie 410 x 0.5 + 420 x 0.5 = £415) by always choosing to spray.

Now suppose the farmer was fortunate to have an adviser who, taking note of the omens, could predict perfectly each year whether the disease would occur or not. The farmer would spray only on those occasions when the adviser predicted disease, and not otherwise. The farmer's expected return would now rise to £430 (Table 3, section b). The difference, between the expected returns with the advice and the expected return without it, is the expected value of perfect information (ie 430-415 = £15/ha in Table 3). This figure might be regarded as the maximum that a farmer would be willing to pay for the advice on a commercial basis, or perhaps as the loss incurred by the farmer if he failed to follow the advice if it were available free.

The preferred choice without the information is known as the 'prior' optimal action, whilst the preferred choice after the information has been taken into account is the 'posterior' optimal action (Lindley 1971).

A more common situation is where the farmer or adviser can improve his original estimates of disease loss, by making field observations and using his experience, but without perfect certainty. Let us say our farmer takes note of the field conditions which indicate disease loss. The farmer finds that having based his actions on these field conditions he gets it right only eight years out of ten. Section c) of Table 3 shows the situation. Firstly, we see that it pays the farmer to follow the signals he receives from the field conditons; to spray when disease is indicated and not otherwise; though there are still years in which the advice is wrong. Secondly, the value of the information contained in the field conditions is given by the increase in expected gross margin as compared with the original expected gross margin. In the case of Table 3 the value of this information is 422-415 or £7/ha. It is of course an expected value in that it accrues over a number of years and in a variety of conditions. It is dependent upon the costs, returns and probabilities. Any change in these would result in a change in the value of the information.

Table 3

An example of the valuation of information

	Disease	No Disease	Expected Values	Optimal Strategy	Expected Value of Optimal Strategy
a) Without Advice					£/ha
probability	0.5	0.5			
actions	outcomes £ G.M./ha		£/ha		
Spray	410	420	415	Spray routinely	415
No spray	360	450	405		
b) With Perfect Advice					
Spray	410	420		- Spray when disease forecast	410x0.5 +450x0.5 = 430
No spray	360	450		- Don't spray when disease not forecast	
c) With Imperfect Information					
c1 'disease' forecast probability	0.8	0.2			
Spray	410	420	412	- Spray when disease forecast	412x0.5 +432x0.5 = 422
No spray	360	450	378		
c2 'no disease' forecast probability	0.2	0.8			
Spray	410	420	418	- Don't spray when disease not forecast	
No spray	360	450	432		

N.B. underlined figures (e.g. 415) indicate maximum expected values.

VALUING AN ADVISORY SCHEME

Cook and Webster (1977) described an advisory scheme whereby specialists would provide tables of estimates of crop loss in various circumstances at the start of the season. The aim was that non-specialist advisers or farmers should be able to recognise these field conditions so that as the season progressed they would be able to make reasonable estimates of expected disease loss from the tables. They could then use their own knowledge of the remaining cost items of Table 1 to decide whether or not to take action.

The value of such a scheme to a farmer arises because he may now be able to estimate losses more precisely and thus take better decisions. It should be remembered though, that the information may not alter what some farmers would have done in any case. For such farmers the scheme has no value.

In order to put a value upon the advisory scheme in a particular area, it is necessary to estimate expected disease losses with and without the information about field conditions. The value is computed as the increase in revenue as farmers act on better, more specific recommendations as opposed to a single regional recommendation.

A conclusion from some earlier work (Webster, 1977) was that expected profit maximisation would be a reasonable decision criterion. The effect of this is to allow the calculations to be simplified considerably by requiring only the mean response for a given set of conditions, rather than the complete probability distribution.

A further simplification was possible after the analysis of some earlier sets of distributions which showed that, for the particular field conditions being considered here, additivity or independence of the effects of the field conditions could be assumed (Menz and Webster, 1981). This assumption implies that the effect of a given field condition upon expected response is independent of the other field conditions present. Thus

$$R|I_1,I_2,..I_i = m + b_1 + b_2 + \ldots\ldots. b_i$$

where $R|I_1,I_2,..I_i$ = mean response given presence of four field conditions.

m = a constant

b_i = difference in mean response between presence or absence of the i^{th} field condition.

Thus, with four sets of field conditions (Table 4), each being manifested in two forms, there are sixteen possible combinations or categories. The value of the field conditions arises because the farmer or adviser can now easily classify each at-risk crop into one of these sixteen categories and thus make more precise recommendations. Without the scheme he must do the best he can.

From the point of view of a cropping region, the scheme's value depends upon the area of the crop which falls into each of the sixteen categories. Again, if the occurrence of the four field conditions are independent, the relative frequency of the sixteen categories can be calculated from the probability of observing each field condition. The total value of the scheme is then the sum of values in each of the sixteen categories weighted by the number of hectares in each category.

Table 4 summarises the data relating to the effects of the field conditions and shows their relative likelihood of occurrence. Mean responses for the sixteen combinations of field conditions were then calculated. The optimal course of action in each case (ie spray or not spray) was next calculated by comparing the expected cost of spraying with the expected value of disease loss. This 'posterior' optimal action was then compared with the 'prior' optimal action, where the farmer knew only of the regional expected response, calculated by weighting the expected responses in each field condition by the probability of occurrence of the field condition in the region. A comparison of the 'posterior' and 'prior' action gives a value to the scheme for each case. The value of the scheme as a whole is then calculated by weighting the probabilities given in Table 4 for the sixteen cases.

Table 4

List of field conditions, their effect on expected response to spraying and their probability of occurrence

Field Condition*	Difference between expected responses with field condition observed (or not) t/ha	Probability of occurrence (non-occurrence) (Kent 1978)
Disease observed (or not)	0.21	0.60 (0.40)
Infection period forecast (or not)	0.14	0.56 (0.44)
Topography favourable to disease (or not)	0.30	0.26 (0.76)
Cultivar susceptible (or not)	0.11	0.70 (0.30)

* for more precise definition of field conditions see Cook & Webster (1977).

Table 5 gives some results for a range of wheat prices and spraying costs. Given that the expected regional response is .14t/ha, the optimal choice without the scheme is not to spray. The value of the scheme accrues because there are many conditions in which it is profitable to spray given that the farmer or adviser can recognise those conditions.

Table 5

Value per hectare of the advisory scheme under various cost assumptions

Spraying costs	Wheat price, £/t			
£/ha	90	110	130	
40	0.5	1.4	2.8	
30	1.6	3.1	4.6	£/ha
20	3.6	6.1	8.6	

VALUING INDIVIDUAL PIECES OF INFORMATION

The second stage of the analysis is to estimate values for individual segments of the scheme. As before, the value of knowing, for instance, whether or not disease is actually present in the crop, arises because the farmer can improve his disease loss prediction. Again it is calculated as the difference between the value of the optimal action with the information and the value of the optimal action without it. Using the additivity assumption, (Menz and Webster 1981) we can write

$$R|\text{without the information} = R|\text{with the information} - b(p - 1)$$

where R is the expected response, t/ha.

b = difference between expected responses with field condition observed or not, t/ha

p = probability of observation of field condition.

The value of an individual piece of information is to some extent dependent upon what the farmer already knows. Two methods of calculation were therefore used. Firstly, it was assumed that the recognition of each field condition was additional to the three other conditions, so that the farmer was regarded as being with and without the ability to recognise only the fourth condition. Secondly, it was assumed that each field condition was used on its own and the farmer was not regarded as having access to the other three.

Table 6 shows some example results for crop protection costs at £30/ha and a wheat price of £110/t. The first method of calculation is much the more sensitive since farmers are assumed to be able to categorise themselves with respect to the other three field conditions. Whilst the values change when different cost-price assumptions are used (eg Table 5) the ordering of values remains generally the same. Thus the value of topography recognition seems generally worth far more than the other three. The second method of calculation produces a non-zero value only on topography recognition. The zero values indicate that recognition would not change the prior decision at these prices. With a price of wheat at £110 and a crop protection cost of £30, the extra yield needed to cover costs is 0.27 t/ha (ie 30/110). Since the regional expected response is only 0.14/ha, it is clear that the prior optimal action is not to spray. Inspection of the difference between mean responses with and without the observation of individual field conditions (see Table 4) shows that only 'Topography' provides a large enough difference (ie 0.30 t/ha) for it to alter the optimal action. Hence only topography has any value at these prices. The other field conditions do have non-zero values as spray costs decrease (to £25/ha) for disease recognition and infection period recognition, and £20/ha for recognition of cultivar susceptibility), because the non-spraying farmers now find it profitable to commence spraying as the information provides them with better estimates.

The above discussion emphasizes that not only does the value of the information depend on costs and prices, but also on the differences in yield response given presence or absence of a field condition. A corollary is that if we could redefine, say, the categories of cultivar susceptibility such that the response difference between them were greater than the 0.11 t/ha of Table 3, the information value would be greater. If the infection period were improved as a predictor of disease, then its value to the farmer would increase. Thus, while the present analysis shows the value of extending existing knowledge to the farmer, it would be quite possible to use to same logic to estimate benefits from research areas.

Table 6

The value of the ability to recognise individual field conditions given crop protection costs at £30/ha, and wheat price £110/t

Field condition	Assuming each as additional to the recognition of the other three £/ha	Assuming each as the *only* condition recognisable £/ha
Presence of disease	0.52	0.0
Infection period	0.26	0.0
Topography conditions	2.21	2.55
Susceptibility of cultivar to disease	0.10	0.0

CONCLUSIONS

The paper has shown how imperfect information can have value. It has demonstrated how a scheme consisting of the use of a number of separate pieces of information can be valued in terms of the improvements which they bring to decisions. The scheme itself is assembled using information available at the time and should therefore be revised as changes occur in the chemicals used, the cultivars, the pathogens and the cultural practices seen on farms. Guidelines for this updating process could be derived by valuing information contained in the components of a scheme.

A final and important point refers to the costs of decision making. These costs arise because it may take much time and effort to assemble all the data before a wise decision can be taken. If such costs are high, the busy manager, who has other profitable things to do, will avoid the process and thereby increase the likelihood of error. Methods of reducing the costs of crop protection decisions include the provision of simple advisory schemes, and calculators and tables, which can be operated by farmers and non-specialist advisers for better prediction of disease losses, spray costs, and the remaining variables shown in Table 1. Armed with such aids, the manager may be more confident that better decisions are taken more often.

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Decision Making in the Practice of Crop Protection

FARMER'S ATTITUDES AND CROP PROTECTION DECISION MAKING

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Summary Research on farmers' pest control decision making has two principal components, (a) the action taken by the decision maker which is generally visible and tangible, and (b) the thought processes, value systems and motivations which underlie these visible outcomes. Knowledge of both components is necessary to achieve the aims of providing farmers with more relevant advice in a form which they will find useful, and of controlling more effectively the use of potentially dangerous chemicals.

This paper deals with farmers' pest control decisions on vegetable brassicas grown in Lincolnshire. Usage of pesticide at two levels, the decision on which pesticide (if any) to use, and the decision on how often to apply pesticide, is described in relation to attitudes and beliefs.

INTRODUCTION

The need to know more about farmers' pest control decision making and the factors which influence these decisions is increasingly being recognized. The aims of this research are to provide farmers with appropriate advice in a form which will influence them more effectively, to assist in controlling the use of potentially dangerous chemicals, and to maximise financial returns to the farmer by helping him to avoid both over-use and under-use of pesticides. The research described here was based on the expectancy-value model of the social and psychological determinants of behaviour (Ajzen and Fishbein, 1980), the behaviour in this case being pesticide usage on vegetable brassicas. Decision making was studied at two levels, (a) the decision on which pesticide to use, and (b) the decision on how frequently to use pesticides.

METHOD

A random sample of 86 farmers, with farms over 25 ha. in size, in the Holland region of Lincolnshire, was surveyed.* All the farmers grew sprouts

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* Copies of the questionnaires used for the survey described here can be obtained from the author.

cabbages and/or cauliflowers and had complete control over their pesticide programmes. The person who made decisions about pesticide use on each farm was interviewed twice during 1978, in spring before pesticide application began, to find out what pesticides they intended to apply to their brassica crops, and again the following winter, to find out what had been done.

The study of attitudes, normative influences, and behaviour of pest control decision makers, was based on Fishbein's expectancy-value model (Azjen and Fishbein, 1980). This predicts that behavioural intention (BI) is a function of attitude (A) and subjective norm (SN). The relationship between actual behaviour (B) and behavioural intention will depend on the time elapsing between stating the intention and performing the behaviour, and also on a variety of intervening factors, such as weather and pest incidence (equation 1). Attitude is determined by a person's salient beliefs that performing the behaviour leads to certain outcomes, and by his evaluation of those outcomes (equation 2) (Tait, 1979). Subjective norm measures the influence of other people on decision making and is determined by the decision maker's beliefs about the views of these others and by his motivation to comply with their wishes (equation 3).

$$B \sim BI = w_1 A + w_2 SN + e \quad \dots\dots\dots\dots\dots\dots\dots\dots \quad (1)$$

$$A = \sum_i b_i e_i \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (2)$$

$$SN = \sum_j b_j m_j \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3)$$

Where

B = behaviour

BI = behavioural intention

A = attitude

SN = subjective norm

w_1 and w_2 = empirically-derived weights

e = residual term

b_i = beliefs about the attitude object or behaviour

e_i = evaluation of the outcomes associated with b_i

b_j = beliefs about the views of other people and groups relevant to the behaviour

m_j = motivation to comply with the wishes of these others.

This paper deals only with the attitude component of the model. Measures of behaviour (pesticide usage) and behavioural intention (intended pesticide usage) were standardized (Tait, 1977), the latter being measured as three levels - maximum, likely and minimum intended usage. All variables in the model were studied in relation to using individual pesticides, and in relation to the use of pesticides in general. Salient beliefs (those opinions expressed most frequently) about using specific pesticides and using pesticides in general were obtained during unstructured, tape-recorded interviews with individuals and groups of farmers drawn from the same population as the survey sample.

RESULTS

Decision Making on The Use of Specific Pesticides

In controlling pests on brassica crops, farmers used demeton-S-methyl almost universally against the aphid (Brevicoryne brassicae), and DDT against the caterpillars (Plutella xylostella and Pieris spp). The chemical chosen by most farmers for cabbage root fly (Delia brassicae) was chlorfenvinphos, but dieldrin or aldrin was used for approximately 30% of all transplanted crops. A more detailed analysis of patterns of pesticide use on these crops will be given elsewhere (Tait, manuscript in preparation). In 1978, the use of these organochlorine insecticides was still officially approved by the Ministry of Agriculture , Fisheries and Food (MAFF, 1978), but this approval was withdrawn in 1981.

Farmers' opinions about using dieldrin and aldrin, DDT and demeton-S-methyl, which were found by the pilot survey to be salient, are shown in Tables 1, 2 and 3. In measuring attitudes, farmers were asked to state the extent to which they agreed (+) or disagreed (-) with each opinion, on a seven-point scale, ranging from +3 to -3. The median scores are given in the tables with farmers divided into two groups on the basis of their likely intended use of the chemicals. Dieldrin or aldrin was used by farmers only once, at planting, so the distinction was made between those who intended to use it and those who did not. DDT and demeton-S-methyl were used by all farmers and the distinction here was between those whose likely intended use was above or below average.

Table 1

Farmers' opinions (b_i) about using dieldrin or aldrin

Salient Beliefs	Median a*	 b**
Using dieldrin or aldrin:		
(1) is dangerous to farm workers	-0.8	0.8
(2) upsets the natural balance of the soil	-0.7	-0.7
(3) makes everything smell terrible	1.1	0.6
(4) is dangerous to the environment	-0.4	0.5
(5) is old fashioned	-1.1	2.1
(6) is causing a build-up of chemicals in the human race	-0.1	0.3
Dieldrin and aldrin are:		
(7) very effective for controlling cabbage root fly	2.4	1.5
(8) cheap compared to other insecticides	2.0	2.6
(9) easy to apply	2.2	1.6

* a = Farmers who intended to use dieldrin or aldrin, N = 43

** b = Farmers who did not intend to use dieldrin or aldrin, N = 40

Table 2

Farmers' opinions (b_i) about using DDT

Salient Beliefs	Median a*	Median b**
Using DDT:		
(1) can leave pesticide residues on the crop at harvest	-0.8	0.7
(2) gives long-lasting control of caterpillars	1.1	0.8
(3) is causing a build-up of chemicals in the human race	0.0	0.8
(4) is harming wildlife and game	0.2	0.8
(5) is dangerous to the environment	-0.2	0.7
(6) is dangerous to farm workers	-0.7	0.1
(7) upsets the natural balance of the soil	-1.6	-1.1
DDT is:		
(8) very effective for controlling caterpillars	2.8	2.3
(9) cheap compared to other insecticides	2.6	2.4
(10) old fashioned	0.6	0.8

* a = Farmers who intended to use more-than-average levels of DDT, N = 38

** b = Farmers who intended to use less-than-average levels of DDT, N = 48

Table 3

Farmers' opinions (b_i) about using demeton-S-methyl (DSM)

Salient Beliefs	Median a*	Median b**
Using demeton-S-methyl:		
(1) gives long-lasting control of aphids on brassicas	2.3	2.1
(2) is harming ladybirds	2.3	1.9
(3) is harming wildlife and game	0.9	0.7
(4) close to harvesting can lead to risk of tainting the crop	2.1	2.0
(5) close to harvesting can leave pesticide residues on the crop at harvest time	2.6	2.3
(6) is dangerous to farm workers	1.9	1.8
(7) is dangerous to the environment	1.1	1.0
(8) makes everything smell terrible	2.6	2.4
(9) exclusively could lead to the build-up of resistance in aphids	1.9	1.8
Demeton-S-methyl is:		
(10) very effective for controlling aphids	2.7	2.6
(11) cheap compared to other insecticides available for the same purpose	0.6	0.5

* a = Farmers who intended to use more-than-average levels of DSM, N = 43

** b = Farmers who intended to use less-than-average levels of DSM, N = 43

Most of the opinions about the side-effects of organochlorine insecticides on people and the environment in Tables 1 and 2 gave rise to median scores which were close to 0. There is not room here to present the data in greater detail, but this finding results from strong opinions being equally divided on both sides of the neutral point, rather than from a large body of neutral opinion. Table 3 shows that farmers were in agreement to a much greater extent about the damaging side effects of demeton-S-methyl with median scores being generally strongly positive. Tables 1 and 2 also indicate some differences in the opinions held by farmers in groups (a) and (b), but in Table 3, the differences appear to be minimal. The significance of these differences can be assessed from the data on correlations between attitude and behaviour given below.

Tables 4 and 5 show those opinions from the attitude scales for dieldrin/aldrin and for DDT which were correlated with at least one of the behavioural measures. Only one measure of intended use is given for dieldrin/aldrin. Since they are only used once in a growing season, likely, maximum and minimum intended use are equivalent. For demeton-S-methyl, the only significant correlations obtained were for opinions 2, 5 and 7 in Table 3, where the variable ($b_i e_i$) was weakly correlated with maximum intended usage, although the sign was unexpected, being negative.

