3.
Case studies of decision making

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Decision Making in the Practice of Crop Protection

WEED CONTROL IN CEREALS - STRATEGY AND TACTICS

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INTRODUCTION

Cereals are the core of British arable agriculture and most cereal spraying is for weed control, so clearly cereal weed control must be very central to this Symposium. Weed science is the youngest of the crop protection disciplines: it has existed in coherent form for less than 40 years; and it has attracted less research than its importance merits. In consequence weed technology lacks a broad base of supporting knowledge, and particularly that relevant to decision making.

Much of the weed control in todays cereals is of a high standard, though capable of improvement, and it is largely based on herbicides. The question is therefore whether these chemicals are used to best effect and whether economies are possible. Both farmers and the Nation have common cause in desiring chemical economy, for reasons of profit and the environment respectively. How does a cereal farmer make his decisions about weed control? I suspect that an expert in the science of decision making would be horrified at the subjective answer that most farmers would give to such a question. Nevertheless most cereal farmers are shrewd in picking their way through the technical minefield which is crop protection. An issue for this meeting is whether their performance could be improved by more scientific decision-making, and what further basic information is needed to help in this process.

A cereal farmer has many things to consider in making his cultural decisions, and the requirements of weed control may need to be consciously relegated. His choice of crops is decided by soil, climate, the market and his own skill; on cereal farms the choice may be for autumn sowing to maximise profitability in the knowledge that this may also maximise chemical needs for weed control.

Similarly with soil cultivation, whether or not a farmer ploughs, direct drills or cultivates depends on his analysis of his soil potential, his availability of labour and tractor power. The farm and farmer exist to grow crops and stock for the market and weed control is but a means to this end. However when that is said, cereal farmers mostly wish to have a continuing weed control strategy which will maximise crop yield and minimise chemical purchases.

The paper title that I have been given mentions strategy and tactics. These are words that may not be understood precisely by many farmers, so they need some definition. I suggest that there can be a continuing whole farm strategy for weed control of which cereals are the whole or an important part where other crops are grown in sequence. Tactics on the other hand are what happens in a single crop by way of cultural and chemical choices, application methods etc.

STRATEGIES IN CEREAL WEED CONTROL

Weeds annual and perennial perpetuate themselves from year to year by means of seeds, roots or rhizomes, the organs of survival. Our increasing ability to calculate the population dynamics of weeds is one of the major advances in weed science of the past decade. My colleague, G. W. Cussans, has described population models elsewhere in this symposium (Cussans, 1982). The importance of this work lies in the way that it allows us to predict what will be the population movements within a particular cropping system, and to concentrate on what changes might be made in the system to reduce the abundance of a particular weed or to reduce the cost of its control by chemicals. A few examples will serve to illustrate this point in relation to rotation and cultivation - our forefathers' main means of strategic weed control.

Most arable weeds are encouraged by repeated cereal cropping. Some, such as Agropyron repens and Avena fatua prosper regardless of whether the crop is sown in autumn or spring. But others are sensitive to time of planting: Alopecurus myosuroides, Bromus sterilis and Galium aparine are discouraged by spring sowing; whereas Sinapis arvensis and Polygonum persicaria are discouraged by autumn sowing, both for reasons of germination periodicity. Thus for some of these weeds a spring barley crop would be a cleaning break from autumn cereals; and for others the converse would be true.

A lack of dormancy in a weed, be it seed or rhizome, can be exploited by inserting a one or two year break in the population cycle, such as is provided by potatoes, sugar beet or ley in a cereal system. Even with weeds of appreciable seed dormancy 'break crops' can help to arrest an increase in population or reduce tactical use of herbicides.

Arrhenatherum elatius is held in check much more by ploughing than by direct drilling because of the effect of inversion and burial on bulb formation and survival (Ayres, 1977). Inversion of surface seed of Alopecurus myosuroides by ploughing before autumn cereals greatly reduces the number of seedlings that might otherwise come, and ensures the activity of urea herbicides (Moss, 1979). Burial by ploughing is almost a complete answer to Bromus sterilis.

So rotation and cultivation can be just as significant to cereal farmers as they were a century ago. There are many cereal farms on which diversity of crop and cultivation is pursued for reasons other than weed control, and which are relatively untroubled by difficult weeds. Even where there are problems, some new development (such as the use of glyphosate pre-harvest on A. repens) may quite alter the overall situation. On autumn cereal farms the problems are difficult because there is so little scope for changes in rotation and the minimum cultivation which is often the rule. Herbicides alone stand between the farmer and the ruination of his system by weeds. While we may feel that we are winning with Avena spp. and A. repens; are we winning with A. myosuroides and B. sterilis on such farms?

Many cereal farmers suffer from difficult weeds more than they need because they or their technical advisers are not adequately possessed of the information that is available on weed reaction to cultivation and cropping. Many broad-leaved annuals can be dealt with cheaply on a tactical basis; the weeds that call for strategic consideration are those that involve the repeated use of expensive herbicides. Couch grass, Agropyron repens, wild-oat, Avena spp, black-grass, Alopecurus myosuroides, brome, Bromus sterilis and a few broad-leaved annuals such as cleavers, Galium aparine, are the worst culprits. With these weeds a cereal farmers strategic questions, calling for answers are:

1. Which of the difficult weeds have I, and in what fields are they, and at what level?
2. Is my policy towards each to be containment, occasional blitz or eradication?
3. Does my choice of crops, and their sequence, generally favour a rise or decline of the weeds population?
4. What effect is my soil handling having on seeds, roots and rhizome populations?

5. Is my general management preventing weed seed moving around the farm in, for example, the combine or straw?
6. Is there an opportunity to use a herbicide to best effect on a crop that will avoid the use of a less efficient or more expensive chemical in a subsequent crop?
7. Since the cost of chemical purchases must be in balance with crop sales, which often depend on land fertility, what is the permissible level of chemical purchases?
8. Within my system, do the answers to the previous seven questions point to possible improvements in the weed control strategy?

Let me now turn to the more complex subject of tactics within the crop. Our present capabilities for tactical weed control in cereals are in marked contrast to those of previous generations. Farmers of the 19th century had little or no means of tactical weed control in cereals, so their approaches were all strategic: this is the big difference that herbicides have made.

THE TACTICS OF HERBICIDE USE

This is today a subject of such complexity that I doubt whether many farmers can have the requisite knowledge for decision making: many of them rely on technical advisers to indicate options or to make the decisions. The complexities operate in various ways. Since most weed infestations are moderate nowadays, does the current infestation merit expenditure for control? If control is needed when should it occur and what should be the choice of materials? What form should the chemical application take and should it be tank-mixed with other crop protection chemicals or a growth regulator? What are the permissible costs? The last question recurs because chemical control is rarely impossible, but is limited by cost or organisational difficulties (usually due to the weather).

Let me now try to dissect the factors underlying tactical decision making.

<u>Phased control in relation to objectives</u>: It is possible to describe four distinct periods in the life of a winter cereal during which weeds may interfere (Fig. 1), these are: (1) from harvest of previous crop to sowing of the current crop, (2) from sowing to the end of the year, (3) spring and (4) during ripening prior to harvest. In each of these periods five control objectives may be considered, which are concerned with prevention of: (1) competition that reduces yield, (2) formation of weed seeds, (3) interference with harvest, (4) transfer of disease or encouragement of pest and (5) interference with the next crop. Consideration of the periods and objectives together allows the construction of a matrix.

<u>Figure 1</u>
<u>Primary Objective</u>

Period	1	2	3	4	5
1	*			*	
2	*	*		*	
3	*	*	*		
4			*		*

In each period and within each objective it is possible to take chemical decisions on the basis of whether weed interference will occur or not. No one chemical can be expected to cope with all the objectives: the time span and range of weeds is too great. Each chemical performance has to be seen as a part of a continuum, linked and partially dependent on those that go before and after. However such qualitative descriptions give no indication of the money involved.

<u>Expenditure on herbicides</u>: When justifying herbicide expenditure most farmers

and technologists concentrate on the effect on yield: yet with a general decline in weed populations due to spraying, major increases in yield are unlikely except in obvious instances of high weed infestation. G. W. Cussans has developed an interesting theory of "Competitive Index" which seeks to calculate the yield damage thresholds of weeds in relation to the cost of their control. There are however other forms of economic damage: for example, weeds at harvest and in grain contamination can have major financial consequences that sometimes dwarf typical expenditure on herbicides. It has been calculated that weed contamination at combining could increase costs by £20/ha for every 0.3 reduction in the ratio of grain to matter other than grain (Elliott, 1980). The presence of G. aparine in wheat for seed involved a loss of £52/ha in a crop that was studied (Elliott, 1978).

It is in the approach to permissible expenditure that current knowledge is demonstrably inadequate for farmers decision making. For example some cereal land will regularly yield 7 t/ha of wheat, other land will only give 5 t/ha with wheat and barley alternating. Technical recommendations for chemical dose (and therefore cost) take no account of such differences in the earning power of the land. Should not weed control be budgeted for on the basis of predicted returns? To stimulate discussion on permissible costs of weed control I have set out below one possible approach in the hope that it will provoke others, better qualified to give their views.

The predicted return from the sale of the crop is a figure easily calculable in advance by most farmers: it is therefore a reasonable figure to relate to the cost of weed control. From studying many budgets and talking to many people a suggested barometer for herbicide costs in cereals averaged over several years and including stubble treatments is as follows:

$<$10% of total predicted return: costs are within bounds, situation is well under control.

10-15% of total predicted return: costs are substantial: they may be justified, but require scrutiny.

15-20% of total predicted return: costs are possibly excessive, expert advice is needed.

$>$20% of total preducted return: trouble ahead.

These calculations are not just a question of the chemical bill. The high figures suggest major and continuing expenditure on grass herbicides at a level that might be reduced by rotation of crop or change of cultivation. Alternatively the problem may be one of inadequate crop yield sharpening the pressure of herbicide expenditure on the system. Farm management experts may be able to suggest better guidance for farmers.

CHOICE OF HERBICIDE

Here is a subject fraught with difficulty on the farm. The ADAS Booklet on cereal weed control 1981 contained 21 products usable on wild-oat and/or black-grass and 58 products for broad-leaved weed control (MAFF 1981). Many of the products may be mixed, and are themselves mixtures. The approved label for each product usually contains several ways of using it. The combinations of herbicides are therefore numerous: to them may be added the possibility of mixing with other crop protection chemicals. In 1981 Farmers Weekly produced a supplement on this subject which contained 46 pages of lists of mixtures of crop protection chemicals for cereals. To date, science has failed to give farmers and their advisers a logical basis for their chemical choices: instead it has emphasised how to use a product once the choice has been made. The situation is made more difficult by the use of subjective criteria of chemical performance: there is no generally agreed definition of the word 'control' which appears on most chemical labels.

In 1981 British agriculture spent more than £100m on herbicides to avoid the interference caused by weeds. That most of this expenditure was necessary and well used should not obscure the fact that much of it occurred without defined objectives and without defined criteria as to performance.

CONCLUSION

I have attempted to assemble views and facts about decision making in cereal weed control. The effort has already been worthwhile because it has indicated to me at least how inadequate is the knowledge of this subject. Though we may take refuge in the small span of years during which herbicides have grown from a minor to a major input in crop production; it is in everyones interest that the objectives of weed control should be clearly defined and quantified, that chemical performances are described against recognised criteria, that patterns of weed and crop growth are identified, and that control tactics are within a pre-determined whole farm strategy. All this may be described simply as putting 'system' into weed control.

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DECISION MAKING IN CEREAL PEST CONTROL

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Summary The ultimate responsibility for making decisions in pest control lies with the farmer, or his nominee. He can call upon information and advice from several sources to help him reach a decision and, ideally, should assess the results of his decisions in order (i) to increase his knowledge of what is best for his farm and (ii) to assess whether further action against pests is necessary. Many of the decisions made about crop husbandry, cultivations, time of sowing, etc. affect the likelihood of pest damage although pests are not directly concerned in this decision making process or are a very small factor; there are opportunities here for avoiding or minimising pest problems. Pest-specific decisions can be helped by the use of crop monitoring, economic thresholds and accurate forecasts of pest numbers and timing, followed by information about the choice, cost and effectiveness of the pesticides or alternative methods available. Threshold levels and pest forecasts currently available are reviewed.

INTRODUCTION

Cereal pests destroy a small proportion of the total UK cereal harvest - an estimated 2.7 per cent of total hectarage under cereals in England and Wales or about £49 million per annum at 1981 yields and prices (ADAS, unpublished). The major pests (wheat bulb fly (Delia coarctata), slugs (Deroceras reticulatum) and cereal aphids (Sitobion avenae, Rhopalosiphum padi and Metopolophium dirhodum)) each cause an estimated mean yield loss of 10-25 per cent where present above critical levels (ADAS, unpublished). Control of invertebrate pests occupies a relatively small part of a farmer's time and is relatively cheap.

In 1980, cereals were grown on 3.87 million hectares of the UK. The areas treated with insecticides and molluscicides were 0.44 and 0.20 million hectare units, respectively, which was greater than previously but still much less than the usage of herbicides or fungicides, which were applied to 5.19 and 2.86 million hectare units, respectively (British Agrochemicals Association, 1981). However, broad spectrum and persistent insecticides may have more impact on the environment than fungicides or herbicides, and the smaller usage figure for insecticides is not, perhaps, a true indication of their ecological importance.

Decision making in pest control can be divided into (i) decisions which have indirect effects upon pests (eg. crop husbandry, choice of cultivars) and (ii) specific decisions on the use of control measures which will have a direct effect on pests.

DECISIONS INDIRECTLY AFFECTING PEST CONTROL

The over-riding factor determining what is grown on a farm is the soil type(s). Most soil dwelling pests are influenced by soil type, for example, slugs are much less damaging in sandy than in clay or silt soils. The larger nematodes such as *Trichodorus* and *Longidorus* spp. need sufficient space between soil particles in which to move and thus tend to be most common in coarse sands.

The initial decisions of what crops and cultivars to plant are based on an overall cropping plan for the enterprise and what is likely to give a good financial return. The implications of these decisions on the likelihood of pest attacks are often not considered or, if considered, discounted, because there are effective chemical control methods for all the major cereal pests, and most minor pests, currently found in the UK. Few pests can be controlled by changes in cropping alone.

Time of sowing

Sowing date can predispose crops to pest attack. Farmers in parts of South Wales were reluctant to grow autumn-sown cereals until the introduction of autumn aphicidal treatments because of the high risk of severely damaging attacks of aphid-transmitted barley yellow dwarf virus (BYDV). In general, crops which have not emerged by the end of October, the end of the aphids' autumn migration, are unlikely to be infected but later sowing in itself carries a yield penalty. *Opomyza florum*, a grass and cereal fly of increasing importance in winter wheat crops, is also favoured by early sowing (Short, 1981) and the general advance of 2-3 weeks in sowing date during the past four years or so is probably one of the main reasons for its upsurgence.

In practice, cereal crops are sown as soon as possible subject to weather, soil conditions and the availability of machinery and men. Some farmers have a deliberate policy, for example, to sow all winter wheat before 30 September because they know from experience that sowing then gives the best potential yield on their soil. There are areas such as the Fens in East Anglia where sowing is traditionally late, and may even be delayed until spring, because the growing of maincrop potatoes, sugar beet and vegetables such as carrots, means that land and resources are not available to sow cereals earlier. Time of sowing is principally determined by soil type and cropping pattern and not usually by a desire to minimise pest problems.

Where a pest attack is expected, it may be possible to manipulate the sowing date to mitigate the pest's effect, as, for example, sowing early where there is a high risk of wheat bulb fly attack in order to produce a forward, well-tillered crop better able to withstand the damage.

Cultivations and sowing techniques

A range of cultivation methods are employed, from traditional deep-ploughing to nil cultivation prior to direct drilling. Disturbance of soil helps to reduce the numbers of soil-inhabiting animals (Edwards, 1975, 1977) by increasing predation by birds and other predators. In some instances, direct drilling and minimal cultivation can favour pest control; oviposition and attack by *O. florum* can be reduced (Short, 1981). With other pests, such as slugs, damage tends to be greater where direct drilling is used (Gair, 1981).

Rotations

Intensification of cereal cropping has not been accompanied by an increase in pest problems (Gair, 1975). 'Ley' pests, which can attack cereal crops following grass, have generally become less common as grassland hectarage on arable farms has decreased. Nematode problems, for example, cereal cyst nematode, can be exacerbated by continuous cereal growing but not necessarily. Naturally-occurring fungal diseases seem to be responsible for reducing cereal cyst nematode populations in some continuous cereal crops (Anon, 1981).

Where some form of rotational cropping is followed, pest problems can be caused by factors such as sowing date, soil condition, hygiene, etc. associated with the previous crop. Oil seed rape leaves debris after harvest which provides a good environment for slugs, and winter cereals following oil seed rape are often badly attacked. On the other hand, ADAS has yet to record significant numbers of wheat bulb fly eggs after oil seed rape (F. E. Maskell, pers. comm.) even though the ground is relatively bare during the oviposition period. Cereals following grass are at risk from 'ley' pests (leatherjackets, wireworms, swift moth, frit fly, etc.) which are attracted by the grass and move to the cereal plants when the grass is destroyed. Grass weeds within intensive cereal systems, particularly blackgrass, are often associated with subsequent frit fly damage in cereals. Control of such weeds, by herbicides or burning, can reduce pest damage.

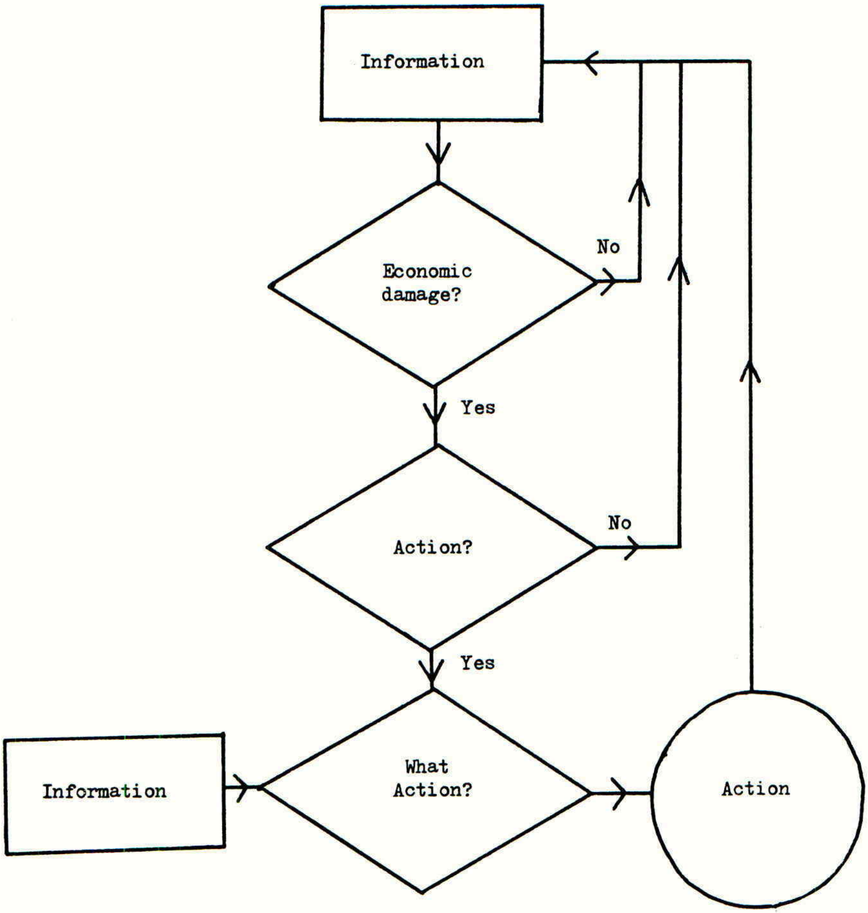
These examples illustrate the possible implications of decisions which, on first examination, have no relevance to pest control but which can, once chosen for economic and agronomic reasons, predispose the crop to particular pest problems. The value a farmer puts upon these 'side-effects' of his husbandry decisions varies; for example, the value of grazing grassland for as long as possible before sowing a following cereal crop, often outweighs the increased risk of frit fly attack by not leaving 4-6 weeks between ploughing and sowing. If the farmer expects a pest problem he is more likely to use a pesticide than change other practices. However, greater awareness of the possible implications of agronomic practices can be used constructively to avoid some pest and disease problems and anticipate others, allowing more time for a rational approach to their solution to be formulated.

PEST - SPECIFIC DECISIONS

The steps involved in decision making in plant protection have been given by several authors (eg. Cock, 1975; Conway, 1982) and presented here in a simple flow diagram (Fig 1). The first step is identification of the pest or the risk of its occurrence, followed by an assessment of its actual or expected effect, using economic damage thresholds if they are available. Based on this information, two decisions are made (i) should action be taken, and (ii) what action? Information about the choice of pesticides and other control measures available is required for the second decision. Ideally, having taken, or not taken, action there should be a reassessment of the problem. Although the farmer may well ask for advice he must make the final decision because it is his money at stake and only he is in a position to assess to the full the consequences of his decision.

Pest-specific decisions can be seen as existing in a time spectrum, where at its extremes a decision is made well before the pest appears (which tends to the insurance or prophylactic strategy) and the 'fire brigade' approach where decisions are made when the pest is very obviously present (Fig 2). There are advantages and disadvantages to both approaches. Insurance treatment has the advantage that more time is usually available in which to take action and it may fit more easily into the crop management programme. The spray operator can be told months in advance

Fig 1. Simple flow chart for pest control decision making



what and where to spray and the chemicals bought in at a convenient time. Against this, there is little information available when such decisions are made about the expected numbers and time of appearance of the pest. Such information as is available is usually derived from some method of forecasting or from the farmer's past experience of the pest and will give him some idea of the timing of routine treatment and whether it will be worthwhile. Pests which occur frequently and which can be controlled by relatively cheap pesticides are the most attractive candidates for insurance treatments, for example, wheat bulb fly seed treatments.

The second approach of waiting until the pest is present maximises the amount and precision of information but the time available in which to take action may be very short and resources may have to be diverted from other operations at short notice. Other problems may be posed by unsuitable weather for pesticide application, and the unavailability of the required pesticide.

At the extremes, the farmer has maximum time in which to act or maximum information on which to act but not both and ideally he has to find an optimum where he has enough information on which to base decisions whilst leaving sufficient time to take action.

1. Identification

Identification of the pest is usually a straightforward task, which the farmer may or may not be able to do depending upon his knowledge and the pest involved. Symptoms of damage are sometimes all one has. Pests that occur frequently and/or are easily visible are more likely to be recognised by the farmer than sporadic pests.

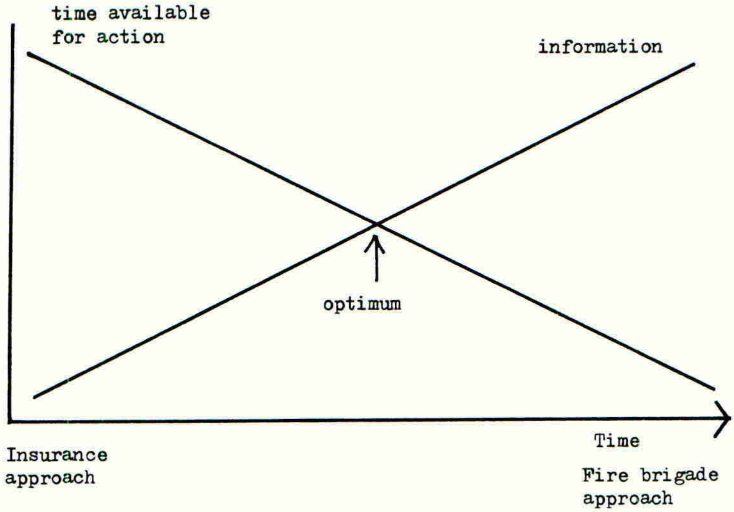
Assessment of the risk of pest attack requires some professional expertise because although crop monitoring for pests is usually within a farmer's capability, forecasting pest attacks is not, as yet. It is possible to identify crops that are particularly at risk to attack by certain pests and this may be sufficient for a farmer to use in his pest control decision making, but to be of most value such forecasts need to be supplemented by information on the pest's actual or expected abundance which can only be provided by professional advisers. Forecasting severity of attack is already done in the UK for wheat bulb fly (Oakley and Uncles,1977; Maskell, 1970) barley yellow dwarf virus (Kendall and Smith, 1981; Tatchell, 1982) and is possible for cereal cyst nematode (Jones and Jones, 1974). ADAS is developing forecasting methods for frit fly and O. florum. At present, the time of attack cannot be predicted accurately for any cereal pest although ADAS is developing a method for wheat bulb fly. The wheat bulb fly forecast already in use is the best developed and tested of the cereal pest forecasts and is based upon egg samples taken in September from fields selected to cover most risk categories. The results are interpreted, using the economic damage threshold of 2.5 million eggs/ha, to give the risk of attack for different cropping patterns and soil types. The main problem with area forecasts is their applicability to individual crops - this could be improved by increasing the sample size but this is usually impracticable. Generalised forecasts are still of use because they can alert farmers and advisers to the possibility of attack and, where appropriate, crops can be monitored locally.

2. Assessment of the effect or likely effect of a pest

The visual effect of pest attack can be very dramatic and damage may appear to be far more severe than the yield finally shows it to have been. The concept of an economic damage threshold (Stern et al, 1959; Headley, 1972) was devised to define when control measures would be financially worthwhile. There are damage thresholds for several UK cereal pests (Way and Cammell, 1979), the best-founded probably being that for grain aphid (S. avenae) on winter wheat in the summer which was determined from the results of 49 trials (George, 1975; George and Gair, 1979).

Economic thresholds should perhaps be viewed as guidelines rather than definitive levels because they are calculated using mean or typical pesticide and grain prices. If a farmer is able to buy or apply pesticides at lower than average prices and/or sell his corn at a better than average price, then the economic damage threshold for his crops will be lowered. Potential yields also enter into the calculations because it may not be worth spending money on a crop with a low

Fig 2. Information v time in pest-specific decisions



potential yield due to factors outside the farmers control. Should economic thresholds be modified to take account of the unwanted or deleterious side-effects of pesticides? The contribution of predators and parasites to cereal pest control has not yet been determined to the stage where it is possible to incorporate this into threshold levels but it should be possible at least to modify control measures where beneficial insects are present.

3. Available actions

Strategies for pest control have to be developed around the chemicals available on the UK market because of the need to find acceptable methods quickly. At present, for example, it would be difficult to construct an integrated pest control programme for cereals because, amongst other reasons, there are no suitable selective pesticides available except for the aphicide pirimicarb. Several criteria can be applied to the choice of action - cost/benefit, environmental effect though this is difficult to quantify, ease of application, personal preference (for example, unpleasant smell, preference for one company's products, etc.).

One of the most expensive single insecticidal treatments applied to cereals is fonofos, used against wheat bulb fly, costing approximately £33/ha. In three ADAS trials in East Anglia on mineral soils containing more than 2.5 million eggs/ha, the mean yield increase given by fonofos granules was 1.57 t/ha, giving a 'profit' excluding application costs of about £127/ha (Maskell, in prep). Multiple treatments costing a total of £64/ha gave a profit margin of £94/ha in a trial in 1981. At the other end of the scale, seed treatment with chlorfenvinphos, often used as an insurance treatment and costing £3.33/ha, gave a net return of £64/ha. The cheapest Approved aphicides in 1981 for the control of cereal aphids require a yield increase of only about 25 kg/ha to cover the cost of the chemical, or less than 1 per cent of the average wheat yield. This can be a powerful argument for insurance treatment, particularly when the chemical can be applied with another which the farmer would be applying anyway.

Ease of application can be an important factor. Best control of slugs is obtained by broadcasting slug pellets before sowing (Anon, 1979) but many farmers are reluctant to do this because it requires an extra pass over the land. They prefer to apply the pellets with the seed which is usually less effective. Seed treatments are usually applied by the seed supplier and provide a convenient, safe and cheap way for a farmer to use a pesticide. Granular formulations are usually applied with granule applicators, which many farmers do not own. Purchase or hire of an applicator adds to the cost of an already relatively expensive treatment. Pesticides whose application methods fit in well with a farmer's present capabilities and management plans are most likely to be chosen, providing cost and effectiveness are acceptable.

4. Reassessment

Reassessment of the pest problem after control measures have been taken shows if application was satisfactory and/or how effective the treatment was under the prevailing conditions. It gives the farmer information which is immediately applicable to his situation. Tait (1977) reported that fruit and vegetable growers generally overestimated the effectiveness of the pesticides they used and cereal growers may make similar overestimates. Few farmers leave unsprayed areas for comparison (Mumford, 1977) although most would be aware when a treatment failed completely.

When a crop is infested by a pest, it is tempting to apply a pesticide, regardless of whether any benefit in yield or grain quality results, because the infestation is usually visibly reduced by treatment and crop appearance and growth are often improved. Threshold values have to be reliable if they are to be used by farmers and leaving untreated areas for comparison would increase farmers' confidence in them.

EXAMPLES OF TACTICAL DECISION MAKING

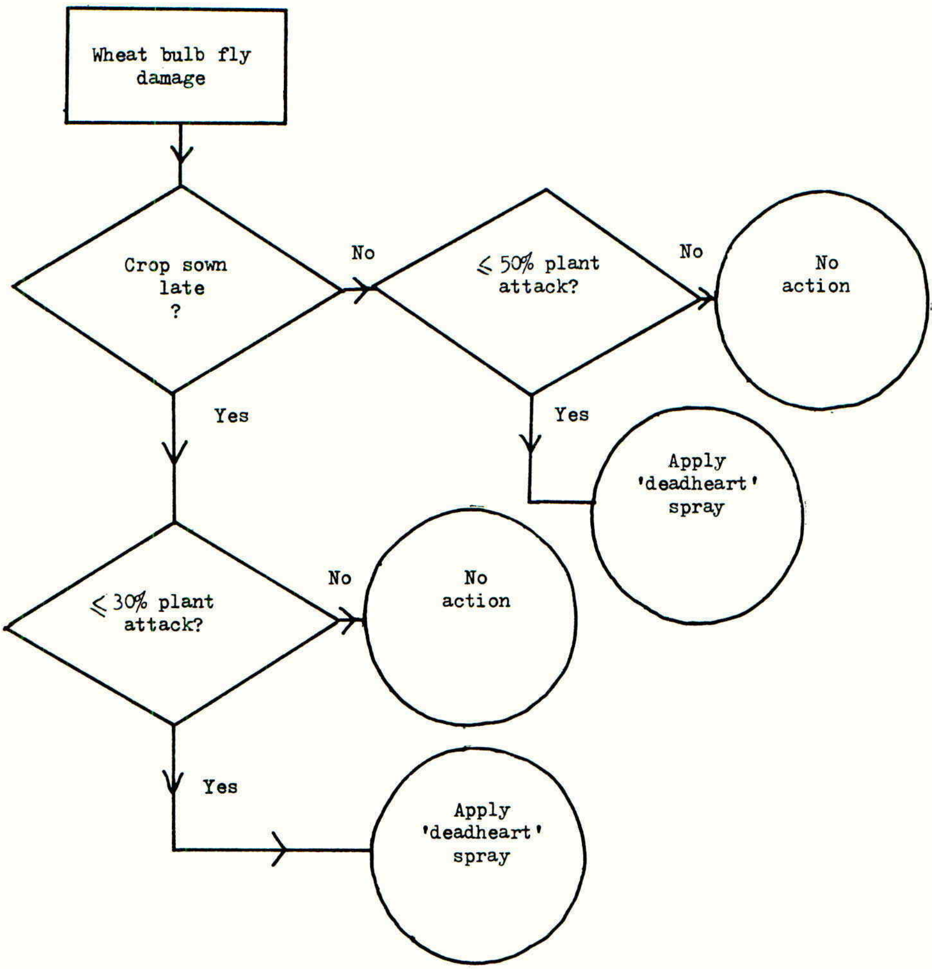
Figures 3, 4 and 5 show for three pests, wheat bulb fly, slugs and cereal aphids, decision trees for determining the action to take in response to an attack on a typical wheat crop. Regular monitoring of the crop is required in these examples. It is assumed in Fig 3. that the plants are tillering, redrilling is not necessary, the wheat bulb fly larvae are still young enough to be killed by the insecticide and that there are no other significant problems. The plant attack levels used as damage thresholds are based on experience. The assumptions made in Fig 4. are that aphids found on ears are *S. avenae* and those on flag leaves are *M. dirhodum*. Terms such as 'Crop sown late?' and 'Severely grazed?' would need further definition if the flow charts were used by inexperienced assessors.

Such flow charts and decision making trees are useful tools in the development of advisory systems and when problems arise in the field but they should not be applied rigidly.

FUTURE DEVELOPMENTS

Ideally every farmer should have rapid access to accurate information and

Fig 3. Simple flow chart for response to wheat bulb fly damage



advice on pest control tailored to his individual crops. At present the farmer receives information from a variety of sources and has to decide how relevant it is to his situation or call for professional guidance. The quality and quantity of information available, particularly forecasts and economic damage thresholds, need improvement. A system like EPIPRE (Rijsdijk, 1982), which uses data from a farmer's own crops in formulating advice for him, may be the next step. Speed of dissemination of advice and information could be increased by making more use of computerised systems, such as Prestel, and the various media (local radio, Fig 4. Simple flow chart for response to slug damage

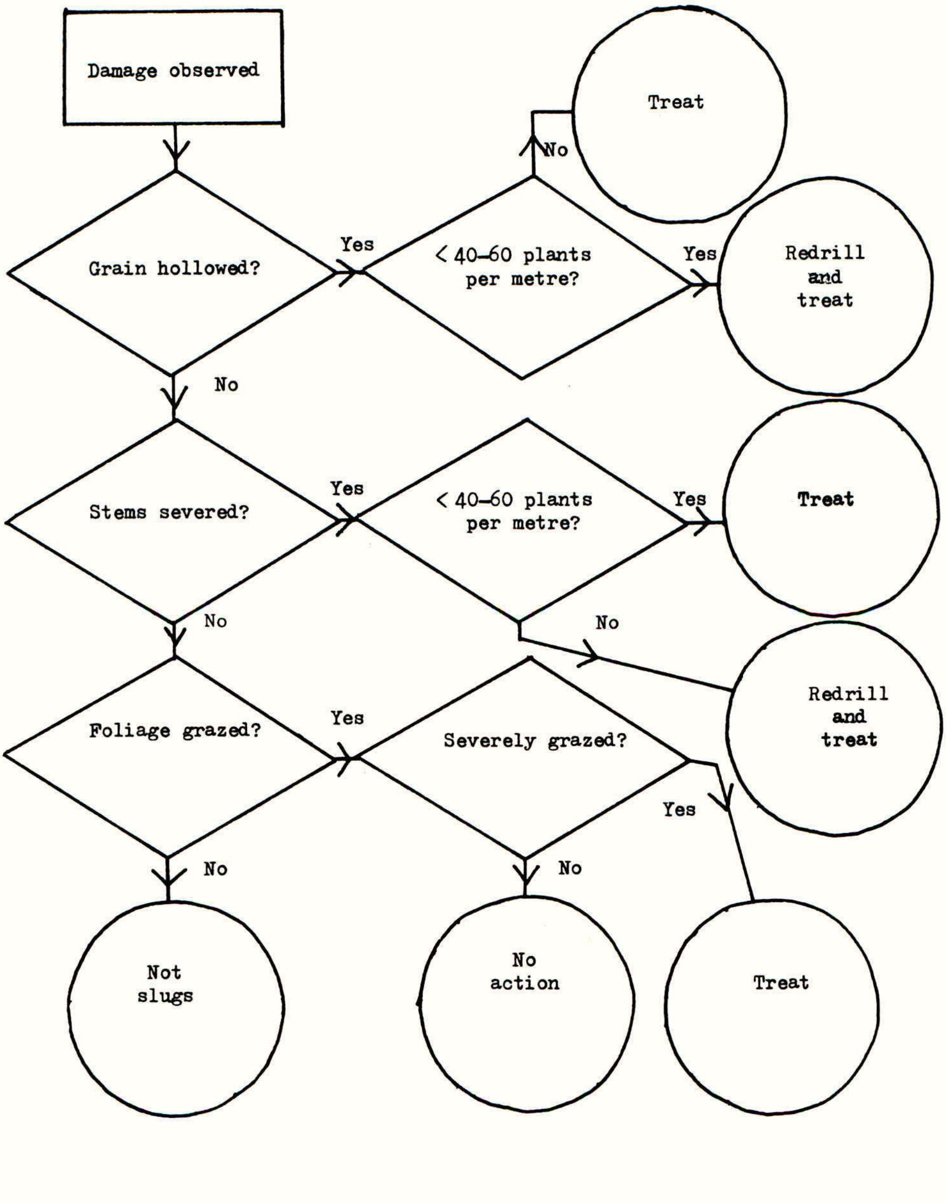
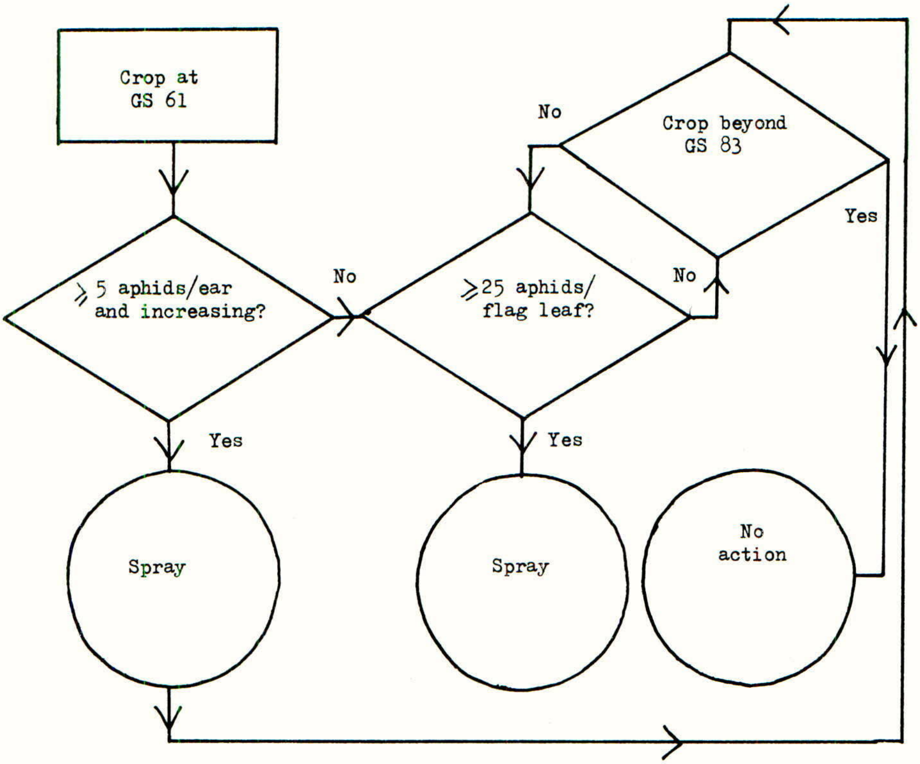


Fig 5. Simple flow chart for cereal aphid control



satellitte TV networks, telephone information services as provided by ADAS, audio and video cassettes, etc.).

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Decision Making in the Practice of Crop Protection

DECISION MAKING IN CEREAL DISEASE CONTROL

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Summary The need to secure improved yields and higher financial returns affects all disease control actions. The availability of fungicides has enabled farmers to reduce the serious effects diseases can have on their crops. But paradoxically the importance of some management decisions related to crop protection has been increased. Risk assessment tables which allow individual farmers to assess spray need are now being developed. These should enable the farmer to assess his own treatment costs and estimate the likely profitability of the proposed treatment.

INTRODUCTION

Fungicide treatment of cereal crops is now an accepted and essential part of all cereal growing systems. With the introduction of the organomercury chemicals for control of seed-borne diseases in the mid-thirties treatment soon became routine without recourse to the sort of management dilemmas discussed later in this paper. More recently the possibilities for fungicidal control of leaf and stem diseases have led farmers to consider options for disease control at all stages of cereal production. Current recommendations for control of cereal diseases are outlined in the ADAS guide Use of Fungicides and Insecticides on Cereals (Anon, 1982).

Fear of disease or other unknown catastrophe was probably the general principle behind the appreciation of rotations emphasised during the eighteenth and early nineteenth centuries (Loudon, 1831). Later, recognition of the importance of soil type and texture was also probably related to the effects of diseases such as take-all (*Gaeumannomyces graminis* (Sacc) Arx & Oliver) on second cereal crops grown on lighter land (Pilley, 1881). Take-all and eyespot (*Pseudocercosporella herpotrichoides* (Fron) Deighton) are still the major considerations governing cropping systems on most arable and mixed farms.

During the last 20-30 y plant pathologists have become increasingly aware of the damage which can be caused by foliar diseases on cereals (eg Large & Doling 1962). When relatively cheap and partially systemic fungicides were developed during the sixties the way for their widespread acceptance had already been prepared by Large & Doling's work on mildew (*Erysiphe graminis* DC ex Merat).

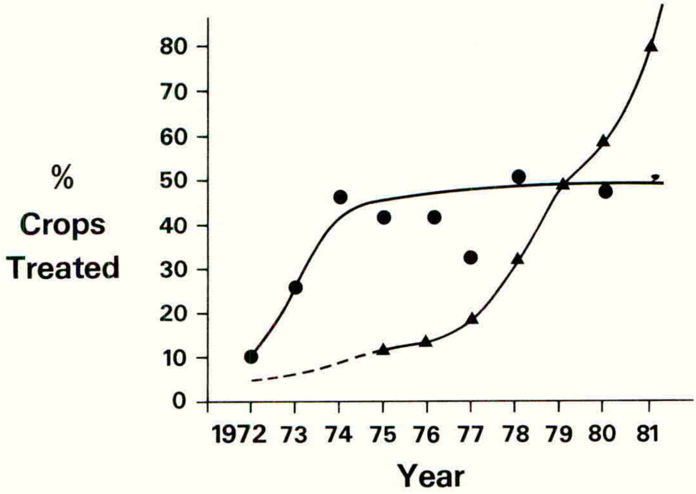
Selection of cultivars with high levels of resistance can make an important contribution to disease control. Minimum standards for disease susceptibility have been adopted by the National Institute of Agricultural Botany (NIAB) in an attempt to prevent the widespread adoption of cultivars susceptible to major diseases. Doodson (1981) has estimated that use of winter wheat cultivars resistant to the major diseases has provided a benefit of about £M15/y during the last 10 y. Disease resistance can also be enhanced by using cultivars incorporating different resistance genes in different fields or in mixtures within a field. Adoption of cultivar resistance is implicit as a method of disease control in this paper.

ACCEPTANCE OF FOLIAR FUNGICIDE TREATMENT

The ADAS cereal disease surveys not only measure the annual variation in disease levels, but have also indicated the general increase in fungicide treatment of cereals during the past 13 y (Fig. 1). For winter wheat the curve appears to follow the characteristic 'S' shape for the uptake of new ideas, as described by Rogers & Shoemaker (1971) in their work on advisory theory. Although fungicides were being used in some seasons against yellow rust (*Puccinia striiformis* West) and occasionally against mildew or septoria (*Septoria nodorum* Berk state of *Leptosphaeria nodorum* Muller) there are no reliable estimates of the crop area treated prior to 1975, so that the early part of the graph is conjecture.

Fig. 1

ADOPTION OF FUNGICIDE TREATMENT ON WINTER WHEAT (▲) & SPRING BARLEY (•) IN ENGLAND AND WALES 1972–1981



The surveys have not demonstrated any recent systematic increase in wheat leaf disease, except in the 1981 season and introduction of new fungicides is unlikely to have had a significant effect on total fungicide use during the last 2 y. The increasing use of fungicides on winter wheat appears therefore to follow the usual pattern for the acceptance of innovation. For spring barley the situation is similar but fungicide use has levelled off at c 50%. Partial explanations for this early cut off include the limitation of need through the exploitation of mildew resistant cultivars and the fact that spring barley is often grown on smaller units where arable crops are not the major farm enterprise, so that these farmers may be among the 'late adopters'.

Reports from several sources including results from NIAB Recommended List trials (Priestley & Bayles, 1982) show increases in yield of some cultivars when given routine fungicide treatment irrespective of disease incidence. Information of this type may have encouraged the increased use of fungicides especially on winter wheat. The results of these trials, however, indicate considerable variation in response not only from year to year but also from site to site. They highlight the need for simple, reliable systems which can identify crops at risk (and thus likely to provide an economic yield response) rather than justify routine treatment.

THE IMPORTANCE OF DISEASE CONTROL

Increased production and subsequent profit are the prime motives in most farm decisions. Attainment of the maximum profit with cereal crops does not inevitably follow if the maximum yield is pursued, although some modern growing systems include routine use of fungicides (Effland, 1981). The yield potential of wheat and barley rather than their disease resistance is often considered by farmers to be the most important factor (Priestley & Bayles, 1980) in their choice of cultivars (Table 1).

Agronomic decisions are based on diverse factors not all related to minimisation of disease. The choice of sowing date is for example influenced partly by consideration of the yield benefit from early sowing as illustrated in Table 2 for winter barley. There is also the requirement, especially on large farms or with difficult soils, to sow extensive areas of crop when opportunity offers rather than wait for optimum dates. From the farmer's point of view the additional yield from early sowing and other benefits from simplification of management offset any additional costs incurred through increased pesticide use. The data in Table 2 represent at 1982 prices an additional return of £84/ha from September sown winter barley compared with sowing in mid October. Additional costs for the earlier sown crop might include two fungicides to control mildew and net blotch and an insecticide for control of barley yellow dwarf virus. Such applications might cost at most about £30/ha, giving a net return of c £50/ha from early sowing, assuming no other additional costs (eg herbicides) are needed. Earlier sowing also increases the incidence of some winter wheat diseases (Table 3).

The choice of cultivation techniques is largely governed by management criteria. But cultivations which leave plant debris on the soil surface may allow survival of fungal pathogens with consequent risk of severe disease the following year. (Yarham & Hirst 1975). Increased fungicide use must then be offset against the convenience of minimum cultivation methods.

Table 1

Percentage of farmers rating various characters as very important or extremely important in selection of cereal cultivars

Character	Winter Wheat	Spring Barley
Yield	96.9	96.4
Yield related features (standing power, ear/grain loss)	70.5	82.5
Shortness of straw	16.4	27.0
Earliness	28.1	52.8
Disease		
Eyespot	55.3	-
Septoria	55.3	-
Mildew	47.4	66.6
Yellow rust	62.5	37.8
Brown rust	35.4	30.8
Rhynchosporium	-	58.2
Loose smut	24.5	24.8

(After Priestley & Bayles, 1980)

Table 2

Effect of sowing date on yield of winter barley 1980

	Sowing Date		
	September	Mid October	Mid November
Relative yield	100 (6.85 t/ha)	88	82

(Data from 7 experiments - MAFF Research and Development, Cereals 1980 unpublished).

Table 3

Relative % infection of Septoria and mildew on winter wheat sown at different times, 1978-80

(mean % infection, leaf 2 GS 75)

Disease	Sowing Date: Before mid October	Mid-late October	November or later
Septoria nodorum	100 (6.9%)	94	60
S. tritici	100 (2.2%)	65	22
E. graminis	100 (1.6%)	86	85

Data from ADAS winter wheat disease surveys, corrected to account for annual variation in disease.

FUNGICIDE DECISIONS FROM DISEASE THRESHOLDS

Experience with barley mildew suggested that critical threshold levels of disease are useful in deciding when to apply spray treatment (Jenkins & Storey 1975). Action threshold levels of disease based on the results of experimental work and adviser experience have been adopted for most of the cereal foliar diseases (Anon 1982). Current or recent weather favourable or otherwise for disease development (Polley & Clarkson 1978) affects the probability of the eventual occurrence of damaging levels of disease. Meteorological considerations might therefore indicate the desirability of fungicide treatment at lower disease thresholds. Decisions based on disease thresholds can also be supported by observations on pathogen spore release. This approach has been used by ADAS to help identify optimum spray timing for spring barley mildew control.

'Action thresholds' will lead to fungicide use only when disease is present and there is believed on the basis of current observation to be a risk of significant disease development. Inevitably, these decisions are subject to error, arising from the absence of information not only on future weather but also the precise effects of recent weather on subsequent disease development. The final spray decision is thus partially subjective.

FUNGICIDE DECISIONS FROM RISK ANALYSIS

A desire to simplify management has now led many farmers to adopt a prophylactic approach to foliar fungicide treatment. This approach is not new. Some seed-borne diseases have been controlled prophylactically since the organomercury seed treatment chemicals were adopted 50 y ago. The costs of fungicide and treatment are absorbed into general costs. Most growers are risk-averse and would rather treat crops than accept a slight risk of yield loss from disease. The view is often expressed that in the long term the returns from fungicide treatment in high disease years will pay for the cost of insurance treatment in years when fungicides are not needed. But spray fungicides are not a close parallel to the organomercury seed treatments. They are considerably more expensive.

Alternative approaches to the prophylactic or insurance use of fungicides are now being developed. Many of these involve risk assessment tables (eg Maumené, Poussard & Prevot 1979, Myram & Kelly 1981). An example derived to provide spray warnings for control of barley yellow dwarf virus is shown in Table 4.

Table 4

Barley Yellow Dwarf Virus Risk Assessment South Wales 1980

			Score	Own Score
Date of sowing		Early September	4	
		Mid-late September	3	
		Early October	2	
Previous crops		Grass or cereals - poor burial of turf	4	
		Grass or cereals - good burial of turf	2	
		Not grass	1	
Aphids		Found in late October	4	
		None found	1	
September/October Weather		Mild open	4	
		Cold wet	1	
Total Score:	12 or more	High risk	Score	-
	6 - 12	Moderate risk		
	less than 6	Low risk		

(Key devised by R J Cook for Advisory work in South Wales).

Decision schemes of this type do have some difficulties. Similar numerical scores awarded to different variables suggest equivalence of importance which might or might not be true. The relative importance of different factors may change from season to season as well as in different geographical situations. Schemes of this type assume that all growers have the same treatment costs and that all crops have the same yield potential. In addition, they could give a false impression of exactitude if it is not realised that the loadings of individual components are subjective assessments, although in the case of the system produced by Maumené et al individual scores were derived statistically. Viewed positively, however, risk assessment tables provide a means by which the considered subjective judgements of a relatively small number of specialists can be utilised by growers at all levels of technical ability. These developments represent a significant advance in attempts to identify and select crops at risk to improve the precision of forecasting spray need.

The results of a recent series of ADAS fungicide experiments (unpublished data) are categorised in Table 5 according to the risk analysis system published by Myram & Kelly. This scheme is not perfect but it appears to be useful.

Table 5

Evaluation of winter wheat fungicide programme prediction for sprays at GS 31 & 39

Risk analysis prediction (Myram & Kelly, 1981)		Response actually worthwhile (ADAS experiments**)	
Prediction	Number of crops	Cost of fungicide only *	Cost of fungicide + application *⁄
Spray recommended	32	22	18
Spray not recommended	7	4	2

* Triadimefon + carbendazim GS 31
Triadimefon + captafol GS 39 wheat at £105/t
Total cost £46/ha

⁄ £9/ha for application

** Treatment comprised carbendazim, 250 g/ha, captafol, 1.4 kg/ha and triadimefon, 125 g/ha at both growth stages

Decision trees require similar judgements. A possible system for control of septoria on wheat was devised by Webster & Cook, (1979). This scheme included estimates of expected yield response. By selecting features such as disease incidence or cultivar susceptibility to disease relevant to his own crop the farmer can gain an estimate of returns and profitability by deducting treatment costs.

Models to simulate disease development are now being developed for some diseases or crops. An example is EPIPRE - Epidemiology, Prediction and Prevention developed in Holland for winter wheat (Zadoks 1981). EPIPRE was derived from field trials and incorporates meteorological and epidemiological parameters.

It is claimed this model has been successful in Holland and it is now being evaluated in some other European countries. The system depends on information on disease frequency (not severity) as well as relevent agronomic conditions. Information on a crop (both historical and current) is passed to a computer and appropriate advice on fungicide treatment is given. The amount of field observation required is often greater than is demanded by action-threshold spray decision schemes.

DISCUSSION

The recent squeeze on the returns from cereal growing is likely to continue and increased costs must be avoided. There will be a need for cereal growers to rationalize pesticide useage with a reappraisal of prophylactic applications. This need is also likely to be supported by advisers and consultants conscious of the risks of pesticide resistance and other environmental pressures.

The increasing complexity of cereal growing will require advisers to provide better decision making methods which include estimates of the expected response in yield and financial terms and the frequency of economic response. The expanding data base from results of experiments will encourage computer-based decision aids to develop. In addition, it is likely that small automatic weather stations will soon be available to warn the farmer of the occurrence of infection conditions for particular diseases. Identified infection periods might then be fed into the computer to give an estimate of likely yield responses and cash benefits from a choice of fungicides on a crop by crop basis. This is the ultimate goal but more work is needed before it can be realised.

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SUGAR-BEET PEST, DISEASE AND WEED CONTROL AND THE PROBLEMS POSED BY CHANGES IN HUSBANDRY

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Summary The sugar-beet crop is well supervised by the British Sugar fieldstaff; records are given showing the results of changes in crop agronomy and pesticide usage. Crop protection decision making is discussed, and data presented in relation to the control of a) weeds and weed beet, b) pests that damage seedling vigour and establishment, and c) powdery mildew and virus yellows. Long, medium and short term decisions have to be made in the expectation of the need to control damage, and further control decisions in response to the presence of the weed, pest or disease. Pesticide usage has increased greatly as labour input has decreased, and has helped to stabilise yields and prevent them decreasing as much as they might otherwise have done. In general, usage is probably excessive; current research aims to provide information for more selective use.

INTRODUCTION

Because sugar beet is only grown under contract to the local sugar factory, there has always been a very close relationship between the grower and the processor (British Sugar). In the endeavour to ensure adequate and reliable supplies of good quality roots for its factories, British Sugar advises growers on all aspects of crop culture. It does this directly through its agricultural fieldstaff which in 1982 comprises 72 Fieldmen, 12 Agricultural Development Officers and 13 Factory Agricultural Managers serving 202,000 hectares of crop. It also advises growers by other means, such as postal advice on the timing of control measures for specific problems (e.g. weed beet and virus yellows), National Spring and Autumn Sugar Beet Demonstrations that are held annually, local field demonstrations of interesting materials or techniques, testing the efficiency of drill and sprayer units and via publications such as the Sugar Beet Grower's Guide and the quarterly Sugar Beet Review.