The opinions which discriminated significantly between users and non-users of dieldrin or aldrin were related to effectiveness, ease of application, and to its being old-fashioned. Opinions about toxic or environmental side effects, on the other hand, appeared not to be involved.

The only opinion which was correlated significantly with actual use of DDT was "Using DDT can leave pesticide residues on the crop at harvest", correlation coefficient +0.20, $p = 0.04$. For the measures of intended use of DDT five out of six significantly correlated opinions concerned side effects on people or the environment, although the highest significance level occurred for the opinion on its effectiveness for controlling caterpillars. For DDT, the prediction of Fishbein's model that attitude will be more highly correlated with behavioural intention than with actual behaviour is borne out.

Table 4

Correlation of attitude (b_ie_i) to using dieldrin or aldrin with actual and intended levels of use

Opinion	Correlation Coefficients*	
	Actual Use	Intended Use
Using dieldrin of aldrin is old fashioned	-	+0.23(0.02)
Dieldrin and aldrin are very effective for controlling cabbage root fly	+0.24(0.02)	+0.31(0.003)
Dieldrin and sldrin are easy to apply	+0.42(0.001)	+0.38(0.001)

* Spearman rank correlation coefficient. Figures in brackets are significance leves (1-tail)

* * *

Table 5

Correlation of attitude (b_ie_i) to using DDT with actual and intended levels of use

Opinion	Correlation Coefficients*		
		Intended Use	
	Likely	Maximum	Minimum
Using DDT:			
can leave pesticide residues on the crop at harvest	+0.30(0.003)	+0.24(0.02)	+0.27(0.01)
is causing a build up of chemicals in the human race	+0.24(0.01)	+0.23(0.02)	-
is dangerous to the environment	+0.25(0.01)	+0.24(0.02)	-
is dangerous to farm workers	+0.26(0.01)	+0.19(0.04)	-
upsets the natural balance of the soil	+0.23(0.02)	-	-
DDT is very effective for controlling caterpillars	+0.41(0.001)	+0.43(0.001)	+0.32(0.002)

* See Table 4

Decision Making on the Use of Pesticides in General

The scale measuring attitude to using insecticides in general on brassica crops contains 31 opinion-items and is too long to reproduce here. The individual opinions which correlated most highly with all behavioural measures were those related to financial risks and the need for insurance use of pesticides. Of the various behavioural measures, minimum intended use of insecticides correlated more highly with more opinion statements than the others, next in the sequence being actual usage, followed by likely, then maximum intended usage.

Of the opinion statements on the general attitude scale, 14 were clearly related to the financial risk dimension, 5 to environmental risks and 3 to personal health risks. Farmers' individual attitudes on each dimension were calculated by averaging over the appropriate items in the scale and these figures were used to calculate sample mean values for attitude to the three types of risk (Table 6). These figures show that, on average, farmers' attitudes to using insecticides were quite unfavourable (negative) on the environmental and personal health risk dimensions and that they were also highly variable. On the financial risk dimension, attitudes were less variable and on balance weakly positive. Table 7 shows the mean individual values on these three dimensions for the first 20 farmers in the survey, illustrating the level of internal inconsistency in attitude to using insecticides which some farmers were expressing.

Table 6

Farmer's mean attitudes to the risks of using insecticides

	Average Attitude Score (range -9 to +9)			
	Mean	Minimum	Maximum	Standard Deviation
Environmental risk	-1.6	-9.0	4.8	2.9
Personal health risk	-1.9	-9.0	7.3	2.9
Financial risk	0.38	-4.6	4.3	1.9

Table 7

20 Farmers' individual attitudes to the risks of using insecticides

(range -9 to +9)

	Financial	Environmental	Personal		Financial	Environmental	Personal
1)	3.0	-0.4	3.0	11)	2.1	-2.8	-1.7
2)	-0.1	2.8	2.0	12)	0.8	1.2	-0.7
3)	1.8	-0.4	1.7	13)	2.0	-6.2	-3.0
4)	2.3	-0.4	-1.0	14)	-1.0	-1.8	-1.0
5)	-0.2	-0.2	2.0	15)	0.4	4.8	0.7
6)	2.4	-4.4	1.7	16)	-1.3	2.0	-1.3
7)	2.3	-1.8	-2.3	17)	0.4	-2.4	-1.7
8)	0.9	-3.4	-2.7	18)	0.1	-0.4	-0.7
9)	1.9	1.4	0.0	19)	0.1	-1.2	-3.7
10)	1.1	0.8	0.3	20)	0.4	-4.0	-3.3

The Spearman rank correlation coefficients between opinions about using insecticides in general and farmers' use of insecticides to control aphids were measured and three opinion items were moderately well correlated:

(a) "Spraying on a routine basis means that insecticides are sometimes used when it is not necessary" (coefficient +0.29, $p = 0.005$).

(b) "Spraying only when we can see the pest leads to a risk of crop losses" (coefficient +0.32, $p = 0.002$).

(c) "Missing out one insecticide application can risk ruining a whole season's spray programme" (coefficient +0.29, $p = 0.005$).

Since 80-90% of the insecticide used for aphids on brassica crops was demeton-S-methyl, this implies that use of this chemical could be predicted more accurately on the basis of general attitude to financial risk than on the basis of opinions about using the chemical itself.

DISCUSSION

The implications of some of these results for research on attitude measurement will be discussed elsewhere. This discussion will concentrate on those points which are relevant to pest control decision making.

It is interesting to note that a very considerable proportion of farmers did not believe that organochlorine insecticides had harmful effects on the environment, in spite of heavy publicity campaigns from a variety of sources to alert them to these dangers. On the other hand, demeton-S-methyl, which has not been the subject of intense publicity, was much more widely believed to be dangerous and damaging. This could be due to the long-term nature of any harmful effects of organochlorines, which would therefore not be obvious to farmers, perhaps combined with the fact that comments on organochlorine use from official sources directed to the farming community have, until recently, been very reassuring. Demeton-S-methyl's reputation for widespread harmful effects is probably related to its obvious unpleasantness in handling. Where chemicals can have effects which are less immediately obvious, a continuing official propaganda effort may be necessary to keep farmers aware of the dangers. This may no longer be a problem for organochlorines, whose use is being phased out since 1981, but it may be difficult to convince farmers of, for example, the possible toxic effects of synthetic pyrethoids in water-courses as these chemicals are widely believed to be very safe.

The three individual chemicals for which results are given here represent different types of attitude-behaviour relationship. For dieldrin and aldrin, only the decision on whether or not to use the chemical was involved; there was no possibility of repeated use. Intended and actual use here were related to opinions about effectiveness and ease of application. DDT was used by all farmers but there was considerable variation between farmers in levels of use. Also, in the year of the survey, bad weather meant that pest problems were lower than expected and farmers' actual use of pesticides was closer to the minimum than to the likely intended levels. This may be one factor, which would explain the general lack of significant correlation between actual use of DDT, and opinions about using this chemical. Where correlations with intended use of DDT were significant, the results indicate that, in a more normal year, farmers' beliefs about the environmental and health effects of the chemical may have been significantly related to actual use, although belief in its effectiveness still appeared to be the opinion with the dominant relationship. A more extensive survey, covering a period of years and a variety of weather patterns would be required to unravel these relationships. Demeton-S-methyl appears to be a case where opinions about using the chemical itself bear little or no relationship to actual intended levels of use. As with DDT, all farmers used demeton-S-methyl but there was considerable variation among farmers in the number of times it was applied. High usage of demeton-S- methyl appears to be related principally to an insurance-minded attitude to spraying and vice versa. If one wished to influence farmers' use of a particular chemical, it would be important to know which, if any, of these situations was applicable.

The finding that, of the three risk dimensions studied here, opinions on the financial risk most accurately predicted the use of insecticides in general, is not surprising. However, the level of internal inconsistency in attitudes expressed by many farmers was surprising. This could indicate an unstable situation, and a change in external circumstances could precipitate unexpected changes in the behaviour of farmers.

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2.

Forecasting techniques as aids to decision making

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Decision Making in the Practice of Crop Protection

METEOROLOGY AS AN AID TO CROP PROTECTION

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Summary Meteorology plays an important role in most aspects of crop protection. It may, for example, partly determine the type of spray equipment to use, the chemical formulations, and the most effective time to spray. Examples are presented showing the close links between crop protection and meteorology. They include the influence of meteorological conditions on spray drift, and the part weather plays in controlling the time available for spraying operations. Further examples show how micrometeorology and plant physiological data may be combined to obtain improved models of the response of disease to weather, and discuss the use of purpose-built automatic instruments for monitoring crop environment and indicating risk of disease development.

INTRODUCTION

The majority of decisions relating to crop protection are made by farmers and growers in response to the day-to-day needs of their crops; in these cases the direct, and apparently most important, meteorological input is the regular weather forecast available via radio, television, recorded telephone message or Prestel. The main problem here is probably dissemination of the appropriate specialised forecast information, because routine bulletins issued to the general public usually do not contain the detail required by farmers to ensure effective, safe, spraying conditions. The general problem of dissemination is likely to be solved in the future, when nearly all farming enterprises will use Prestel or its successors. When Prestel is more widely used it will justify the expense of setting up, and frequently updating, forecasts on a regional basis for specialist activities such as crop spraying. With these developments in prospect there is no need to dwell further on the significance of weather forecasts in crop protection, except to point out that the present high level of investment within the Meteorological Office on forecasting research and computing systems will produce continued improvements in the forecasting service.

Many aspects of meteorology apart from forecasting can make a significant contribution to crop protection. Attempting to list and describe them all in this paper is less informative than selecting a few cases which can be considered in more detail. Accordingly, four examples will be discussed in this presentation.

The first is the perennial topic of spray drift. Despite a host of experiments and theoretical studies the quantification of the drift hazard has not yet been achieved. Further progress requires continuing inputs from a variety of areas of experience, but it will be demonstrated how the principles of micrometeorology alone can probably produce some useful advances.

The second example considers the way in which weather controls the time available for spraying to take place with an acceptably low hazard to off-target areas, and low wheeling damage. The meteorological criteria for low-hazard spraying will vary with the active chemical, its formulation, and the nature of adjacent crops and farming enterprises, but modern methods of meteorological data storage, retrieval and sorting allow estimates to be made, quickly and cheaply, of available spraying time for many different combinations of the relevant variables.

Next is a brief consideration of some ways in which synoptic (ie current) meteorological data can assist in deciding on the tactics of plant disease control. Here the emphasis is now beginning to turn away from the use of crude, simple weather/plant disease relationships such as Beaumont or Smith criteria in the case of potato blight. Instead, the application of micrometeorology with reasonably comprehensive biological data now allows the development of logical, rather than empirical, schemes for calculating plant disease progress; this, and the availability of computer data banks containing both current, as well as climatological, weather data are leading to the introduction of more comprehensive and rational schemes providing daily advice to plant pathologists on the expected development of disease in response to weather.

The final example shows how developments in meteorological instrumentation can be applied to the automatic monitoring of crop environment. Microprocessors incorporated in the same instruments may be programmed with weather/plant disease relationships for a number of different diseases. These developments will eventually allow individual farmers employing these devices to maintain more reasoned schemes than simple insurance spraying for disease control.

EXAMPLES OF METEOROLOGICAL CONTRIBUTIONS TO CROP PROTECTION

(a) The quantification of spray drift

The damage which can result from spray drift has naturally led to a great deal of experimental and theoretical work directed towards the goal of estimating the amount of drift, and the hazard from it, for the foreseeable combinations of chemical agent, spray equipment and weather. Progress has undoubtedly been made, but many of the experimental studies in particular have lacked generality, so that their results have been impossible to apply with any confidence to cases with meteorological conditions outside the range of those in the experiments.

The effects of spray drift on sensitive plants will continue to be determined largely by experiment. However, estimating the amount of drift, over the whole range of meteorological conditions experienced in spraying operations, will depend strongly on adequate theoretical treatments of the effects of weather at the time of spraying. Weather (chiefly wind speed) will determine what proportion of spray drops fails to be taken up by the target surface almost immediately after leaving the spray nozzles ('initial' drift). Weather (wind speed, atmospheric turbulence and humidity) will influence the subsequent drift downwind of these drops, their evaporation, and uptake by the off-target surface, although chemical formulation and the aerodynamic properties of the surfaces will also be important. Weather also plays an important role in the volatilisation of chemicals and the drift and uptake of chemical vapour.

A tentative attempt to estimate how drift hazard varies with, inter alia, meteorological conditions has been made recently by Rutherford and Thompson (1981); however it is clear that a considerably larger amount of background information on a variety of topics ranging from chemical toxicity and plant pathology to the dynamics of evaporating drops is required before reliable indices of hazard can be derived.

It is not appropriate to review here, and identify the shortcomings of, the various theoretical treatments which have been put forward to explain drift in terms of meteorological variables. Instead I will describe a technique now in use in the Meteorological Office which has been little exploited in the past, and promises to shed some further light on the magnitude of the drift problem. This is the so-called "random-walk" method (eg Hall, 1975; Ley, 1982) in which the vertical movements of single drops as they move downwind are described by a connected series of random, discrete, displacements whose magnitude is derived from atmospheric boundary layer theory. The method is well-suited to studying the effects of drop evaporation, and of varying the collection efficiency of the surface. Statistically reliable results are obtained by following individually the progress of a sufficiently large number of drops, although this leads on to the main drawback of the method, its demands on computer time.

Table 1

Random-walk simulation of the drift of water-based (W) and non-volatile (N) drops of 100μ initial diameter (number of drops released = 10000/m), for a wind speed at 10m height of 18 km/h

Release height (m)		Average deposit (drops/m^2) at: 10m	30m	100m	300m	1000m	Drop numbers airborne at 1000m
0.5	N	270	29	1.8	0.2	0.02	20
	W(a)	280	32	2.8	0.5	0.12	470
	W(b)	280	28	1.8	0.5	0.14	870
1.0	N	460	57	4.4	0.4	0.04	100
	W(a)	400	52	4.4	0.8	0.18	1100
	W(b)	400	35	3.4	0.8	0.32	1890

(a) Collection efficiency of the surface equal to 1
(b) Collection efficiency of surface decreasing linearly from 1 (100μ drops) to 0.1 (20μ drops)

Table 1 shows results obtained for drops 100μ in initial diameter, released along a crosswind line at heights of 0.5 or 1.0m; the source strength is 10000 drops per metre of the line. The drops are either non-volatile, or else contain 99% water which is assumed to freely evaporate in air at 50% relative humidity (20°C) until only pure chemical remains. These few results are shown in order to indicate the general versatility of the technique rather than demonstrating any particular point.

However, the consequence of drop evaporation on the amount of drift is clearly shown. It is also seen that release height, drop evaporation and collection efficiency interact in a complicated way in their control of drift.

Meteorology may also be used to clarify the vapour drift problem. The hazard from spray chemical vapour volatilising from the target area, and drifting downwind over sensitive crops has been well-documented but not well-quantified. It is not easy to estimate what the rate of volatilisation is likely to be, but if this is assumed to be known, then a relatively straightforward application of micrometeorology and crop physiology can be used first to estimate vapour concentrations downwind, and from these the theoretical maximum rates of uptake by plants. An example of these calculations for a summer situation with a windspeed at 10m height of 7km/h is shown in Table 2. Actual rates of uptake will usually fall short of these (which are seen to approach 1% of the rate of production of vapour, even at distances of several hundred metres from the target area) for a variety of reasons which are more the concern of the pesticide scientist than the meteorologist. Nonetheless, these meteorologically-based estimates provide a useful starting point in the determination of the vapour hazard.

Table 2

Estimated maximum rates of uptake of vapour (molecular weight = 300) by a dense plant canopy via cuticular (C) or stomatal (S) pathway (vapour is assumed to be emitted from broad fields of various alongwind lengths, at a rate of 1 unit/m^2/s)

Downwind distance	Rate of uptake (units/m^2/s)					
	Field length = 100m		200m		500m	
from field edge(m)	C	S	C	S	C	S
10	.036	.022	.047	.028	.063	.038
100	.011	.007	.019	.012	.031	.019
1000	.002	.001	.003	.002	.007	.005

(b) The frequency of suitable spraying occasions

If the meteorological criteria for the safe use of a particular chemical can be properly defined, it is then possible to use climatological data to assess the probable frequency of suitable spray occasions at different times of the year (Adams, 1979; Spackman and Barrie, 1981). If such an analysis indicates a low probability of the correct conditions, it is then appropriate to consider how the criteria may be relaxed, for example by the use of lower spray pressures in order to raise the windspeed limit. However, one must use any windspeed criteria cautiously: in terms of spray drift it still seems to be acceptable to define upper windspeed limits for safe spraying, but this is an unjustifiable practice - some spray chemicals might be harmless enough to spray in gale-force winds, whereas 10km/h might be too high a value for very toxic sprays used in the vicinity of sensitive horticultural enterprises.

An example of a spray-day analysis for a few stations in the United Kingdom is given in Table 3, for three limiting windspeeds. Such studies may be carried out quickly by data-sorting routines used with computer-based meteorological data banks, and, provided the necessary criteria for safe spraying can be laid down for the particular spraying system and pesticide used, can quickly indicate any difficulties which might be experienced because of small numbers of spraying occasions at any time of the year.

Table 3

Average number of spray occasions (1971-1980) for low ground pressure vehicles

Station	Wind speed limit(km/h)	Month I	II	III	IV	V	VI	VII	VIII	XI	X	XI	XII
Kinloss	< 11	0	2	1	5	3	2	4	8	4	5	1	.5
(Northeast	< 18	1	6	8	16	16	16	19	23	13	12	4	2
Scotland)	< 24	2	8	13	20	25	25	27	29	19	17	6	2
Shawbury	< 11	1	3	4	8	9	10	13	15	10	8	3	1
(West	< 18	3	8	12	19	24	25	28	32	24	20	7	4
Midlands)	< 24	5	10	16	27	32	37	37	37	30	26	9	5
Gatwick	< 11	1	3	3	5	5	5	7	9	9	7	3	1
(Southeast	< 18	3	8	14	19	19	26	30	31	29	21	8	4
England	< 24	4	11	20	29	28	35	41	40	36	29	11	6
Plymouth	< 11	2	2	2	4	5	4	5	6	7	4	3	2
(Southwest	< 18	4	7	11	15	19	20	24	24	20	12	7	5
England	< 24	5	10	17	24	27	27	34	34	28	21	10	7

Criteria: (a) Daylight, but between 0600 and 2000 (b) no precipitation (c) air temperature > 1°C during spraying (d) > 7°C at some time during spraying (e) all criteria satisfied simultaneously for at least 5 successive hours

The analysis may be extended to the estimation of numbers of spray occasions when conventional, rather than low-ground pressure, vehicles are used. Here the problem is in defining the limit for soil moisture which allows movement over the soil, without serious damage to soil structure and subsequent loss of yield.