All these services for growers are in addition to those obtainable from the Ministry of Agriculture, Fisheries and Food (MAFF), agrochemical companies, etc. The research on which much of the advice is based is done either by British Sugar or by independent workers financed by the sugar-beet research and education scheme. Growers pay a levy (currently 8p/tonne of sugar-beet roots, whose value is approximately £25, i.e. a 0.32% levy), towards a fund to which British Sugar contribute an equal amount. The total fund (£1.3 million in 1981/82) is administered by a MAFF advisory committee - the Sugar Beet Research and Education Committee (SBREC); in 1981/82 79% of this fund was allocated to sugar-beet research centres, especially Broom's Barn and the Plant Breeding Institute, and 18% allocated directly to education and advice (Anon, 1981).

Similar arrangements exist in other European countries and the Institut International de Recherches Betteravieres (IIRB), based in Brussels, fosters international collaboration between research workers, advisors, the industry and its suppliers.

In England the research, education and advice available for sugar-beet growers is more extensive, and probably better, than for any other crop, and yet yields have not increased in recent years as they have with other crops. This is mainly a result of dramatic changes in agronomy which have taken place during the last two decades and which have followed the need to convert sugar beet from a labour-intensive crop to one in which the labour input per hectare is comparable to alternative crops. British Sugar, from their annual survey of 800 fields (5% of the national crop), obtain reliable information on all aspects of crop agronomy and protection (Maughan, 1982); the most recent data, in comparison with earlier years to show trends, are recorded in the Tables and some of the Figures in this paper.

The labour required for the crop, in man hours per hectare, has declined from 500 in 1950 to 50 in 1980 (Sturrock, 1979). This decline has been brought about by changes: 1) using monogerm seed planted-to-stand instead of sowing multigerm seed closely and spacing out the plants by subsequent hand hoeing, 2) controlling weeds by using pre- and post- herbicides (often obviating the need for any mechanical weed control) instead of hand hoeing and mechanical inter-row cultivation (Table 1), and 3) machine harvesting instead of hand harvesting.

Table 1

Changes in agronomic methods of establishing the crop

(% of total area)

Year	Precision drilled[1]	Planted to stand[2]	Monogerm seed used	Pelleted seed used	Herbicide used	Hand hoed[3]
1960	24	0	0	0	Exp[4]	100
1965	74	Exp[4]	1	3	35	99
1970	100	30	63	83	85	92
1975	100	65	86	99	98	62
1980	100	86	99	100	99	42

[1] Drills that space each seed at a predetermined distance.

[2] Seeds spaced at 12.5cm or more apart, with the object of no further plant-spacing work by hand or machine.

[3] Hand hoed to single plants to achieve correct plant population; does not include any hand hoeing to control weeds.

[4] Experimental only.

(See Table 3 of Dunning & Davis (1975) for data for each year between 1960 and 1975)

These changes have enabled the crop to remain profitable, but have probably prevented sugar yields from increasing steadily over the years as they might otherwise have done. The change to monogerm seed, for instance, gave a yield penalty that has only recently been removed by plant breeders.

The dramatic decline in man hours per hectare has been paralleled by a dramatic increase in pesticide usage on the crop (Table 2).

Table 2

Pesticide usage : % of crop receiving at least one treatment

Omitting seed treatment (fungicide and insecticide is applied to all seed) and the minor usages of mouse poison, slug bait, and insecticides to control foliage-eating pests.

Year	Soil spray[1]	Seed furrow[1]	Foliage sprays		
	(pre-emergence) Gamma HCH	Granular insecticides /nematicides	Contact insecticides to control seedling pests	Aphicides	Fungicides (Erysiphe only)
1955	<1	0	15	Exp[2]	0
1960	<1	Exp[2]	5	54	0
1965	<1	Exp[2]	3	41[3]	0
1970	1	Exp[2]	4	65[3]	0
1975	7	23	4	91[3]	0
1980	19	45	1	7[4]	6

[1] A very small proportion of the crop is now treated with both soil spray and granular pesticide.

[2] Experimental usage only.

[3] A small proportion of the crop was treated with foliage-applied granules in 1965-75, instead of, or in addition to, aphicide sprays.

[4] A very low incidence of aphids in 1980.

How far can success in crop protection claim to have facilitated the decrease in labour, or its failure be blamed for the lack of increase in yield? Research, education and advice on sugar beet exceeds that on any other crop: is the grower taking the advice and using it wisely?

CROP PROECTION DECISION MAKING

Sugar beet suffers from a plethora of pest, disease and weed problems. Only some of the major problems can be considered here, and these are grouped below under three headings; within each group crop protection decisions must be made.

a) Control of weeds and weed beet

Traditionally, sugar beet was regarded as a cleaning crop in the rotation. The advent of modern herbicides for cereals and other crops has very largely removed this benefit of the beet crop, although better control of grass weeds of cereals is achieved when sugar beet is included in a cereal rotation. On the other hand, sugar beet can now benefit from, for example, the ability to control Agropyron by pre-harvest application of glyphosate in cereals.

For the sugar-beet crop there simply remains the need to prevent weed competition during the growing period, especially the early part of the season (Scott et al, 1979) and to decrease weed problems at harvest. However, the objectives of some sugar-beet weed control advisors appear to be to achieve maximum weed control in the crop, rather than the minimum necessary, using herbicides to replace hand and machine hoes. Herbicide usage has increased steadily (Table 1) and good weed control is usually achieved. There is now an increasing trend for growers to use overall, rather than band application of herbicides and to use frequent, low dosage post-emergence treatments alone rather than both pre-emergence and post-emergence treatments; there seems to be little or no advice as to whether all these treatments are necessary or economically justified. The grower's herbicide strategy should be on the basis of the expected weed flora; he is much better able to do this if he has good records of previous years' weed infestation in his fields.

Excessive reliance on chemicals may alter the weed flora, and is certainly part of the cause of the weed beet problem; it may also, through efficient control of weeds, lead to increased aggregation of pests on the beet and the risk of greater crop damage from them.

Weed beet infestations are most severe where there is a combination of a close beet rotation (especially 1 in 3), light soil, and reliance on weed control by herbicides rather than hand and machine hoeing (Longden, 1980). As a result of extensive publicity about weed beet, growers can easily recognise them, even where there are small populations. However, weed beet used to be regarded simply as bolters and there was then no fear that they would set seed and so create a weed problem for future crops; because of this ingrained belief growers now seem reluctant to heed advice to control them by hand rogueing when the population is still small, although they are often prepared to use this technique to control wild oats effectively. Table 3 records the percentage of beet fields infested with weed beet, and the much smaller percentage in which control measures are taken. When the problem has become severe growers must widen the rotation, or even stop growing beet for many years; such a decision has then been forced on them. To avoid such crises occurring on a much wider scale, considerable publicity efforts are made to persuade growers to control weed beet whilst populations are still low.

Table 3

Incidence of weed beet (bolter) infestations in sugar beet fields, and the percentage in which direct control measures were taken

Year	% of fields with bolters at harvest	Bolter control (% of fields) By handwork (hoeing or pulling) >10hr/ha	<10hr/ha	By cutting, or treating chemically 1x	2x	3x	Nil
1978	82	-	-	-	-	-	52
1979	70	6	42	8	2	0	41
1980	80	5	36	12	2	2	42
1981	78	4	44	5	3	2	42

b) Control of pests that damage seedling vigour and establishment

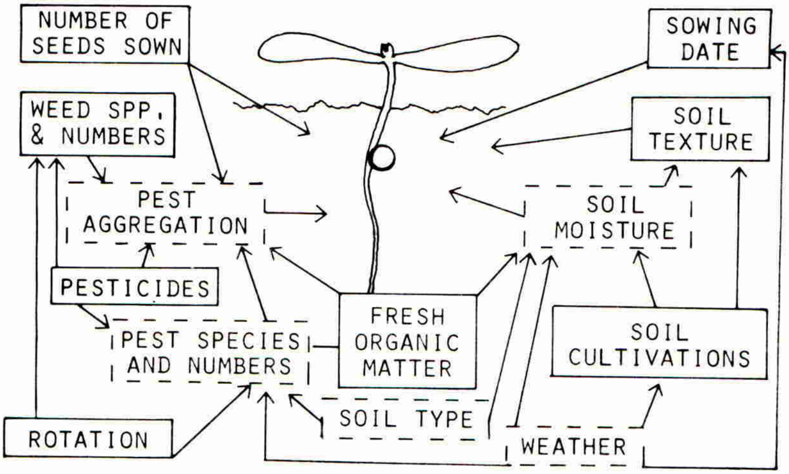
Before the 1960s approximately 600,000 sugar-beet fruits (900,000 seeds) were sown per hectare and the resulting 'hedge' of seedlings thinned by hand to give the optimum of 70,000 plants per hectare. Numbers sown decreased with the advent of precision drilling and monogerm seed (Table 1) and today 130,000 or fewer seeds are usually sown in an endeavour to obtain a uniformly spaced plant population of 75,000 per hectare (Maughan et al, 1982).

During the 1970s establishment (the number of plants per 100 seeds sown) in field trials averaged only 55%, ranging from less than 20% to more than 90% (Scott & Durrant, 1981). More recent surveys (Durrant, 1980) suggest that average establishment has improved to just over 60%. However, the national mean plant population of about 65,000 per hectare is still too low and, furthermore, in most crops the plants are irregularly distributed. Many factors, of which pests and diseases are only two, cause this sub-optimal population and distribution. Growers are encouraged to improve their management of the soil, the drill units, sowing depth, etc., but they increasingly rely on soil-applied pesticides for protection against pest damage (Table 2); such treatments are in addition to seed treatment with fungicide and insecticide, and are often used as an insurance rather than against known, specific pest problems.

Decisions on which fields really need treatment with soil pesticides can at present only be based on previous damage in each field, although in the case of Docking disorder the soil type is clearly defined. There seems to be justification, nationally, for treating about 10% of fields to control damage by soil insects, and 10% to control free-living nematode damage (Docking disorder) on the very light soils where soil insect pests are not a problem (Cooke, 1973). However, in practice, about 60% of the national acreage is treated with soil pesticides (Table 5: 43% + 18%). Of this, some 5% is treated primarily to control aphids and yellows, and probably justified. Approximately 35% of the national crop is therefore receiving an insurance treatment that is rarely necessary and much of our current research is aimed at developing methods of deciding which fields are at risk from soil-pest damage. With this knowledge, the growers could take account of the many other field factors involved (Fig. 1) and make more rational decisions on seed spacing and pesticide usage.

Figure 1
Factors affecting soil-pest damage to seedlings

(Factors in solid boxes are under the farmer's control; the other factors are not under his control)



Advice to growers on the best pesticide(s) against each problem is based on extensive field trials (e.g. Dunning & Winder, 1973) and is given directly to growers (e.g. Winder, Dunning & Thornhill, 1977; Dunning & Thompson, 1982). Each product has advantages and disadvantages (safety to crop, spectrum of activity, cost, safety to operators, effect on beneficial organisms, etc.) but, in general, growers probably make the correct choice (see Table 5 for 1981 usage). Their main error seems to be in excessive use of gamma-HCH in south eastern East Anglia; the benefits of cheapness apparently outweigh the well-publicised risk that its use can lead to increased incidence of virus yellows via its control of the insect predators of the aphid vectors. It appears that growers prefer to rely on this material to help improve crop establishment and are prepared to apply extra aphicidal sprays if necessary to control virus yellows.

c) Control of powdery mildew and virus yellows

Powdery mildew (Erysiphe betae) has become recognised as an important disease of beet foliage in England only in the last decade, as a result of experiments with fungicidal treatment showing large yield increases. The incidence of the disease has also increased, probably due to an increase in varietal susceptibility. There is also speculation as to whether pesticide and, especially, herbicide applications have made the crop more susceptible.

Joint trial work between Broom's Barn, British Sugar and agrochemical companies has rapidly led to positive advice (Byford, 1981). Crops should be sprayed with sulphur or alternatives as soon as the very first mildewed leaves can be found, provided it is not later than 10 September. British Sugar advises the grower each year, by postcard, when the disease is likely to appear, but further studies are needed on the weather factors which favour the disease so that its appearance or non-appearance can be forecast more accurately.

As a result of trial work, publicity, and the spray warning system, there has been a dramatic increase since 1979 in the area of the crop treated with fungicide (Table 4); however, the timing of spraying is not always optimal because this can clash with cereal harvest so there is a tendency, exacerbated by the cheapness of the treatment, for growers to apply a prophylactic spray before symptoms appear. Such treatment can be ineffective if applied too long before the disease develops.

Table 4

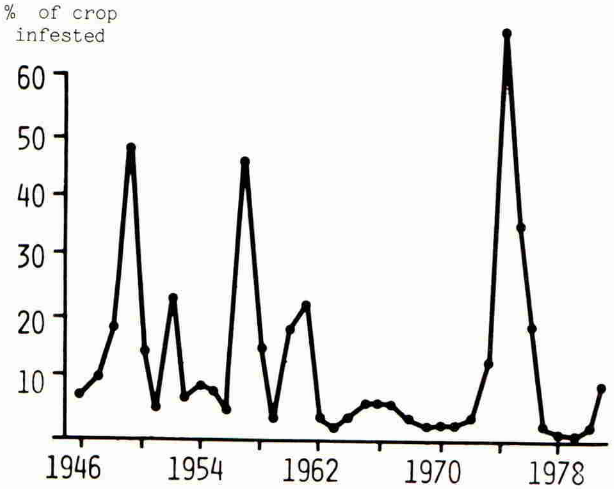
Control of powdery mildew:
percentage of crop treated with fungicide (principally sulphur)

Year	National	East Anglia only
1979	experimental only	
1980	6	15
1981	27	49

Decision making on control of virus yellows, via the control of its aphid vectors, has been a problem since the first efficient ahicidal spray became available in 1957. The importance of good crop hygiene, early sowing and full plant population has always been stressed but growers have relied mainly on crop protection chemicals.

Figure 2

National incidence of virus yellows
(end of August)



Attempts made by some chemical companies to introduce and encourage routine aphicide spraying, by the calendar month or growth stage, were prevented in the early 1960s; such systems would greatly ease management decisions, but would be uneconomic because of the variable incidence of the main vector aphid (Myzus persicae) and especially the subsequent yellows (Fig. 2). Furthermore, it was feared that unnecessary spraying might induce the development of resistant aphids (Hull, 1961). Instead, in England, as in many continental countries, a "spray warning" system has evolved. The development of aphid populations on the crop is monitored throughout the country by daily counts in each of 3-4 fields per fieldman. The data are summarised weekly at Broom's Barn and issued to British Sugar, ADAS and chemical companies, together with a disease forecast based on winter temperatures (Watson et al, 1975), the prevalence of virus sources, the stage of crop growth, etc. The decision to issue a "spray warning" is taken by the local British Sugar agricultural staff, and a warning card is posted to growers in a parish, a group of parishes, a fieldman's area or even the whole factory area. When the aphid infestation is prolonged, a second warning is often issued two to three weeks after the first, and in extreme years a third warning may be issued still later. The wording of the card is decided locally to cater for the circumstances, especially with regard to the urgency of the advice. In general, there is good agreement between the area sprayed nationally and the extent of warnings (i.e. the mean number of warnings given per fieldman's area), (Fig. 3).

Demeton-S-methyl was first used commercially to control aphids in 1957. Growers soon had a choice of aphicides and followed advice on the relative efficiency of the products; by 1975 they were using, in decreasing order of frequency, demeton-S-methyl, pirimicarb, dimethoate, phosphamidon, phorate (foliage-applied granules), formothion, oxydemeton-methyl, thiometon and demephion. M. persicae resistant to organophosphorus compounds were found in 1974 (Dunning & Winder, 1975) since when most of these compounds have proved ineffective and are no longer used. Other materials, especially acephate and ethiofencarb, have been introduced but, due to commercial reasons, have subsequently been taken off the market. It is salutory to note that in 1982 the grower only has the choice of demeton-S-methyl and pirimicarb; in 1981 these were already being used on most of the treated areas (Table 5).

Figure 3

The effect, on the total area sprayed, of British Sugar advice to apply aphicide sprays

(1974-1981)

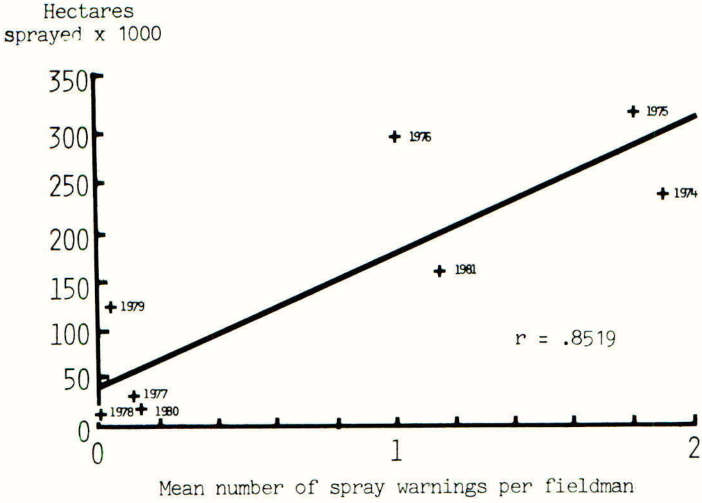


Table 5

Insecticide/nematicide usage on the 1981 crop

(% of crop treated)

Seed-furrow granules		Foliage sprays (aphicides)	
Aldicarb	25%	Demephion	2%
Bendiocarb	6%	Demeton-S-methyl	40%
Carbofuran	8%	Dimethoate	5%
Oxamyl	1%	Ethiofencarb	2%
Thiofanox	3%	Oxydemeton-methyl	3%
		Pirimicarb	43%

Soil-incorporated spray

Gamma-HCH 18%

No pesticide 5%

Note: 1-2% of the crop was treated with both a seed-furrow granule and soil-incorporated gamma-HCH.

The increasing use of soil-applied, broad spectrum, insecticide/nematicides (Tables 2 and 5), primarily for control of nematodes and soil-inhabiting arthropod pests, influences advice on aphicide sprays. Aldicarb and thiofanox can both control aphids on the foliage, by systemic action, early in the season; where they have been used (28% of the national crop in 1981) growers are advised that the first spray warning to control aphids should only be heeded if sowing was very early and/or much rain has fallen because in these circumstances activity of the compounds will no longer be sufficient to be effective.

Because the incidence of virus yellows varies greatly from area to area, and from field to field, attempts are being made to improve the spray warning advice to individual growers. Progress is being made in understanding the field factors involved; this is relayed to British Sugar fieldstaff but not yet direct to growers other than in the most general terms. However, because of the decreasing numbers of fieldmen it is envisaged that growers will need to exercise more skill and care in making decisions on crop protection, and they will need to be supplied with adequate but simple information to aid this decision making.

DISCUSSION

The farmer grows sugar beet mainly for direct profit; he also grows it to increase profit from other crops, and in some cases to profit from the by products. Sugar beet prices are fixed before harvest so the value of the crop to the grower is in direct proportion to its sugar yield. The greatest yield is achieved by maximising leaf cover of the ground as early as possible in the season, and then maintaining the health and vigour of this cover until harvest (Scott & Jaggard, 1978). Pests, diseases and weeds can delay or limit ground cover by healthy leaves and/or impair their health and efficiency, thereby decreasing yield. In addition, weeds can decrease the efficiency of harvesting.

Sugar beet is a fairly high value crop worth, on average, about £1,000 per hectare at harvest, and investment in crop protection chemicals has increased enormously as labour input has decreased. Having spent approximately £120/ha on cultivation, £34 on seed, £105 on fertilisers, and having to spend approximately £135 on harvesting and delivery (Sturgess, 1981), no grower wishes to jeopardise the profit from these investments by risking weed, pest or disease damage. He therefore applies a range of prophylactic or curative treatments on the basis of various types of strategic and tactical decisions.

a) Long term decisions Pre-eminent must be the decision on rotation; how frequently should sugar beet be grown? The minimum interval is determined for the grower by the terms of the contract, which demands at least two years between crops; the two crops that precede beet cannot, with very limited exceptions, be beet or other chenopodiaceae, or any cruciferae (Dunning & Dyke, 1977). Without such constraints, some farmers would grow beet two or more years running; on some soils there would then be devastating attacks by pygmy beetle (*Atomaria linearis*) that pesticides do not always entirely control (Thornhill & Dunning, 1980), by beet cyst-nematode (*Heterodera schachtii*), and other specific diseases and pests. It is probable that rotations have shortened slightly on average over the last two decades as a result of greater specialisation, and investment in machinery, by fewer growers on a narrower range of soil types. Nevertheless, a maximum cropping frequency of 1 year in 3 is still considered the maximum tolerable for sugar beet in both the short and long term.

b) Medium or short-term decisions Weed, pest and disease problems that originate from within the field do not develop spontaneously in the cropping year; they have been there previously, probably for many years. Growers should record problems systematically each year in each crop on a field by field basis to aid predictions of likely problems and the need for countermeasures. Such an approach seems particularly necessary for weeds; herbicide treatments, which can damage crop growth, would then only be used where there was a potential threat from the weeds they were designed to control.

When the grower is aware of the likely problems he must know the best means of combating them. His decisions are influenced by his general approach, which can range from minimal to maximal reliance on chemicals. Maximal use is prevalent, especially in the case of herbicides; growers feel that clean crops are essential, on the basis that it is good farming to keep weed populations well below a damaging threshold.

When the grower has decided his strategy for post-emergence herbicide treatments he then has to decide whether pre-emergence herbicides are needed and, if so, whether they should be applied overall or in bands; if the latter, should the application be combined with drilling or done later.

Is gamma-HCH to be used? If so, it must be applied overall and incorporated, and can be combined with pre-sowing herbicide treatments. Alternatively, are pesticide granules to be applied in the seed furrow during drilling? The need for such prophylactic treatments should be governed by knowledge of the pests' presence in the field, and the likelihood of them causing damage because, for example, the seed spacing is wide or the seedbed loose. The grower seems able to judge this need correctly in the case of Docking disorder but on the evidence of Tables 2 and 5 apparently overreacts to the risk of arthropod damage. Field trials on random sites in England have shown profitable yield increase from aldicarb treatment in only about 30% of fields, and some of these increases were due to control of virus yellows (Dunning & Byford, 1979).

In a limited number of fields where seedling diseases or pests are known to be present from previous experience, the grower will sow the seeds more closely than he would otherwise have done. Normally, however, seed spacing is most likely to be dictated by soil type, seedbed conditions and date of sowing.

c) <u>Curative treatment decisions</u> Post-emergence herbicide treatment to control weeds present in the field is a stride towards a more rational policy and the new low volume/small droplet system of application has been adopted very extensively in 1982 as a result of its convenience and efficacy. However, because overall application is almost always made there is the risk of greater damage from wind and some pests because no weeds are left temporarily between the rows. It is better to band spray, leaving weeds for removal later by steerage hoeing, which also controls some 90% of the weed beet in the field.

Growers do not seem adept at responding to the obvious long term threat from weed beet (Table 3) even when it is clearly visible in the field. Nationally, they are ready to respond to advice to spray to control aphids and yellows (Fig. 3) but this advice is, unfortunately, very generalised and not always correct; it is based on small numbers of aphids infesting the crop, their viruliferousness and the extent to which they are likely to spread within the crop is unknown. There is now a risk that growers might overrespond to advice to control powdery mildew because treatment costs only £7/ha and the crop yield response can be £100/ha.

For weed beet, aphid, and powdery mildew control, warning cards are posted when treatment is advised. However, British Sugar do not send out advice saying "do not control: it is not necessary"; postage is expensive and the advice might be wrong. As a result, growers consider in some seasons that British Sugar is dilatory in its advice on these problems. There is the need for British Sugar to install recorded telephone information, giving the current situation, updated weekly at least, as is already the case at some ADAS centres. British Sugar have the advantage over ADAS of concentration on one crop, and very good information available on which to base positive advice.

"Supervised" control, as with these three major problems, is far better than non-supervised control, but there is great scope for further improvement in control by identifying, understanding and quantifying the factors that produce the marked field to field variation in the problems; identifying these factors is one of the main objectives of current research.

In answer to the questions posed at the end of the introduction the grower is certainly taking advice, but sometimes applying treatments excessively. Success in chemical control has greatly decreased labour requirements, but at the expense of some loss in yield; this loss is due both to herbicide phytotoxicity, and to irregularly spaced plant populations as a result of drilling-to-stand. The decreased labour input, in the form of hand and machine hoeing, is one of the causes of the weed beet problem. Satisfactory control of Docking disorder has helped towards establishing yields on very sandy soils, but in the case of soil arthropod pest problems the situation is less clear; control is only fairly satisfactory because no single pesticide will cope with the complex of pests involved (i.e. pests of differing arthropod classes and orders, and hence widely differing biologies). Some growers have therefore reverted to close seed spacing in addition to maximal soil treatment with mixed pesticides.

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Decision making in the practice of Crop Protection

PLANNING CROP PROTECTION PROGRAMMES TO SAFEGUARD YIELD AND QUALITY FOR THE POTATO CROP

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Summary Potatoes are planted, stored and consumed in the vegetative state - the tuber. This feature imposes special crop protection problems, both in safeguarding the health of the growing crop and assessing the suitability of the produce for storage. This paper examines weed, pest and disease problems in the seasonal sequence in which crop protection decisions have to be made. It shows that many of these must be taken (and in some cases applied) before the crop is planted, and that these decisions will also determine or narrow the options for later measures, leaving only decisons as to need and timing to be made at the various stages of the growing crop. It is emphasised that integrated programmes are essential and a cost benefit analysis indicates that the money spent on crop protection is well justified for this high cost and high output crop.

INTRODUCTION

Potatoes are planted, harvested, stored and consumed in the vegetative state - the tuber. In this respect they differ from most major temperate arable crops and this feature imposes special crop protection problems. For example, the opportunity the true seed phase affords in other crops to eliminate various diseases and some pests through non-transmission or by effective chemical treatment, is not available. Most potato diseases are readily transmitted to the new crop via the seed tuber and they continue in the same way to the progeny tubers (seed and ware), with the additional risk of new infection by some diseases from sources outside the crop. Transmission may be through the foliage, eg blight and blackleg, or directly to the tubers via soil infection. In some cases, eg virus diseases, vectors may be involved. Some diseases may be detrimental to the appearance, and thus the marketing of the ware tubers, eg common scab, while others may contribute directly to deterioration of the crop in store, eg soft rotting following field infection with blackleg, although such rotting may occur even where there was little evidence of infection in the growing crop. Certain pests may also be spread by contamination of seed tubers, notably potato cyst nematode.

Thus vigilance in monitoring and safeguarding the health of seed potato crops is essential. For commercial seed this is provided by inspection under the various Classification Schemes, extending at the highest health standard to closely monitored propagation of virus tested stem cuttings derived initially from meristem cultures which eliminate virus infection.

Sound crop protection programmes hinge on good basic husbandry and suitable rotations. Effective planning is crucial since only in the case of a few diseases and pests can full remedial action be taken after the crop is planted, eg potato blight.

Appropriate choice of varieties for each situation is also essential if crop protection measures are to be as effective as possible. These measures must also be properly integrated to ensure that they do not conflict, for example the irrigation regime to control common scab may predispose a susceptible variety to infection with powdery scab.

Some storage diseases can now be contained by chemical treatment of the tubers at or soon after store loading, but where the disease risk to the stored crop is unduly high prompt marketing is often the best course to follow. Efficient store management continues to be the most important crop protection measure.

This paper examines both short and long term aspects of crop protection programmes for the potato crop, indicates where forecasting can be particularly helpful in planning integrated control measures, and attempts a cost benefit analysis of some programmes designed to safeguard both yield and quality.

PLANNING

Planning implies a time scale. It is most logical to discuss a crop protection programme in seasonal sequence, since this is how decisions will have to be made. Later options will often be limited by decisions made much earlier, even before the crop was planted. This approach is preferable to discussing crop protection by scientific specialisation because that approach runs the risk of overlooking interacting influences and effects.

For the purposes of the paper certain assumptions are necessary:

That the standard of husbandry is suitably high
That there are no nutrient deficiency problems
That crops follow a 'normal' planting and harvesting date sequence
That varieties suited to the intended markets are being grown.
However, marketing intentions may have to be changed to mitigate loss should particular conditions develop, eg common scab.

Illustrations will be drawn mainly from maincrop production, but most of the points will apply with equal relevance to the early potato crop, except that storage will not normally be a part of that production system except in the case of seed. Also, any set-back to growth of first early potato crops is particularly serious, since it will delay the attainment of marketable yield and move the crop out of the high market price period which is so essential to profitability.

Crop protection advice can be given on a broad basis for which forecasting of aphid build-up or the occurrence of weather periods favourable for potato blight are particularly helpful, but eventually it becomes a matter of guidance for the individual grower and indeed the individual crop. At the time a crop programme is being planned - or the crop being planted - the weather conditions of the season are unknown; therefore, especially when irrigation is not available, planning should take account of the widest range of circumstances which the crop may encounter, so that remedies to the problems which may arise have at least been considered. The factors which need to be considered can best be set out in a logical tree or decision chart, but since many interact this is difficult within the confines of the printed page, and is not therefore attempted here.

INFORMATION REQUIRED AND DECISIONS TO BE MADE BEFORE THE CROP IS PLANTED

Background information needed for effective crop protection is best considered against the aspects it will influence because this also serves to indicate interactive circumstances. The items which follow are not necessarily listed in order of importance, since this will vary from site to site and year to year.

The field and the soil

Previous rotational history

This gives an indication of possible sources of infection or infestation. Close rotations pose the greatest risks except in the first early situation where potato production may be possible year after year on the same field. Examples are wireworm, leatherjacket, potato cyst nematode and powdery scab. The presence of groundkeeper potato plants poses special risks and may render seed production impossible or inadvisable.

Isolation

This is especially important in safeguarding seed crops from aphid-vectored virus diseases.

Nutrient status and pH

High pH may affect the incidence of common scab (or the occurrence of manganese deficiency).

Soil type

This will affect available water capacity, tilth, the occurrence of clods and thus the ease of harvesting and incidence of mechanical damage. It will also influence the choice of herbicide programmes and will affect the 'normal' planting date and the possible risk of occurrence of conditions such as 'little potato', or development of *Rhizoctonia* as stem canker when emergence is slow. The risk of spraing is greatest on light soils.

Occurrence of stone

The occurrence of stones, especially if flat or angular, will affect the level of mechanical damage at harvesting and thus the risk of tuber diseases in store. A decision must be made on stone separation programmes before planting and these may interact with other practices such as incorporation of nematicides.

Moisture status, availability of irrigation, risk of drought

All these factors may affect crop growth and thus will influence varietal choice to cover risks of common scab, powdery scab, spraing (nematode), slug damage, second growth and cracking.

The potato cyst nematode status

Fields must be sampled at least as early as the previous autumn to determine whether potato cyst nematode is present, and if so which species and pathotype and the level of infestation. This will determine crop potential, the choice of resistant varieties (if species is G. *rostochiensis*) and whether a full nematicide treatment is also needed. In turn the incorporation of nematicides will affect seedbed cultivation programmes and, as indicated above, may interact with the stone separation programme on stony soils.

The environment

Temperature and aspect

The speed at which the field soil warms up in spring will affect speed of emergence and may influence the incidence of certain diseases eg. Rhizoctonia.

Rainfall distribution and weather

This will affect the likelihood of drought, risk of blight particularly in South West England, and in some areas past experience will indicate whether hail insurance is advisable. In some areas late harvesting may be a special risk if rainfall is high in autumn.

Irrigation

This may affect blight fungicide protection protection programmes and make aerial applications preferable to ground spraying.

The risk of aphid build-up

This will decide the need to apply aphicides at planting or later, possibly linked to blight spraying. This is specially important for seed crops and interacts with isolation.

The market

Tuber appearance

If blemishes, such as scab and silver scurf are particularly unacceptable, varietal choice will be influenced.

Seed

Is seed to be taken from the crop? This will influence the selection of the health grade of seed for planting.

Storage

Is treatment of the tubers against storage diseases likely to be required?

The following crop

Herbicide residues

If ploughing is not intended for the following cereal crop, the choice of herbicide for the potato crop may be restricted.

Armed with all this information (and of course market intention and knowledge of storage facilities etc) suitable varieties and the appropriate grade of seed can be chosen. Seed grade is particularly important for seed crops or when seed is to be taken from ware crops. The chemical treatment of seed may be considered advisable and must be specified at the time the seed grower is harvesting his crop, so early decisions need to be taken.

Choice of variety

The following factors, which are not necessarily in order of importance, must be considered. They are listed with brief indications of where they interact.

1.	Herbicide susceptibility/tolerance	
2.	Drought resistance	Linked with irrigation and control of common scab.
3.	Resistance to potato cyst nematode	
4.	Resistance to spraing	Incidence greatest on light soils, in wet conditions or with heavy irrigation.
5.	Resistance to common scab	Problem greatest on dry soils without irrigation and on alkaline soils.
6.	Resistance to powdery scab	Most important on wet soils or under heavy irrigation.
7.	Resistance to virus diseases	This will influence seed source and will affect decision to keep own seed.
8.	Resistance to blight, foliage and tuber	This may be especially important in some areas
9.	Susceptibility to slug damage	The risk is greatest on some silts and other 'heavier' soils, and will influence time of harvesting.
10.	Susceptibility to external damage and bruising	The risk is especially important on stony soils and increases the risk of infection in store.
11.	Susceptibility to storage diseases	Especially important in relation to seed crops of some varieties.

Some factors cannot be counteracted through choice of variety, notably blackleg and Rhizoctonia.

Seed potatoes

Most diseases can be transmitted by seed tubers. In the case of the virus diseases, potato leaf roll, potato virus X, potato virus Y and some other conditions the risk of infection is greatly reduced by the use of classified seed stocks which come from crops in which infection cannot exceed the statutory tolerance and in which freedom from potato cyst nematode is required. Although the occurrence of infection with blackleg is a factor in the classification schemes it is unfortunate that its non-occurrence in the seed crop cannot absolutely guarantee that it will not be present to some degree as a surface contaminant of seed tubers. The classification schemes provide for tuber inspection after harvest at the time of despatch to the purchaser. This reduces but will not eliminate the risk of skin spot, gangrene, silver scurf, and dry rot particularly in varieties susceptible to one or other of these conditions. The best defence against latent diseases in seed potato tubers is to sprout them under controlled conditions and thereby reduce the risk of eye or sprout death. If seed is not to be sprouted it is wise to have it treated with 2-amino butane or thiabendazole. The cost of treatment is fairly small, £3-£7 per tonne, and is likely to reduce the chance of problems arising between the seed supplier, and the ware grower. For some varieties, eg Ulster Sceptre, it is an essential precaution to control gangrene. The risk of infection with most latent tuber diseases is reduced by earlier harvesting of the seed crop.

Unfortunately, seed treatment against Rhizoctonia (stem canker/black scurf) does not yet give wholly reliable yield benefit despite good control of visual symptoms. This alone may be worth achieving in crops intended for seed in which confusion of symptoms of stem canker infection with those of virus infection can inhibit field inspection and classification. Unfortunately no chemical treatment is yet available for the control of blackleg. While seed is in store or being sprouted, the only crop protection measure required is routine fumigation with an aphicide to ensure that aphids do not colonise the sprouts since in this way virus diseases can be transmitted.

Seed tubers are rarely cut in the UK (except for Ulster Prince in Lancashire) but if this is done the application of fungicidal dusts at the time of cutting is recommended. However, this does control bacterial infections.

Potato cyst nematode

Fields should be sampled to detect the presence of potato cyst nematode (PCN) at least as early as the autumn before the potato crop is to be grown. For seed crops this is a statutory requirement and the presence of any nematode cysts or eggs will preclude seed production and may result in land being scheduled. Where PCN is present the control measures taken for maincrop will be influenced by three considerations.

1. The species present, whether Globodera rostochiensis or G. pallida.

2. The pathotype present.

3. The level of infestation. Low levels of G. rostochiensis may be countered by growing a resistant variety (eg Pentland Javelin, Maris Piper or Cara), but high levels of infestation will require the application of a nematicide and this may also be advisable for some resistant varieties whose growth can be weakened by larval invasion. So far there are no commercial varieties fully resistant to G. pallida (one is partially resistant), thus the use of nematicides (or nematostats) is essential, and this applies also to fields infested with mixed populations.

The PCN control programme must be viewed both in short and long term - short term to ensure the success of the current crop, and long term to control nematode build-up which will influence cost and efficiency of control measures in later cropping cycles. Over much of East Anglian Fenland the widespread growing of Maris Piper has reduced G. rostochiensis levels to the point where a crop of a susceptible variety could be grown, but the PCN build up in one crop year could then negate all that had been gained. When mixed populations of the nematodes occur, growing a variety resistant to G. rostochiensis may lead to a build up of G. pallida. The decisions on a PCN programme should always be made in consultation with an advisory nematologist.

Apart from these measures the only palliative steps that can be taken if PCN infestation is detected after planting a crop, is to ensure that it receives a satisfactory water supply and some additional nitrogen to keep it growing on a damaged root system. Seed must not be taken from such crops and traffic between infested and clean fields should be avoided. The control of groundkeepers and potato seedlings is also important to prevent nematode build up between potato crops.

The use of nematicides may also be justified in some cases to control the free living nematodes which transmit the tobacco rattle virus which causes spraing. The primary measure must, however, be to avoid the cultivation of susceptible varieties in this situation.

Pre-planting treatment against aphids/virus infection

When granular nematicides (insecticides) are applied to control PCN the crop will also be protected from aphid attack for some weeks. Many growers now like to ensure protection from early aphid migration into potato crops by application of insecticides into the seed furrow. This is generally effective although in some areas resistance to organo phosphorus and carbamate insecticides may lead to control problems. If aphids are observed to survive on treated crops specialist advice should be sought.

The foregoing shows that before the crop is planted many crop protection decisions must have been made and the options for later measures are either wholly determined or narrowed leaving only decisions as to need and timing to be made at the various stages of the growing crop.

DECISIONS AFTER PLANTING AND CROP EMERGENCE

Herbicides

The herbicide programme should have been planned and, if pre-emergence, correctly carried out. At-emergence desiccant treatments must be carefully carried out because if they are too late they can lead to serious breaking of potato stems at the point of regrowth. For some varieties, though not on early crops, metribuzin can be applied post emergence, but on others there is some risk of crop yellowing and foliage distortion.

Currently new chemicals are becoming available especially for grass weed control, which can help considerably to overcome this problem after full crop emergence.

Control of aphids

Aphids entering seed crops early in the season can be important in spreading virus diseases. This risk is best safeguarded against by application of granular aphicides at planting. Later, as aphid numbers increase, direct damage to the foliage may be caused if large numbers are present, and control is advisable. The cost is modest and generally an appropriate aphicide can be added to routine blight sprays. Forecasts are helpful but should not be a substitute for regular crop inspection.

Potato blight

Late blight infection is still the greatest potential threat to the UK potato crop. Blight forecasting has for many years been a service provided by MAFF and the Meteorological Office to guide farmers on the need to begin protective spraying. It is obviously inadvisable to grow susceptible varieties in predictably high risk situations but when this is done, or a high risk subsequently develops, these varieties must be the first to be protected. The development of systemic blight fungicides was a significant advance since they allow protection of new foliage as well as old; the occurrence, so far restricted, of strains of Phythophotora resistant to metalaxyl has led to modification of recommendations, limiting these to three applications of the material followed by a return to conventional protective sprays. The systemic fungicides are particularly helpful in irrigated crops in which the integration of irrigation cycles with the application of blight protectant fungicides has to be carefully planned and controlled. In this the wider availability of aerial contracting services is helpful especially if wet weather follows irrigation, when ground conditions can make entry by ground spraying equipment difficult or impossible. The important decision is to begin blight control programmes early enough, especially on susceptible varieties such as King Edward or Bintje, and to have effective contract arrangements with an aerial spraying company if appropriate. Later applications of fungicides should be with tin-based compounds to limit the risk of tuber infection.

The other important decision in relation to blight comes when the level of infection reaches the point at which control is breaking down. The farmer must then burn off the crop, preferably with acid, to limit the risk of spread of infection to the tubers especially in susceptible varieties such as Pentland Dell. If mechanical haulm destruction is used foliage regrowth must be sprayed off to prevent later development of blight.

Irrigation and control of common scab

By keeping the soil moist during the early stages of tuber growth, the development of common scab can be largely prevented. The 'little and often' practice of watering must start in June, generally before the crop requires irrigation to maintain vigorous growth. This programme can however lead to conditions favourable for the development of powdery scab so a decision must be taken, as indicated earlier, to avoid varieties susceptible to this disease and, so far as possible, to ensure that the seed used is free from infection.

Irrigation and control of spraing

Excessive irrigation especially in localised areas adjacent to sprinkler heads or rainguns can lead to the occurrence of spraing, which, even on a patchy distribution can render a crop almost unmarketable.

Second growth

Irrigation can also help to limit the occurrence of second growth and will also improve the general dry matter distribution in tubers and within the crop and it has not been shown that irrigated crops store less well than non-irrigated ones.

Slugs

Generally slugs do not occur in significant numbers on soils where irrigation will be required or practised, but on some soils, especially certain silts they can cause serious damage and loss of marketable yield, especially in the susceptible varieties Cara and Maris Piper. These should, of course, be avoided where risk is high, but treatment with methiocarb during July and August at periods of slug activity as detected by test baiting, will mitigate the problem. Treatment later will be largely ineffective.

Cutworms

Outbreaks of cutworm attack are fortunately fairly infrequent, being associated mainly with hot, dry summers which favour the survival of the larvae of the moths which are the cause of the problem. Forecasting can help, but treatment (with DDT) is only effective if carried out very promptly. This means almost as soon as the risk is detected, and the best advice is to heed carefully both weather conditions and entomology forecasts.

DECISIONS TO BE MADE AS HARVEST APPROACHES

Haulm destruction

Haulm destruction may have been carried out earlier as an aid to controlling a blight epidemic, but more usually it is done to assist the control of tuber size and to advance tuber maturity and skinset, thereby enabling earlier harvesting. This has the benefit of reducing the risk of mechanical damage (which is greatest when soil conditions become cold) and will also limit the extent of slug damage.

The reduction in mechanical damage is particularly important to contain the risk of infection with gangrene in store, but this risk is increased if the interval between burning off the haulm and harvesting the crop is excessive.

DECISIONS DURING THE HARVESTING AND STORAGE PHASES

The field crop protection programme should have provided potatoes which are suitable either for immediate marketing - as in the case of early crops and some maincrops - or for storage, which will apply to most maincrops and all potatoes grown for seed. Continued protection during the storage period is essential, and in the main depends on efficient store management. This is not the place to describe store management in any detail, but some important points in relation to crop protection must be stressed.

1. Only potatoes suitable for storage should be stored. Prompt marketing is the best course to follow for crops with a high risk of deteriorating in store, such as those with many blight-infected tubers; or those harvested under very wet conditions with high incidence of mechanical damage when the risk of bacterial soft rotting may be unacceptable. Unfortunately there is as yet no effective chemical protection against soft rotting despite the advertisement of some products for this purpose. Potatoes which have been rained on must <u>never</u> be stored.

2. Mechanical damage, which causes direct loss of marketable tubers, is also a major pre-disposing cause of infection and development of tuber storage diseases, especially gangrene. It should therefore be kept to the minimum by careful harvesting and handling.

3. Store management must take account of the condition of the crop when it is being loaded into store and be varied accordingly. A curing period is normally essential.

4. An effective ventilation system is essential to allow store temperature to be maintained near the optimum. Risk of deterioration will be greatest in stores maintained at relatively high temperatures to suit particular market requirements eg. the 10°C regime, commonly used for storing potatoes intended for crisping.

5. For long term storage - into May, June or July - fully controlled environment stores provide the only certain way of maintaining tuber condition.

In summary, careful handling, minimum damage, avoidance of wet loads, correct curing and appropriate temperature and ventilation regimes will reduce the risk of deterioration.

Chemicals can aid this programme, but they are no substitute for it. As for the seed crop, thiabendazole and various products containing it are most easily applied. In approved stores, 2-amino butane can be used, but only after curing has taken place. The decision to use chemical treatment will be affected by the state of the crop, the level of mechanical damage inflicted and the length of the intended period of storage. When potatoes are to be sold in pre-packs late in the season, the occurrence of silver scurf will be detrimental, thus use of thiabendazole to control this condition can be particularly important for such marketing. However, the decision has to be made at store loading since later treatment is not very practical unless a crop is being split-graded to remove seed from ware.

This disease control programme must also be compatible with the sprout suppressant programme and, with some products, both can be carried out concurrently. TCNB is active in controlling dry rot but the other sprout suppressant products do not have fungicidal action. However, by limiting sprout growth they prevent the occurrence of conditions which are likely to induce generalised rotting of tubers.

ECONOMICS

The potato crop again differs from most arable crops in that the cost of growing is much higher than, say, for cereals, and in the value of its output. Taking fairly intensive farming in which crop protection features most strongly, and comparing winter wheat in high output systems with potatoes:

At 20% dry matter a 40 tonne potato crop yields 8 tonnes of dry matter per hectare.

At 85% dry matter an 8 tonne wheat crop yields 7 tonnes of dry matter per hectare.

The value of the potato crop at say £70/tonne (it is higher in 1982) is £2,800/hectare compared with wheat at £109/tonne giving £870 output. It costs around £1600 per hectare to grow potatoes, some £300 per hectare to grow winter wheat. Crop protection costs for high output wheat systems are up to £155 per hectare, the figure for maincrop potatoes being very similar. This seems a reasonable insurance to pay for a much higher value crop in which the risks of outright calamities are perhaps rather higher than in cereals.

When potatoes require a full nematicide programme against potato cyst nematode the cost of the crop protection goes up by a further £195/hectare, but as it will be impossible to grow the crop satisfactorily without such treatment, the overall benefit to the farm economy and rotation must be decided on this basis.

For other disease and pest conditions it is less easy to provide direct cost/benefit relationships. A full blight programme now costs about £90/hectare assuming 3 systemic and 3 non-systemic applications. There are no very recent figures for direct yield benefit, but Holmes and Storey (1962), present data for the early years of dithiocarbamate fungicides (1958-61) showing yield benefits in blight years from 5.7 - 7.0 tonnes/hectare. The risk attendant on tubers infected with blight being put into store is also much reduced.

The cost of insecticide programmes involving granules and sprays is quite modest, ranging up to £34/hectare for a full programme for a seed crop, with a potential gain through preventing classification at FS grades ' slipping' to AA1 grade, a price differential of at least £40/tonne at a seed yield of 20-25 tonnes/hectare. A comparable differential would apply between AA and CC grade. In ware crops direct benefits are less easy to quantify, but with the cost equivalent to less than ½ tonne of ware produce/hectare the insurance against severe aphid attack is wholly justified. Moreover the decision to apply sprays can await the build-up of infection, unlike a seed crop where it must be anticipated.

Financial evaluation of irrigation for the control of common scab is a more complicated calculation. If irrigation is available in any case, then its use for scab control can be wholly justified but it would be more difficult to justify solely on this basis. When available it greatly improves the management of the crop as a whole and is also likely to ensure more satisfactory marketing.

The treatment of seed potatoes with fungicides involves only a modest cost of £3-£7 per tonne when carried out at store loading or subsequent handling on the seed growing farm, and can nearly always be justified especially for varieties susceptible to gangrene. For protection of ware crops in store it would generally be unnecessary for crops to be sold before the end of the year, but thereafter it can be a valuable aid at the modest cost of £2-£4 per tonne especially for potatoes to be sold in quality markets.

CONCLUSIONS

Crop protection for the potato crop is about 80% planning and 20% decision making after the crop has been planted. It will often be difficult to overcome problems arising during the growing season or storage period if planning has been in any way inadequate.

References

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Decision Making in the Practice of Crop Protection

DECISION-BASED MANAGEMENT OF ORCHARD PATHOGENS AND PESTS IN THE UNITED KINGDOM

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Summary Economic and biological factors that influence growers' attitudes to pests and pathogens are considered in relation to 'management' of orchard protection. In contrast to scheduled spray programmes, modern strategies are decision orientated: current and forecast information determines the tactical use of pesticides. Monitoring, data interpretation and the use of decision rules are discussed. The nature and implementation of supervised and integrated control strategies in the U.K. are described.

INTRODUCTION - APPLE GROWING IN THE UNITED KINGDOM

This paper deals mainly with dessert and culinary apples, with minor reference to other orchard crops. This bias reflects the degree to which the management of apple pests and to a lesser extent pathogens, has been researched and developed in the United Kingdom (Cranham, 1978; Way, 1978; Easterbrook et al., 1979; Anon., 1981; Cranham and Solomon, 1981), mainland Europe (Gruys and Mandersloot, 1977; IOBC/WPRS, 1975; Steiner et al., 1979; Wildbolz, 1979; Baggiolini et al., 1980; Gruys, 1980a; Mathys, 1981; Gruys, 1982) and in the U.S.A. (Croft, 1975; Croft et al., 1976; Hoyt and Gilpatrick, 1976; Asquith and Hull, 1979; Jones and Croft, 1981; Seem and Jones, 1981). Another reason for this content is the prominence of apples in the U.K. orchard industry (Tables 1, 2).

Table 1

Cropped area of orchard fruits ('000 ha) in the United Kingdom

Crop	1971	1973	1975	1977	1979	1981
Dessert apples	23	22	21	20	19	17
Culinary apples	14	13	12	12	12	11
Cider apples	6	6	6	5	5	5
Pears	5	5	5	5	5	4
Plums	7	6	6	5	5	4
Cherries	3	3	2	2	1	1

Anon. 1982a

Table 2

Gross production ('000 tonnes) in crop years in the United Kingdom

Crop	71/72	73/74	75/76	77/78	79/80	81/82
Dessert apples	284	257	229	133	198	153
Culinary apples	153	169	128	132	136	81
Cider apples	40	22	34	22	24	36
Pears	64	43	26	36	60	40
Plums	34	48	16	34	35	10
Cherries	9	7	5	2	5	3

Anon. 1982a

In England, the greatest concentration of orchards is in the south east where in Kent, dessert (8,200 ha) and culinary (5,100 ha) apples are grown. In the east substantial areas are grown in Essex (2,000 ha), Suffolk (2,000 ha), Norfolk (1,600 ha) and Cambridgeshire (1,300 ha), with a large proportion of culinary apples in the last two counties. In the west midlands, cider and dessert apples are important in Hereford and Worcester (4,300 ha) and in the south west cider and some dessert apples are grown in Somerset (1,200 ha). In Northern Ireland, culinary apples (2,400 ha) are grown.

These areas differ in climate (Table 3); in spring, the main differences are

Table 3

Climatic data (1941-70) for ten apple areas in the United Kingdom, spring and summer

Average mean air temperature ($^{\circ}$C)	Average total rainfall (mm)		
a) MARCH-MAY	<150	150-200	>200
⩾8.7	NK**, E*	So**	
⩾8.5 <8.7	MK**, S*, N*, C*, W		
<8.5		H	NI
b) JUNE-AUGUST	<175	175-200	>200
⩾16.0	NK**, E**		
⩾15.5 <16.0	MK**, S*, N*, C*, W		
⩾15.0 <15.5		So*, H	
<15.0			NI

Average daily sunshine (h): March-May: ** ⩾5.4, *⩾5.1 <5.4, rest <5.1.
June-August: **⩾ 6.5, * ⩾6.0 <6.5, rest <6.0.

Area code: NK = North Kent, MK = Mid-Kent, E = Essex, S = Suffolk, N = Norfolk, C = Cambridgeshire, W = Worcestershire, H = Herefordshire, So = Somerset, NI = Northern Ireland.

(Data from Smith, 1976; Anon., 1982b).

in rainfall whereas in summer the temperature differences predominate. Somerset is notable for combining warmth and wetness in early spring. Worcestershire, although classed with the eastern and south-eastern areas as 'dry' is the wettest area in this group in both seasons. In the 'dry' group, north Kent and Essex are the warmest areas in both seasons and, with mid-Kent, receive the most hours of sunshine in summer. The climatic differences influence the occurrence of certain pests and diseases. The wetter areas of the west and south-west favour, for example, outbreaks of scab (Venturia inaequalis) and canker (Nectria galligena) but reduce the intensity of powdery mildew (Podosphaera leucotricha). These distribution patterns are, of course, considerably modified by weather. When, as in recent years, the east and south-east experience relatively wet weather in spring and summer, serious outbreaks of scab and canker occur and mildew is easier to control in these regions.

A weak feature of the industry is the extent of relatively old orchards of both dessert and culinary apples (Table 4). For Cox and Bramley, the most widely

Table 4

Approximate areas (ha) of main apple cultivars in age classes (England and Wales)

Cultivar	Age of orchard (years) <10	10-24	>24
Dessert apples			
Worcester Pearmain	139	599	1,189
Laxton's Superb	75	187	494
Laxton's Fortune	35	118	122
Cox	3,546	3,892	3,142
Tydeman's Early Worcester	68	376	193
Egremont	178	282	58
Lord Lambourne	25	163	111
George Cave	54	151	19
Golden Delicious	642	49	6
Discovery	538	227	83
Crispin	302	121	22
Spartan	287	68	48
Idared	177	36	21
James Grieve	75	50	63
Culinary apples			
Bramley's Seedling	1,709	1,596	3,705
mid-late season cvs	143	217	581
early season cvs	230	303	251

Orchard Fruit Census 1977, MAFF.

grown cultivars, 30 and 53% of their respective areas in 1977 consisted of trees at least 25 years old. This unsatisfactory age structure contributes to the problem of producing good-quality fruit at a time when the industry is facing increased competition from growers in Europe and other regions; in 1980, for example, home-grown apples satisfied only 47% of the U.K. market compared with an average of 62% in the years 1970-72, before the U.K. joined the European Economic Community.

A typical small apple farm (e.g. 10-20 ha) is managed by the owner who may grow few other crops. Larger fruit farms (e.g. 100-300 ha) may grow a range of orchard crops, soft fruits, hops, cereals and vegetables and engage one or more managers. The regular labour force averages one person to each 12-16 ha. Some farming businesses have a broader base with arable and livestock enterprises alongside fruit (Scott, 1979). The objective of most growers is to maximise the production of top-quality fruit (Banwell, 1981) although some adopt a low-input 'ranching' policy and accept less than the attainable yield and quality. Quality determines price and the crop is graded into classes of defined fruit-size and appearance, the latter taking into account blemishes, colour, russet, and shapes atypical of the cultivar (Anon. 1973). Many growers take advantage of marketing expertise through membership of co-operatives or similar growers' associations.

The structure of an orchard varies with the choice of clonal rootstock, clonal scion cultivars, planting pattern and disposition of pollinators. Plants in modern orchards are often on dwarfing or semi-dwarfing rootstocks and are, therefore, smaller and closer spaced than formerly and sometimes arranged in hedgerows. Intercropping with other crops is rare. Costs of orchard establishment and of crop production are high (Table 5).