Simple criteria might be used, for example no rain in the previous 48 hours, or soil moisture deficit greater than a given minimum, but these are subjective criteria which take no account of the structure of the soil, its water-holding capability and hydraulic conductivity, nor of the stresses the soil is subjected to by the vehicle (represented perhaps by wheel pressure per unit area). A more versatile method involves the calculation of the vertical profile of soil moisture potential and its response to rainfall and evaporation, for a range of soils. Periods of safe working may then be identified by selecting a limiting potential appropriate to vehicle type and soil structure: this approach is at present under development in the Meteorological Office.

(c) The estimation of plant disease development in response to weather, on a national scale

National meteorological services use communications networks for transmitting meteorological observations between observing and forecasting centres. In many countries such data are also stored at the headquarters unit in computer data banks, from which they may be recalled in order to provide a veriety of operational services. Within the United Kingdom such data have been used for a number of years to produce daily information for plant pathologists on the probable progress of a number of plant diseases (Adams and Seager, 1977). Until recently in the British system the responses of disease to weather have been represented by very simple associations with standard meteorological data. For example a period of leaf wetness, essential to the development of many fungal diseases, has been assumed to begin with the start of rain, and conclude when the relative humidity measured in the standard thermometer screen falls below 90%. The actual disease development has usually been described by very simple relations which, while found useful by plant pathologists, make no attempt to represent the real progress through each generation of disease. Developments have now turned away from these unsatisfactory schemes. In Holland, for example, the very comprehensive EPIPRE system is now in use (Rijsdijk, 1982). In Britain the obsolete Beaumont-based scheme for potato blight is being replaced by a system which models explicitly each important stage in the cycle of infection (Sparks, 1980). In either case these advances have been in part the result of automation which has allowed the operational use of more complicated disease/weather relationships. Sparks models the cycle:- growth of spores - survival of spores - incubation of infections - formation and senescence of lesions - growth of spores, and so on, which while still a greatly simplified representation of reality, is found to give good estimates of the dates of outbreaks of disease (Figure 1). Of practical interest is that Sparks was able to show how use of the model outputs on a daily basis in conjunction with routine weather forecasts would lead to spray programmes as effective as "insurance" spraying at 10-day intervals, but requiring little more than half the number of spray applications of the routine system.

(d) Environmental monitoring in plant disease control

A major problem in the operational use of weather/plant disease relationships in determining control programmes is that the environment to which the disease responds, in a cereal crop for example, may differ markedly from that obtained by routine monitoring of weather by standard meteorological instruments. As indicated above, the duration of leaf wetness, which is important for the development of fungal

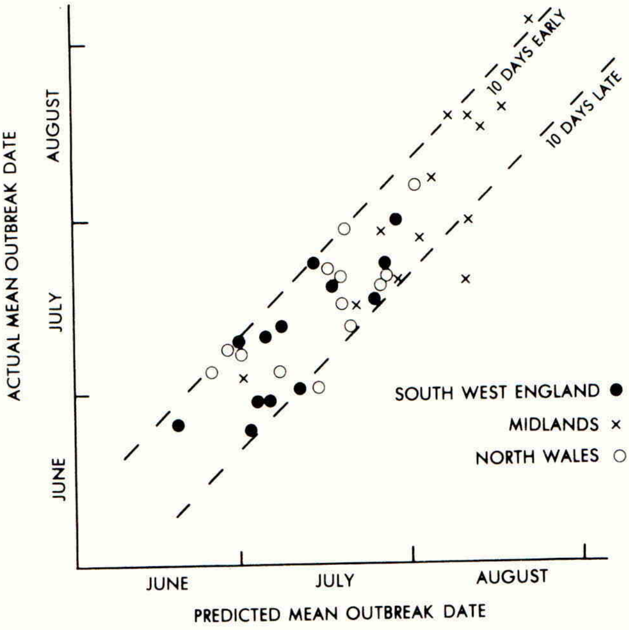

Figure 1. Comparison of predicted and actual outbreak dates of potato blight (1958—1970)

diseases, has usually to be estimated indirectly from meteorological observations which are made well above crop height. Thus, not only is the observation made in the wrong place, but it does not even represent the desired quantity. The problem will persist in the case of national schemes based on the national weather observing network. On a more local scale it is possible to circumvent this difficulty by the employment of purpose-built instruments which can monitor the crop environment, and also relate this environment to the development of plant disease. Use of such equipment in crops adjacent to standard weather stations additionally allows the possible development of simple empirical relations between conditions in the crop and at the standard observing height.Micrometeorological theory may also be used to relate standard and crop environments (eg Thompson, 1981) but the calculations are too complicated for routine applications.

A specially-designed crop disease environment monitor (CDEM) which has been tested over the last two years in England measures, within the crop, environmental variables of importance to plant disease development, with control by microprocessor (Sparks, private communication). The microprocessor also uses the observations to evaluate simple plant disease/weather relations for a number of diseases. The various indexes and averages which CDEM produces are stored for several days and may be immediately recalled. With the development of devices such as this, it can be envisaged that farmers and growers will be able to obtain local, more accurate, information on disease development in response to weather than it has ever been possible to supply before by use of the national meteorological observing network. At present these national data are supplied, not to farmers, but to plant pathologists who interpret them in the light of current disease levels and then issue their recommendations for protective spraying. The question then arises whether the individual farmer or grower can bypass the plant pathologist and still make effective use of outputs from devices such as CDEM, but without a detailed knowledge of plant pathology. This is an area of debate into which meteorologists will be reluctant to stray. Putting on one side this contentious issue, which will need to be thoroughly considered in the future, there seems little doubt that instruments such as CDEM can provide outputs which, when correctly interpreted, will lead to significant improvements in both the strategy and tactics of disease control.

CONCLUDING REMARKS

Weather influences most aspects of crop production. Meteorology, which is essentially our understanding of weather, has therefore connotations for crop protection over a wider range of topics than those usually associated with the BCPC. Effective protection from the effects of drought, for example, will depend on irrigation schemes based in part on meteorology. However, in those areas traditionally discussed at BCPC meetings (weeds, pesticides and diseases), it is clear that there are direct and indirect links with meteorology. The present paper has selected a number of topics which demonstrate how meteorology aids crop protection, and at the same time has indicated the diverse ways in which meteorology, both as a science and as an organisation of communications networks and data bases, can contribute to the maintenance and improvement of British agriculture.

Acknowledgements

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Decision Making in the Practice of Crop Protection

THE EPIPRE SYSTEM

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SUMMARY

EPIPRE is a computer-based pest and disease management system for wheat. The system requires information of individual fields, to be supplied by the farmer-participants, and combines this information with data from epidemiology and crop husbandery. Communication between the computer and the farmer-participants is done by postal service. Recommendations produced by the system are based on calculation from future disease and pest development and calculation of the costs of treatment. A description is given of the data organisation and the principles used in calculation of the recommendations. Training and education of farmers is indicated. Results of four experimental years are given. Concluded is that EPIPRE results in general in optimal or near optimal use of insecticides and fungicides in wheat growing.

INTRODUCTION.

EPIPRE is a supervised pest and disease management system for winter wheat in the Netherlands. The decision to start EPIPRE was made after two heavy epidemics of yellow rust on wheat in 1975 and 1977. The aim of the project was to control epidemics of yellow rust using new knowledge and new epidemiological insights on yellow rust and to study the need to individualise the recommendations. The project was financed by the Netherlands Grain Centre and carried out in collaboration with different research institutes, the extension service and a group of more than 600 wheatgrowers. During the project it became clear that recommendations for only one disease was inadequate and other diseases and pests were introduced stepwise. For 1982 EPIPRE generates recommendations for yellow rust, brown rust, mildew, Septoria leafspot, glume blotch, and cereal aphids. In Table 1 a summary of the history of EPIPRE is given.

General setup and data organisation of the EPIPRE system.

EPIPRE produces recommendations on a field by field basis.
Data from each individual field are stored in a computer. Data which do not change during the season, e.g. variety, soil type, seedrate, and previous crop, is supplied by the farmer before the season starts.

During the growing season farmers carry out field observations, according to well defined prescriptions at time intervals indicated by the computer. Each field observation leads to a recommendation. Besides the field observations, the farmers supply information on the use of fertilizers, growth regulators, herbicides and pesticides. Each recommendation is combined with a request for a new observation after a certain period calculated by the computer. The

Figure 1

The exchange of information between farmer and computer.

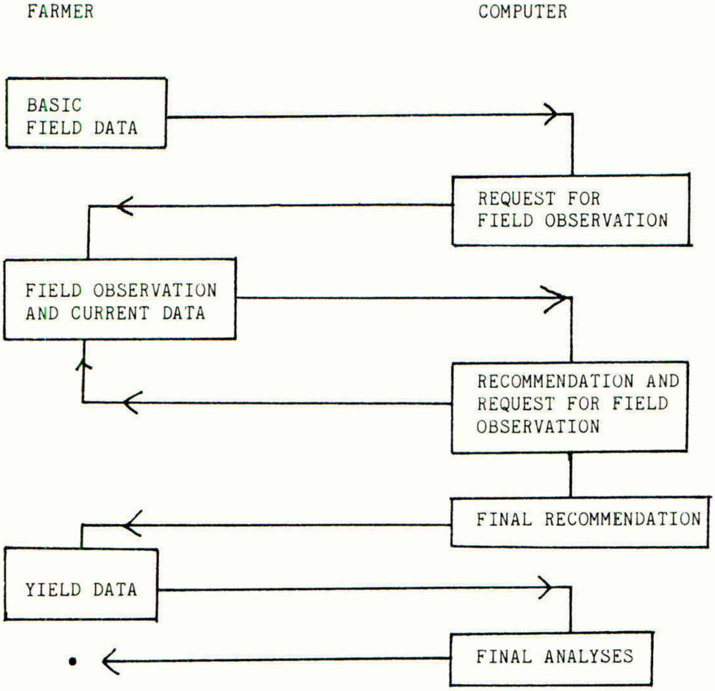


Table 1

The development of EPIPRE (EPIdemics PREdiction PREvention)

Supervised pest and disease management system for wheat in the Netherlands.

1978	Yellow rust	*Puccinia striiformis*	400 fields
1979	Yellow rust	*Puccinia striiformis*	450 fields
	English grain aphid	*Sitobion avenae*	
1980	Yellow rust	*Puccinia striiformis*	840 fields
	Mildew	*Erysiphe graminis*	
	English grain aphid	*Sitobion avenae*	
	Rose-grass aphid	*Metopolophium dirhodum*	
	Bird cherry-oat aphid	*Rhopalosiphum padi*	
	Brown rust	*Puccinia recondita*	
1981	like 1980		1155 fields
	Leaf speckle	*Septoria tritici*	
	Glume blotch	*Septoria nodorum*	

information is stored in the data bank and used to calculate new recommendations. The exchange of information between computer and farmer is illustrated in Figure 1.

The databank is used to store data on cultivar, soil conditions, geographical location, field history, observations, control measures, and recommendations. By using a databank management system rapid access to the relevant data during production of recommendations is possible. Figure 2 shows how the data is organised.

Figure 2

Data organisation

1. Region record ; all fields of a region; regional differences

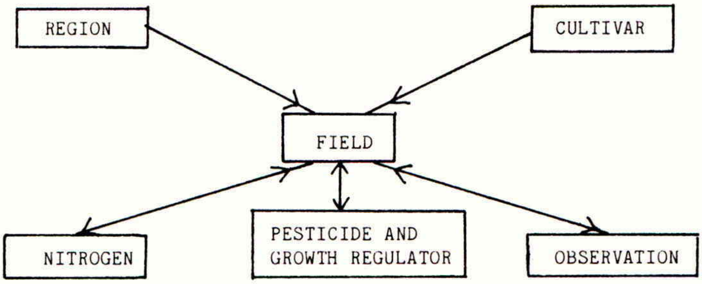
2. Cultivar record ; all fields with the same cultivar; varietal differences

3. Field record ; all information of one field; status of a field

3.1 Nitrogen record ; status nitrogen application

3.2 Pesticide ; status of growth regulator, herbicide, fungicide and insectide application

3.3 Observation record ; field observation and recommendations



Six different data records are defined:
1. A region record, connecting all fields of a region, to be used for production of summary tables during the season.
2. A cultivar record connecting all fields with the same variety and containing information on susceptibility of the variety to the pests and diseases.
3. A field record, containing all the basic data of the field and data on the status of the field.

Each field record is connected with :

*

4. A set of fertilizer records with data on nitrogen fertilisation.
5. A set of application records with information on the use of chemicals.
6. A set of observation records containing the field observations and the recommendations given.

Training and education.

To participate in EPIPRE knowledge of disease symptoms and developmental stages of the crop is needed. Therefore farmers are supplied with written information on the general setup of the system, background information about the principles used, a description of the symptoms of the pests and diseases and sheets with summarised information on developmental stages and observation procedures.

Table 2

Training and education of the participant

WRITTEN INFORMATION	ORAL INSTUCTION	TIME
-Instruction book	-Introductary instruction	(March)
-Background information	-Field instruction	(May)
-Color pictures of cereal pest and diseases	-Field instrution	(June)
	-Evaluation	(November)
-Summary of observation procedure and development stages	-Special telephone line during season	

In addition to the written information, participants may attend oral instructions of different types (Table 2). The field instruction much appreciated, as over 75 % of the participants attending these meetings. During the season the farmers can send leaf and ear samples to the EPIPRE-team for diagnosis. A telephone line is reserved for EPIPRE, so that urgent questions of farmers can be answered immediately.

The principles of calculation.

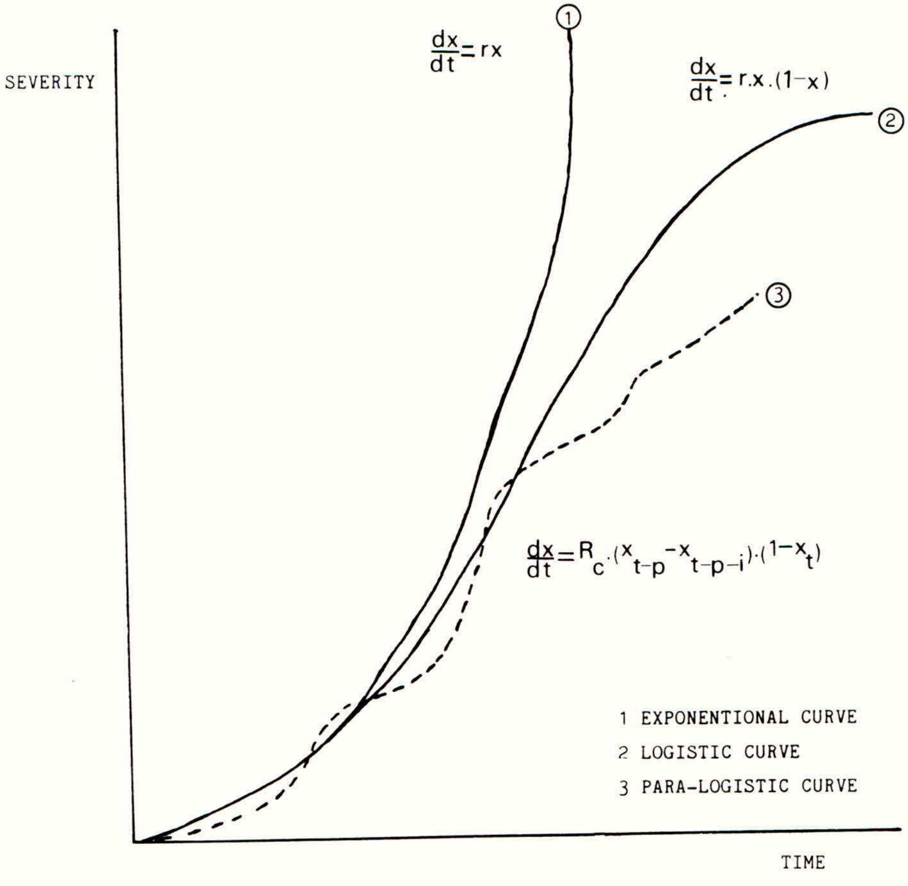
Epidemics of polycyclic organisms initially follow an approximately exponential pattern. Later on the development of an epidemic becomes logistic, due to the effect of a maximum infestation level of the epidemic. With fungal epidemics, the logistic pattern is not complete as delays in the epidemic occur due to latent periods and infection periods of limited duration. In insects different developmental stages have to be distinguished. Vanderplanks' formula decribes the rate of progress for such a para-logistic growth (1).
In Figure 4 an exponentional, a logistic and a para-logistic curve are represented.

$$\frac{dx}{dt} = R_c .(x_{t-p} - x_{t-i-p}).(1 - x_t) \qquad (1)$$

where x = the severity, t the time, R_c the corrected basic infection rate, p the latent period, and i the infectious period.

x_{t-p} and x_{t-i-p} represent the severity one latent period ago, and the severity one latent period plus one infectious period ago, respectively. Substracted, these terms represent the amount of infectious disease one latent period ago.

Figure 4. Exponentional, logistic and para-logistic curves



A limitation of the formula is that R, p, and i are assumed to be constant. Simulation models are used to describe the progress of an epidemic in more detail. By means of such models the influence of changing climatic conditions, developmental stage of the crop, crop susceptability, nutritional status and so on, can be studied. The complexity of these models and the necessity for detailed knowledge of site specific parameters limits their use in agricultural practice. These models are in the first place research tools to help the scientist understanding the dynamics of population growth. Although the models themselves may be of limited use, the results of the models may help us to develop decision rules in such a way that they can be used in agricultural practice.

Simulation studies have shown that the relative growth rate of populations tends to be conservative. In other words, they may change considerably when a long period is considered, but they are almost constant over a limited time span. This may be due to delays, which are characteristic for para-logistic processes. Moreover, in the case of wheat diseases, differences in severity levels above 0.3 are irrelevant for decision making in crop protection, because in all cases the action threshold values for treatment are surpassed. This means that approximation of the development of epidemics of polycyclic nature by exponential growth is acceptable when the severity levels are below 0.3 and the time span for a forecast is limited. The relative growth rate has to be defined as a function of factors such as varietal suseptibility, developmental stage of the crop, nutritional status of the crop, soil characteristics, etc. A time span, during which the relative growth rate is considered to be constant (prognosis time), is used. By defining a relative growth rate and a prognosis time, which depends on the developmental stage of the crop the effect of changing climate during crop development is introduced implicitly.

The relative growth rates and their correction factors, based on field specific information, can be derived from results of comprehensive simulation models or directly from detailed field experiments. When field data are used, empirical relations are introduced, a less satisfactory approach than using simulatiom models. Figure 4 demonstrates a relation between the relative growth rate of yellow rust of wheat, its prognosis time, and the developmental stage of the crop according to the decimal code (DC).

The simplified general model is represented by:

$$x(t) = x(0).\ e^{r.t}$$

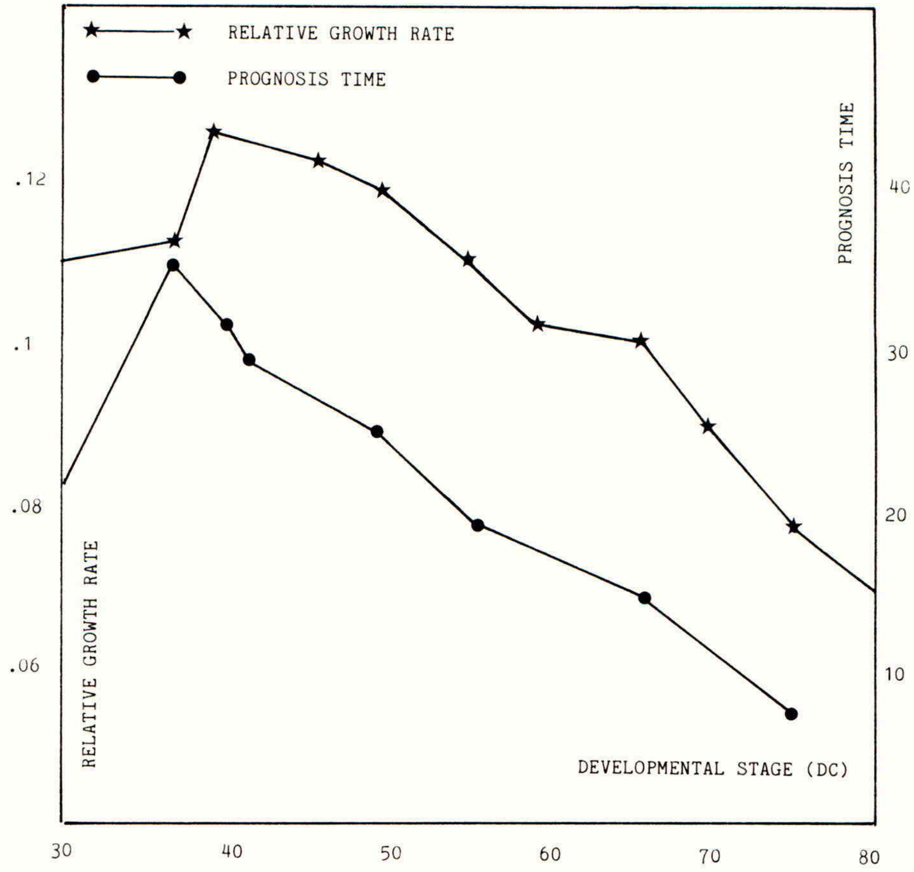
where x(t) is the expected severity, x(0) the initial severity, r the relative growth rate, and t the prognosis time. The variables r and t are given by:

$$r = f\ (\text{disease},\text{DC},\text{variety},\text{nutrition},\text{soil},...)$$
$$t = f\ (\text{DC})$$

x(0) is obtained from incidence counts by the farmer- participant. The incidence figures are transformed into severity figures for the diseases and into population densities per culm for cereal aphids. The relations between incidence and severity are derived from existing observation scales or empirical determined from experiments.

It should be noted that these relations hold only for relatively low severities (<= 5 %). With higher severities the transformation becomes useless; however the aim of the system is keeping the diseases at low levels.

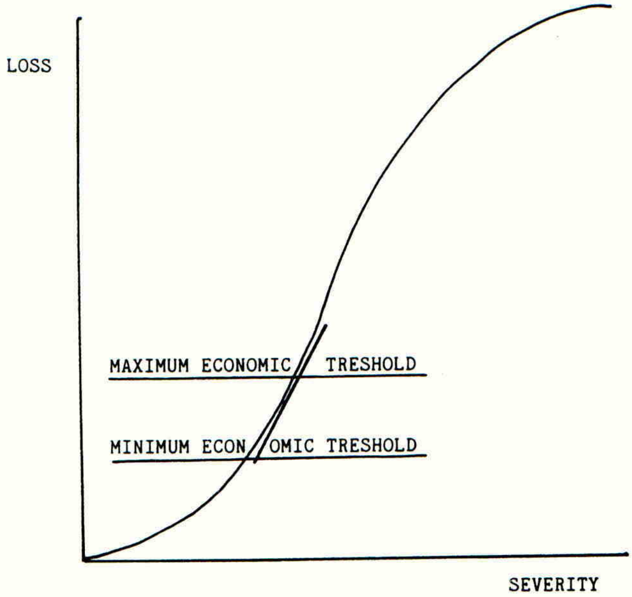
Figure 5. Relation between the relative growth rate of yellow rust and its prognosis time, combined with the developmental stage of the crop according to the decimal code scale.



Crop loss calculation.

The expected severities for the different pests and diseases are used to calculate a loss expectation for each pest and disease. Relations between severity and loss often show an S-shaped curve, where with low severities no loss appears and with high severities the loss stabilizes (Figure 5). For decision making only a very limited part of the curve is important. When a certain severity leads to a loss more than the maximum economic threshold (i.e. the loss equals the costs of treatment for only one pest or disease) treatment is economical, irrespective of the real amount of loss to be expected. When a certain severity leads to a loss less than the minimum economic threshold, the decision is always 'no treatment at that time' against the pest or disease. The interval between the two thresholds is so small that linear interpolation is adequate.

Figure 6. Relation between severity and loss



The interval from minimum economic threshold to maximum economic threshold, given the costs of treatment in the Netherlands, is within or close to the normal variation interval of the field experiments from which these values have to be obtained. This means that uncertain values have to be introduced in the loss calculation.

The calculated loss is expressed as a loss proportional to the expected yield. Multiplication of the calculated loss with the yield expectation results in a loss expectation in kg/ha. The relation between severity and loss for the diseases is again defined in relation to the developmental stage of the crop. For cereal aphids a peak-density is calculated and the loss depends, according to new data (R. Rabbinge, personal communication), on both the number of aphids per culm and the yield expected in the absence of aphids.

The costs of treatment.

The costs of treatment are defined by the sum of the costs of chemicals, the costs of labour and machinery, and the wheeling damage, where ground equipment is used. The price of the chemicals and the costs of labour and machinery are assumed to be constant during one season. The costs of wheeling damage depends on the width of the spraybeam, the expected yield, the developmental stage of the crop, the existence of tramlines, and how often wheeltracks were used in the past. After three treatments, either with fertilizer or with growth regulators or pesticides, wheeling damage for further treatments is assumed to be zero.

The calculation of the decisions.

Given the expected loss for each pest and disease and the costs of treatment for each, the cost-effectiveness of treatment can be calculated. If treatment of any one pest or disease is cost-effective a check is made on the value of adding further chemicals to control other pests and diseases which may be present. If no single treatment is cost-effective the possible value of combined spraying is checked.

Recommendations are issued as either:

1. No spraying, with a request for new field observations at, or shortly before a defined date, or
2. Spraying is recommended for control of specified diseases or pests, with a request for new field observations on a defined date.

At the end of the season a message is added to indicate that further spraying is no longer economical.

The time between two field observations depends on the developmental stage of the crop and the disease and pest severity. Starting from Decimal Code 30, four to five recommendations per field are given during the season, which ends at Decimal Code 75.

Errors and uncertainties.

Since EPIPRE is a system that uses forecasts, errors are inevitable. Sometimes it is possible to trace down the cause of errors. When a farmer is not able to recognise the disease symptoms, wrong recommendations will be the result. During the testing phase of EPIPRE hundreds of fields were checked by the EPIPRE-team, independently of the farmers' observations . Serious mistakes were rare. More frequently we found that farmers overlook very low disease incidences. Missing these very low disease incidences almost never leads to problems because during the next observation the disease is still below the threshold values used.

Other sources of errors may be introduced when wrong values of parameters are used to calculate the relative growth rates. Hard data are not always available and therefore parameters are replaced by 'guesstimates'. The system has become so complex that verification experiments for separate parameters have become meaningless. Fortunately, the system is strongly buffered against the effects of small errors because of the field observations. A overestimate of the growth of an epidemic leads mostly only to put forward a treatment; an underestimate is mostly easily corrected by the next observation which shows than the need for treatment still before substantial damage develops.

A source of error is the uncertainty of parameters obtained from yield trials, especially those describing the relation between pest and disease severity and loss. This uncertainty, derived from the variance in the experimental results, does not disappear in the calculation process. Differences in results of EPIPRE calculations and experimental data of less than about 250 kg/ha cannot be avoided.

*

RESULTS.

In 1978, EPIPRE was tested on four sites in the Netherlands on experimental plots using four varieties artificially infected with different physiological races of yellow rust. Chemical treatment according to EPIPRE resulted in the same yields as treatments according to general recommendations. The number of applications in EPIPRE was only half that in the fields using general recommendations. Analysis of data from of the participants' fields showed that in 50 % of the fields with yellow rust, no treatment was necessary.

In the 1979 season mildew was added and, on a limited scale, grainaphid (Sitobion avenae) and brown rust. The reason for including mildew was mainly the introduction of triadimephon which gave rise to the desire for early treatment with this chemical against mildew as a standard measure. Yellow rust was completely absent in 1979, mildew was of minor importance, and so was brown rust. Aphids were the main pest, but not S. avenae. Heavy attacks of rose grain aphid (Metopolophium dirhodum) resulted in losses up to 1.8 t/ha but S. avenae was almost absent. Since only S. avenae was included in the system, no recommendations for treatment were given. Experiments proved that the recommendations for S. avenae were correct, despite the yield loss from the infestations with M. dirhodum. Based on field observations in 250 fields, and results of experiments, an analysis was made of the effect of a treatment with Bavistin M or Bayleton during heading and flowering. In only 25 % of the treatments, the costs of treatment were repayed by the increase in yield.

In 1980 the system was extended to all cereal aphid species. Comparison of the EPIPRE recommendations with schedule treatments indicated that EPIPRE was economically optimal in all cases. However, the variability in the experiments was too high to prove this statistically. Analysis of data from fields with EPIPRE treatments and fields with more treatments then EPIPRE recommended showed that in case of superfluous treatments a mean yield increase was achieved which was equivalent to 40 % of the costs of the extra treatments.

Septoria leafspot and glume blotch were added in 1981. During this year an unusually high disease incidence was observed for mildew early in the season and for Septoria spp, mainly Septoria tritici, later in the season. Also cereal aphids were of importance. EPIPRE was tested in trials on participant-fields and on experimental farms. Differences between EPIPRE treatments and no treatment were in generally high, up to 2 t/ha. In two experiments an extra treatment, above the EPIPRE recommendation, resulted in a significantly better result than EPIPRE, probably because of an underestimation of the growth rate of Septoria. In the other cases no significant differences were found between EPIPRE treatments and "more than EPIPRE" treatments. In general the difference between EPIPRE and "more than EPIPRE" was one extra application of fungicides.

Analysis of the data of participants' fields showed that at relatively low yield levels (less than 6 t/ha) a net economic benefit of 0.4 ton/ha , at medium yield levels (between 6 to 8 t/ha) the benefit was 0.23 tons/ha, and at high yield levels (more then 8 t/ha) the result was only 0.03 tons/ha. The data are summarised in Table 3.

Another aspect of the results is the farmers' reaction to the recommendations. When farmers follow the recommendations, they agree with EPIPRE and so confidence in the system may be assumed. Farmers often decide to treat their crops immediately after a field observation, without waiting for the EPIPRE

Table 3

Comparison between net yield of fiels treated according to EPIPRE and field treated "more than EPIPRE" in 1981.

yield class	less than 6 t/ha	6 to 8 t/ha	more than 8 t/ha
net yield in t/ha EPIPRE	5.34	6.90	8.16
net yield in t/ha "more than EPIPRE"	4.93	6.77	8.13
costs of treatment EPIPRE in t/ha	0.15	0.23	0.31
costs of treatment "more than EPIPRE" in t/ha	0.45	0.41	0.45
% of fields treated in accordance with EPIPRE	75	57	41
number of fields	69	524	263

recommendation. If EPIPRE would also have given a recommendation for treatment such an "early" treatment is "in accordance with EPIPRE". In the years 1978 and 1979 it was difficult to judge farmers' treatments since only a limited number of pests and diseases were included. A treatment may have been carried out to control a disease which was not included in EPIPRE. In 1980, 38 % of the farmers' fields were treated according to EPIPRE. In 1981, 54 % of the farmers' fields were treated according to EPIPRE.

The reluctance of farmers to follow the EPIPRE recommendations completely can be explained by the fact that EPIPRE recommends significantly fewer treatments than other recommendations such as those provided by the extension service and the chemical industry. However, the increase in fields treated in accordance with EPIPRE shows increasing confidence in the system. It is not to be expected that such a system ever will reach a 100 % acceptance, since there are sometimes good reasons for a farmer to deviate from the recommendations.

The proof of the usefulness of the system will be the willingness of farmers to participate in and pay for, the system.

DISCUSSION.

EPIPRE is a supervised pest and disease management system for wheat. It enables the scientist to put in detailed information on population dynamics and crop loss, which can be put into commercial practice. Changes in variety, disease spectrum and disease virulence are easily introduced in the system, as are effects of changing agricultural practice. EPIPRE requires farmer-investment in time, money, and a basic training to participate properly in the system. The benefits for the farmer are recommendations which in general lead to optimal or near-optimal results in crop protection. Apart of the recommendations, farmers also appreciate EPIPRE for the education they receive in crop protection, and the "pressure" to follow the development of their crops more frequently and accurately, which also influences other aspects of crop management.

For agriculture as a whole the system can lead to a considerable decrease of the use of pesticides without loss of money by the farmers. This decreases the risk of development of resistance by fungi and insects to pesticides. One of the disadvantages of EPIPRE is the time required for field observations, by the farmer. Possibly the introduction of professional pest and disease scouts may solve this problem.

The question whether the Dutch EPIPRE system can be transferred to other countries and climates remains to be answered. Much information put in the system is of Dutch origin, and therefore partly an expression of Dutch farming system and climate. Nevertheless the system may be of more general use outside the Netherlands. In 1981, first experiences with EPIPRE in Belgium and in Switzerland were positive. In 1982 EPIPRE will be introduced at an experimental scale in Belgium, Switzerland, France, Sweden, and the United Kingdom. Each country will use its own version of the system, adapted for differences in climatological conditions and in agricultural practice.

Until now, the system is centralised on a big computer, storing data from many fields. In the near future EPIPRE may be available for micro-computers for use by individual farmers. It will remove the delay between observations and recommendations, but it will also diminish the possibility of keeping track of the development of epidemics at a regional or national scale during the season. The ultimate perspective of EPIPRE is its integration in a complete crop management system.

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Decision Making in the Practice of Crop Protection

RATIONALISING THE NEED FOR A FUNGICIDE PROGRAMME ON WINTER WHEAT USING A RISK ASSESSMENT SCHEME

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Summary A risk assessment scheme is described in which nine agronomic factors are used to predict the cost-effective application of a routine prophylactic fungicide programme for winter wheat disease control, involving triadimefon/carbendazim followed by triadimefon/captafol. The agronomic factors are quantified in a scoring system and their relative importance and modified use in the prediction scheme are discussed. Using the scheme, a retrospective analysis of 105 trials results conducted over 4 years is described and discussed. An overall prediction accuracy of 93% was obtained. In addition, the results of a pilot project involving the prediction method to decide upon fungicide treatment of commercial wheat crops in 1981 in Northern England are described and evaluated.

INTRODUCTION

The intensity of wheat production in recent years, encouraged by the high value of grain has led to increased inputs and closer attention to the correct use of seed, cultivars, nutrition, soil conditions and control of weeds, pests and in particular, diseases. The introduction of broad spectrum fungicides such as triadimefon, alone and in formulated mixtures with carbendazim or captafol, has made possible the effective control of most of the major cereal diseases. This attention to maximising yield together with availability of effective fungicides has created a great incentive to adopt routine prophylactic spraying programmes to prevent significant yield losses. The use, however, of such fungicide programmes has been questioned because of the need to rationalise pesticide usage and also to maintain profitability in the presence of currently escalating production costs and comparatively static grain prices. (Jenkins and LeScar 1980). In addition, there are available in the U.K., disease monitoring and forecasting schemes to determine the need for fungicide treatment using disease threshold and other criteria related to the incidence of disease. Such systems are well developed for barley diseases, particularly barley mildew (Erisyphe graminis) but are currently less effective for wheat diseases such as mildew, eyespot, (Pseudocercosporella herpotrichoides), rusts (Puccinia spp.), and Septoria spp. and particularly the interaction of several of these diseases with yield potential. Practical difficulties are also frequently experienced in the correct and accurate utilisation of disease threshold and related criteria used to make decisions on fungicide applications! In individual crops disease thresholds are extremely critical and tend to require regular and frequent crop inspections by expert personnel capable of identifying diseases at early and incipient stages. Much fungicide timing information suggests that applications made later than the critical threshold fail to achieve optimum yield responses. In addition, application decisions made on weather and disease threshold criteria for each wheat disease could lead to complex over-application and incur unnecessary chemical application and wheeling damage costs. In scrutinizing the costs of inputs, difficulty arises in identifying those inputs which are not cost-effective, and resisting the temptation to cut those factors contributing significantly to increased production (yield and quality) and in the final analysis, profit.

It was therefore desirable to identify those wheat crops which respond economically to the use of fungicides applied as a routine prophylactic programme and equally important, to also identify those crops where routine treatment was not economically justified but required a close monitoring, "wait and see" approach to fungicide use based on disease incidence.

A prediction scheme was devised (Myram and Kelly 1981) based on a system developed and used in Northern France, (LeScar 1980/1981, Maumené 1981). This scheme defined with a high degree of accuracy those wheat crops which would and would not provide financial benefit from the routine, planned use of a two spray programme.

This paper reports a further modification of the scheme, based on a retrospective analysis of trials carried out with a specific fungicide programme on wheat in the U.K., during the last 4 years and evaluates the usefulness of such a scheme when used in a commercial "pilot" project in Northern England in 1981.

METHODS AND MATERIALS

A modified risk assessment table was devised (Table 1), based on the nine agronomic and cultural factors of the previous scheme, but changed in the emphasis placed on the nine factors relative to each other and also the breakdown of the risk score given to each factor. In addition, as a reaction to comment from farmer/adviser experience in using the scheme in the 1981 pilot study, the method of scoring the risk factors was changed to dispense with negative points and also the use of the additive constant, whilst still retaining the psychologically acceptable threshold score of 10 points: a score of 10 or more indicates that routine treatment with the specified fungicide programme was predicted to be economically justified; a score of less than 10 points required crop monitoring and treatment according to disease threshold or other criteria to decide curative disease control applications.

Using the modified risk assessment table, a total of 105 results from trials carried out in the U.K., between 1978-81 was examined, involving the use of the two spray fungicide programme compared with an untreated control: 125 g ai triadimefon + 250 g ai carbendazim as a w.p. (Bayleton BM (R) per hectare applied at GS 30-32 (Zadoks et al 1974) followed by 125 g triadimefon + 1300 g ai captafol as a w.p. (Bayleton CF (R) per hectare applied at GS 39-59. Of the total, 57 came from Bayer UK Ltd., field trials and the remaining 48 came from MAFF (43), Norfolk Agricultural Station (4), and Kenneth Wilson Ltd., (1). The results from Bayer UK Ltd., were sited at 27 locations and the independent trials at 29.