FACTORS INFLUENCING GROWERS' ATTITUDES TO ORCHARD PROTECTION

Orchardists have a reputation for using large amounts of pesticides, particularly for the control of pathogens. Insecticides, acaricides and fungicides are often applied in accordance with a complex scheduled programme, pre-planned by the grower, adviser or agrochemical salesman before the growing season begins. Treatments in a scheduled programme are timed according to phenological host stages, calendar dates or pre-set regular intervals, with few or no tactical decisions based on current or forecast pest and pathogen levels. What reasons are there for a strategy that is often criticised as being environmentally and socially irresponsible and scientifically naive?

Consider the following background against which orchard protection must be examined:

1. A large capital investment is at risk, as is evident from the cost of orchard establishment over the first 3 years (Table 5).

Table 5

A 1982 guide to orchard establishment and production costs for cultivar Cox planted in two systems

Planting pattern ...		Rectangular	Hedgerow
Rootstock ...		MM.106	M.9
Spacing (m) ...		6 x 4	4.5 x 2
Trees per hectare ...		417	1,111
		£/ha	£/ha
ESTABLISHMENT (years 1-3)			
Write off over 20 years		4,822	7,987
PRODUCTION YEAR			
1) Growing			
labour (e.g. pruning, mowing)	248		
nutrients	46		
sundries	73		
protection (chemicals and labour*)			
- pathogens	285		
- pests	81		
- weeds	64		
Total growing costs	797		
2) Harvesting			
25 tonnes	925		
3) Marketing	2,800		
Total production costs (less overheads)	4,522		

Steer (1982).

* Allows 14 foliar spray rounds at 75 min/ha/round, 10 charged to pathogens and 4 to pests.

2. The consumer demands a high quality and today's growers are especially mindful of crop quality in their consideration of protection measures (Banwell, 1981). The requirement for high quality in the fresh-fruit market inevitably lowers the level of acceptable damage so that low levels of certain pests and pathogens become important (Southwood and Norton, 1973; Southwood, 1979), though less so to the producer of apples for processing - an important distinction in setting tolerance levels (Thompson, 1980).

3. The apple agro-ecosystem supports a large number of pathogens and pests, many attacking regularly (Tables 6, 7). Some features are noteworthy:

a) Many commercial cultivars, including Cox, are susceptible to pests and pathogens. Of the newer scion cultivars (Table 4), Spartan

Table 6

Some diseases of apple in the United Kingdom

Disease	Pattern of distribution most years*	Intervention most years?	Number of fungicide treatments in typical scheduled programme**
powdery mildew (*Podosphaera leucotricha*)	W(R)	Yes	10-18
apple scab (*Venturia inaequalis*)	W(R)	Yes	5-10
canker (*Nectria galligena*)	W(R)	Yes	0-3
brown rot (*Sclerotinia fructigena*)	W(L)	No	0
collar rot (*Phytophthora cactorum*, *P. syringae*)	W(L)	No	0-1
crown rot (*Phytophthora cactorum*)	W(L)	No	0-1
Gloeosporium fruit rot (*G. perennans*, *G. album*)	W	Yes	0-3+
storage rots (*Nectria*, *Sclerotinia*, *Botrytis*, *Penicillium*)	W	Yes	0-1+
Phytophthora fruit rot (*P. syringae*)	R	No	0-1+
fireblight (*Erwinia amylovora*)	R(L)	No	0
blossom wilt (*Sclerotinia laxa*)	L	Yes	0-2
sooty blotch (*Gloeodes pomigena*)	L	No	0

* L (local) - often limited to scattered individual orchards/farms; R (regional) - large differences between fruit-growing areas; W (widespread) - common overall; W(R) - widespread, but tendency for differences between areas; W(L) - widespread, but local outbreaks; R(L) - regional, but local outbreaks.

** Many treatments are combined: on average 16 (range 12-24) fungicide applications in 1981 on dessert and culinary cultivars in the mid-Kent area (Hamer, 1982).

\+ Allows for post-harvest dipping/drenching of fruit before storage.

Table 7

Some pests of apple in the United Kingdom

Pest	Pattern of distribution most years*	Intervention most years?	Number of pesticide treatments in typical scheduled programme**
rosy-apple aphid (*Dysaphis plantaginea*)	W(L)	Yes	0-1
apple-grass aphid (*Rhopalosiphum insertum*)	W	No	0-1
woolly aphid (*Eriosoma lanigerum*)	W(L)	No	0-1
winter moth (*Operophtera brumata*)	W	Yes	0-1
codling moth (*Cydia pomonella*)	W	Yes	0-2
fruit tree tortrix (*Archips podana*)	W	Yes	0-2
fruit tree red spider mite (*Panonychus ulmi*)	W	Yes	0-1
apple rust mite (*Aculus schlechtendali*)	W	No?	0-1
common green capsid (*Lygocoris pabulinus*)	W(L)	No	0-1
apple blossom weevil (*Anthonomus pomorum*)	W(L)	No	0-1
apple sawfly (*Hoplocampa testudinea*)	W(R)	No	0-1
apple sucker (*Psylla mali*)	W	No	0-1
earwig (*Forficula auricularia*)	W(L)	No	0-1
summer fruit tortrix (*Adoxophyes orana*)	R	Yes	0-2
clouded drab moth (*Orthosia incerta*)	W(L)	Yes	0-1
apple leaf midge (*Dasineura mali*)	L	No	0-1

* L (local) - often limited to scattered individual orchards/farms; R (regional) - large differences between fruit-growing areas; W (widespread) - common overall; W(R) - widespread, but tendency for differences between areas; W(L) - widespread, but local outbreaks.

** Many treatments are combined: on average 4.5 (range 1-9) pesticide applications in 1981 on dessert and culinary cultivars in the mid-Kent area (Hamer, 1982).

is particularly susceptible to canker and Crispin is very susceptible to scab and powdery mildew. The popular rootstock MM.106 is susceptible to crown rot (Phytophthora cactorum).

b) Diseases such as canker and collar rot (Phytophthora spp.) can cripple or kill trees and jeopardise the long-term productivity of an orchard.

c) Some pests and pathogens, such as codling moth (Cydia pomonella) and scab, attack fruits directly and so reduce quality even when present at a low number.

d) Mildew debilitates trees and has the potential in many areas to be severe every year; experience has shown the need for numerous fungicide treatments. The intensive mildew programme is a convenient 'vehicle' for adding 'insurance' treatments against other diseases and pests - just in case!

e) Some pathogens, such as Gloeosporium perennans and Sclerotinia fructigena cause rots of stored fruit.

f) Many pests and pathogens overwinter in orchards so that high levels in autumn are liable to cause outbreaks the following season.

Given these economic and biological factors and the availability of a wide range of pesticides, the strategy of the scheduled programme - minimum crop loss through maximum control - is pragmatic. Nor should it be assumed that scheduled programmes are irrationally planned. For example, the intensive, regular use of mildew fungicides recognises the ability of the pathogen to infect almost daily and its potential to multiply rapidly. Also, fungicides, which constitute the greater part of the schedule (see Tables 6 and 7), are nowadays varied through the vegetative season to match their physical mode of action with control needs and to minimise risks of spray damage. Examples of rationally-planned but scheduled fungicide programmes are given by Burchill and Butt (1975) and Butt and Burchill (1976).

Banwell (1981) considers that the days of the scheduled programme in apple orchards are gone. Certainly, a shift towards decision-based strategies is being encouraged by shrinking profit margins and savings are sought, therefore, in the 46% of growing costs spent on pests and pathogens (Table 5). In a recent survey of 164 English fruit growers, 62% replied 'yes' to the question, "do you prefer to time sprays in relation to weather and other factors affecting diseases and pests in order to be more cost-effective?". Furthermore, growers have witnessed the loss of successive acaricides to resistant strains of fruit tree red spider mite (Cranham, 1971), and are aware of the long-term importance of judicious pesticide usage. The fruit industry is now, therefore, receptive to the concepts of pest and pathogen management.

THE NATURE OF MANAGEMENT IN ORCHARD PROTECTION

What is 'management' of pests and pathogens? Zadoks and Schein (1979) define disease management as the total of all actions that serve to regulate disease levels so that they remain below the action threshold. We prefer to list features which can be identified as management:

1. Decision making considers both the short- and long-term health of the crop and is a continuing process.

2. Strategic decisions embrace the management of crop protection resources as well as the management of pests and pathogens.

3. Decisions have an economic basis.

4. Tactical decisions are based on the principle of tolerating pests and pathogens below certain thresholds.

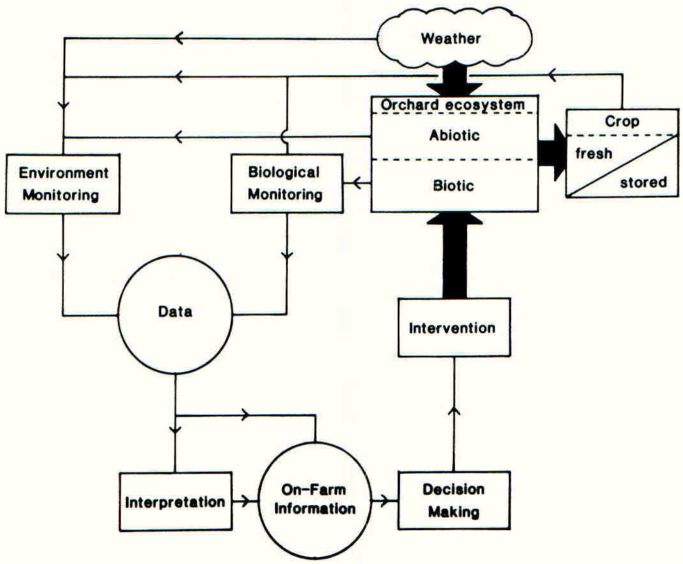
5. Tactical decisions are made in the knowledge of current or forecast pest and pathogen levels.

The more these features are evident in the practice of crop protection, the more rational the decisions become in economic, ecological, social and scientific terms, and the more logical the approach to an optimal solution. It is evident from this list that decision making is as important a function of the manager in this as in other areas of responsibility.

A scheme showing the processes leading to rational decisions and tactics is shown in Fig. 1. In this idealised scheme, which forms the basis of the following Sections of this paper, provision is made for the monitoring of weather and of the abiotic environments of the orchard and harvested crop. Biological monitoring of the orchard and the harvested fruit produces data on the stage, quantity or rate of tree growth and the levels and states of pests and pathogens or of injuries and diseases. All data, some after interpretation, provide information with which the manager makes decisions - sometimes with the aid of formalised decision rules, and may lead to tactical interventions by the manager. Fig. 1 is a closed-loop system since provision is made for the continuation of monitoring after every intervention. Tummala (1976) pointed out that a special merit of such a feedback of information from the agro-ecosystem to the manager is the opportunity given for later corrections to be applied. Tummala and Haynes (1979) stressed that this facility to 'control' the system can compensate for imprecise monitoring, interpretation and decision-making: this only applies, however, if damage can be avoided by subsequent action: for organisms which cause direct crop damage in the first attack of the season (e.g. codling moth, scab), there may be little opportunity to alter the effects of an initial decision.

Fig. 1

A conceptual scheme of the processes leading to rational crop protection decisions



DECISION MAKING PROCESSES

Data collection on farms

a) The monitored unit

Experience gained principally in orchards in Michigan within the framework of a centralised pest management system led Welch and Croft (1979) to define a monitoring unit as one or more decision-making units with a geographical identity and an assumed agro-ecosystem homogeneity. They define a decision-making unit as a production unit plus a decision maker. Data collected by 'scouts' sampling at the monitoring level were assumed to apply to all decision-making units in the monitored unit.

In the United Kingdom there has been no development of a public-sector, centralised, pest management system. Therefore, data collection is the responsibility of the grower. How does this affect the choice of monitoring unit? The typical fruit farm is divided into orchards often subdivided into blocks (sections) varying in area from perhaps 1-6 ha, each block being characterised by the size and spacing of trees and the choice and pattern of cultivars. The block is the production unit, with inputs geared to its structure. This specificity in allocating resources to blocks is apparent in crop protection measures and can include choice of spray volume in relation to tree size, and choice of fungicide in relation to the phytotoxic sensitivity of certain cultivars, such as the sensitivity of Bramley to captan.

The block, with its spatial, physical, phenological and genetic homogeneity is the natural monitoring unit. The extent to which estimates of pests, pathogens and diseases in one block are representative of their states in other blocks on the farm or in the district probably varies with the species of pest or the disease. With mildew, considerable differences occur between neighbouring blocks on a farm so that monitoring at the block level is important (Butt, 1977; Butt and Barlow, 1979). With codling moth, Cranham (1980) reported a variation between orchards in a district of up to 4 weeks in the date when pheromone trap catches first exceeded a threshold; Trottier (1980) warned that in Canada differences in pest development between orchards in a district can make the difference between success and failure of a management programme.

b) Biological monitoring

Most growers 'walk' their orchards - a useful surveillance - but there has been a need for objective assessment methods that are fast and designed for use on farms. Assessment methods based on incidence rather than intensity (severity) are favoured for their simplicity (Baggiolini, 1980), because only presence or absence is noted, as with the method for monitoring secondary mildew on extension shoots (Butt and Barlow, 1979). Dutch pest assessment methods have been adapted for the United Kingdom (Carden, 1977; Anon., 1981); these involve visual assessments, beating techniques and the use of pheromone traps for codling and certain tortrix moths. The visual and beating records are made on 5-6 occasions each year, the first two being timed by host development stages. Of a total of 28 possible records of 13 pests, half are of incidence and the rest require a count of pest numbers.

c) Environmental monitoring

In recent years instruments have been adapted or designed to record conditions favourable for infection by some orchard pathogens, notably the apple scab fungus: these include chart recorders (Weltzien and Studt, 1974; MacHardy, 1979; Richter, 1980), an electronic instrument (Richter and Häussermann, 1975) and a field-based microcomputer (Jones and Fisher, 1980). On farms in the United Kingdom, however, there is currently, to our knowledge, no monitoring of within-orchard climate for this purpose nor any recommended system for acquiring weather data. A recent survey by the authors of English fruit growers showed that rainfall, temperature, humidity, and surface wetness are recorded, in various fashions, and not for specific crop protection purposes, by 65%, 50%, 4% and 2% respectively.

Interpretation of data

Biological data are often used for decision making without further interpretation, as when assessments of pest and disease levels are compared with action thresholds. (See under Decision Rules.) Alternatively, biological data are, together with abiotic data, used as inputs to "models" which in turn generate information for the decision maker. In some countries, notably the U.S.A., models have played a major role in centralised 'on-line' pest management systems, whereby incoming current biological and environmental data are interpreted by means of complex models operated by a powerful computer (Tummala and Haynes, 1979), and information is communicated back to the decision makers. The models simulate predator-prey systems and population dynamics (Croft, 1981), and there are phenological models that indicate the timing of developmental stages (Welch et al., 1978; Riedl, 1980). In general, however, complex models have not been widely adopted in pest management (Telleen and Hersh, 1981); simpler models, needing less computing power, are needed to support decision making and this has led to interest in the use of microprocessors. In this context an instrument to interpret a few, automatically monitored, weather variables for the coincidence of conditions favourable to apple scab infection has been developed for use on farms (Jones and Fisher, 1980; Jones et al., 1980).

In the United Kingdom there are no complex models in use but a field-based microcomputer, the Crop Disease Environment Monitor (CDEM), has been developed to give warnings of diseases on several crops, including apple scab (Sparks and Wass, in press). The importance of interpreting data at farm level cannot be overstressed when rapid decision making is imperative for effective intervention. The importance of minimal delay is well illustrated in the case of apple scab, for the tactic of using a curative fungicide against fresh infections is only successful when the spray is applied soon after criteria for infection have been satisfied. In this respect, although a computer at the U.K. Meteorological Office Headquarters scans the hourly data recorded at synoptic weather stations, searching for apple scab infection periods as part of a wider disease intelligence role (Adams and Seager, 1977), the service fails to provide useful information for the decision makers. Firstly, warnings are not communicated sufficiently rapidly to growers. Secondly, the resolution of weather data is low, for the network of synoptic stations covers many fruit areas inadequately. These difficulties with respect to scab have been resolved in some countries by using recorded telephone messages in conjunction with a local-area, high-resolution network of monitoring instruments (Boue and Chaffurin, 1980; Jones and Croft, 1981). A fireblight model is being used at East Malling to trigger warnings for field inspections (Billing, 1980a, b).

Decision rules

Most decisions during the growing season concern tactical, short-term actions. The most frequent decisions concern the need for treatment and choice of pesticide.

a) Is Intervention necessary?

Baggiolini (1980) reviewed the use of action thresholds in orchards in western Europe, and action thresholds for pests in U.K. apple orchards have been published (Anon., 1981). The action threshold is, ideally, the lowest level of pest population at which intervention is economically justified; failure to intervene at this economic threshold (sensu Stern et al., 1959; Stern, 1966) may allow the population to exceed the economic injury level (EIL) sensu Stern et al., 1959, the optimal pest level at which the economic benefits of intervention are maximised. Carlson (1971), Headley (1972), Conway et al., 1975, Norgaard (1976), Apple (1977), Main (1977) and Walker (1980) consider these cardinal pest levels and their intrinsic complexity.

Thompson and White (1979) argue that because New York State apple growers who participated in an integrated pest management scheme saved on pesticide costs without detectable reduction in fruit quality or quantity, the action thresholds used by their trained pest management advisers had been set too low. Clearly, the action thresholds did not allow pests to reach the EIL, the economic optimum, and the two were not, therefore, 'coupled'. Reasons given are that advisers, like growers, are conscious of the importance of quality and tend to be risk averse; also, fundamental information on relationships between pest numbers and crop damage - the damage function - is not available and until known it will be impossible to operate an economically optimised decision rule.

An attempt is being made in the U.K. to measure the damage function for apple powdery mildew. A long-term field trial at East Malling has indicated differences between cultivars in their response to low levels of secondary mildew, with Golden Delicious and Jonathan being less sensitive than Cox. On Cox, increasing the mean annual midsummer incidence from 2 to 20% mildewed leaves has reduced vegetative growth, total crop weight and mean fruit size over 8 years (Lovelidge, 1981). Demonstration of damage at these levels is important because many growers considered the 20% level 'commercially acceptable'.

An area of uncertainty in decision making arises when information is limited to environmental data. With apple scab, for example, 'infection' periods are detected by certain coincidences of surface wetness and temperature (Mills and LaPlante, 1951); the user assumes that susceptible host tissue and inoculum are present. These assumptions lead to uncertainty in the operation of the model in a decision-supporting role. In this and other cases the value of biological information must be emphasised - for improving the quantification of warnings and forecasts and for matching tactics to differences between orchards.

b) Which pesticide to use?

It is becoming increasingly difficult for growers to choose chemical treatments, especially fungicides, because of the wide selection available against some target organisms. Factors normally taken into account are cost, risk of phytotoxicity - especially reduced fruit set and increased fruit russet - and the physical mode of fungicide action (e.g. curative, antisporulant) appropriate to the state of the disease (Schwinn and Urech, 1981; Szkolnik, 1981). Also, there is the need to reduce risks of tolerance by avoiding excessive use of related chemicals (Delp, 1981). In this context growers have used great restraint in minimising the use of benzimidazole-type fungicides in orchards in order to 'preserve' them as post-harvest dip treatments to control storage rots. There is, perhaps, scope for developing a form of decision analysis, to assist a grower to select from among pesticides on the basis of evaluating weighted attributes of each against the grower's weighted requirements in terms of cost, formulation, mode of activity, spectrum, phytotoxicity, etc.

Pest management

Carden (1981) estimates that supervised pest control has been introduced on at least 2,500 ha in south-east England. With this strategy, pesticides are applied only when pest levels reach action thresholds, set to limit the incidence of fruit blemishes due to any one pest to c. 1% of the crop and to keep phytophagous mites below the injury level.

Apple orchards are rich in the natural enemies of pests, and integrated control is being tested in the U.K. to make better use of this beneficial fauna. Fruit tree red spider mite has been the commonest apple pest for biological control in several countries and provides the best opportunity for implementing integrated control (Cranham, 1979; Gruys, 1980b). Two approaches are being explored in the U.K. In one, the predatory phytoseiid mite Typhlodromus pyri is preserved by using only selective insecticides, notably diflubenzuron to control larvae of codling moth, winter moth and the fruit tree tortrix (Archips podana), and pirimicarb to control aphids (but not woolly aphid (Eriosoma lanigerum)). This approach to integrated control has led to a small increase in blemished fruits in this country (Easterbrook et al., 1979; Carden, 1981) and in the Netherlands (Gruys, 1980a). An alternative approach takes advantage of indigenous populations of organophosphorus-resistant T. pyri to control mites, whilst many other pests are controlled with OP insecticides and carbaryl (Cranham and Solomon, 1981).

Integrated control requires management activities additional to those needed for supervised control. Firstly, it is necessary to monitor, by visual inspection, the Typhlodromid populations and possibly to measure the predator-prey ratio. Secondly, there is need for greater surveillance, especially where only selective insecticides are used, for upsurges of some lepidopterous pests, mussel scale (Lepidosaphes ulmi), apple sucker and woolly aphid have occurred in trials. The tactical response of researchers to these outbreaks has been to apply a broad-spectrum treatment, followed by an acaricide to restore a favourable Typhlodromus-Panonychus ratio. Finally, fungicides must be limited to those that are non-acaricidal, such as bupirimate and triadimefon (Gruys, 1980b). This imposes a constraint on pathogen management, giving less choice in considerations of cost, phytotoxicity and physical mode of activity.

Pathogen management

Table 8 shows the kind of disease monitoring schedule being developed from experience with a large-scale pathogen management trial in which data collection, interpretation and decision rules are being evolved and tested (Butt et al., 1982; Anon., 1982c). All assessments are of disease incidence on the sample units, and the schedule focuses on stages of host and disease development when information is especially valuable for decision-making. Scab serves to illustrate this point. The presence of wood scab at bud swelling is an early warning that this overwintered source of conidial inoculum will augment the spring discharge of ascospores and will continue as an inoculum source after the ascospore phase ends: vigilance will be necessary, therefore, throughout the vegetative season. Foliar scab is first detectable at pink bud, on the rosette leaves. If colonies are found at pink bud, or at petal-fall, control measures are 'strengthened'. If scab is absent

Table 8

A monitoring schedule used for research in the supervised management of apple pathogens

Stage	Month	Disease	Sample unit
Dormant	Dec-Jan	mildewed terminal buds	1-year shoot (not 'silvered')
Bud swelling	Feb-Mar	wood scab	1-year shoot
Green cluster	April	blossom wilt	flower truss
Pink bud	Apr-May	foliar scab	rosette of leaves
		mildewed blossom	flower truss
Petal-fall*	May	foliar scab	rosette of leaves
Shoot extension	May-Aug	foliar mildew) foliar scab)	'5-leaf' shoot zone**
Fruitlet	June	fruitlet scab	fruitlet cluster
Fruit	June-Oct	fruit scab) brown rot)	fruit cluster
End of shoot extension	Aug-Sept	foliar scab	distal 3 leaves

* Record only if foliar scab not detected at pink bud.

** (See Butt and Barlow, 1979.)

from wood, rosette leaves and fruitlets, subsequent weather-triggered monitoring will be confined to extension shoots. If scab is already present, however, post-fruitlet monitoring will be on extension shoots and fruits, and vigilance will be necessary in wet weather. The final assessment of foliar scab allows intervention with a post-harvest pre-leaf-fall treatment when necessary to prevent formation of the next generation of ascospores.

Simple guidelines for the supervised management of apple mildew based on summer disease ratings were issued in 1979, whereby the intensity of chemical control is based upon the monitored incidence of infectious disease, weather and shoot growth (Butt, 1979). The guidelines are likely to be modified in the light of new information being gathered at East Malling on the damaging effects of mildew on tree growth and crop (see Decision Rules).

Reference was made in the previous section to the restriction imposed by integrated mite management on the range of eligible fungicides.

IMPLEMENTATION

Since 1979 growers have been introduced to decision-based strategies through demonstrations and courses. Tuition in supervised pest management is given by Agricultural Development and Advisory Service (ADAS) entomologists, and in supervised mildew management by East Malling Research Station pathologists - sometimes jointly with the Agricultural Training Board (ATB). This amounts to a slow, incremental implementation of integrated crop protection (Norton, in press). In the case of orchard pests the approach is via supervised pest management and the biological control of fruit tree red spider mite. For pathogens the first stage has been the rational use of mildew fungicides. The instruction of growers concentrates on biological monitoring and the use of the collected information in decision making. This type of implementation is having several benefits. Firstly, many growers are able to assess pests and mildew objectively using standard methods, thereby adding a new dimension to their crop protection decisions. We regard this self-reliance in acquiring data as important because we share with Zadoks and Schein (1979) the belief that an involvement in collecting data is more likely to motivate a grower to adopt optimising strategies and tactics. Secondly, growers are becoming accustomed to judging pest levels in terms of action thresholds (syn. control/treatment threshold; tolerance level; economic threshold sensu Stern et al., 1959). The notion that it can be uneconomic to control pests at levels below the action threshold is influencing the general approach to pest control, even among those not using the supervised pest management strategy (Carden, 1981). Thirdly, in these early stages of implementation there has been no introduction to environmental monitoring, nor to using meteorological models. The restriction to biological monitoring is probably helpful in winning the confidence of growers in decision-making. In this manner a 'platform' of experience is being established. In future, disease monitoring can be made more comprehensive (e.g. Table 8), and systems of environmental monitoring and interpretation added.

Continued implementation and improvement of decision-based management in the U.K. relies upon further research and development. Some topics, many already the subject of study are listed below:

1. Introduce standardised biological monitoring methods that are simple, practical and robust, and designed to assess incidence rather than pest density or disease intensity. For example, visual assessment methods for the supervised control of apple grass aphid, bud moth, sawfly, winter moth, clouded drab and fruit tree red spider mite involve counts (Anon., 1981); these should be reduced to incidence records in the way Bassino (1973) has done for red spider mite.

2. Develop robust and easy-to-maintain instrumentation for monitoring, on farms, weather and other environmental variables, e.g. surface wetness.

3. As necessary, build simple models for predicting overwintering, phenology and population dynamics of pests and pathogens.

4. Implement simple, but reliable, crop protection models on microcomputers stationed at farm and district level, with growers and advisers involved in the design of systems. Where feasible, these devices should function for other farm needs such as frost protection, irrigation and crop forecasting. Table 9 ranks pests and diseases chosen by growers for inclusion in any future environmental-monitoring device programmed to give information in the form of warnings.

5. Derive functions estimating the damage done by important pests and diseases.

6. Improve the basis of control decisions by using action thresholds related to economically optimal pest and disease levels.

Table 9

Leading eight choices of 179 fruit growers and advisers on the apple pests and diseases to be programmed into any future microprocessor-based warning system

Pest/disease	Times mentioned for inclusion in system (%)	Average ranking (1-8)
scab	93	1.6
powdery mildew	84	2.0
codling moth	41	4.6
fruit tree red spider mite	39	4.7
tortrix moths	28	4.9
aphids	18	5.0
canker	12	4.4
Phytophthora	10	5.6

7. Make better use of fungicides by integrating their physical modes of action to the state of disease, thereby to fully utilise curative activity (Schwinn and Urech, 1981) and antisporulant activity (Butt *et al.*, 1981).

8. Integrate fungicide usage with partial resistance of the host cultivar.

9. Find further selective insecticides and techniques needed, for example, for the control of certain tortricid larvae, e.g. *Adoxophyes orana*.