Using Table 1, a prediction score was obtained and, based on the costs given below, this was then compared with the yield response obtained from the fungicide treatment and assessed for cost-efficiency. The break-even was determined by obtaining the increased return from the yield response achieved, and subtracting the chemical cost, an arbitrary cost for application, and 2% of untreated yield level as a further arbitrary cost attributable to wheeling damage incurred. Over the four year period, the following costs were used:

Year	Wheat per tonne	Application per hectare	triadimefon/ carbendazim	triadimefon/ captafol
			per hectare	
1978/9	£95	£3.70	£16.02	£17.52
1980	£100	£3.70	£19.07	£22.00
1981	£105	£3.70	£19.07	£24.70

Table 1

Risk assessment table for winter wheat to predict the need for a routine fungicide programme of triadimefon/carbendazim followed by triadimefon/captafol

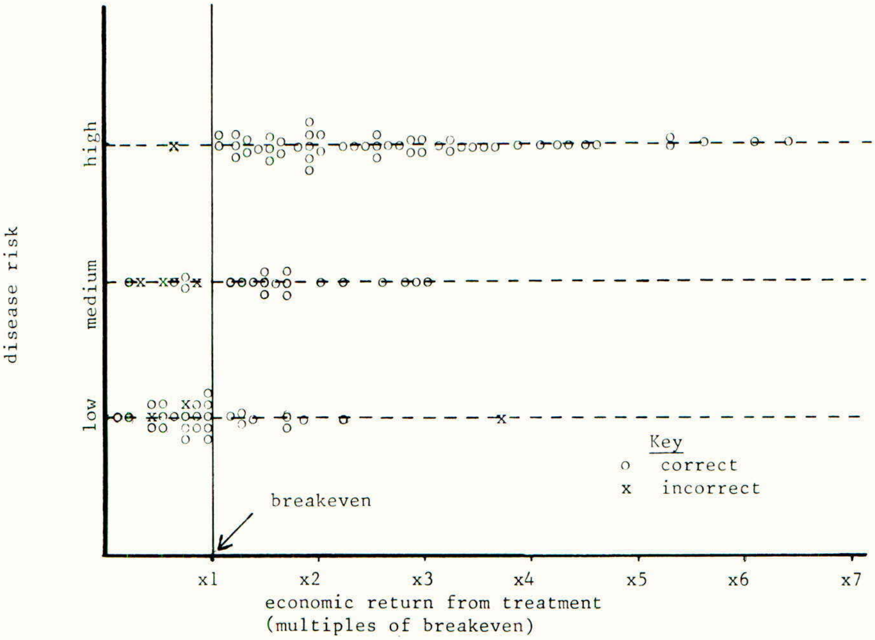
Previous crop	Risk Score
Oil Seed Rape, Peas, Potatoes	3
Grass, Wheat	2
Barley, S. Beet, Oats	1
Maize	0
Variety	
Brigand, Hobbit, Hustler, Norman	3
Copain, Kador, Kinsman, Longbow, Mardler, Pageant, Virtue	2
Aquila, Armada, Atou, Bouquet, Fenman, Flinor, Prince, Rapier, Sportsman, Templar	1
Avalon, Bounty, Flanders, M. Huntsman, Sentry	0
Sowing Date	
Before 15 October	2
15 - 31 October	1
After October	0
Local Disease Risk	
High	3
Moderate	2
Low	0

Cultivations	Risk Score
Plough	2
Tine/disc	1
Shallow/minimal	0
Land Grade	
Class 1	3
" 2	2
" 3	1
" 4	0
Susceptibility of soil to drought	
Susceptible (moderate/high)	1
Not susceptible (low to nil)	0
Nitrogen Usage	
High	2
Medium	1
Low	0
Crop Density	
High (> 250 plants or 550 tillers/m^2	1
Normal/Low	0

From the updated analysis of the four years of results utilising the previous risk assessment table, it was evident that greater emphasis within the total risk score should be placed upon the locality disease risk factor in comparison to some other factors in the analysis (Fig. 1, Table 2). In particular, the response obtained at high and moderate disease risk assessments suggested a greater value compared to low risk and other factors. Cultivar scores were updated in the same manner as previously, using disease susceptibility ratings (NIAB 1978, 1979, 1980, 1981 and 1981a and 1982) correlated with response to routine disease control (Priestley 1980; Priestley and Bayles 1981, Priestley 1982). Whilst retaining the previous emphasis and priority in the risk assessment of the effect of cultivar, it was now possible to reduce the number of categories to four. Similarly, the effect of sowing date was simplified into three instead of the original four categories, since trials analysis indicated little additional effect from very late sowings (Fig. 2) except where influenced by organic soils.

Fig. 1

Economic return from treatment in relation to the local disease risk factor



Susceptibility of soil to drought was also simplified as a result of examination of this factor in relation to response indicating that the major differences occurred between soils being either susceptible (moderate or high) and not susceptible to drought (Table 3).

Table 2

Economic return from treatment in relation to disease risk

Disease risk category	No. of results in category	Multiplication Factors Mean Response	Multiplication Factors Range of response
High	52	x2.72	x0.7 - x6.4
Medium	23	x1.5	x0.3 - x3.0
Low	30	x0.98	x0.1 - x3.7

Fig. 2

Economic yield response in relation to sowing date

Categories

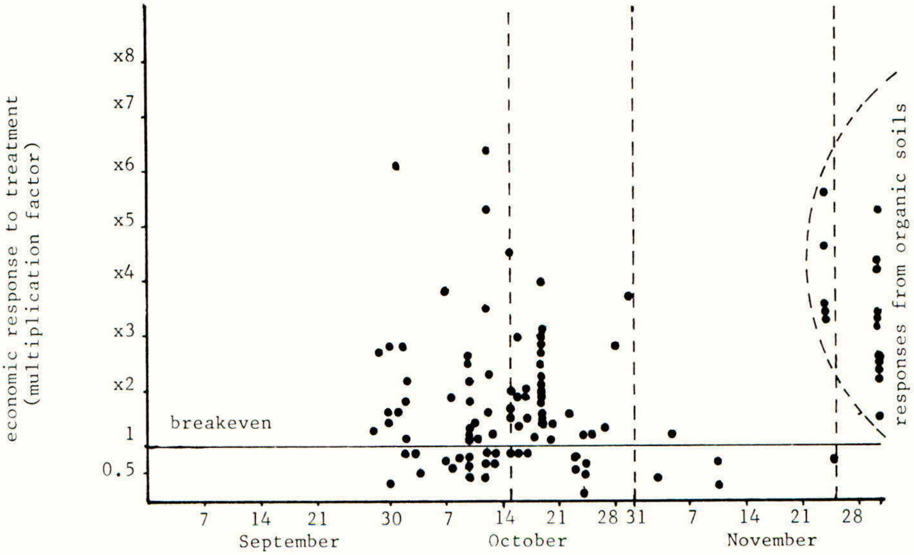


Table 3

Economic return from treatment in relation to susceptibility of soils to drought

Drought susceptibility old category	No. of results in category	Multiplication Factors Mean Response	Range of response
High	7	x1.2	x0.4 - 2.8
Medium	62	x2.5	x0.7 - 6.4
Low	36	x1.1	x0.1 - 4.5
New category			
Susceptible	69	x2.4	x0.4 - 6.4
Not susceptible	36	x1.1	x0.1 - 4.5

In addition during 1981, a pilot study was undertaken in Northern England to evaluate the scheme. A total of 97 farms involving 277 fields were assessed using the scheme and prediction scores attributed to assist the farmer to plan his fungicide usage. Of these, 18 farms (69 fields) had reliable measurements of yield taken, although no direct comparisons of predictions and treatments were possible within fields. The details of the predictions are shown in Table 4.

Table 4

Bayer Wheat Prediction Scheme

1981 Farmer Usage - Northern England

	Total Predictions	No. where yield measured
Farms	97	18
Fields	277 (2.8 per farm)	69 (3.8 per farm)
Score 10+	89 (32%)	28 (40%)
Score <10	188 (68%)	41 (60%)
Area	2,769 ha (6,842 acres)	764 ha (1,888 acres)

RESULTS

On examination of the 105 trials results, 81 were predicted to require the two spray routine programme, having been rated at 10 points or above, while 24 scored less than 10 points and so were predicted to require a "wait and see" or curative approach to fungicide application. Table 5 indicates the results in terms of the cost-efficacy and therefore accuracy of predictions. It also shows the breakdown of the results into those trials carried out by Bayer UK Ltd., and those from independent sources. Fig. 3 shows the spread of individual results when the prediction score is related to the degree of yield response.

The overall accuracy of the prediction score was 93%, a marginal improvement on the previous risk assessment method (Myram and Kelly 1981). Once again however, the analysis was weighted heavily (3.4 : 1) in favour of high prediction scores and economic responses because of the utilisation of retrospective trials site evidence (presumably chosen initially for testing response to fungicides) rather than commercial usage experience. The accuracy of the comparatively fewer cases predicting a non cost-effective response from routine treatment was 96%, again superior to the positive predictions of cost-efficacy and a slight improvement on the scheme previously reported.

In Figs. 4 and 5, the breakdown of individual risk factors into the alternative components of each factor are given and presented in terms of correct and incorrect predictions respectively.

Table 6, illustrates the involvement of cultivars in the analysis, showing the relative frequency of individual cultivars, and the accuracy of prediction for each as assessed by economic response.

The results obtained from the commercial usage of the prediction scheme are given in Fig. 6 and expressed as a comparison of mean yields obtained from fields with prediction scores above or below the threshold of 10; together with the number of sprays applied related to each prediction category.

Table 5

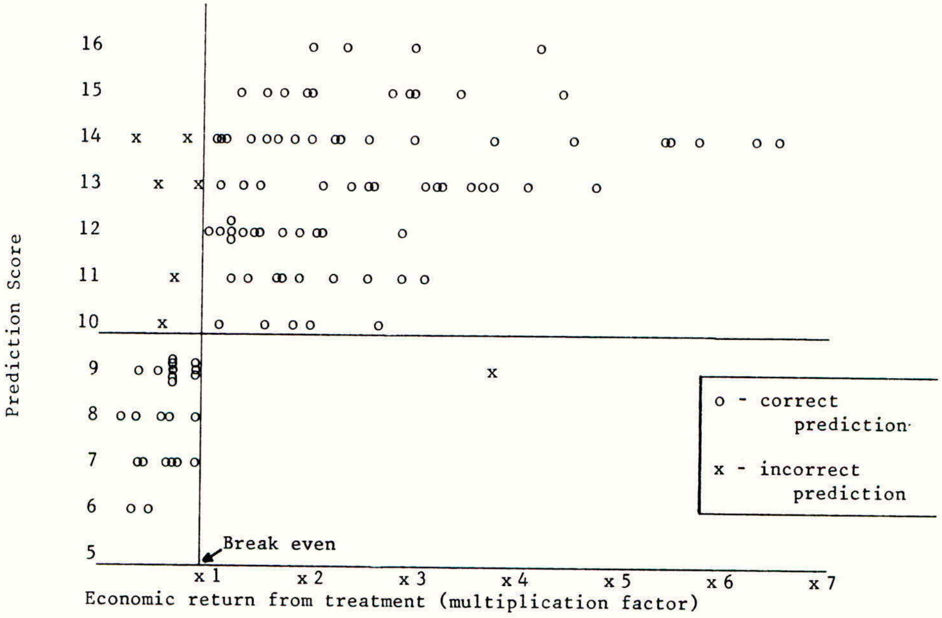
Accuracy of prediction of the economic need for a routine fungicide programme on winter wheat

Analysis of Trials Results 1978 - '81

Prediction Score	Total in each category	Number of Predictions		% Accuracy
		Correct	Incorrect	
Bayer Results				
10+	48	46	2	96%
<10	9	9	-	100%
Total	57	55	2	96%
Independent Results				
10+	33	29	4	88%
<10	15	14	1	93%
Total	48	43	5	90%
Bayer & Independent Results				
10+	81	75	6	93%
<10	24	23	1	96%
Total	105	98	7	93%

Fig. 3

Prediction scores in relation to economic response to fungicide treatment



DISCUSSION

The results of the analysis in Table 5 indicate that this modified and updated Prediction Scheme has defined with increased accuracy those winter wheat crops which respond with financial benefit to the planned use of a programme involving triadimefon/carbendazim followed by triadimefon/captafol. Modifications were made to the risk assessment table in order to overcome the difficulties and objections experienced in practical use of the scheme: the results in Table 5 also show that this removal of negative scores and an additive constant figure has been accommodated without impairing accuracy.

The results also demonstrate that changes in the relative emphasis of scores for both individual factors and categories within certain factors have been beneficial in improving the accuracy of predictions.

An analysis of each individual factor in relation to the accuracy of predictions (Fig. 4) suggests that all factors are important in defining correctly the responsive crops, with only land classification, previous crop and cultivar showing no special emphasis towards high scores in comparison to the correctly predicted non-responsive crops. In the case of the latter predictions, most factors were equally important including cultivar, and land grade since the majority of such predictions fell into the lower score categories for these factors. In this instance, the influence of previous crop and sowing date appeared less important in predicting crops not requiring prophylactic treatment than those indicating the converse. Locality disease risk was equally important in selecting correctly the appropriate crop situation, as was the influence of cultivations, nitrogen use, drought susceptibility and crop density.

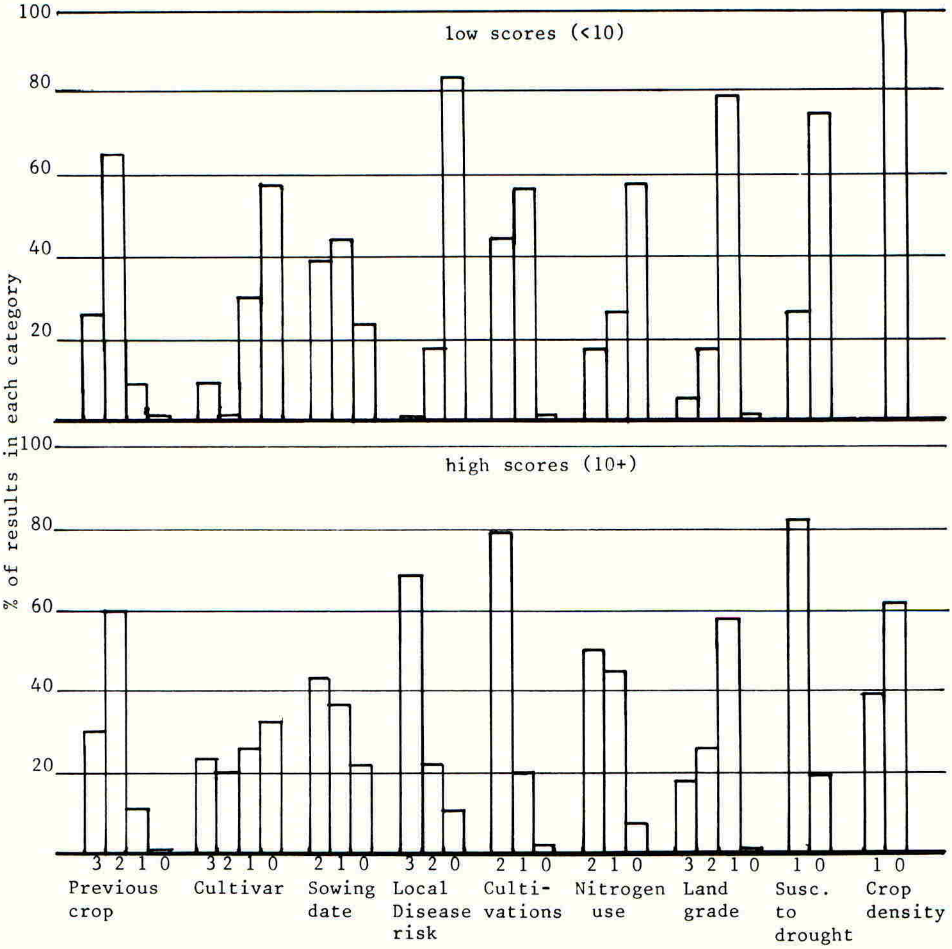
On examining the incorrect predictions by individual factors (Fig. 5), the major influence in the otherwise generally correct prediction of a non-response was a large and profitable response to the control of a severe infection of Septoria nodorum in a locality scored as generally of low disease risk. It would appear that previous crop cultivations, nitrogen use, crop density and susceptibility to drought factors may have been significant influences in the level of response obtained to the fungicide treatments. In those crops predicted to respond economically to the treatment, but failed to do so, the influence of early sowing, previous crop, responsive cultivars, and cultivations were the main sources of the incorrect scores, whilst the low disease risks, low crop density and low drought susceptibility factors tended to correctly indicate uneconomic response.

It can be concluded therefore, that each factor is an essential part of the risk assessment and prediction, although the influence of sowing date and cultivar appeared to be less effective than might be expected, particularly the latter when used to identify those crops requiring routine fungicide protection. This may be due to the influence of certain cultivars in the total analysis as indicated in Table 6. The presence of relatively high numbers of Maris Huntsman, Flanders and Bouquet, may have affected the estimated importance of cultivars in the prediction scheme since these cultivars can be correctly placed into either the responsive or non-responsive categories, depending to a greater extent on the influence of other factors.

On examination of the commercial pilot study data, it can be seen that in Northern England, the weighting of high scores calling for routine treatment compared with the "wait and see" approach was reversed from that obtained in the trials analysis. Only 32% of the total fields were identified as responsive to a planned routine treatment of triadimefon/carbendazim + triadimefon/captafol. On the 69 fields where yield measurements were obtained, the spread of scores was more

Fig. 4

Analysis of Correct Predictions by Individual factors



evenly balanced possibly because the 18 farms involved had a greater commitment to and degree of intensification of the wheat crop, as evidenced by the average of 3.8 wheat fields per farm, one field per farm more than in the overall study. This may have influenced the level of inputs used to achieve higher yields and quality. Certainly the mean yield of 7 tonnes per hectare from the 69 fields was well above the national average in 1981. When the mean yields from each prediction category were compared (Fig. 6), there was a substantial difference of 0.958 tonnes per hectare in favour of those fields predicted to require the planned treatments. Although not conclusive evidence of the value and accuracy of the prediction scheme, as there were no within field comparisons of different fungicide regimes with untreated, the yield differences are corroborative evidence to that from the trials data already referred to. A further difference also illustrated in Fig. 6 and which emanated from farmers use of the prediction scheme, was the number of fungicide sprays applied to wheat crops in the two prediction categories. Again, ar accuracy of prediction of approximately 90% was confirmed by the proportion of crops in the 10+ category receiving the two spray programme, especially when compared to the almost complete reverse of proportions of single sprays to double sprays in the <10 category. In a season of above average disease incidence on wheat crops in Northern England, this evidence of numbers of fungicide applications made is interpreted as further confirmation of the reliability of predictions made for wheat crops regarding the use of the specified fungicide programme.

Fig. 5

Analysis of incorrect predictions by individual factors

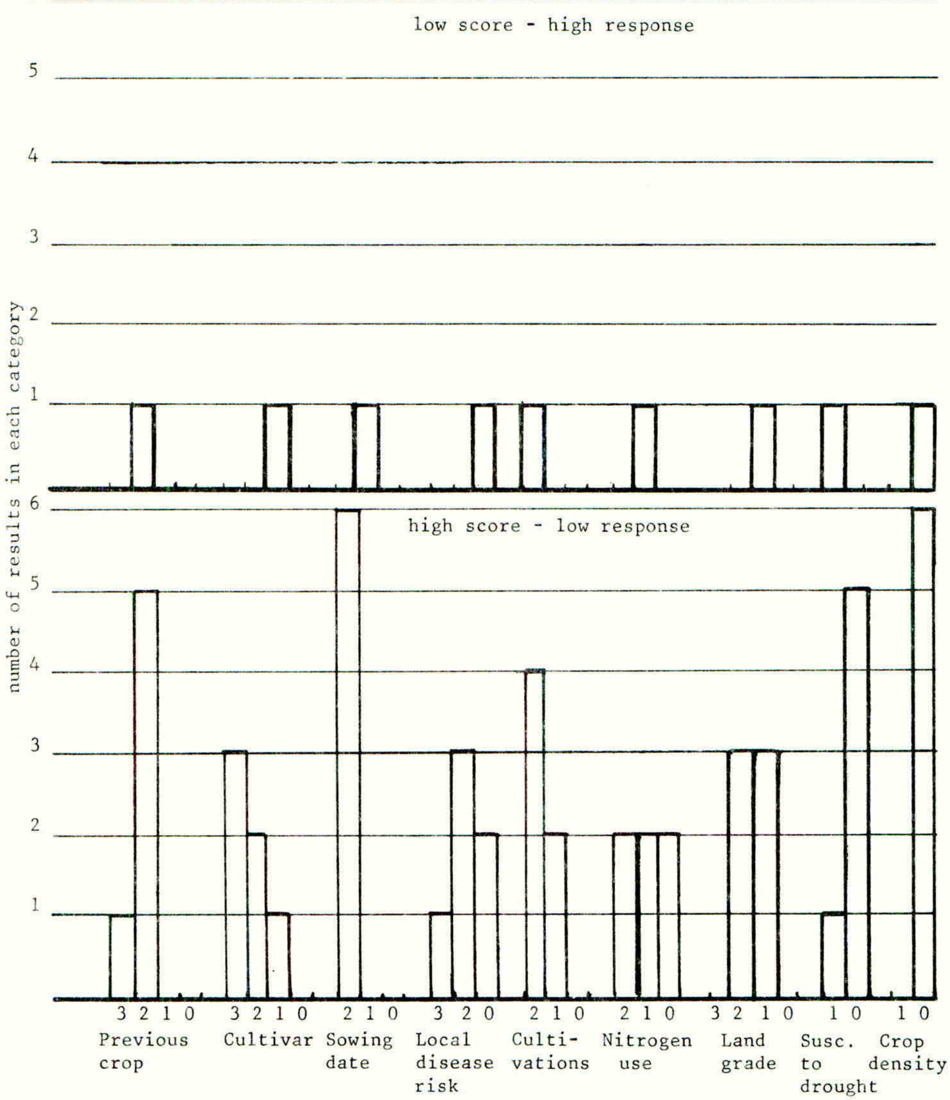


Table 6

Analysis by variety of response and prediction accuracy

		Prediction Score				
		10+		<10		
VARIETY	Score	Correct	Incorrect	Correct	Incorrect	TOTAL
Aquila	1	2		2		4
Armada	1	8		1		9
Avalon	0	4				4
Bounty	0	7		3		10
Bouquet	1	4		3		7
Brigand	3	3		1		4
Copain	2	1				1
Flanders	0	5		5		10
Flinor	1	1				1
Hobbit	3	9	3	1		13
Hustler	3	5				5
Kador	2	3				3
Kinsman	2	2				2
Mardler	2	8	2	1		11
M. Huntsman	0	7		5		12
Pageant	2	1				1
Prince	1	2				2
Sentry	0	1				1
Sportsman	1	1	1	1		3
Templar	1	1			1	2
Total		75	6	23	1	

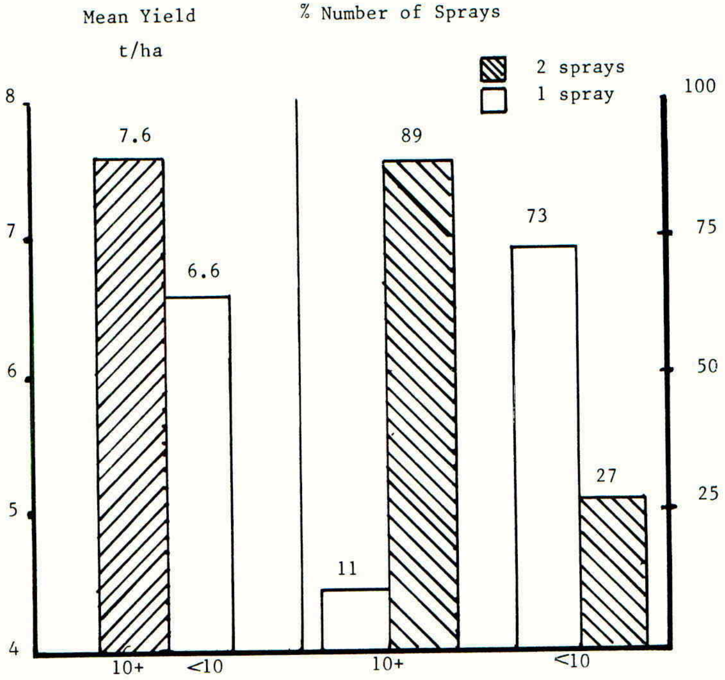
All 18 farmers who co-operated in obtaining yield measurements, agreed that the prediction scheme was a useful aid to the management of their wheat crops. In practical terms, an accurate means of providing responsible advice and forecasts of the value of a routine disease control programme, allowed them to plan the overall management of their crops more thoroughly. Those fields scoring above the threshold and requiring routine treatment could then have all other intended inputs planned around the fungicide applications, thus simplifying application and timing. Equally important, those crops predicted not to justify routine spraying could similarly be planned to receive greater attention to crop inspections to better determine if and when disease control was necessary.

The wheat prediction scheme described enables the identification with greater accuracy than hitherto of those winter wheat crops which will benefit from the planned fungicide programme of triadimefon/carbendazim followed by triadimefon/captafol at the prescribed application timings. Such a scheme could be utilised to supplement and complement existing disease monitoring and forecasting models, and therefore be of benefit in rationalizing fungicide usage in a responsible and cost-effective manner.

Fig. 6

Bayer Wheat Prediction Scheme

1981 Farmer Usage - Northern England



Acknowledgements

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Decision Making in the Practice of Crop Protection

POPULATION DYNAMICS OF ANNUAL GRASS WEEDS

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Summary Weed control has two elements; tactical, based on the expectation of short term benefits to the treated crop, and strategic, based on the long term requirement to prevent unacceptable population increase.

Population studies of many pests and diseases have been concerned with the development of 'tactical' models, to predict when or if the population will build up to a damaging 'threshold' level. However, it may not be practicable to base decisions on whether or not to spray herbicides on the concept of an economic threshold level of weed populations. This is because such threshold levels would vary from field to field, be difficult to define and difficult to assess. More information is needed on the relationship between weed populations and their economic consequences, but not necessarily to further the concept of economic thresholds.

Some recent research at the Weed Research Organization has concentrated on the long-term strategic aspects or "weed management". In large scale experiments, the response of weed populatons to changes in cultural techniques have been studied. As a complementary approach, specific elements in the life cycle have been studied in detail. The studies have been concerned particularly with the seed cycle in annual species notably *Avena fatua* and *Alopecurus myosuroides*. A modest start has been in developing long term population models and some examples are given.

One of the problems of weed control at the present time is that the existence of herbicides permits the development of cultural techniques which favour some major weeds. This ecological imbalance may be so great that the herbicides available are not effective enough to control the situation their existence has permitted. Population models may be a useful aid to developing and testing the economics of integrated control strategies.

INTRODUCTION

There are four basic reasons for killing weeds; to prevent loss of yield, to prevent interference with harvesting, to avoid contamination of the crop produce and finally as an investment for the future to prevent weed seeds or other propagules from being returned to the soil and thus influencing future crops.

The farmer's decision whether to spray to control weeds or not will depend on his own attitudes to the problems and his judgement on which of the four objectives referred to above will be of greatest economic significance to him.

The first three elements; yield loss, harvesting effects and sample contamination could, in theory at least, all be rationalised by a knowledge of an economic threshold. This is a weed population at which the expense of spraying equals the expense of leaving the weed there. A higher population would be economic to spray, a lower population uneconomic to spray in the short term. The concept of an economic threshold is very useful for some pests but may not be relevant to practical weed control for the following reasons.

1. Thresholds as measured in field experiments are extremely variable. The same absolute yield loss has been obtained in WRO experiments from black-grass and wild-oat populations varying by a factor of greater than 10. Some of the reasons for this variability include: crop population, crop vigour, the time of emergence of the weed seedlings relative to that of thecrop, crop variety; all can have a profound effect on the course of competition. It may be possible, with increasing knowledge, to correct for some of these factors so that thresholds applicable to individual fields could be derived, but it is clear that there is no simple weed population threshold which can be applicable under all field conditions.

2. Many of the economic thresholds are large. It takes a population of somewhere between five and fifty wild-oat plants per m^2 to produce a yield loss equivalent to the cost of application of herbicide. However, even if a low figure is taken, e.g. 10 plants/m^2 a population of 9/m^2 would be left unsprayed. This is a very high level of weed infestation. It would be an affront to many farmers' pride, but more seriously would produce of the order of 500-700 viable seeds/m^2 and create very severe weed problems in future cereal crops.

3. Although economic damage thresholds are frequently quite high the 'future' effects could be taken account of by using a threshold low enough to give a margin of safety. An arbitrary 'false' threshold for spraying could be calculated by dividing the lowest economic threshold by the potential for population build-up. However, this use of 'false' thresholds makes decisions even more difficult because weed population density varies considerably from point to point in large fields with low overall weed populations and accurate assessment is difficult.

All of these considerations suggest that many farmers base their decision making on (3), the need to avoid the future build up of weed populations. Thus, weed spraying is done for much the same reasons as painting gutters and cleaning ditches; as an insurance against trouble in the future, rather than as a short term remedy to trouble which has occurred. Clearly there are many fields where trouble is imminent and weed control does indeed give a useful worthwhile response. However, it is not only those sprays which give an immediate short term economic benefit that are, in the longer term, economic.

The study of population dynamics

Accepting the principle that spraying is done for long-term benefit, there still remains the need for rationalisation; to avoid wasteful use of herbicide when weed populations have declined below the point at which they are economically significant and, on the other hand, to avoid weed populations insidiously building up. Thus, having reduced weed populations to "uneconomic" levels, the input of herbicides has to be balanced against the potential build-up of the weed which is permitted by the cultural system employed. Weeds are a record of past husbandry and succeed because they are well adapted to the conditions that are created for them.

Because of all these factors the Weed Research Organization has devoted a great deal of effort to study of the population dynamics of some major weeds with two broad aims in mind. First, to understand some of the effects of changing cultural systems on the population dynamics of our major weeds. Second, to explore the possibility, by creating population dynamic models of these weeds, of providing practical assistance in forecasting the demands for weed control and matching herbicide use to cultural systems. This paper discusses the possibilities in respect of black-grass (Alopecurus myosuroides) and refers briefly to a contrasting species, wild-oat (Avena fatua).

A POPULATION MODEL FOR BLACK-GRASS

Fig. 1 shows a flow diagram of a model for computing the annual changes in black-grass populations in winter cereals based on that described by Moss, 1980a.

Each of the boxes in Fig. 1 represents a state through which the black-grass seeds or plants must pass during the life cycle, when the individuals can be counted. Each of the arrows represent a transition state in which the population may increase or decline. So it is apparent that if simple figures are ascribed to each of these transition states a numerical value for increase or decrease in the total population can be derived at the end of the cycle. Seeds in the soil are divided into two classes; those in the surface 2.5 cm and those below it. It is well documented that most seedlings emerge from seeds in this top 2.5 cm of soil (Naylor, 1970; Cussans et al., 1979). Figures applied to the transition states are based in most cases on a number of critically observed experiments although in one instance inspired guesswork has been used. In other instances the figures used are the mean of a wide range of recorded values.

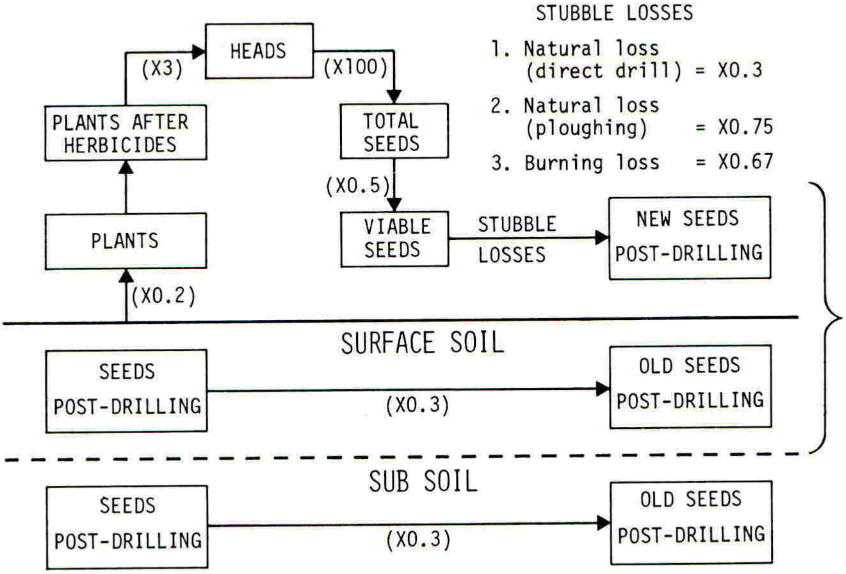

Fig. 1. BLACK-GRASS SEED CYCLE

First, it can be seen that 20% of the seeds in the surface soil are assumed to produce plants. For the plants remaining after the use of herbicides a figure of 3 seed heads per plant with 100 seeds per head has been assumed but viability has been estimated at 50%. The next transition state, stubble losses, relates to a number of factors. Seed may be destroyed by burning straw (Moss, 1980b), it may be eaten by birds or small mammals, it may be destroyed by fungal infection or very commonly it may germinate and produce plants which are killed before the next crop is sown (Moss, 1980a). This is a very critical stage in the life of the seed when more die than survive. Three figures have been used for losses at that stage: with direct drilling where seed has maximum exposure on bare stubble only 30% of the seed is assumed to survive; if the straw is burnt only 67% of the 30% survive so factors 1 and 3 must be multiplied together; where land is ploughed it is estimated that only 25% of seed stocks are lost, in the absence of burning, provided that ploughing is done early as for winter cereals.

The seed sycle shown in Fig. 1 is simplified by illustrating the direct drilling condition, where all the new seeds remain in the surface 2.5 cm together with approximately 30% of the old seeds which have survived for the intervening 12 month period. There is however a further complication if the land is ploughed or otherwise cultivated for there will be some redistribution of seeds between the surface soil and the deeper horizons. Table 1 shows the assumptions that have been made for ploughing in our models. The experiments that have been conducted, on two contrasting soil types, have given rather better inversion than has been assumed in the model.

Table 1

Assumptions made in the model for the redistribution of seeds between surface soil (2.5 cm) and deeper layers by ploughing

1. 5% of surface seeds remain in surface layer
2. 20% of old buried seeds are transferred to the surface layer

Histograms of black-grass populations calculated using the model for direct drilled land or ploughed land where straw has been burnt or not burnt and where no herbicide has been applied are shown in Fig. 2. Calculated populations show exponential increase but in practice, at high population densities, there would be intense competition between black-grass plants and the rate of population increase would decline. This simplification is justified on the basis that the main interest is in computing population changes at low "sub-economic" population levels. The assumptions for both straw burning and ploughing were relatively conservative in this model, lower than have been recorded in practice and yet it can be seen both have a dramatic effect on population increase. The population increase factor of 6.3 -fold per year with burning and 9.3-fold without in the case of direct drilling is reduced by ploughing to 1.5-fold with burning and 1.9-fold without burning. The histograms shown in Fig. 2 accord reasonably well with what has been recorded in field experiments although clearly the smooth progression of the curves is unlikely to be encountered in a natural field population.

Table 2

The annual percentage kill by herbicides needed to maintain a static population

	STRAW BURNT	NOT BURNT
PLOUGHED	50	65
DIRECT DRILLED	88	92

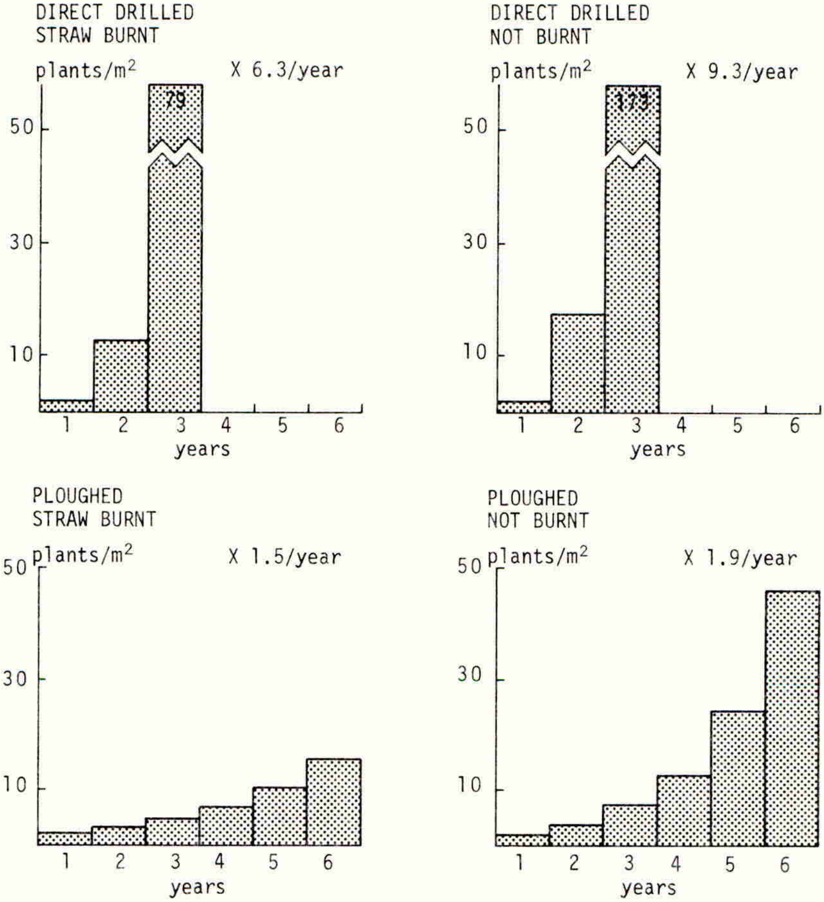

Fig. 2. Some estimates of population increases for black-grass where no herbicide is used.