10. Develop ultra-low-volume spraying technologies in order to achieve faster intervention with treatments. Fungicides that inhibit ergosterol biosynthesis have been shown to act curatively against apple scab when applied 72 h after the start of an infection period, but at least 9 h should be discounted to allow for the infection process to take place. This leaves two effective days. The modern mistblower applying 300-500 l/ha sprays only 10-12 ha in two days!

A few growers employ technical advisers and some pay for the 'scouting' services of independent advisers, or advisers attached to co-operatives or agrochemical merchants. It is important that these advisers participate in the development of the new strategies and associated techniques. In this respect a forum for exchanges of views and experiences between advisers, ADAS specialists, leading growers and researchers is provided by the British Working Group on Integrated Control in Fruit Crops, formed in 1973. A special feature of the group is the balanced representation of pathologists and zoologists, an integration of disciplines that augers well for the managed protection of the orchard system.

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Decision Making in the Practice of Crop Protection

DECISION MAKING IN THE CONTROLLED ENVIRONMENT

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Summary The protected crops include salad vegetables, mushrooms and many major and minor ornamental crops. This diversity makes generalisations on crop protection decisions difficult.

Whilst areas of cultivation of the protected crops are small, their unit value is, in general, high which demands exceptional standards of crop protection. This is particularly true of ornamental crops.

To highlight the problems in decision-making in the protected crops, two cases are examined in detail in which the grower or the agricultural research service is faced with a number of options. Some attention is given to how the decisions which are made now may be improved in the future.

Can the grower control disease economically by manipulating the growing environment? Of the many radical changes which have overtaken the glasshouse industry, the tendency for crops to be grown in higher humidities is a retrograde one, as it encourages disease. Recently, the glasshouse industry has begun to equip with computers dedicated to environmental control. The improved monitoring of the physical environment which such systems offer, may provide the grower with information from which spraying may be timed. Alternatively, the computer may be programmed to act on the most economic option to interrupt periods of humidity unfavourable to disease.

A significant option which is available to glasshouse growers is biological control of pests such as whitefly and red spider mite by the introduction of parasites and predators. The decisions involved are complex because the programme must often be integrated with chemical control of these and other pests and the strategy for optimising biological control involves the controversial introduction of the pest into an otherwise uninfested crop.

INTRODUCTION

A wide variety of capital-intensive crops are grown in controlled environments. In the U.K., at least 10 species of vegetables and 20 species of ornamentals are grown in heated glasshouses. To these must be added the mushroom and forced bulb crops. Because of this diversity, and with the attendant diversity of their cultural requirements, I have not attempted to review decision-making for all crops grown in controlled environments. The paper considers some features common to glasshouse crops, with emphasis on tomatoes.

It may appear that crop protection in a controlled environment should be easier because the grower can influence the conditions to which the crop is exposed, whilst the farmer has no such control in field crops. This is true to an extent, but the provision of a favourable environment for crop growth can also provide conditions favourable to pests and pathogens.

Because protected crops are grown in fixed structures, no rotation is possible. Therefore, the risks of the carry-over of pests and diseases to succeeding crops makes hygiene an important aspect of crop protection. The answer to this problem is regular sterilisation of soil by steam or methyl bromide or the use of soil-less methods of cultivation such as disposable peat bolsters or circulating hydroponic systems. Whilst soil sterilisation is costly, it is usually highly effective in combatting a build-up of pest and disease organisms and obviates the need for weed control. Herbicides are used only beneath propagating benches or outside glasshouses where weeds may harbour pests such as whiteflies, but weeds are rarely a problem within glasshouses.

The enclosed nature of glasshouses and other controlled environments allows for alternative methods for the application of pesticide chemicals, such as thermally-generated fogs and smokes, dusts and a variety of LV and ULV spraying equipment. In general, these alternatives to HV or MV applications have been introduced to reduce labour costs rather than to improve the efficacy of the treatment.

I propose to highlight the processes of crop protection decision-making in the protected crops by making two case studies, one the environmental control of disease and the other the biological control of pests. They offer alternatives to chemical control, but are likely to be most effective in integrated programmes in which chemicals are also used. However, decision-making in the two cases is somewhat different.

The environmental control of disease is limited by our knowledge of appropriate methods whereas in the biological control of pests, the methodology is well established but the complexity of the subsequent interactions may be the limiting factor. In these studies, the role of computers, which are increasingly used to control the growing environment in glasshouse cultivation, will be discussed.

HUMIDITY AND DISEASE CONTROL DECISION-MAKING

One of the major problems facing the glasshouse grower in the 1980s is high humidity and the likelihood that it will lead to a greater incidence of foliar diseases. Attention has been focussed on this aspect of disease control for a number of reasons:- (i) because certain modern growing techniques have caused humidities in glasshouses to be higher; (ii) because humidity is difficult to monitor and control; (iii) because our knowledge of the fundamentals of the interaction between humidity and disease in glasshouses is scant.

The control of disease by manipulation of the environment has always been an attractive idea, especially when fuel was cheap. However, it seems unlikely that regulation of air humidity will eliminate a disease from the glasshouse, but it may avoid the need for frequent fungicide applications. Also, it may be the only method of disease control which is possible at times when for other reasons fungicides may not be applied.

Many growers perceive and control humidity in glasshouses using their 'nose' and there must be doubt about the value of human perception as a sensor of humidity. Growers encapsulate their policy on humidity control as the maintenance of a 'buoyant' atmosphere, but there has never been any attempt to define this elusive condition physically or to give it a physiological or pathological basis.

Whilst growers may be able to develop by experience a 'feel' for the optimum growing environment, this approach leaves much room for error. And in an industry where every other parameter of the growing regime is carefully monitored and controlled, there may be great benefit in applying more precision and fundamental knowledge to humidity.

Computers are now used increasingly to monitor and control environmental conditions in commercial glasshouses. Growers with computers are now faced with the option of automatic humidity control but there is little biological information on which to base a programme for control of humidity so that the best use can be made of the computer's power and precision.

Why are humidities higher? Since the 'oil crisis' of 1973, fuel costs have become a greater proportion of the direct costs of producing early-season crops. Thus in 1978, for early tomato production, fuel represented 25% of costs, whilst in 1980 this had risen to 31% and is now £60,000/ha. The market for these 'semi-luxury' crops is limited and will not support the price rises necessary to compensate for the steady increases in fuel costs. In many cases, there is severe competition from imports from northern Europe where fuel prices are kept artificially low by a form of subsidy, or from southern Europe where the only fuel cost may be for transportation.

Glasshouse growers in the UK have therefore been forced to modify their glasshouse structures or techniques of growing to make production more efficient in terms of fuel usage. This is particularly true of growers who specialise in crops which require high temperatures, e.g. cucumber (commonly 19^{o}C at night); or in crops grown 'out-of-season' during winter, when greater heat inputs are required to maintain the day and night minimum temperatures, e.g. early tomato crops with night temperatures maintained between 13 and 16^{o}C; or in crops grown throughout the year, e.g. chrysanthemum (commonly between 13 and 17^{o}C at night).

A number of approaches to fuel saving are possible:-

a) The glass may be replaced with a cladding which has a lower thermal transmittance, e.g. a double-skinned, rigid plastic material. This reduces the rate at which heat is lost.

b) A 'thermal screen' of polythene or reflective plastic may be drawn across the crop at night, above the crop-supporting wires and along the walls. This reduces the volume of air to be heated and, by the addition of a second skin, reduces the rate of heat transfer to the glass.

c) Increasing the air-tightness of the structure prevents cold air from entering the glasshouse. The glass overlaps may therefore be sealed with a transparent sealant and the seating of the glasshouse doors and ventilators improved. The ventilators are only opened as a means of controlling the maximum temperature in the glasshouse.

d) The minimum temperature at which the crop is grown at night may be lowered. This reduces heat loss because the gradient of temperature across the glass becomes less.

All these methods save fuel. But they also increase humidity.

A manifestation of the fuel-saving properties of all forms of 'double-glazing', whether of a fixed cladding (a), or a movable thermal screen (b), is the higher temperature of the internal surfaces in contact with the glasshouse air (Bailey, 1978). The higher the temperature of these surfaces, the less water condenses from the humid air in the glasshouse: if the temperature of the cladding is above the dew point of the glasshouse air, then there will be no condensation. Moreover, purpose-built double-skinned claddings are, by design, well sealed, and thermal screens have been found to be more efficient in saving fuel when they are well sealed at the perimeter and of a material impermeable to water vapour (Bailey and Cotton, 1979). Whilst well-sealed glasshouse structures (c) prevent the unwanted exchange of cold outside air for warm inside air, they also prevent the exchange of humid air for the relatively drier outside air. When night temperatures are lowered as a means of conserving fuel (d), it would seem likely that whilst the absolute humidity in the glasshouse may remain unchanged or even fall slightly, the relative humidity will increase as the water vapour in the atmosphere becomes closer to saturation.

All methods of saving fuel result in less use of the heating system and consequently less convectional movement of the air. This further increases the likelihood of a highly humid microclimate within the crop canopy and of conditions at the plant surface favourable to the development of disease.

Air has a very limited capacity to hold water vapour: thus at 13°C it is saturated with only 11.3 ml/m³, whilst at 16°C the concentration at saturation rises to 13.6 ml/m³. A young cucumber crop evaporates 10-20 ml of water per m² of leaf surface per hour at night and 2 to 3 times this amount by day, when evapotranspiration is powered by solar radiation (Hurd and Sheard, 1981). But the glasshouse air does not necessarily reach saturation, because water is removed elsewhere. The humidity attained is the result of a dynamic equilibrium which depends upon the rate of supply of water from the plants, the rate of air change and the rate of condensation of water on cooler surfaces.

What advice is given to growers on humidity control? Guidelines for environmental regimes in which a number of glasshouse crops could be grown with maximum profitability, were formulated by the agricultural research service in the late 1960s and early 1970s. These 'blueprints' give precise information on the regulation of temperature, but are necessarily vague with respect to the control of humidity: ventilation should be "adequate" to prevent periods of "high" humidity. This contrast between the advice on temperature and that on humidity stems from the very nature of the parameters. Temperature is easily measured, its effect on crop growth and yield is well understood, and it is the prime determinant of fuel costs. In contrast, humidity is measured only with some difficulty or expense, its influence on the physiology and pathology of the crop is poorly understood, and its relationship with the energy requirements of a heated glasshouse is complex.

Current recommendations for the control of a number of foliar diseases of heated protected crops include both cultural and chemical treatments (Anon., 1980a and b, 1981a, b and c). However, there are very few cases where a level of humidity has been specified which growers should attempt to maintain in the glasshouse. Following the work of Winspear *et al.* (1970), it has been recommended that in tomato crops, grey mould (*Botrytis cinerea*) can be controlled by maintaining the r.h. at 75%, whereas disease can be kept at an acceptable level if the r.h. does not rise above 90% (Anon., 1981a). In general, the advice on cultural methods of control attempts to identify periods of high risk of high humidity, e.g. when temperatures are falling at nightfall and when ambient temperatures are high, and recommends growers to maintain as low a humidity as possible by heating and ventilating, simultaneously if necessary. Growers may be very reluctant to follow this advice because it forces them to increase their fuel costs whereas, in every other respect, they are working to conserve fuel.

Mushroom growers also suffer from disease problems associated with high humidity. The bacterial blotch organism (*Pseudomonas tolaasi*) infects the mushroom cap in films of free water which are often caused by the formation of dew in the growing house (Gandy, 1981). Because chemical control has not been successful, cultural control, by maintaining the r.h. at 85% has been suggested by Fletcher and Atkinson (1977). However, this poses a dilemma for the grower because the quality of the mushroom is improved by growing in a high humidity, which is frequently maintained by steam injection.

Growers' decisions on the glasshouse environment. These are likely to be made on horticultural rather than pathological grounds. Thus, high temperature and early seed-sowing promote early fruit production in the tomato crop. An early crop, sown between mid-October and the end of November, must be heated during the period of lowest ambient temperature until fruit picking begins in April. During this period, the grower makes a high investment in fuel and hopes for a good return by reaping the premium prices for an earlier crop. Both sowing date and the temperature regime must be decided by the grower according to his horticultural strategy, which depends upon his ability to fund the high investment in fuel.

If a grower is to use environmental control as a method of prophylactic disease control, he must make the decision at the start of the crop to use more fuel. He is more likely to decide to use the minimum amount of fuel compatible with horticultural requirements, and to apply either a routine programme of fungicide sprays or to resport to chemical control when disease is first apparent.

Comparisons of the relative economics of environmental and chemical disease control and assessments of the losses due to disease in protected crops have rarely, if ever, been made. Therefore, the grower has no knowledge other than his own experience on which to base his decision as to which of the two approaches to disease control he should follow.

There are circumstances in which the grower should always be prepared to open the ventilators. For example, when the ambient temperature is greater than the minimum temperature setting of the glasshouse heating system, then the risk of high humidity is great and ventilation is energetically "safe" because the heating system is not in use. Also, in the period before harvesting edible crops or during flowering of some sensitive ornamental crops when chemical control may not be used, environmental control of disease is the only method possible. Ventilation has been shown to be very effective in the control of lettuce downy mildew (*Bremia lactucae*) in the period before cutting (Morgan, 1980).

<u>Computer control in glasshouses, what is its role in crop protection?</u> There are about 20 commercial glasshouse holdings in the UK which now have computer control systems. In Holland, where these systems were first developed, there are believed to be about 1000 computer controllers in use. They can be used to control air temperature, heating pipe temperature, ventilation, humidity, thermal screens, misting benches, irrigation and the flow of nutrient solution in hydroponic culture. They offer many advantages over conventional analogue control devices. Thus, the control of temperature should be more precise because the system provides better, and automatic monitoring of conditions within and outside the glasshouse and improvements in control algorithms. They provide a central point from which conditions on a large nursery can be monitored and controlled. The systems can process environmental information as integrals and provide a permanent record of past events. The installation of computer systems usually include new and more reliable temperature and humidity sensors. The systems have the capacity for greater flexibility in the environmental regime, especially at night, and can transmit warning messages in the event of mechanical failure.

For the first time, growers with such systems are able to monitor and control humidity automatically. In some systems, the programme allows a level of humidity to be set above which avoiding action will be taken. The grower may select whether this will involve heating or ventilation or both and whether humidity control will over-ride air temperature control or vice versa.

Unfortunately, technological advance in humidity control has preceded our knowledge of the biological effects of humidity and how they should best be controlled. Neither the manufacturers of the computer control systems nor the agricultural research service can yet offer firm advice on the control settings for humidity. There is a clear need for more research on both the physiological and pathological consequences of high humidity and a need to identify critical levels of humidity. Growers require this information to decide their disease control strategy, now that they have the means to control humidity.

In the next generation of computer controllers, improvements must be made in the software which will allow information on the thermodynamic characteristics of the glasshouse or mushroom cropping house to be used to compute the effects on fuel usage of the various options in humidity control. Computers can then select the most economic option. For example, in a glasshouse fitted with a thermal screen, the computer could compare the cost of reducing humidity to a set level by:- (a) raising the air temperature, (b) withdrawing the thermal screen and allowing water vapour to condense on the glass, (c) opening the ventilators or (d) switching on a refrigerative dehumidifier.

Is there a case for environmental control of disease? Although pathologists in the protected crops sector intuitively accept that control of disease by environmental manipulation is worthwhile, there is, as yet, little experimental evidence to support this view.

Winspear *et al.* (1970) investigated disease incidence in an early season tomato crop in which the humidity was coarsely controlled by ventilation. Humidistat switches were set to open the ventilators to 13 cm when the r.h. reached 75% or 90%. The 75% r.h. regime controlled leaf mould (*Fulvia fulva*) and fruit blemishes caused by *B. cinerea* whilst the 90% regime reduced the incidence of both diseases in comparison with a crop in which the humidity was not regulated. Similarly, Morgan (1980) showed that the incidence of grey mould lesions on tomato stems, leaves and fruits can be substantially reduced by allowing a 7.5 cm ventilator opening at night. Night temperature also, was shown to have a considerable influence on grey mould in tomato. As the night temperature was reduced from the 'blueprint' temperature of 16^{o}C, so the incidence of grey mould increased (Morgan, 1980 and 1981).

In glasshouse lettuce, ventilation at night reduced the numbers of leaves infected with downy mildew (*Bremia lactucae*) by 90%, a level of disease control comparable with the best chemical fungicides. In contrast, a heat-purging regime of 30 min heating followed by 30 min ventilation immediately before dusk, which has been recommended as a means of controlling the physiological condition "glassiness" by reducing atmospheric humidity, increased the number of *B. lactucae* infections (Morgan, 1980).

Refrigerative dehumidification has been shown to give some control of downy mildew in lettuce. Dehumidifiers also raised the air temperature due to their action as a heat pump. In the same experiment, thermal screens also reduced the humidity by increasing air temperature but did not decrease downy mildew. This was probably due to drips of water from the underside of the polythene screen which caused local foci of infection (Morgan and Molyneux, 1982).

In investigating the case for environmental control of disease by controlling humidity, it is important not to overlook the natural control of glasshouse humidity. A higher r.h. was detected in an early tomato crop beneath a thermal screen than in an unscreened crop, but only when the ambient temperature was low. However, when ambient temperatures were low, the humidity at night was lower in both screened and unscreened crops than would be expected to contribute to high levels of disease (Morgan and Molyneux, 1982).

Clearly, the control of disease by manipulation of the glasshouse environment is possible, but a number of questions remain unanswered. Can the recommendations be tailored to the epidemiological requirements of the pathogen? Does the use of double-glazing and thermal screens increase disease, in practice? Sims (1978) and Morgan and Molyneux (1982) have failed to show experimentally that the early tomato crop was more susceptible to disease under thermal screens. Can dehumidification with heat pumps be used economically? This may be the only method by which the humidity can be reduced without raising heating costs. The latent heat of vapourisation, released when water condenses in the dehumidifier, can be used to heat the glasshouse air. Dehumidifiers are now being evaluated as a means of disease control.

How can chemical control be most effectively integrated with environmental control? There is often a temptation to rely too heavily on a single chemical for disease control and to neglect other aspects of crop protection, such as hygiene and the glasshouse environment. When there is a breakdown in disease control due to insensitivity to a fungicide, the effects are all the worse: insensitivity to benomyl and carbendazim, which developed in the 1970s, in *Botrytis cinerea* in glasshouse crops and in *Verticillium fungicola* in mushrooms serves as a reminder of the dangers.

An advantage of environmental control over chemical methods is that disease organisms are unlikely to develop insensitivity to low humidity. Integrated programmes of control, which include environmental methods, would be likely to prolong the useful life of fungicides. Growers may be tempted to increase their use of chemical fungicides because, in order to save fuel, they have made the glasshouse environment more conducive to disease. At present, this may be cost effective, but it is probably a short-sighted strategy! It can only increase the selection pressure on the disease organism to develop insensitive strains and so shorten the life of fungicides. One such chemical, under threat, is metalaxyl, to which insensitivity has developed in the potato blight organism, *Phytophthora infestans*, but which is still effective in the control of downy mildew of lettuce. The loss of this chemical through the development of insensitivity in *Bremia lactucae* would leave lettuce growers without an effective means of chemical control. Growers should therefore, be conscious of this when making decisions about ventilation in glasshouse lettuce crops.

Experimental evidence is limited on the effects of integration of chemical with environmental methods of control of foliar pathogens in protected crops. Morgan (1982) has shown that in the control of lettuce downy mildew, the effect is additive and that environmental conditions may profoundly affect the performance of the fungicide. Thus, growers may achieve more effective disease control where they use both methods simultaneously. However, a more common approach may be to use one method after the other has failed. Better environmental monitoring is a feature of computer control systems which may open the way for better timing of fungicide sprays by relating the conditions in the glasshouse to the epidemiological requirements of the pathogens.

What is the future? A clear need for further research has been highlighted in the epidemiology of the major pathogens of protected crops. For example, for organisms which require free water on plant surfaces for germination and infection, what is the time x temperature integral needed for the completion of the process? For organisms which can obtain water from a humid atmosphere, what is the critical level of humidity at which germination and infection can proceed?

There are other gaps in our knowledge. Glasshouse environmental monitoring systems are not sited at the leaf surface. They are usually in aspirated screen boxes, suspended for convenience, not in the crop canopy but in pathways. Because leaves are the source of water vapour and because their temperature can fluctuate above or below the air temperature, the humidity measured in an aspirated screen is unlikely to reflect conditions at leaf surfaces. This is an area of research at the interface of engineering, physics and biology: we must either be able to predict the humidity at leaf surfaces by a mathematical modelling approach, or improve sensor technology to monitor these conditions directly. It must then be a part of the function of computers for environmental control, armed with an epidemiological model and a model of the thermodynamics of the glasshouse, to automate the disease control decision-making process either by adjusting the environmental conditions or requesting an application of fungicide.

DECISION-MAKING IN THE BIOLOGICAL CONTROL OF PESTS

The biological control of two commonly-occurring and damaging pests, red spider mite (*Tetranychus urticae*) and the glasshouse whitefly (*Trialeurodes vaporariorum*), has been one of the major successes of crop protection in the U.K. glasshouse industry (French *et al.*, 1976; Parr *et al.*, 1976). It is an approach to crop protection in which successful pest management depends upon glasshouse growers developing a good understanding of the biological interaction and the effect of chemicals on it. These growers must also be prepared to monitor carefully their pest populations and have the confidence to take on-the-spot decisions.

A serious problem facing the glasshouse grower is that populations of red spider mites and whiteflies can rapidly develop resistance to chemical pesticides, resulting in failure to control the pest. This is an acute problem because the supply of new pesticides with distinct modes of action has slowed as the costs to the agrochemical trade of the development of new chemicals have increased. Biological control is a method of great potential and one to which resistance is unlikely to develop; it reduces spray residues and the risk of phytotoxicity. When used in integrated control programmes with chemicals, biological control effectively reduces the selection pressure on the pest by making the survival of resistant individuals less likely. The useful life of chemical pesticides can, therefore, be extended.

Because the natural enemies of red spider mites and whiteflies cannot feed on plant material, their survival is dependent on the maintenance of an equilibrium between the parasite or predator and its prey. Ideally, this means introducing the pest into the crop in order to establish or preserve a predictable interaction which will keep pest numbers under control for a long period. The concept of introducing red spider mites or whiteflies into crops is one which does not come easily to growers new to biological control. But the benefits of reduced costs, improved quality and yield, and a more efficient labour force, accrue to those who are able to overcome their instincts.

Why do growers decide to use biological control? It is often cheaper to use chemical control if there is no problem with resistance in the pest population. However, if resistance develops, then the concentration, number of applications and number of chemicals in the programme must be increased. If resistance persists in the population, biological control becomes the cheaper option. Because prediction of resistance is effectively impossible, growers who have a history of such problems are likely to opt for biological methods of control. At present, the predator of red spider mites, *Phytoseiulus persimilis*, is introduced into *c.* 70% of heated crops of tomatoes and cucumbers; the parasite of whiteflies, *Encarsia formosa*, is introduced into *c.* 40% of these crops. Growers may attend courses organised by the Agricultural Training Board in order that they might become familiar with the methodology.

If a crop, in which red spider mite is being controlled biologically by its predator, or whiteflies by parasite, should subsequently become infested with aphids, then the application of a chemical aphicide may be necessary. However, this creates a problem for the grower because the chemical which he decides to use must be compatible with the biological control programme, i.e. it must not be toxic to the beneficial moiety of the biological interaction. The decision-making process whereby a suitable chemical is selected, can be complex and the consequences far-reaching.

The choice may be further complicated by the increasing number of other methods of biological control used in glasshouses. For example, the biological control of aphids on chrysanthemum by the parasite, *Aphidius matricariae*; the biological control of leaf miners on tomato and chrysanthemum by the parasites, *Opius* spp.; the use of the insecticidal bacterium, *Bacillus thuringiensis*, to control *Lacanobia oleracea*, the tomato moth caterpillar; and the growing use of the fungal pathogen, *Verticillium lecanii*, to control aphids in glasshouse crops. As each of these beneficial organisms is added to the overall control strategy, another degree of complexity is added to the decision-making process. Integrated programmes of control have been formulated for pests of tomato (Scopes and Ledieu, 1979), cucumber (Anon., 1978) and all-year-round chrysanthemum crops (Wardlow, 1981). These serve as guidelines, on which the grower may base decisions according to his own strategy of pest management.

Methods of biological control

(a) Red spider mite

(i) Spot treatments This approach follows the philosophy of chemical control, i.e. the grower waits until mite damage is visible before introducing predators. However, the timing and the size of the introduction are critical if the numbers of spider mites are to be prevented from reaching the threshold level at which crop yield begins to be reduced. It is unlikely that this approach will give a lasting control of spider mites, because the predator can survive for only a limited period in the absence of prey. Predators therefore need to be re-introduced when the next infestation occurs. For long-term control, spider mites must be eliminated from the crop by mid-August, by which time they begin to hibernate in the glasshouse structure. Spot treatment is unlikely to ensure this elimination.

(ii) The 'pest-in-first' method This co-ordinated approach to pest management is one in which a stable interaction is maintained between pest and predator, and which, ideally, keeps pest numbers below the damage threshold. It may call for frequent introductions of the pest into an otherwise uninfested crop. In the first year, or where red spider mites from hibernation habitually infest the crop during propagation or soon after planting, spider mites are introduced on to young plants, to be followed by an introduction of predator. This will result in a distributed population of predators which will be sustained by red spider mites which have emerged from hibernation or by fresh pest introductions. The predator population is thus maintained until mid-August to prevent hibernation and the early re-infestation of subsequent crops.

If the early 'pest-in-first' preventative treatment has successfully eliminated over-wintering spider mites, then in subsequent years introductions need not be made so early. Alternatively, spot treatments may be successful, but the risk of introductions being "too little and too late" means that, in some cases, control may only be achieved after the crop has been damaged. Sometimes, chemical control must be integrated into the programme. For example, on early planted crops, the short day-length may cause hibernation of red spider mites which prevents the establishment of the interaction. Otherwise, in mid-summer, spider mites may migrate to and multiply unchecked at the tops of the plants. In these cases, a single application of a chemical pesticide may be necessary.

(b) Glasshouse whiteflies

The success of biological control of whitefly with the parasitic wasp *Encarsia formosa* depends upon an integrated approach. If whitefly numbers are above a critical level, then the parasite is unlikely to contain the infestation. Sooty moulds, which grow on the honeydew excreted by whiteflies on the foliage, flowers and fruit, are the principal cause of yield loss. On tomato, sooty moulds are likely to develop later in the season if *E. formosa* is introduced when the pest population is greater than 0.2 whiteflies per leaf. Therefore numbers must first be reduced with a compatible chemical such as resmethrin before introduction of the parasite. Therefore, correct decisions on whitefly control depend on accurate estimations of pest numbers.

Three methods have been proposed which are designed to ensure the maintenance of a stable interaction between whitefly and parasite populations (Scopes and Ledieu, 1979).

(i) Timed introductions An early introduction of whitefly pupae is followed by three introductions of black, parasitised scales, timed to coincide with the development of susceptible third instar whitefly scales.

(ii) Multiple introductions (or 'dribble') method Where whiteflies are a recurring problem, commercial rearing companies introduce parasites every fortnight until black, parasitised whitefly scales have become established. In the tomato crop, the first introduction should be as early as three weeks after seed sowing. A single application of insecticide may be required to "re-structure" the age range of the whitefly population by killing all stages except whitefly eggs before the parasite is introduced.