This model can also be used to compute the % kill required from herbicide use in order to maintain a static weed population and to avoid any weed population increase at all. Table 2 shows the data calculated in this way to correspond with the histograms in Fig. 2. It can be seen that with direct drilling, an 88% kill is needed to maintain a static weed population if straw is burnt and a 92% kill if it is not burnt whereas with ploughing only 50% kill each year is needed to maintain a static population if the straw is burnt and a 65% kill if it is not burnt. These changes due to straw burning appear small for in these population models per cent survival is used rather than percent mortality. With direct drilled crops the effect of straw burning appears more dramatic when considered as a change from 8 to 12% survival rather than a change from 92 to 88% mortality.

Another use of population dynamics model is to compute possible effects of phenomena for which there is inadequate direct experimental evidence, recognising the limitations of the model. One such study was concerned with a problem which affects some soils where direct drilling or other forms of minimum tillage have been carried out for a number of years. In these soils it appears that the performance of some of the soil-acting black-grass herbicides gradually declines with the build-up of ash from burning straw and organic matter near the soil surface (Moss, 1979).

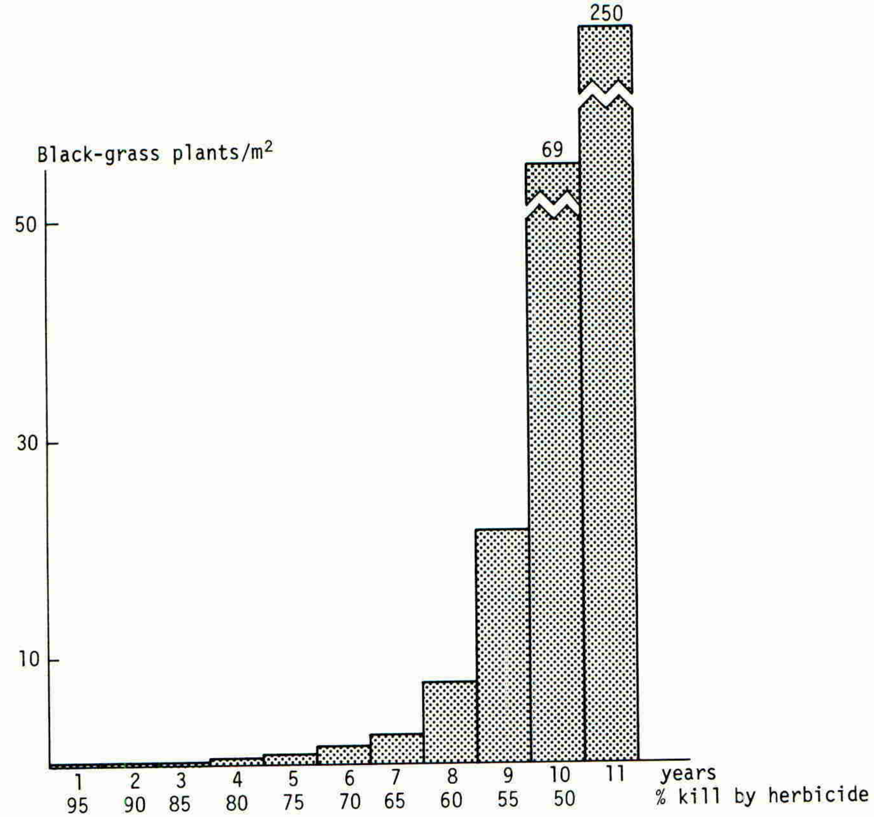

Fig. 3. A model for black-grass populations on direct drilled land which assumes kill by herbicide to be 95% initially but to decline by 5% for each year of direct drilling.

Not enough is known about this phenomenon, to be able to predict the rates at which the ash and organic matter builds up though it is very likely to differ from year to year. However, Fig. 3 shows a simple model of what would happen if herbicide performance declined from 95% kill by 5% each year. In these circumstances a farmer would be untroubled for three or possibly four years, convinced that his system was a viable one and that the herbicide was keeping him out of trouble. Eventually an exponential increase in weed population would lead to double spraying or to the collapse of his system. Whilst this phenomenon has only been observed on a few farms the results obtained from the model closely resemble what has actually occurred. The problem could increase in periods of prolonged direct drilling or minimum tillage, so the model has been useful in drawing attention to the problem. On farms with this problem a change in cultural practice is essential. Clearly it is quite unrealistic to return to ploughing every year on this very heavy land. It would not be possible to achieve a high proportion of early sown winter cereals which is the main purpose of the system, and it would probably not be good from the point of view of population changes of the weeds because each year a proportion of the old ploughed down seed would be ploughed back up again. The question arises: is rotational ploughing sufficient and if so how frequently in the rotation should it be done? Fig. 4 shows a model in which an unrealistically extreme situation has been assessed, where herbicide performance declines from 95% kill by 10% each year that direct drilling is continued. It can be seen that despite this rather extreme assumption, ploughing one year in every five or six appears to be quite satisfactory in preventing excessive population increase. This indicates a practical solution and it would appear from this model that such a technique would allow a considerable degree of latitude so that a farmer could plough slightly more than one sixth of his acreage in good years and none at all in bad years while still preventing the catastrophic decline in herbicide performance and increase in weed population shown in Fig. 3.

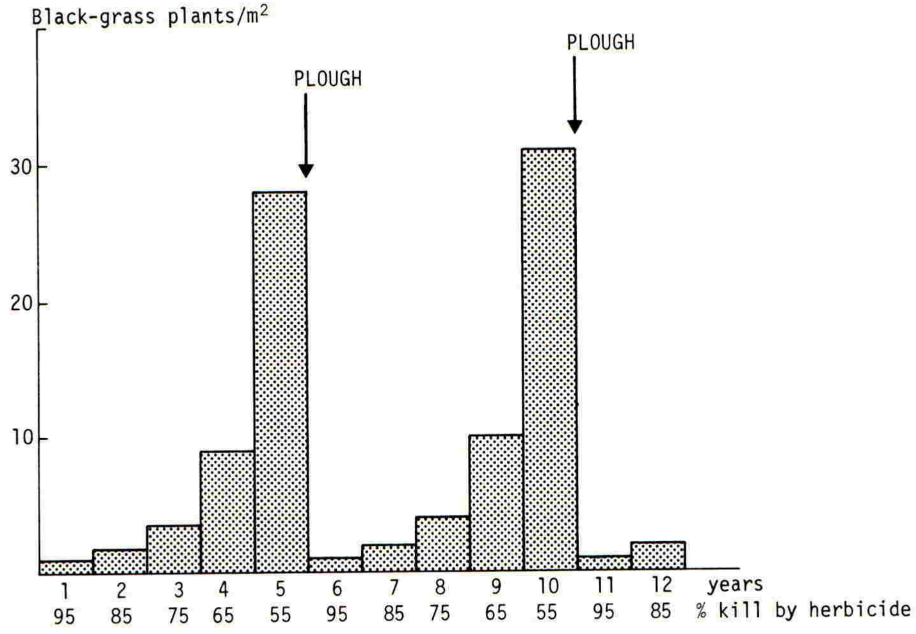

Fig. 4. A model for black-grass populations on direct drilled land with occasional ploughing. Kill by herbicide assumed to be 95% initially but declining by 10% for each year of direct drilling.

Questions of the kind discussed above are likely to be of more concern in the future especially if there are changes in the economics of cereal growing. Clearly, rotation is good farming practice; however, a return to a "four course" type of rotation is extremely unlikely in the present economic climate. How much rotation is needed to be effective in controlling weed populations is, therefore, an important question. It is difficult to answer by means of conventional long term rotation trials which tend to be very large, very demanding in manpower and just as vulnerable as any other field experiment to accidents of climate or indeed to being completely overtaken by economic changes, variety changes and so on. Therefore, although the capacity for computing population models may be limited at the moment there is considerable potential for extending this approach and it may give some useful guidance to strategic planning.

DISCUSSION

This paper has discussed only strategic, long term models, not the tactical models which have been used by entomologists and other pest specialists. The strategic approach is appropriate in view of the need for a long term view of control and the fact that weeds are essentially immobile. They are moved on and off fields as seed but this represents a very small proportion of the population and to a very large extent the weeds occur in patches in fields reflecting weed populations over many years or decades. It must also be remembered that knowledge may never be adequate to allow accurate tactical models to be produced.

Mention was made earlier of some of the factors which control competition between crop and weed and some figures will illustrate this. With wild-oats in spring barley it has been noted that there is at least a fourfold difference in the production of seeds per plant between wild-oats emerging before the barley has one fully expanded leaf and those plants emerging after the barley has three fully expanded leaves. With winter cereals the difference can be even more marked. For example, wild-oats emerging before the wheat has three emerged leaves have produced 150 seeds per plant and in the same experiment those wild oat plants emerging after tillering of the crop have produced only 20 seeds per plant. Climate and soil type may also influence the course of competition, both wild-oats and black-grass being favoured on clay soils and by wet summer weather.

It is concluded that a strategic model could be of some value for planning herbicide application programmes and in esimating the likely variable costs. Any such strategic plan can, of course, be modified by tactical decisions taken nearer the time. WRO has plans for improving its modelling techniques to introduce risk elements and carry further sensitivity analyses. It should be remembered that at present the ability to forecast is relatively poor and the models should be a stimulus to thought, and not a substitute for it.

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Decision Making in the Practice of Crop Protection

APHID MONITORING AND FORECASTING AS AN AID TO DECISION MAKING

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Summary To increase the precision of insecticide usage it is necessary to base pest control decisions on a knowledge of levels of pest infestation and an established economic threshold. The suction trapping network of the Rothamsted Insect Survey provides long-term monitoring data for pest aphids from which expected mean levels of abundance and distribution have been established and can be continuously improved. A knowledge of pest aphid biology and ecology makes possible the interpretation of current population data in relation to these established averages and to agricultural problems. Three examples are described, each of which represents a very different agricultural problem. Suction trapping data provides information that determines action to be taken on the levels of infestation of *Aphis fabae* on spring-sown field beans, the timing of the migration of *Phorodon humuli* to hops, and the risk of infection of autumn-sown cereals by barley yellow dwarf virus transmitted primarily by *Rhopalosiphum padi*. The information is disseminated to the agricultural industry in time to make decisions. The most serious deficiency is now the lack of realistic economic thresholds.

INTRODUCTION

Insecticides to control pest aphids are often applied on the basis of inadequate information. The aphids are the most important group of insect pests in Britain; every crop may be affected by the direct feeding damage of large colonies, or by the plant pathogenic viruses they transmit, or both. Aphids do not present a threat to the production of each crop every year, but when outbreaks do occur crops may be lost entirely if appropriate control measures are not applied. The erratic nature of pest outbreaks poses considerable problems for the farmer when deciding the best pest control strategies to follow (Taylor, 1973). Pest control decisions can be taken at many stages during the planning and cultivation of a crop, but once the crop is growing, and the farmer becomes aware of a particular pest problem, the choice of strategies becomes restricted. Prophylactic treatments may be applied without regard to the level of pest attack, or control measures may be applied in response to current information on levels of pest infestation related to economic thresholds (Taylor, 1974; Norton, 1976). The first strategy may be the easier option for the farmer to follow, and sometimes the most profitable in the short-term (Brown, 1979), but the intensive use of pesticides is posing increasing problems. The increasing public awareness of the harmful environmental side-effects of intensive pesticide usage, the ever increasing resistance of insects to insecticides, the shortage of alternative pest control methods and materials, and declining farm profits are leading to a necessary reappraisal of these strategies (Anon, 1979). Therefore, if pesticides are only to be used against damaging infestations of insects it is necessary first to know what levels of infestation cause an economic loss, and, also, to have suitable methods available to monitor the abundance and distribution of pests and to forecast whether or not damaging infestations will develop (Taylor, 1977).

The effect of different pest infestation levels on crop loss is a complex dynamic relationship requiring considerable research to determine accurately for each crop. In Britain, economic thresholds have been determined for few insect pest species (Taylor, 1977; Lewis, 1981), and for aphids we are restricted to those for the peach-potato aphid (*Myzus persicae*) on sugar beet (Heathcote, 1978), the black bean aphid (*Aphis fabae*) on spring-sown field beans (*Vicia faba*) (Way and Cammell, 1973), and the grain aphid (*Sitobion avenae*) on winter wheat (George and Gair, 1979). Provisional thresholds are also available for the rose-grain aphid (*Metopolophium dirhodum*) on wheat, and the timing of aphicide applications on potato ware crops. For all other aphid/crop combinations, the pest infestation levels requiring control are decided by the intuition and experience of advisers and farmers, and these vary greatly between individuals. This is a subject that requires urgent attention if the most efficient use of pesticides is to be achieved in Britain. Perhaps the first step towards this would be to collate the experiences of experts throughout the country and arrive at approximate economic thresholds for the major pests. These could then be used by everyone, but could also be improved in the light of further experience and more detailed research, similar to that in some states in the USA (e.g. Edwards *et al*, 1981).

The second requirement, if pest control decisions are to be based on known levels of infestation, is a suitable method of continuously monitoring, and possibly forecasting, when and where these infestation levels are reached. Continuous monitoring, both during and between epidemic periods, is essential if pest biology and ecology in relation to agriculture is to be adequately understood and suitable information provided. Ideally each field should be monitored throughout the development of the crop in it, but the myriad of fields, crops and varieties grown throughout Britain, and the large samples required to estimate satisfactorily pest populations with aggregated distributions currently put this beyond the available resources of time and manpower in this country (Taylor, 1974). In contrast, pest control in China is organized down to commune level which enables individual fields at risk to be monitored. Each commune has its own plant protection team which monitors general insect activity by a number of different sampling methods. At the appropriate time each brigade within the commune is alerted to the need to monitor all the fields vulnerable to pest infestation and to take the necessary action. The data from this monitoring is compiled in the commune, and sometimes at the county or provence level, or centrally, for use in long-term forecasting (Chiang, 1977).

The closest to this ideal that has been achieved in Britain is the sampling of up to about 1000 sugar beet fields for aphids, carried out each week during the spring and early summer by the fieldsmen of the 13 factory areas of the British Sugar Corporation. Warnings of damaging infestations and the likely spread of virus yellows are issued on the basis of these samples and previous disease history (Watson *et al*., 1975). Increasing numbers of private farm consultants are also providing farmers with information on pest abundance and consequently the necessity for pesticide applications within individual fields.

The temporary nature of arable crops means that aphids have to fly to them each year from other host plants and, as such flights can occur over great distances, it becomes more appropriate to monitor aphids on a national or even a continental scale than at the field level. Furthermore, the potential risk of infection of crops by non-persistent plant viruses may not be detected by conventional crop sampling, as viruses are transmitted very rapidly and often by aphid species that do not habitually live on the crop but only visit it briefly while searching for their own preferred host plants (Heathcote *et al*., 1969). A practical solution, although not always ideal, is to monitor the aerial distribution and abundance of aphids to provide synoptic data on aphid movement that can assist in pest control decision making. In some instances aerial sampling has been shown to be more suitable than practical crop sampling, particularly for the detection of the first migrants of *M. persicae* (Heathcote *et al.*, 1969) and *S. avenae* and *Rhopalosiphum padi* (Taylor, 1974) in the spring.

The problem therefore becomes one of interpretation of the aerial samples in relation to the various agricultural problems, based on a sound knowledge of the aphids biology and ecology. This varies in complexity from the comparatively simple holocyclic life-cycle of the damson-hop aphid (*Phorodon humuli*), which is a pest on hops every year, to the notoriously complex anholocyclic life-cycle of *M. persicae*, which can be a pest on many crops by causing direct feeding damage and, perhaps more importantly, as a vector of many plant pathogenic viruses, particularly potato leaf roll and potato virus Y on potatoes and beet yellows virus on sugar beet (Taylor, 1977).

This paper outlines the nationwide suction trapping network of the Rothamsted Insect Survey and describes, with the aid of a few examples, some of the methods used to interpret and disseminate the resulting data to provide information to assist with agricultural decisions.

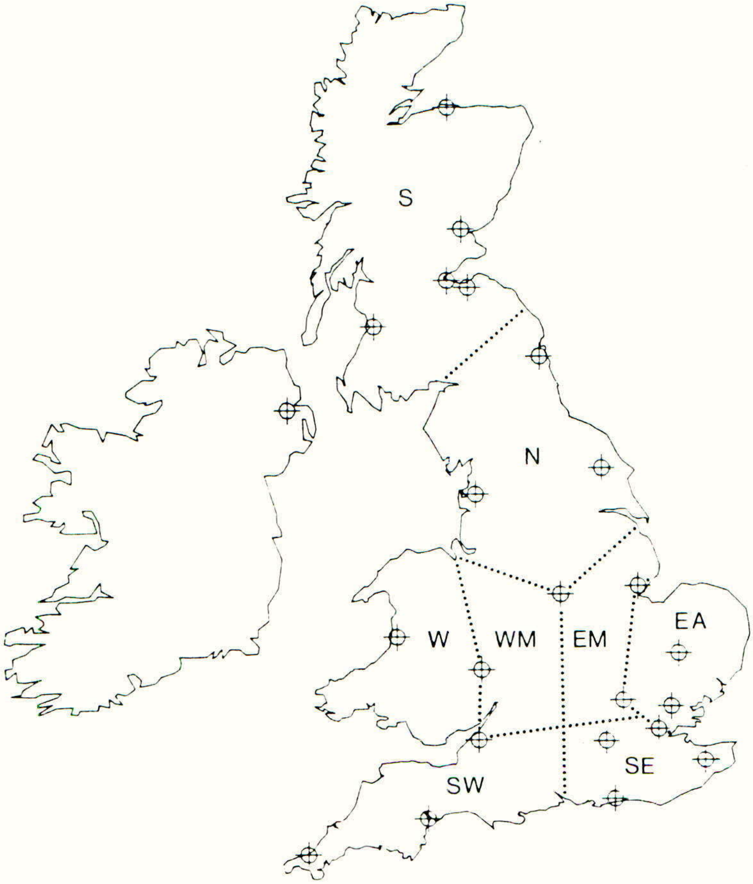
APHID MONITORING AND DATA HANDLING

The aerial insect fauna is monitored continuously at an altitude of 12.2 m above ground by a network of suction traps distributed in open agricultural land throughout Britain. The first trap began continuous operation at Rothamsted in 1964 after considerable experimentation to determine its design and efficiency (Taylor and Palmer, 1972). The network of suction traps of the Rothamsted Insect Survey has been extended to the 24 traps now operating throughout the United Kingdom (Fig. 1) and due to the initiative from Rothamsted and individuals in mainland Europe, there are now three in the Netherlands, two in Belgium and 10 in France (Taylor *et al.*, 1981a). The traps in mainland Europe are run independently from those in Great Britain, but the data are directly comparable, and freely exchanged, as all traps are of identical design. Although traps are well spaced, the samples appear to be representative for distances of up to 20 to 50 km around the trap when considered as means over several days (Taylor, 1979). In Britain the operation of most traps is organised from Rothamsted, except for those in Scotland where the responsibility has recently been transferred to Dr. Turl of the Department of Agriculture and Fisheries for Scotland. The traps at Aberystwyth and Brooms Barn are operated, and the samples identified locally by Dr. A'Brook and Dr. Heathcote respectively.