(iii) The 'banker' system Tomato growers who have become independent of commercial suppliers by rearing their own parasites, have the option of using the 'banker' plant method. Plants, on which a vigorous whitefly/parasite interaction has been established, are grown on in pots and then distributed throughout the crop. This provides a constant source of parasites in the crop and a better guarantee of establishment of a balanced and, therefore, controlled population of host and parasite.

The interaction between the whitefly and *Encarsia formosa* is greatly influenced by temperature. The parasite population will predominate at temperatures above 22°C, whereas at lower temperatures the pest develops faster than the parasite. Therefore in early tomato crops during winter, chemicals are essential for whitefly control. Growers must be judicious in their choice of pesticide because a persistent chemical may interfere with attempts to control the pest biologically later in the season.

The integration of pesticides with control by natural enemies

It is essential for the effectiveness of natural enemies of pests, that growers are able to assess the risk to their biological control programme of using all biologically-active chemicals, whether they are acaricides, insecticides or fungicides. Pesticide chemicals used in protected crops are always tested for their effects on target organisms, some non-target organisms and on the crop plant. This work is undertaken both by the agrochemical trade and by the agricultural research service in order to fulfil the requirements of the Pesticide Safety Precautions Scheme and the Agricultural Chemicals Approval Scheme. Thus, approved pesticides may be used with relative safety to the operator and the crop. An important aspect which is overlooked by these schemes is the safety of chemicals to programmes of biological control.

Laboratory studies at the Glasshouse Crops Research Institute and by the A.D.A.S. have attempted to bridge this gap (Ledieu, 1979a, b). These tests are intended as guidelines to the disruption likely to occur to natural enemies due to the use of chemicals in commercial glasshouses. The information is constantly updated as new chemicals and new formulations of existing chemicals are introduced for use in glasshouse crops. It attempts to categorise the effects of chemicals on adults and immature stages of *Phytoseiulus persimilis* and *Encarsia formosa* and the fungus *Verticillium lecanii* and gives an indication of the likely persistence of the chemical under glasshouse conditions.

It is no suprise that many insecticies are harmful to both *Phytoseiulus* and *Encarsia*. Whilst some may be used with safety, others only harm adults which allows their judicious use at certain stages in the programme. Acaricides are generally less harmful to *Encarsia* than to the predator of red spider mite, and fungicides with a few exceptions are generally safe. Benomyl, which is still widely used in disease control programmes is safer as a drench than when applied as an HV spray. Therefore, it is important that the method of application be considered when determining the safety of the chemical and that the disease control programme be integrated with biological pest control.

How does a grower decide which chemicals to use?

The grower who is considering using these natural enemies must plan ahead to integrate his crop protection methods. His planning must follow a logical scheme to ensure that he has considered all eventualities.

Having decided which natural enemies he may use, the grower must draw up a list of all the chemicals which he intends to use for the control of minor pests and diseases. This list will vary from grower to grower according to his stock of chemicals, his preferences, his equipment for application and (because of the pre-harvest restrictions on chemicals used in sequentially-harvested crops such as tomatoes and cucumbers) his picking frequency.

Each chemical must be checked for its known effects on natural enemies and rejected if it is harmful. For many chemicals, the information may be scant, in which case, whilst erring on the side of safety, he must make assumptions based upon the available evidence: e.g. if a chemical is benign in its effects on adult *Encarsia*, it is certain to be safe on pupae.

If the list does not contain a 'safe' chemical for any particular pest or disease problem, then the information on persistence must be considered so that the interference with biological control can be minimized.

There are, of course, many factors which prevent this decision-making process from being exact. After the introduction of a natural enemy, chemical applications are likely to be less harmful if the parasite or predator has already had time to establish itself in the crop. A chemical will also vary in its effects according to the thoroughness of the application in covering the foliage: spot treatments will be generally less harmful than overall treatments. Furthermore, the effects of weather and crop management may affect the persistence of a chemical. In these respects the grower's experience and management skill are crucial to a successful integrated control programme.

Decision-analysis programmes in the integrated control of pests

Glasshouse growers are becoming increasingly familiar with computers installed for environmental control. There may be scope in the development of these computer systems to fulfil more than one function by providing software which will aid the management of the crop in other ways. This may be feasible in some cropping programmes because there is often time between crops when the computer is idle in its function as a controller. This would be a suitable time for economic analysis of the next crop, for deciding strategies for environmental control of disease or for planning an integrated programme for pest control.

A decision-analysis programme for biological control would proceed by elimination of harmful chemicals in the same way as is done at present on paper by the grower. The computer could draw on a data-base of information on safety to natural enemies, persistence data, and pre-harvest restrictions on use of chemicals on edible crops. It would also require information on sowing dates, crop type and his stocks of chemicals. Such a programme may also assist decision-making in the week-to-week management of a biological control programme.

It appears that the glasshouse control computer is here to stay. The protected crops industry must therefore demand an expansion of the capability of their computer systems so that full use is made of this potentially powerful and versatile tool.

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4.
Conversazione

CROP WEIGHING AND RECORDING

P.R. Hill

Weighwrite Ltd., 49 West St., Farnham, Surrey

Correct decision making depends on having the maximum amount of reliable information available. One source of information can be past experience. How effective were last season's applications of fertilisers and pesticides ? Did some crops or fields respond to treatment better than others ? These and similar questions can only be answered if the yield from each field is measured individually.

This is possible using an In-Motion Axle Weigher. All types of vehicle can be weighed. As the vehicle passes slowly across the weighing platform individual axle weights are recorded on a tally roll with gross weight, time and date of weighing. A vehicle identification code can also be added to the record.

A data collection terminal can also be added to produce a highly automated crop weighing and recording system. Up to 99 tare weights can be stored in the terminal against a vehicle identification code. The gross vehicle weight is automatically entered into the terminal from the weighing machine and the net weight calculated and stored against the vehicle code for future use. The data can be printed out in journal form or transferred to a main farm computer for processing.

Measurement of crop yield is not only necessary for telling the farmer how much produce he has available for sale or how much silage he has to feed the cattle. It also indicates the success of different treatments and allows him to keep detailed field records. Decisions on crop protection measures can then be taken with the benefit of this experience.

THE USE OF VIDEOTEX SYSTEMS IN CROP PROTECTION DECISION-MAKING

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Videotex systems currently available in the UK are either broadcast (teletext) or interactive (viewdata).

Teletext services have carried ADAS pest and disease intelligence data for a number of years. Since 1978 ADAS have been an information provider on Prestel, British Telecommunication's viewdata system, and has steadily expanded the range of information it provides.

Awareness information is provided to remind farmers of possible future situations, especially on the likely impact of certain pests and diseases during the crop year.

News information is supplied regularly so that farmers can monitor changing situations prior to making a decision on the need for crop protection measures. Encyclopaedic information is also made available so that guidance on identification, life cycle, economic threshold levels and control measures can be given. The Meteorological Office provides local weather forecasts which enable farmers to identify likely periods of suitable weather for applying control measures.

The interactive facility of Prestel means that it is possible to order leaflets and booklets through the system.

THE 'OATS' PROGRAM AND ITS ROLE IN TRAINING FOR DECISION MAKING IN CEREAL GROWING

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The 'OATS' program, operating on a microcomputer, is derived from the successful 'WHEATRACE', ICI's original crop management game, which has been played by over 3,000 farmers participating in teams over the last three winters. The 'OATS' program is designed to be used as part of a training programme with decision making sessions interspersed with discussion periods. It was originally designed for and has been used mainly in the training of staff from agrochemical and fertiliser distributors, and it has applications in training students and farmers.

The 'OATS' program, devised jointly by ICI's Plant Protection Division and Agricultural Division, simulates the growing of crops of winter wheat and winter barley from establishment through to harvest, storage and eventual sale. Decisions are made by participants on variable inputs, such as establishment techniques, fertiliser and agrochemical use and timing, varieties and marketing. These interact with the programme which contains details of soil, weather and growing conditions. The programme allows up to three decision periods. All inputs and sales are charged at market value so that the profitability of crops 'grown' by participants can be assessed.

THE INFLUENCE OF FORECASTING ACCURACY ON CEREAL APHID CONTROL STRATEGIES

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The aim of the research demonstrated has been to assess different control strategies against *Sitobion avenae* (the grain aphid) on the basis of information on yield loss, forecasting accuracy, outbreak frequency and the relevant costs and benefits involved. The data on yield loss are derived from field experiments.

In the analysis, three control strategies are compared:

(a) no control measures
(b) prophylactic insecticide usage
(c) insecticide used or not depending on forecasting advice of varying degrees of accuracy.

These options are compared in a computer model which is based on equations derived from Bayesian decision matrices. By comparing each pair of options in turn, a complete picture of the relative merits of each option emerges over a range of values of any given variable or variables, e.g. expected yield, forecasting accuracy or both. Among the conclusions which have emerged are that:

1) Forecasting, even when only 75% accurate, is the best strategy over a wide range of expected yield.

2) A forecasting system which successfully predicts all aphid outbreaks but which may predict outbreaks which subsequently fail to develop, i.e. a system which identifies likely aphid years, is a superior option, under all circumstances, to prophylaxis.

3) These conclusions are very robust, e.g. they are unchanged by increasing the cereal aphid outbreak frequency to a level greater than that currently observed.

This system for comparing control strategies is extremely flexible and research is planned on several further aspects. For example, it can be used to show how cereal aphid control strategies are affected by:

1) the inclusion of the effects of aphid-induced changes in grain quality.

2) the inclusion of the effects of other aphid species, especially *Metopolophium dirhodum*.

3) different damage threshold, grain prices and control costs.

4) differently-timed aphid attacks.

This research has relevance to other areas of research. In particular the value of forecasting systems is demonstrated, even though they are imperfect.

GLASSHOUSE ENVIRONMENTAL CONTROL

M.S. Tribick

Richwest Electronics Limited, Oakesway, Hartlepool TS23 0RD

A distributed microprocessor-based glasshouse control and monitoring system was demonstrated. The system embraces all aspects of glasshouse control and monitoring, making full use of meteorological measurements and providing data for decision making.

SPRAYPLAN

R.T. Richardson

Ciba-Geigy Agrochemicals, Whittlesford, Cambridge CB2 4QT

Many farmers are aware of the grass and broad-leaved weeds which may grow in their fields of winter cereals. It is much less likely that they will fully understand how competitive these weeds can become and which species will compete the most seriously with their crop. Sprayplan has been devised to help the farmer decide on the selection of a suitable herbicide and the timing of its application for the best control of particular problem weeds. Very often the only opportunity to assess the results of a chosen herbicide programme is at harvest. Obviously it is then too late to look back and compare the likely effectiveness of alternative programmes which could have been used. Sprayplan has been designed and developed to show the cost effectiveness of weed removal. Comparisons can be made of different types of herbicide and timings of application. Data is stored in a computer which is capable of displaying information graphically to show the expected effect of chosen herbicide treatments. The data for Sprayplan originate from Ciba-Geigy and other agrochemical companies whose products are listed in the product options. The effects of weed species and infestation level are derived from data obtained in independent research establishments. In use, farmers are asked to describe the expected weed problem in a particular field, and give other general information on cropping. A range of herbicide programmes is evaluated by Sprayplan, and the levels of weed control achieved and the most cost-effective option are predicted.

ADAS NATIONAL PEST AND DISEASE INTELLIGENCE SERVICE

D.V. Alford and D.C. Gwynne

ADAS, Burghill Road, Westbury-on-Trym, Bristol.

This scheme involves the collection, the collation and the dissemination of topical advice on the crop pests and diseases in England and Wales. The reports constitute aids to decision-making in crop protection and draw attention to potential problems which farmers and growers should be looking for in their crops at any given time. The reports serve to advise and remind farmers and growers that spray or other treatment may be required, to advise them on the optimum time for treatment, or, if appropriate, to advise against treatment. Reports are issued weekly from April to October, and when necessary during the winter months.

Spray warnings and forecasts, including relevant details of crop pest and disease incidence, and the interpretation of local data by regionally based ADAS science specialists, are forwarded to ADAS Bristol by Telex. This information is supplemented by data obtained directly from certain universities and research institutes. At Bristol all data are reviewed by specialist advisers. They produce co-ordinated reports (one for pests and one for diseases). The reports are then reproduced and issued to advisers throughout England and Wales, to commercial organizations, to the farming and horticultural press and to the TV and radio network. Edited in an appropriate form, the reports are also made available on teletext and viewdata.

SOME ASPECTS OF AGRICULTURAL METEOROLOGY

N. Thompson

Meteorological Office, London Road, Bracknell RG12 2SZ

This exhibit consisted of six display boards which illustrated:

The function of the Agrometeorological Section of the Meteorological Office.

The relationship between weather and the development of plant diseases and insect pests and thus how weather information can be used as a component in the spray/no spray decision making process.

An analysis of the frequency with which spraying can, from a meteorological point of view, be successfully carried out.

Some meteorological aspects of spray drift.

GLASSHOUSE COMPUTER CONTROL SYSTEM

S.W. Burrage

Wye College, University of London, Wye, Ashford, Kent.

The model demonstrated was based on a system designed to control a three-glasshouse complex at the Commercial Horticulture Department at Wye. It can easily be expanded to control more houses.

The system is modular, consisting of a series of linked 'black boxes'. The sensors in and above the glasshouse produce analogue signals, the computer converts them into engineering units, ^{o}C or Watts, etc., and compares them with values previously programmed into the computer. Should the values exceed the limits set in the programme, the computer will operate relays, through an interface, to turn on the heating systems, open the ventilators, etc. The system allows the parameters, temperature, radiation, windspeed, etc. to be interrelated, giving the most effective control of heating and ventilation. Irrigation can be based on solar input and the timing capability of the computer provides for thermal screen and blackout control. The data acquired by the computer can be stored in memory and recalled as hard copy on a printer. The computer system, due to its data handling capability, should be regarded more as a management tool rather than simply a control system.

CASP - A COMPUTERISED ADVISORY SERVICE FOR CROPS

J.O. Walker

BASF (U.K.) Ltd., Lady Lane, Hadleigh, Ipswich, Suffolk.

CASP is a computer based advisory service which is designed to provide comprehensive recommendations to optimise the profitable production of arable crops in the United Kingdom.

The system is based on programmes held in a central computer which can be accessed via portable or fixed VDU or printer terminals connected from anywhere in the UK via standard British Telecom lines. The system will be available to the farmer via specialist agrochemical distributors.

CASP provides a complete written crop husbandry plan for each field. This plan covers all inputs required for profitable crop production, including variety to be sown, fertilisers, herbicides, fungicides, growth regulators and insecticides. In each case, rate of use and treatment timing are included.

The plan, which takes account of field history and soil analysis results, is prepared by the CASP central computer. The treatment programme is based on the yield potential of the field and crop variety to be grown. Each field plan includes an analysis of expected gross margins. The cropping plan can be updated and amended to meet changing requirements as the season progresses.

Long-term records of each field will be stored on the central computer.

In order to maintain and update the programmes in the central computer, a team of research agronomists will constantly keep up to date with new scientific and technical developments on each of the major arable crops.

These developments will then be evaluated at field agronomy centres. Only when their value has been confirmed will new techniques be written into the computer to add to the list of recommendations. Three agronomy centres have been established in England to represent typical soil types, cropping techniques and climatic conditions in the major farming areas. A fourth will be set up in Scotland.

The CASP computerised advisory service will become commercially operational during 1983.

THE CEREAL UNIT OF THE NATIONAL AGRICULTURAL CENTRE

Catherine S. More

National Agricultural Centre, Stoneleigh, Warwickshire.

Publications from the Cereal Unit aid decision making in two ways: by helping farmers to keep accurate records of arable activities and by providing valuable technical background information.

In the recording category the Unit produces a Cereal Recording Scheme and an Arable Work Report. These are designed for practical use by farmers and consist of sets of forms stored in sturdy ringbinders. The cereal records have field record forms on which concise records of activities and costs incurred throughout the season fan be made for each field, also cost record forms for seeds, sprays and fertilisers and financial summary forms.

The Arable Work Report is a utility item designed for the transfer of daily work instructions from the farmer to his operators and for their reports back to the farmer. The forms are simple and straightforward to use. They aid record keeping and complement the Cereal Recording Scheme.

Other publications give technical information: The Yield of Cereals and Yield of Oilseed Rape course papers are from farmer study courses. A Farmer's Guide to Wheat Quality describes the uses of wheat in the UK. It has detailed sections covering the quality standards required in wheat marketing and explains how these standards are measured. The Cereal Development Guide is a comprehensive guide to the accurate identification of the developmental stages in wheat and barley. The lucid text is illustrated with great clarity by 120 photographs and accompanying diagrams and a section covering the dissection procedure is included.

THE HP9845C, A DESK-TOP COMPUTER WITH COLOUR GRAPHICS

D. Roberts

Hewlett Packard Ltd., 106-118 Station Rd., Redhill, Surrey.

Computer manufacturers have for some time appreciated the requirement for graphics to aid decision making. Graphics allow the decision maker to display processed data in a manner convenient for him, indicating options for taking control action.

Several software suppliers, with expertise in agricultural applications, have written successful crop protection programs to run on the HP9854C, taking advantage of its powerful graphics capability.

As technology improves, and the costs of computer hardware fall, the processing power of computers and the complexity of the problems which they can deal with, will increase. It will continue to be important that the user is allowed complete control over his computer system. It is important that the results of complex calculations are presented in such a way as to be easily interpreted. Colour graphics form a natural interface between man and the computer to achieve this objective.

THE FARMSTAT DATA BASE

A.M. Houghton

Produce Studies Ltd., Northcroft House, West Street, Newbury, Berks.

FARMSTAT is an annual sample survey of 1500 farms representative of all types of farming enterprise and all regions in Great Britain. It was originally designed to supply market research information to the agricultural supply industry. Using a field recording system based on a farmer's pocket diary, all crop inputs on each of the 35,000 fields on our members' farms are recorded. At the end of the season yields are estimated. The following variables for any given crop can then be tabulated and correlated.

Soil type
Previous crop
Weed infestation
Yield
Sowing date
Seed rate
Sowing method (direct drill, etc.)
Whether undersown
Variety
Herbicide use (type, timing, rate)
Fungicide use (type, timing, rate)
Insecticide use (type, timing, rate)
Fertiliser use (timing, rate)
Growth regulator use

All the information for the 1980-81 harvest year already exists in the FARMSTAT data base. The information for the 1981-82 harvest is now being added. Examples showing some correlation found in the 1981 data set were displayed. These included:

Yield v. sowing date
Yield v. variety
Yield v. sowing rate
Yield v. drilling method
Yield v. nitrogen use
Yield v. herbicide use
Yield v. fungicide use

A FINANCIAL AND ARABLE MANAGEMENT SYSTEM

Jenny Wilson

Comput-a-Crop, 3 Cornmarket, Louth, Lincs.

The Financial and Arable Management System (FARM) provides an integrated crop and financial management package. The system maintains and analyses both technical crop production records and performance, and the related farm business costings and forecasts.

The aim is to provide farmers with a financial and management accounting system, which can objectively present the information necessary to make informed decisions about their enterprises, in the light of local conditions and past performance.

The system contains two types of information:

1) Permanent or annual data, consisting of certain farm information.

2) Seasonal data, a detailed record of current crop production practices; a narrative journal of events, field by field, and crop by crop, on the one hand, and the costs pertaining to such operations, apportioned field by field and crop by crop, on the other hand, against a budget forecast, together with accounts records based on the farm's financial year.

The application of costs to a specific enterprise occurs automatically at the time of recording crop husbandry operations. The material stock levels are also automatically updated as the product is consumed.

At any time during or after the growing period the accumulated costs to date for a given field, crop or variety can be reviewed and compared with budget forecast figures. In addition the system generates reports as required on any aspect of financial or crop management, specified by the user.

Other Exhibits

A MICROPROCESSOR CONTROL SYSTEM FOR THE GLASSHOUSE

M.J. Dowe

Serck Controls, Queensway, Leamington Spa, Warwickshire, CV31 3JT

PLANNING FARM WEED CONTROL STRATEGY

J. Elliott

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EPIPRE - A SUPERVISED PEST AND DISEASE MANAGEMENT SYSTEM FOR WINTER WHEAT

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(see paper in these proceedings)

A PROGRAM FOR COST/BENEFIT ANALYSIS IN CEREAL FUNGICIDE SPRAY DECISIONS

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5.
Future needs and prospects

Proceedings 1982 British Crop Protection Symposium

Decision Making in the Practice of Crop Protection

A FARMER'S VIEW

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I am very aware that we have a highly professional audience here today. In yesterday's morning session, I was not quite sure who was under the microscope, the farmer or the pests, though I was rewarded by the comment of one participant who said that a farmer ultimately does what he likes !

First, I would like to remind you that there are many pressures on the farmer which are outside the remit of this conference but which, I think, have a considerable influence on his attitude to crop protection. In particular, the CAP price review that is going on at the moment is absolutely vital to us because commodity prices, if lowered in real terms, may reduce the inputs, including crop protection chemicals that can be afforded.

It is a salutary thought, that agriculture must be one of the few industries where the major decision in production, crop planting, is done long before it is known what return one will get for the produce, assuming somebody wants it. In particular, cereal growing is a subject over which there are considerable question marks at the present. There are other factors that greatly influence what a farmer does; both what crops he grows and the measures he takes to protect those crops. For example, in a farm on the edge of a town it is not possible to use shotguns for pigeon control, because neighbours will lobby against the noise. Also, bird scarers are always a lively topic of conversation if you leave near a village or town. There are less obvious factors like the bank manager, the wife, or in my case my daughter, who seems to accumulate horses. This has quite an influence on what I do adjacent to my farm buildings and probably on some of the most valuable land, from the point of view of the herdsman. There is also the environmental lobby which has been mentioned today by Dr. Dunning, and the problem of resistance to pesticides and the emotive responses to this from the public. Mr. Elliott reminded us of the importance of cultivation techniques and rotations in the control of weeds. Mr. Cussans illustrated this in relation to blackgrass control, and he showed how the judicious use of cultivations and chemicals can give good and economical control. Another important area, which has not been sufficiently emphasised in this symposium, is the role of the plant breeder in producing varieties with greater resistance to diseases and pests. Breeders have made considerable strides in this direction, and although fundamental in disease control strategy, it has been mentioned only in passing as a major method of disease control.

None of the papers presented at this symposium has considered the important grassland sector and I think this is something that we should give much more attention to in the future, as it is a vital part of our industry as a whole. Research on pests and weeds of grasslands should receive much more attention than it does at present.

I would also point out that the acceptability of the produce from agriculture and particularly horticulture receives little attention from researchers. Take for example apples. I often speak to women's groups and one of the points I raise with them is that of "grub acceptability", which simply is: if you buy a pack of cellophane-wrapped apples, would you accept one grub, two grubs, three grubs or so on ? I have not yet had a reply that any grubs would be acceptable. Yet the pressures against the use of pesticides in apple orchards are considerable. The same applies to the potato crop, and we heard mention of this from Mr. Gunn, and there is of course the matter of wheat and bread quality.

But to return to the symposium itself, a great deal is happening at the moment in research and development which is proving very difficult to disseminate to those other than enthusiasts. There is a major difficulty in communicating information to farmers effectively. Joyce Tait spoke about some farmers' attitudes and beliefs and we saw how these were sometimes at variance with the facts of crop protection. So it is important to consider where we as farmers and growers obtain our information. There is the media, the press, television, radio and, increasingly, local radio. There is the local agrochemical company, and it may be that BASIS representative, or it may be the local producer's or the manufacturer's representative, and so on. More recently, we have the consultant, and the services of the meteorological office, and, not least, the state advisory service. I am very conscious of the wealth of information that is available to farmers and growers, but it is clear that it is not reaching its target. Therefore, we need to exploit all the different methods of communication now available to us. On the role of Prestel, and of computers in general, we need to work out how we can get them, as it were, into the field in the way that will enable us to maximise benefits that are there for the taking. On rare occasions a new development will take off and rapidly gain acceptance. An example of this is the low volume spraying of sugar beet. This technique spread across the country in only one or two years. It shows that farmers will take up new developments if they are attractive to them and if there is a financial return. If farmers are to survive as primary producers, and manufacturers and food producers are to survive in our consumer society, then they must produce the products of the required quality at the right price and at the right time and they need to make them as attractive as possible to the housewife. We have to use all the options open to us to achieve this objective, because in the end we will only stay in business if we sell the products we produce. This symposium has shown new ways and directions in which this end might be achieved more economically. We need to exploit all the aids available to us because we are in economic circumstances which are increasingly against us. The security that we have enjoyed through the EEC will be of limited duration. If we are to stay in business we shall need all these aids, to enable us to compete effectively with others who are, climatically, in a better position than we are.

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MORE, AND BETTER, AGROCHEMICALS ?

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The views presented in this paper are mine and not necessarily those of the agrochemical industry as a whole; however I have consulted some colleagues in arriving at the views.

The title to which I am asked to speak states first: 'More agrochemicals ?'. I doubt whether there will be a flood of new products in the future - the escalating costs of developing and registering new molecules will see to that. However, there could well be more brands for existing molecules and certainly more mixtures and tank-mix recommendations. Secondly, it asks 'better agrochemicals ?'. I shall not be drawn here until someone defines what is meant by 'better'.

My view of the future for agrochemicals in arable farming, given below, touches upon one of the objectives of this symposium, namely examination of the kinds of information needed for more effective decision-making.

Farming is a complex business demanding, for a successful arable operation, a high degree of awareness of the numerous inputs (e.g. crop, cultivar, seed rate, fertilizer, soil husbandry, growing techniques, pesticides and their application) which go to make up a farm programme. Pesticides are just one input in the matrix; the effect of them and the other inputs cannot be considered in isolation - there is obviously interdependence and this must be taken account of in the decision-making process. Decision-taking is weighing options and selecting from the choices those, which when acted upon will (or might), meet the given objective. The farmer has to be aware of the options open to him and their consequences if he is to take the 'right' decisions and thus to succeed. As stated earlier, the complexity of the data required by the farmer for his decision-making and the possible interactions of components, viz. in cereals (the mainstay of arable farming) variety, fertilizer, seed rate, pesticide programme, suggests to me that the farmer is often operating at less than optimum. He will need in the future, as operational success becomes more critical, to ensure that his operating effectiveness is higher almost irrespective of his objective.

No matter how sophisticated the on-farm, or for-farm, decision-making apparatus, its success depends upon adequate data input. As farming is complex, there is a need for much data on the various inputs <u>and</u> on their interdependence and interactions with soil and weather.

In the future farmers, or the farm decision-maker, will need to have at their disposal a greater awareness of how individual agrochemical products can fit into their crop protection programmes. Both agrochemical companies and suppliers of the other inputs will have to make provision for the supply of such data. This requirement will be essential irrespective of the advisory chain upon which the farmer may depend.

I consider arable farms will become larger and rely heavily on the farm 'planner' - the decision-maker. I do not see the consultants increasing as an independent force but rather becoming absorbed into farm businesses. I see the distributors' representatives as becoming, necessarily, more skilled in dealing with the input factors, and more able to take on a broader advisory role, with backing in specific skills (biological disciplines, land management, farm economics, cropping systems) coming from the official advisory bodies.

This rather simplistic view, condensed for the purpose of this paper, will enable complex data - originating from those responsible for the input product, e.g. pesticide manufacturer, or for systems research - to flow to the farm decision-maker. Counterflow of data back to the pesticide manufacturer will also be important if he is to improve his products.