The continuously operated traps provide daily samples from mid-April to early-November, and weekly samples for the remainder of the year. The samples from traps in England are sent twice a week to Rothamsted, and in Scotland to East Craigs, Edinburgh, by first class letter post. During 1982 a special courier service will be used to overcome some of the postal delays in the transfer of samples to Rothamsted. All aphids are identified to species, after separation from the other insects, by specialists using a visual key (Taylor *et al.*, 1981b). A constant standard of identification is maintained by centralizing this operation at Rothamsted and East Craigs. At some times of year subsampling is necessary to reduce the insect material to a manageable quantity by halving the air flow through the trap or by subdivision of the aphid sample in the laboratory. As soon as aphid samples have been identified, the records for the full sample are entered on to standard record sheets and appended to our main database on the mainframe computer, an ICL system 4, via a MSI/77 hand-held datalogger which uses bar-codes for the standard data items of date, site and species. During 1982 the current data will

Fig. 1

Distribution of suction trapping stations in Britain. Dotted lines represent boundaries between regions for which interpretations of current aphid samples are made. The regions are defined as Scotland (S), Northern England (N), Wales (W), West Midlands (WM), East Midlands (EM), East Anglia (EA), the South West (SW) and the South East (SE).



be handled on a Midas 3-D microcomputer enabling the rapid production of summaries, particularly the 'Aphid Bulletin' and the information required to make immediate interpretations of the samples. Summaries will initially be produced in tabular form, but soon it will be possible to present the data graphically, and eventually in the form of distribution maps. The use of a microcomputer will speed up the production of weekly reports, by the use of its word processing software, and will decrease the time taken to disseminate information to all Agricultural Development and Advisory Service (ADAS) offices by connection to the telex.

INTERPRETATION OF APHID SAMPLES

The large quantities of data obtained from monitoring networks, such as the Rothamsted Insect Survey suction trapping system, can provide quantitative information to assist in pest control decision making. The type of information that can be provided falls into two main categories. The sampling data may be issued directly in a suitably condensed form, or some form of analysis or interpretation may be applied before release.

Since 1968 the "Aphid Bulletin" has been issued each week giving the seven-day totals for each of 33 aphid species or species groups of economic or scientific interest for each suction trap station in Britain. It is currently circulated to about 150 interested individuals and organizations, each of whom pass the information to an average of 30 others, in Britain and mainland Europe who use it for both advisory and research purposes (Bardner *et al.*, 1981). However, these data require further local interpretation, and at present there is often little background knowledge, so its potential cannot be fully realised.

The interpretation of current samples can be approached in a number of ways. The most detailed methods require an understanding of the biological and numerical relationships between the stages of the aphid life-cycle being monitored and the critical stages of crop development. Data of this type, particularly the necessary economic thresholds, are only available for a few aphid/crop interactions. However, it is possible to make useful interpretations with only a limited knowledge of these relationships based entirely on monitoring data, emphasis being placed on relevant stages in the aphid life-cycle such as the date of first migrants in the spring, or the size of the population infesting a crop at a particular growth-stage or season.

By the late 1970's many traps had been operating for more than 10 years so it was possible to establish mean levels for pest aphid abundance and distribution, which can be continuously updated, (Taylor *et al.*, 1981a, 1982) against which current samples can be compared.

Current data are interpreted for individual traps, particularly if the crop is grown in a restricted area, or for a group of traps within one of eight regions, which do not correspond exactly to the ADAS regions (Fig. 1), if the crop and its associated aphid problem are more widely distributed. Each region contains between three and five traps and data from traps near the boundaries of regions may be used for more than one region. After deciding on a suitable grouping of traps, the first step is to compare the current geometric mean sample for a region with the long-term geometric mean, based on all available data, and the sample for the same time the previous year. An attempt is then made to quantify all these comparisons. For the long-term average the following categories are used: differences of up to twice the mean are termed 'similar', between twice and four times the mean are termed 'slightly above' or 'slightly below' average, between four and ten times the mean are termed 'above' or 'below' average, and differences greater than ten times the mean are termed 'much above' or 'much below' average.

Comparisons are made with data for the previous year as advisers and farmers memories of the outcome of these pest infestations within an area are thought to be more reliable than for earlier years. Interpretations of current monitoring data are limited to eight economically important species covering the aphid pests of the three major arable crops, namely cereals, potatoes and sugar beet, as well as two of lesser importance, spring-sown field beans and hops (Table 1). In the near future the development of suitable software will make possible the comparison of current samples for an extended list of species with data for any particular year and, with the knowledge of what happened then, obtained from suction trapping data and field records, it should be possible to give an indication of the expected pest levels in the current season. An analysis of numbers at an individual site or for a region will be extended in future to enable the comparison of distributions, by the use of suitable contouring programs, and hence the movement and spread of aphid populations throughout Britain and possibly western Europe.

Table 1

Aphid species and crops for which detailed interpretations of suction trapping data are made

Aphid species	Crops
Sitobion avenae	Cereals
Metopolophium dirhodum	Cereals
Rhopalosiphum padi	Cereals
Macrosiphum euphorbiae	Potatoes
Aulacorthum solani	Potatoes
Myzus persicae	Potatoes, sugar-beet
Aphis fabae	Sugar-beet, field beans
Phorodon humuli	Hops

Research at Rothamsted and elsewhere is providing information on aphid biology, particularly in relation to agriculture, that enables further interpretation of suction trapping data to be made and, in some instances, forecasts of the probable levels and timing of aphid infestations. The methods of analyses vary with each problem and are well illustrated with three contrasting examples.

A. fabae infestation of spring-sown field beans

The black bean aphid (*A. fabae*) is a pest of sugar beet and field beans, usually those sown in the spring, causing direct feeding damage on both crops and spreading beet yellows virus on sugar beet. The timing and particularly the level of infestations varies considerably in both time and space. Way *et al* (1977) have shown that on spring-sown field beans a level of 5% of plants colonised on the south west headlands of fields in early to mid-June is a reasonable economic threshold above which control measures are justified. This date corresponds approximately to the end of the primary migration of *A. fabae* from the winter host plant, spindle (*Euonymus europaeus*), and is therefore a measure of the initial infestation of the crop. At this time a single application of a suitable insecticide will give effective control (Gould and Graham, 1969). Extensive sampling of eggs in winter and active stages on spindle in May, followed by the monitoring of subsequent infestations on field beans, have made possible the development of a forecast of the need for, though not the accurate timing of, chemical control of *A. fabae* in each of 18 areas in the southern half of England (Way *et al.*, 1977). This forecast is not as yet applicable to infestations of *A. fabae* on sugar beet. If spring-sown field beans were treated only on the basis of this forecast, insecticide usage would be reduced and there would be considerable financial saving to the farmer (Cammell and Way, 1977).

More recently this forecast has been expressed in terms of the numbers of autumn and spring *A. fabae* migrants, as monitored by the suction traps. The numbers of *A. fabae* migrating in the autumn after mid-September provide the earliest forecast of the likely infestation of the following spring bean crop. It has been shown that in autumns when 15 or fewer individuals were found in samples from a single trap, damaging infestations did not generally arise the following spring; however, if this value of 15 was exceeded, the economic threshold for control on the crop was also exceeded on 87% of occasions. In the spring the suction traps monitor accurately the timing of the migration from spindle and also give the most accurate forecast of the level of infestation. On occasions when less than five *A. fabae* were found in samples from an individual trap by mid-June damaging infestations did not generally develop, but when five or more individuals were recorded by this date, the economic threshold of five per cent of plants infested on the south-west headland of fields was exceeded on 88% of occasions and indicated the need for control (Way *et al.*, 1981). The suction traps monitor the numbers and timing of spring migrants in a particular season in relation to this economic threshold (Fig. 2) enabling timely warnings of the need for, or otherwise, of chemical control on spring-sown field beans to be issued for that area.

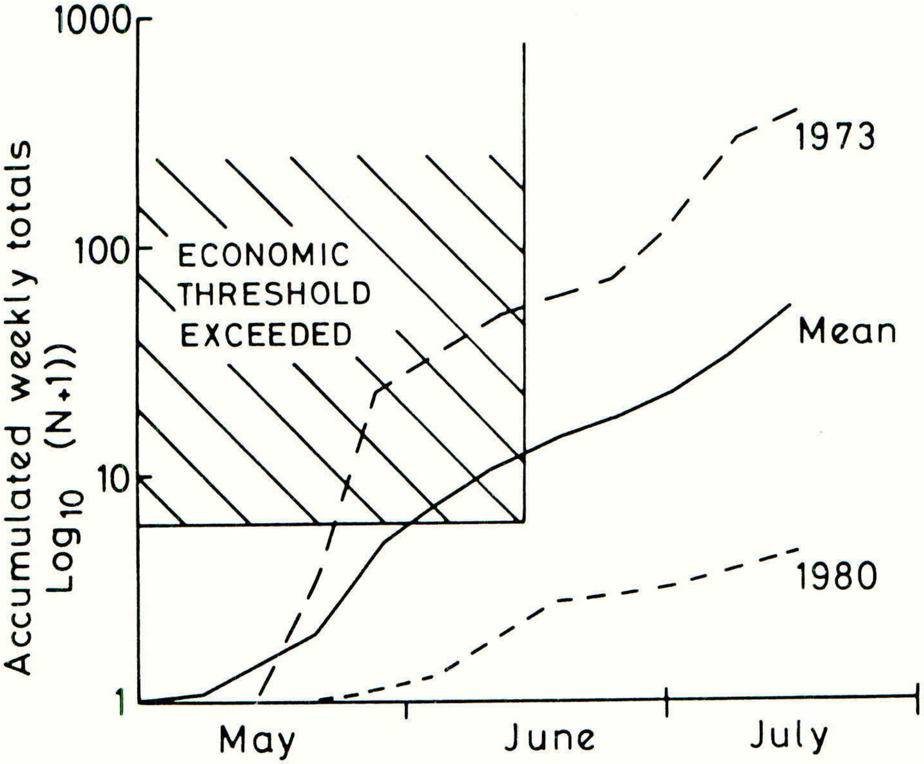
The timing of *P. humuli* migration to hops

The damson-hop aphid (*P. humuli*) is a pest of cultivated hops every year; the numbers of aphids migrating to the hops in the summer is of less importance for adequate control than the timing of migration. *P. humuli* is normally controlled by a single application of a soil-applied systemic insecticide in late May followed by an average of between six and seven high volume sprays at intervals of seven to 14 days (Umpelby and Sly, 1980). The number and timing of insecticide applications depends on the duration of aphid migration from its primary hosts (*Prunus* spp.) to hops and on the effectiveness of earlier treatments. Migration begins during the second half of May or the first week of June and may terminate between early July and late August. Therefore, a forecast of the end of immigration to hops would enable the more precise use of insecticides and perhaps slow the development of resistance (Muir, 1979).

The Rothamsted Insect Survey suction traps at Rosemaund Experimental Husbandry Farm, Herefordshire, and Wye College, Kent, are close to the two major hop growing regions of Britain (Taylor, *et al.*, 1979) and the daily records from these traps have been used in the development of a forecast of the timing of the beginning and end of the migration from its primary hosts based on associations with weather

Fig. 2

The comparison of accumulated suction trap samples of *Aphis fabae* with the long-term geometric mean and samples for individual years, with the economic threshold for chemical control on spring-sown field beans.



data. Periods in the year were identified when the date of aphid migration was significantly correlated with single weather variables at both sites by regressing the dates of the beginning and end of migration for 1967-1979 at Wye and 1972-1979 at Rosemaund on the mean values for periods, ranging from five to 30 days, for each of maximum, minimum and mean temperature, sunshine and rainfall, starting on 1st January and advancing sequentially by one day the starting date for the weather period. These regressions were then used to predict accurately the dates of the beginning and end of migration in 1980 and 1981 (Thomas *et al.*, in prep). This information was circulated to all hop growers in time to assist with pest control decisions at the beginning and, particularly, the end of the season.

Barley yellow dwarf virus infection of autumn sown cereals

Many aphids transmit plant pathogenic viruses which can cause serious damage to agricultural crops. The approach to providing suitable information from a monitoring system is complicated by the virus-vector relationship ranging from non-persistent to persistent, and especially the time needed to acquire and transmit the virus, ranging from a few seconds to several hours. The crop, be it feed barley to Virus-Tested Stem-Cutting seed potato crops, will also influence the approach used. I will confine discussion of this subject to an assessment of the risk of infection of autumn sown cereals by barley yellow dwarf virus (BYDV).

Infection of BYDV causes the greatest yield loss when crops are infected at an early growth-stage (Doodson and Saunders, 1970), so autumn crops are especially vulnerable shortly after they emerge. The risk of primary infection depends on the numbers of aphids migrating in the autumn, the proportion that transmit virus, and the length of time the crop is exposed to migrating aphids. The trend towards earlier autumn sowing, especially in September, increases the proportion of the crop at risk from BYDV infection before aphid migration ends in late October or early November.

Strains of this virus, which differ in the severity of their effect on the host, are transmitted with different efficiencies in a persistent or circulative manner by about 23 aphid species (Kennedy, *et al.*, 1962; A'Brook and Dewar, 1980; Jedlinski, 1981), but for practical purposes in the UK only three, the bird-cherry aphid (*R. padi*), the grain aphid (*S. avenae*) and the rose-grain aphid (*M. dirhodum*), are important (Plumb, 1981). The numbers of migrant aphids are obtained from the suction trap samples and vary in both time and between different areas of Britain, but of the three important vectors, *R. padi* occurs in by far the largest numbers in the autumn migration and is distributed throughout Britain (Taylor *et al.*, 1981a, 1982).

The proportion of aphids transmitting virus is determined at Rothamsted by feeding identified individuals, caught alive in a modified suction trap, on oat seedlings and noting BYDV symptoms after two to four weeks (Plumb, 1976). Similar tests are done at Long Ashton Research Station (Smith *et al.*, 1978) and the Welsh Plant Breeding Station (A'Brook and Dewar, 1980). The development of sensitive serological techniques, such as enzyme-linked immunosorbent assay (ELISA) and immunosorbent electron microscopy may increase the speed with which vectors of BYDV can be identified (Plumb and Lennon, 1981).

The proportion of aphids transmitting BYDV at Rothamsted in the autumns of 1970 to 1981 varied from 0 to 11.6%; the proportion also varied between different parts of the country in the same year (Plumb, 1981). When the number of those species of aphid transmitting BYDV found in the Rothamsted Insect Survey suction trap samples closest to the live trapping site is multiplied by the percentage of each species transmitting BYDV, two of the most important factors determining infection are integrated and the product is called the 'Infectivity Index.' The accumulation of the infectivity indices for each week after the sowing date of the crop allows an index to be given for crops with different sowing dates (Table 2) (Plumb *et al*, 1981; Plumb, 1982). A comparison of infectivity indices for different years and sites with known levels of crop infection, and the response to aphid control, will allow the establishment of a threshold index which, when reached, will indicate the need to spray crops at risk. This threshold will differ between regions and the infectivity index may require further refinement. The suction traps provide data on the abundance of all BYDV vectors throughout Britain which, together with the infectivity index for the three locations where it is determined is issued to ADAS who use it as a guide to advise farmers on the need to control the aphid vectors and hence BYDV in early November.

Table 2

Cumulative weekly Infectivity Index (rounded to the nearest whole number) for BYDV at Rothamsted Experimental Station in autumn 1980 (after Plumb, 1982)

Date	8/9	15/9	22/9	29/9	6/10	13/10	20/10	27/10	2/11
Sowing date									
1/9	14	26	107	131	174	185	192	195	195
8/9		12	94	118	161	172	179	182	182
15/9			81	106	148	160	167	170	170
22/9				24	67	78	86	88	88
29/9					43	54	61	64	64
6/10						11	19	22	22
13/10							7	10	10
20/10								3	3
27/10									0

DISSEMINATION OF INFORMATION

Once data have been collected and any necessary analysis performed, it is essential to disseminate the relevant information as effectively as possible to those that have to make decisions. In Britain, this subject has not yet been approached as an overall programme, possibly due to the many competing sources of public and commercial information.

The 'Aphid Bulletin' is sent by post each Friday to about 150 people and organizations, while the 'Commentary', comprising the interpretations of the data, is sent by both post and telex to all ADAS regional offices and most sub-centres and to the Crop Pest and Disease Intelligence Unit of ADAS at Bristol. The data in the aphid bulletin may be interpreted locally and used for advisory purposes, while the commentary is used more directly. The Crop Pest and Disease Intelligence Unit produce a weekly report, often incorporating information from the Rothamsted Insect Survey, which is sent to about 260 people and organizations in Britain including all local ADAS offices, the press, pesticide firms, seed merchants and a few growers organizations. It may reach farmers by the telephone information service, post, viewdata, television, radio or by personal contact with advisers and representatives from pesticide companies. Some information, such as the predicted dates of migration of *P. humuli*, is sent by post from ADAS to all growers of hops, while for the potential risk of infection of autumn sown cereals with BYDV, ADAS now relies on the Rothamsted Insect Survey to coordinate all the information on vector abundance and infectivity on which they base their advice.

When information from the Rothamsted Insect Survey is received by the decision maker, the data on which it is based is a minimum of 5 to 12 days old. This delay does not cause major problems with forecasts of events more than two weeks ahead, such as the risk of infection by BYDV, which include time for appropriate action to be taken, but it is not ideal for current awareness information. The production of information from the suction trapping data is as efficient as it can be under the current operating procedures. However, we are investigating possible methods to reduce this delay. An approach we are actively pursuing is the use of remote sensing equipment, such as radar which, operated in conjunction with suction traps, could give an immediate measure of the aerial aphid density at different altitudes, while the traps will give the species composition.

In Britain, great reliance is placed on the postal services and personal contact for the dissemination of agricultural information, and little progress has been made towards the use of modern computer technology. It should now be possible to link the many microcomputers to be found in farm offices, advisory centres, commercial organizations and research stations in a network for the communication of both encyclopaedic and current agricultural information. This has already been achieved in some states in the USA where microcomputers and remote terminals in county extension offices and on a few farms are linked to a central computer enabling the rapid exchange of information on pest abundance and the issuing of warnings (Croft *et al.*, 1976).

CONCLUSIONS

Continuous aphid monitoring is essential if more precise use of pesticides is to be based on a knowledge of the levels of pest infestation and suitable economic thresholds. The suction trapping network of the Rothamsted Insect Survey provides a suitable measure of the level of pest aphid infestations. Now that many traps have been operating for more than ten years, current data may be interpreted in relation to an historical database or in conjunction with available predictive models, based on known aphid biology, to provide the valuable information that can assist in pest control decision making. The value of these interpretations will increase as our knowledge of pest aphid biology improves for a larger number of species. It is imperative that all relevant information is disseminated as efficiently as possible if the data from monitoring systems is to have a large effect on pest control practices. The suction trapping network is operating effectively, but the lack of suitable economic thresholds required for the accurate interpretation of the data remains a serious deficiency.

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