I see a real need to move away from considering one input, i.e. a pesticide, in isolation, to examining its place in a cropping system. There must be more detailed data on product performance in specific situations and on the interaction with other input factors. This will enable the pesticide manufacturer to supply more information about his product and its performance and limitations in specific systems and regions. Such information can only come from extensive field trials which in turn will call for increased development expenditure. I do not see the pesticide manufacturer being able to ascertain the interactions of his pesticides with others.

To resolve this a division of labour will be needed. Currently, resources are wasted by allowing a hotch-potch of product testing, often duplicated by industry and research bodies, and ignoring the equally vital aspect of programme and system. Separation of development work could see the manufacturer dealing with his product, and state research concentrating upon the role of products in specific cropping systems and programmed approaches. Perhaps for major arable crops a crop-orientated approach will be needed.

This division of responsibility would benefit the farmer by giving him or his decision-maker the data on pesticide performance needed for more effective decision-taking.

The dissemination of data on products will be the responsibility of distributors with the manufacturers being charged with training representatives. In future there will be greater demands upon both the decision-maker and those responsible for advising him. Without regular training and refresher courses the representatives will fail in their duties. Herein lies the merit of working through the distributor chain as this forms a natural and established pathway for training. The data from these representatives will be complemented by advice from the state service.

In conclusion, we prosper as the farmer prospers - in the future his prosperity will depend upon the quality of his decision-making. All concerned with providing him with the information he needs to make sound decisions must work together to ensure this prosperity.

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THE ADAS CONTRIBUTION

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It may come as a surprise to my ADAS colleagues that there is an ADAS view on the subject of this symposium. The view I intend to present is that of a resource manager and not a collective view of my colleagues, some of whom have spoken enthusiastically here already.

The ADAS contribution I shall speak about relates to the 20% of manpower resources which go into advisory work rather than the 80% which are concerned with all its other activities. The objective of this advisory work is to improve the productivity of British agriculture. To obtain this improvement ADAS has to help the farmer to make the best use of his resources. Since about 1973 ADAS has given advice to the entire agricultural industry in a very broad sense. If it is within our expertise and ability ADAS gives advice to those industries which have a fringe contact with agriculture, though the farmer and grower have the highest priority, particularly in terms of face-to-face consultancy advice. For every ADAS representative who deals with farmers and growers, there are two more ADAS staff acting as consultants to him. In its development role, ADAS has the primary objective of producing reliable data for the purpose of giving sound advice, both technical and economic.

It frustrates us that farmers do not behave rationally in economic terms. In other words their objectives are not necessarily to maximise economic returns. This gives us a great deal of difficulty in planning and helping them with the decision making process. Farmers are concerned to meet a number of objectives. All have a different range of objectives, and a great deal of our work is concerned with influencing their objectives and attitudes, particularly in the context of the sensible use of pesticides. Within his own personal objectives, we try to advise the farmer to make the best use of his resources, in particular of his limiting resource. In most instances, in spite of the financial restraints, the limiting resource which determines the major part of farmers' objectives is the area of land which he controls. Most farmers are short of land in relation to meeting these objectives. Therefore, in improving the productivity of British agriculture, it is in our interest and in their interests to optimise the output from each area of land that is farmed. Of the decisions which have to be made by the farmer and grower we are largely concerned with those at the tactical level. ADAS is involved at present in detailed consultancy work to only a limited extent and this is likely to decrease in the future. However all ADAS staff must get their feet muddy in order to make sure that their work meets the needs of the industry. They need to be involved in the development phase of any new activity, whether it is in decision making, new technology or the development of new farming systems. ADAS' major contribution in this area is to help to elucidate principles which will be of value when making tactical decisions at the farm level. In meeting its objectives ADAS has to respond to environmental and conservation pressures, particularly since the passage of the Wildlife and Countryside Act in 1981. It has also to be concerned with the development of resistance to pesticides. Both put pressures on the decision makers to use less pesticide. On the other hand, modern markets demand that quality and continuity of supply are paramount, and products leaving the farm nowadays are expected to be pest and disease free. To achieve this farmers have to make extensive use of pesticides.

What are ADAS' needs in the context of this Symposium ? They can be stated very simply. We need better data, better methods for its interpretation, and better means of communicating to farmers. In our development work we can contribute a great deal to advancing these three needs. In some of the roles we shall complement those of other organisations, whether in research or commerce, and vice versa. In other words, we can contribute to new knowledge in biology, on pesticide performance, on the effects of agronomic factors, and the interaction of all these. We are concerned with improving monitoring methods, including the automation of these methods, and as we have been in the past, our work will be complementary to that of many other organisations. We have a major role to help others write specifications for models, and in particular to help improve existing models. I don't see our role as that of producing models because the resources needed cannot be made available. We accept that the way ahead in pest control is through integrated pest management, and I believe it will be understood by all why this attitude is held. Integrated pest management requires improved data and improved interpretation of it, as well as good models, if it is to be effective. In this context, computer simulation models should be extremely helpful and we use them a great deal in the advisory service, though at present most are concerned with animal production systems. From our experience with these models, we are hopeful that good crop simulation models will become available, and if so we shall certainly make use of them. One way we will use them is to help to identify what sort of experiments need to be done. Sensitivity analysis will enable us to decide which are the priority areas, what experiments need to be done to give improved data, and provide the basis for more realistic models. When we have discussions on the economics of pest management models really come into their own, as they can do the arithmetic given the inputs and so can cope with changing prices, costs or, in relation to the individual farm, cost structures. Models will also provide much more reliable data for advice. They will allow us to extrapolate more reliably the results of experiments into the wider situation. Even more important, they will reduce the need for too many subjective judgments, or the use of 'experience' in formulating advice. Ultimately, models will be an integral part of production systems, whether they are crop production systems or farm production systems. The primary object of our experimental husbandry farms is for systems proving, and models will have a very important contribution to make in this activity. We plan to increase our work in this area.

Economic appraisals and data are provided for advisers in ADAS. These consider the options for crop production systems involving inputs at varying levels, including pesticides. Farming systems are also included, analysed to provide gross margins taking into account fixed costs. A difficulty in this work relates to fixed costs and this is currently being studied. This information is not published as it is forward-looking and includes forecasts of prices and changes in costs.

ADAS must develop new methods of communication with farmers. We have a good track record in this area. We are now starting to examine how our data banks can be more accessible to people outside the service. There are mechanical problems in achieving this, as well as those which relate to the type of data which exist and the difficulty that farmers and others may have in interpreting the data in a sensible manner. Our farm computing team has identified that about 8% of the farmers in this country could justify at the present time the purchase of a computer. In the future these computers could contribute to data banks and could access data banks. We hope that one of the data banks they will access will be that held by the ADAS.

These then are the needs which we have and the ways I see that the ADAS may contribute in the future. There is only one thing certain about the future, that there will be changes. No doubt also there will be changes in the role and attitude of ADAS.

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THE ROLE OF THE AGROCHEMICAL MERCHANT

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Many new factors will affect the selling of agrochemicals to farmers in the 1980s and the advice they receive. The two main areas of influence will be:

1) legislation - voluntary and compulsory

2) the requirements of the manufacturer.

These will be the overriding considerations governing investment in the agrochemical industry and the handling and delivering of chemicals and the services given to farmer customers.

We have seen voluntary legislation with PSPS and BASIS. In recent months it has become apparent that these schemes could be infringing the Treaty of Rome. Should this be the case, there will be increasing pressure for voluntary schemes to become mandatory, backed by government legislation. The voluntary schemes have served us well but, if mandatory schemes are introduced, then in the interests of fair competition and safety to the customer, user and for the environment, changes will need to be made which will influence how advice is given.

The 1960s and 70s were years of innovation in agrochemicals and the 1980s will be the decade when many patents run out. This will lead to lower prices, more mixtures and the availability from large distributors of 'own brand' products, the ingredients for which will be purchased from base manufacturers. Profit margins will tend to fall and the ability of the manufacturer to operate large sales forces will decrease. This will pass the onus for giving field advice to the distributor or consultant. This trend has already commenced and will continue. These changes will increase the requirement of capital for the distributor, and mandatory legislation will undoubtedly lead to increased costs of storage, handling and delivery. Also, the industry will require a higher standard of technical training to enable farmer customers to receive the technical back up for the products he purchases.

What will be the role of the agrochemical distributor and what kind of business will it be ? Increasingly, agrochemicals will be handled by fewer companies. These are likely to be of three types:

1) manufacturers selling directly to farmers

2) traditional merchants, with specialist departments

3) specialist companies offering additional advice as part of their service.

These latter two types of companies will have turnovers in excess of £500,000 with the average being £2,500,000 or 1% of the UK market for agrochemicals. The smaller units will be unable to justify the compulsory standards required for distribution. Some distributors will join together to increase their purchasing power and this will further reduce the outlets available to manufacturers. These larger units will combine the roles of adviser and supplier to the farming community, possibly using computer technology to link direct with farmers. They will need to have close links with ADAS, NIAB, processors and manufacturers in order to ensure that they are aware of technical changes, although many new innovations will be generated by specialists in the field. This will be enforced by the lack of research into the use of agrochemicals for minor crops.

A service will be needed which can advise whether mixtures and sequential treatments are safe. The existing PSPS scheme does not cater adequately for mixtures or sequential treatments.

Where will trained personnel come from ? At present there are few courses run by colleges and universities that train personnel for this important area serving the agricultural industry. The trade has carried out considerable training but often after technically qualified staff have left to set up as consultants. This puts considerable financial stress on businesses.

Finally, I believe it will be the large manufacturer, the large merchant and the large farmer who will dominate the agrochemical industry in the future. Profits for all will be harder to earn. Changes are not always good but we must work to ensure that there is an efficient agrochemical distribution industry that will meet the highest standards of safety and serve agriculture efficiently.

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THE WORK OF THE RESEARCH SERVICES

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Losses of potential yield in crops caused by pests, diseases and weeds continue to amount to about 20% annually in the UK, and this is reflected in the extent of funding in official research and development in the agricultural research service (ARS), for which work in crop protection is a major component, accounting for 16% of total expenditure. It is also significant that crop protection measures represent the largest variable cost in farming. In 1980, pesticides cost farmers a total of £203M; this being made up of herbicides, £134M (66%); insecticides, £19.6M (9.6%); fungicides, £42.9M (21%); and seed treatments, £6.6M (3.2%).

The research services contribute to the farmers' decision-making on crop protection measures through short-term work on applied problems and from longer-term, strategic research. In the former, economic considerations are important factors, whilst in the latter the research scientist is more concerned with technological and economic feasibility. There are, of course, essential links between the research and advisory services, and the pesticide industry, and with farmers and growers.

The maintenance and improvement of yield and quality in modern intensive and extensive systems of crop production require the highest standards of crop protection measures. Effective control by chemicals is made more difficult by the increasing incidence of resistance to pesticides in pests and pathogens, and even in some weed species, and by the rising cost of discovering and developing new compounds. These cost increases are due largely to the more stringent requirements of registration by national and international agencies.

The Royal Commission on Environmental Pollution in its 7th Report (1979) expressed concern about pesticide use in relation to safety and to adverse environmental effects. The Commission argued that research should be directed towards achieving minimum usage consistent with agricultural objectives, and there was concern about the development of resistance to insecticides and fungicides. The Report concluded: "We accept that the continued use of pesticides is essential to maintain food supplies ...", and recommended, "... the development of strategies to combat resistance and to problems that would arise in introducing them."

The need then is for research to maintain and improve crop protection measures and to facilitate their economic introduction into commercial practice. In reviewing the role of the state research services, one can distinguish research which is of immediate value to the farmer in making decisions about crop protection, and research which will be much longer-term in its application.

Forecasting, monitoring, epidemiology and modelling

There is a continuing need for research to detect new pests, diseases and weeds, and those which have re-emerged into prominence because of the breakdown of existing control measures or because the pest or pathogen population numbers have passed the threshold levels where they cause serious damage thus requiring new control measures.

One example of pest forecasting and monitoring relates to the control of aphids on cereals. The ARC Joint Cereal Ecosystem Study involves collaboration between Rothamsted, GCRI and the Game Conservancy, and is located in a cereal-growing area on the South Downs extending over 17,000 acres. The effects of natural enemies, predators, parasites and pathogens on aphid populations are being monitored and this will lead to advice to farmers on if and when to spray and what chemicals to use. All the relevant data from the study are now being used to develop a predictive model which it is hoped will provide advice to farmers on husbandry and crop production practices which will improve natural control and minimise the need for chemical control, and be both effective and economic.

Discovery and development of new chemicals

It is generally accepted that the main thrust in the synthesis of new pesticides should be left to industry which has much greater resources for such work and a relatively large investment in it. There are, however, notable exceptions: the selective herbicides 2,4-D and MCPA, were the result of collaboration between the research services and industry, and Dr. Michael Elliott and his colleagues at Rothamsted discovered the synthetic pyrethroids. Industry's development of new pesticides tends to be empirical in approach and involves the screening of large numbers of chemicals. Ideally, the research service seeks to complement such an approach by studying modes of action and structure/activity and relationships. Increasing emphasis is being given to selectivity, resistance and the behaviour of pesticides in the environment, including persistence and biological availability both to the target organisms and to possible side effects against beneficial organisms. These types of research are generally uneconomic for industry, as is work directed towards clearance of chemicals for what are considered to be minor uses. The ARS, therefore, has a vital role to play in providing data for clearing chemicals through the Pesticide Safety Precautions Scheme (PSPS) and this can have an immediate benefit to the farmer or grower in deciding what chemicals to use.

Application and formulation

The overriding need in research on formulation and application is to develop methods which will allow chemicals to be applied precisely to the target area at the right time and in the smallest possible amount to produce effective control. Research both in the ARS and in industry has been directed towards controlled droplet application (CDA), ultra low volume spraying (ULV), and to electrostatic sprayers. The prospects for the use of electrostatic techniques are very promising and are proving especially successful with mobile pests and systemic pesticides. Reducing the droplet size can also reduce the amount of chemical required, and formulation may further reduce the active ingredient. All these researches show that in the future there may be reductions in the amounts of chemicals that have to be applied, and consequently in the risks of spray drift and environmental pollution.

Breeding for resistance

The use of crop varieties resistant to disease has for many years been the preferred way to avoid crop losses. However, when such resistant varieties are dependent on a single major gene, the host plant resistance often breaks down after only a few seasons. As a consequence, plant breeders have turned their attention to multigenic or field resistance to establish greater durability. Recently methods of more stable disease control have been established by using partial resistance or mixed varieties combined with the use of systemic fungicides. Such combinations are intended to extend the durability of resistant varieties and the useful life of fungicides, although they make greater demands on the farmer or grower for good crop management.

In the much longer-term there are prospects for genetic engineering to produce more stable, resistant crop varieties, and for the more rational development of new pesticides when we have more knowledge of the molecular basis of host-parasite relations and the ways in which they can be modified by chemicals.

Integrated control and the use of biotic agents

The incidence of resistance to pesticides has led to the development of biological control and integrated crop protection systems in glasshouse and orchard crops in which the use of predators, parasites and microbial pathogens is combined with compatible chemicals. The extension of such integrated systems to field crops is likely to be dependent on the encouragement of natural enemies by the modification of husbandry methods rather than by the introduction of predators and parasites though microbial pathogens may be applied as biocides.

Conclusions

Finally, and returning to the more immediate tactical requirements of farmers and growers, there is a need for the development of more fully integrated systems of crop protection which combine the use of cultural techniques and resistant varieties with chemical and biological controls, planned and developed for each crop. Such systems require more collaborative research and development and the devising of packages of control measures leading ultimately to the provision to the farmer of a complete crop production and protection service. Such "packages" are not likely to be provided by industry, and it is therefore important that the ARS and ADAS co-operate with industry and with contractors, consultants, farmers and growers to devote a major effort to this integrated activity.

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A CONTRACTOR'S VIEW OF FARMERS' DECISION MAKING

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Farmers' decisions are of vital importance to everyone as well as to themselves, because unless they get their decisions right all will be hungry. Farmers' prosperity is the basis of the livelihoods of most of us here today, and we all need to do our best to make sure farmers have every possible help we can provide. Obviously the best decision the farmer can make from the contractor's point of view is to use contractors on his farms. The question is, which of the farmer's operations should we be most involved with ? If a farmer has a choice between several jobs he may well do best to use a spraying contractor, because no other single operation can increase his yields or so dramatically reduce them according to how well or badly the job is done. On many farms the spraying is carried out grudgingly and nervously by people who dislike the work and fear the effects the chemicals may have on them. They are often equipped with machines that are old or not properly maintained, or both, and which have to be a compromise to do a wide variety of jobs. A spraying contractor can supply a man who likes the job, has great experience - one of our men has sprayed around 70,000 hectares - and will turn up with a machine that is appropriate for the particular job on hand. Having taken the decision to use a spraying contractor's services, the farmer should decide to deal with a good contractor who is set up with the best of machines, men and advisors, and is also properly insured against the possibility of accidents - a few are inevitable. Members of the NAAC have to be insured to an adequate standard by virtue of their code of conduct agreed to by the National Farmers' Union. For advice on what needs spraying, when and with what, the obvious choice is the local ADAS officer or someone who has the necessary BASIS qualification. These persons can advise based on approved treatments. All reputable contractors are registered with BASIS and their advisors have certificates to this effect. Having decided to use a reputable contractor, individual farmers' requirements will differ, some having all their spraying done on contract, others having just one or two specialised operations carried out. One of our farmer customers often needs to call upon two or three machines on the same day. We do all his work and are able to give him very favourable prices and service as a result. On other farms we may only be required for, say, defoliation of an oilseed rape crop or some similar operation. Contractors have a particularly valuable role to play in aerial spraying. For example, in pea moth spraying, the cost of damage from tractor wheels and other application expenses associated with tractor mounted machines can make spraying by helicopter a far more economic alternative.

The worst way of using a contractor, but still better than not doing so at all, is the 'fire engine' call. This is needed when spraying is so far behind that help has to be called in to cope with a rampant pest problem at the last moment - or worse, later. The result of such a decision is often only slightly better than that which occurs when a farmer decides to leave the pest uncontrolled altogether. If I could attend to all such jobs each year, my profits would probably double, and those of some of my farmer friends would also increase substantially. Contractors can often face a particular problem of which customer should come first when there is an epidemic. It is quite untrue that we run decibel tests on our telephones and then attend to whoever is shouting the loudest. We try to forestall the panic resulting from sudden epidemics by anticipating their start and completing the work on some clients' farms before the epidemic peaks. Then we can cope with the quick decision makers, leaving the 'fire engine' calls to be attended to when possible.

There are so many aids to decision making these days, with manufacturers' leaflets so beautifully illustrated that they could take prizes in photographic competitions. Manufacturers give away superb magnifying glasses, some even illuminated to assist with the matching of plant disease symptoms to their illustrations, to facilitate identification. Instructions on how to deal with the diseases, once identified, are legion, with manufacturers' computer linked enquiry services, more leaflets, demonstration farms, and for non-readers like myself, the Agrifax tapes from Ciba-Geigy. All these aids greatly improve farmers' capacity to make sound decisions. They are, coupled with that provided by the state research and advisory services, a major source of information for contractors. Unlike many farmers, contractors specialize in agrochemical applications and so are more likely to have their hands on the best information for making correct decisions on crop protection.

Contractors' strategic decisions are at least as difficult, yet important to our livelihood, as those we have heard about in this symposium. They include: how much less can be charged this year ? which machine will be fashionable next year ? will electrostatic sprayers make all our existing machines obsolete ? how soon will ADAS, consultants, and the written word make our advisory role unnecessary, so that we can concentrate on the application of chemicals ? In the meantime we try to help the farmers make the very best decisions.

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AN INDEPENDENT ADVISER'S VIEWPOINT

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The future needs and prospects for independent advisers in agriculture should not differ too greatly from those of the farmer because they are generally working as an extension of the existing farm management. In the future, increasing pressures from economic, technical and environmental factors will encourage the crop protection decision maker to apply more precision to the following processes: 1) identification and analysis of problems, 2) selection of suitable and safe remedies, 3) forecasting the likely response to treatment, and 4) application of the remedy. This paper briefly considers these processes.

Identification and analysis of problems

The historical weed problem is probably the easiest to identify and good field records are beneficial when weed control strategies are being planned. Any plan made at this stage, however, should take into account the expected cost/benefit ratio. This is a highly subjective assessment because it has to be based mainly on farmers' memory of the area and intensity of weed infestation. To make the decision more objective, information is needed on the likely weed populations and their effect on crop yield. The latter will require data on 1) germination patterns of weed species, 2) the economic threshold levels of weeds at varying crop densities, 3) the effects of weed removal at different phenological stages of the crop, 4) the effects of weed survival on the harvesting and subsequent cleaning requirement of the crop and effects on its storage and marketing, 5) the effects of different agronomic practices and environmental conditions on weed populations, and 6) the requirements for a treatment to be successful.

The identification of weed problems in growing crops can be more objective, in that the real situation may be assessed and treatments selected accordingly, but again information is needed on the interactions of weed populations, crop density and time of weed removal to achieve optimal weed control.

Advance planning of disease control strategies can only be broadly considered. It is based on knowledge of the sensitivities to disease of the cultivars to be grown but not on the conditions which the crops will experience throughout their development. Practical decisions at the planning stage are therefore limited to determining the intensity of monitoring or assessment during crop growth, which will depend on disease susceptibility. If the prevailing environmental conditions invariably result in the development of a specific disease, a prophylactic control strategy will be drawn up.

During the season, the identification and assessment of disease levels, varietal susceptibility to disease, crop yield potential and crop phenological stage are used to determine the appropriate control measures. As crop yields increase, the economic threshold levels for disease control decrease. Provided that fungicide costs do not rise in relation to crop values, there will be an increasing requirement to apply fungicides to more crops. The wheat crop and wheat mildew provide a good example of this. Using the formula proposed by Large and Doling (1963) :

$$\% \text{ yield loss} = 2\sqrt{(\% \text{ disease infection on top 4 leaves at Feekes Large G.S. 10.5 (Zadoks 59)})}$$

the following values given below are arrived at for economic threshold levels based on the cost only of a control chemical. The value of grain is taken as £110 per tonne and the cost of the control chemical £12 per hectare.

Crop Yield t/ha	Crop Value (£)/ha	Economic Threshold Yield Loss (%)	% Leaf Infection (GS 10.5) Required for Threshold Loss
10	1100	1.09	0.297
8	880	1.36	0.462
6	660	1.81	0.819
5	550	2.18	1.188
4	440	2.72	1.848

If infection levels were to reach 5% the yield losses would become:

Potential Yield t/ha	Value £/ha	Yield Loss (%)	Value of Yield Loss £/ha
10	1100	4.47	49.17
8	880	4.47	39.37
6	660	4.47	29.50
5	550	4.47	24.59
4	440	4.47	19.67

It can be seen that the economic threshold yield losses are below those detectable in field trials, raising the question, 'is it possible to acquire better data ?'.

To obtain maximum benefits from disease control, it is important to apply the chemical at the earliest opportunity. If applications are to be other than prophylactic, much more information is needed for each crop, viz. 1) its yield potential, 2) the likely development of disease, 3) the efficacy and persistence of any control treatment which may be applied, and 4) the relationship between disease level, leaf area index and the sensitivity of the crop at different phenological stages.

Crop growth models currently under development within the ARC, run in parallel with epidemiological models, may in the future be of great value in providing this information on a regional, farm or even on a field basis, rendering decision making in disease control much more precise than it is at present.

Selection of suitable and safe remedies

In the past, advice has been relatively simple and the speed of technological change relatively slow, so that it has been easy to select the most economic control measures. However, many new product mixtures and compounds are now becoming available. The expiry of patents and the innovation of new production techniques will further increase the number of products available and help to stabilise and, in some cases, reduce costs. In general this should be good for farmers and growers. Though their fixed costs have increased, they can select the most cost effective of options available to them for pest control and so offset part of the more general increase in costs.

The continuation of a strong 'approvals' scheme would ensure that products are closely matched to crops and pests. However, there is a major difficulty: the scheme can only approve label texts as submitted by the manufacturer. The retention of an efficient PSPS will maintain farmers' confidence in the approved chemicals in terms of safety to the crop, the operator, the environment and the consumer.

Work carried out by the state organizations, which include ADAS, NIAB and ARC institutes, is very valuable to farmers and agronomists but much of the information they generate is not as readily available as it should be, though the machinery for its dissemination appears to exist. For example, every six months the WRO produces a guide to its publications. Copies of the publications used to be available at reasonable cost but, in recent times, the restrictions of copyright as applied by the publishers have caused costs to increase to unacceptable levels. So there is a widening information gap between the bodies involved in agricultural research and those working at the farm level. There is also a need for the continuation of independent testing of products, perhaps best done by government organisations.

One area where more information is needed is in the field of ecosystem conservation. It is often assumed by those not concerned with food production that the majority of those who are are intent on spoiling the countryside in their ceaseless pursuit of profit. This mistaken assumption could have very far-reaching consequences in the future, if not countered by the presentation of the responsible farmers' viewpoint.

Forecasting of likely responses to treatment

The forecasting of the likely responses to a treatment is an inherent part of crop protection decision making. In weed control, for example, an application of a residual herbicide before the germination period of the weed should be effective whereas one which only partly covers the germination period may allow some weed seedlings to escape, so that the weed problem recurs. Diseases, particularly the more 'mobile' ones, represent a continuing problem in that re-infection of the crop may occur following treatment. The level of fungicide in the crop may be expected to decrease with time as the plant dilutes or degrades the fungicide until its concentration falls below that which is toxic to the fungus, allowing re-infection to occur. Is it possible to predict the decline of fungicide concentrations in relation to the density of the crop and rate of degradation ? If so, it should be practical to apply the minimum amount of fungicide necessary to protect the crop throughout its most vulnerable stages. Is it also the case that the concentration of fungicide within an individual crop plant will vary with the mass of the crop ? In other words, would crops of five and fifteen tons per hectare respectively contain the same concentration of fungicide immediately following an application of a similar amount to each ? Also, would this influence the rate of decline of concentration in the crop ? Answers to these questions would be of considerable value to those advising on farms and do not appear to be available from state or commercial sources.

Application of the remedy

The application technique chosen must be related to the position and accessibility of the target, the mobility of the material through the air, plant or soil, its mode of action in and its retention by the target. Better information on these aspects would be beneficial when selecting appropriate application methods. Some product literature already contains advice on spraying technique, e.g. nozzle size and operating pressure for the effective application of the material. Factors affecting or limiting the performance of materials are not sufficiently well publicised in manufacturers' literature and more information on this should be given so that adjustments can be made to the application rates and methods as required. Time of application in relation to crop development is important for the effective removal of the pest problem and, in the case of hormone-type herbicides, the safety of the crop. There is scope here for the development of procedures to predict crop developmental and phenological stages with more precision than is currently possible.

Summary

All the processes with which we are dealing are changing in relation to one another and the rates at which they change are determined by influences, some of which are common to all processes and some of which are not. As knowledge of the factors influencing development of organisms, both crops and pests, increases, our ability to simulate complex pest-weather-crop interactions will improve. The success of this work will lead to simulation models which will enable, after the initial conditions of a crop have been specified, the likely development of disease and pest epidemics to be predicted. This will put decision making on a far more precise basis than at present. The successful development of models for practical use in crop protection in agriculture will necessitate the multi-disciplinary approach with a major input coming from environmental physiologists. Ultimately, we may look forward to the time when it is possible to use these models on microcomputers at the farm level. As a small step towards this objective, we are currently using a simple model as a guide to the timing of fertiliser and herbicide applications to wheat crops.

Reference

Large, E.C. & Doling, D.A. (1962) The measurement of cereal mildew and its effect on yield. Plant Pathology 11, 47-57.