SESSION 7

THE USE OF COMPUTER AIDS IN CROP PROTECTION

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POSTER PAPERS 7A-1 to 7A-8
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SESSION 7

A NEW DEVELOPMENT - THE PESTICIDE DATABANK

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ABSTRACT

The information used to prepare the 7th edition of The Pesticide Manual has been stored in a computer and is being regularly updated. Hard copy new editions can be produced when appropriate. The computer files, 'The Pesticide Databank', can be searched on-line via the telephone network. They will shortly be available on tape.

INTRODUCTION

The first edition of The Pesticide Manual (Martin 1968) was introduced by Hubert Martin. When he was Director of the Science Service Laboratory, Ontario, it had been preceded by a series of mimeographed publications by Hubert Martin, E.Y. Spencer and their colleagues (Martin & Miles 1952). The Pesticide Manual drew on these for details of some old compounds that lacked patent coverage (Martin 1968). Since then a further six editions of The Pesticide Manual have been published and the current 7th edition (Worthing & Walker 1984) contains details of about 550 active ingredients which are in use, and of a further 300 which have been superseded by more effective or less hazardous compounds. This publication is regarded world-wide as the leading reference work on active ingredients used in crop protection, for the control of pests in public health and of animal ectoparasites, and on plant growth regulators. Some users have stated that the information it contains on common names is more valuable and more up-to-date than that in their national standards!

Experience with preparing the earlier editions had shown that the typing of the text for each entry was time-consuming and ran the risk of introducing errors, especially when dealing with complicated chemical names, strings of digits in patent numbers and in toxicological data.

HARD COPY

Accordingly, the text for the 7th edition of The Pesticide Manual was stored in a computer at the Commonwealth Agricultural Bureaux at Farnham Royal. Index terms were chosen at the same time. Various automatic checks are performed on parts of the data, for example to verify that the numbers of opening and closing brackets and parentheses in chemical names agree. Entries on individual compounds can be retrieved easily and these corrected or updated without having to retype the whole entry with its attendant possibility of introducing fresh mistakes.

The data on the entries was processed and used to typeset the copy for the 7th edition. Similarly, the indexes were generated and set. After the chemical structures had been added the text was printed from the camera-ready copy thus obtained. New editions can be produced easily because the data are kept up-to-date.

TABLE 1

Subject areas in The Pesticide Databank which may be displayed

Entry numbers
Entry names
Molecular formulae
Relative molecular masses
Wiswesser Line-formula notations
Common names - with organizations accepting them, national exceptions
Chemical names - in accord with IUPAC rules
  - as used by Chemical Abstracts
Chemical Abstracts Registry numbers
Trivial names
Code numbers - used by WHO or USDA
  - used by manufacturers or formulators
Development - first scientific reference etc
Early patent numbers
Trade marks - for main manufacturers or suppliers (or of mixtures if they are the only formulations available)
Physical and chemical properties - melting point, boiling point, refractive index, density or specific gravity, vapour pressure, solubility in water and common organic solvents (or those used for formulations), stability to pH, to light and heat
Biological activity - type of activity (using specified terms)
Use - principal uses
Principal crops treated - using specified terms
Scientific names of principal pathogens, pests and weeds controlled
Toxicology - acute oral, percutaneous and chronic LD50 values for leading species, no-effect levels, toxicity to birds and fish, mutagenic or teratogenic tests etc, acceptable daily intake for man
Species on which these tests made (using specified terms)
Formulations in use - containing a single active ingredient or mixtures
Discontinued formulations - containing either a single active ingredient or mixtures
Analysis - Statement of method(s) used for formulation or residue analysis with references to methods recommended by manufacturer, Collaborative International Pesticides Analytical Council Ltd or Association of Official Analytical Chemists
Index terms - Wiswesser Line-formula notations
  - molecular formulae
  - official and manufacturers' code numbers
  - common names, chemical names (abbreviated), trivial names, trade marks
  - Chemical Abstracts Registry numbers

TABLE 2

Items under which entries may be searched on-line

Entry numbers
Entry names
Molecular formulae
Wiswesser Line-formula notations
Code numbers - official (WHO and USDA) and manufacturers'
Names for parent compound(s) and for mixtures
- common names of main entry and for other components in mixtures
- chemical names (abbreviated) for parent entries
- trivial names for parent entries
- trade marks for single active ingredient and for mixtures
Chemical Abstracts Registry numbers for mixtures and for all their components
Names for parent compound(s)
- common names for main entries
- chemical names (abbreviated)
- trivial names
- trade marks for single active ingredient
Chemical Abstracts Registry numbers for parent compounds, important salts or esters
Principal crops treated
Principal pathogens, pests and weeds controlled
Animals on which toxicological tests are mentioned

THE PESTICIDE DATABANK

It was realised from the outset that the information in the computer could be arranged for searching on-line using standard equipment linked to the telephone network. Indeed, the data were assembled with this in mind. In practice, the format has been modified and improved since the hard copy was printed.

The information contained in the databank which can be displayed is shown in Table 1 and the items which may also be searched are listed in Table 2.

Both hard copy and on-line versions have limitations but they are different ones. The hard copy has problems with length; so if full details were included on all 850 or so entries (including compounds no longer in use) the text would run to two volumes and be more expensive - one is often asked for The Pesticide Manual to be supplied as a paper-back so as to fit into the purchaser's pocket! Moreover, like all reference books, the text becomes obsolescent the day the data are released for processing and printing. The on-line version, in contrast, uses visual display units and printer terminals which cannot easily cope with italic type, small capitals or Greek letters (all of which are used in many chemical names). In addition, subscripts and superscripts present problems. For the time being, this problem has been overcome by showing the chemical names in a simplified, but recognisable, form with Greek letters spelt out in full. Some terms normally displayed with subscripts or superscripts have their meaning clear without them, for example LD50, pKa (which loses its italics and subscript) and molecular formulae (C17H12C1004). An indication of superscripts has been retained for cases such as

dodecachloropentacyclo[5.2.1.$0^{2,6}$.$0^{3,9}$.$0^{5,8}$]decane

where failure to differentiate the superscripts would cause confusion within the chemical name. There are methods of linking adjacent entries so that their length is not a limitation. We are also working on the presentation of chemical structures on-line.

ADVANTAGES OF ON-LINE USE

The possibility of regular and frequent updating of the database is an important benefit. Several users have asked why a few entries in the 7th edition are not in alphabetical order. After the computer entries were processed, new common names that had been approved by BSI were added to the page before printing took place, thus the name 3,6-dichloropicolinic acid was updated to clopyralid. Assuming regular updating every three months, new common names can be included three to six months after their approval. Similarly new formulations, trade marks and mixtures can be added. Thus the entries in The Pesticide Databank do not become out of date, other than for the short time between two updates.

The main advantage of searching the on-line version is that various simple questions can be asked initially and subsequent questions added in the light of earlier replies; also far more indexes are available than in the hard copy (see Table 2). This approach is illustrated in the examples below, the number of compounds listed in each has deliberately been kept low in order to illustrate in the limited space available the principles involved. Instructions sent to the computer have been preceded by [KEY IN] and its answer by [REPLY]; commands and terms selected are shown in CAPITALS. An asterisk * means any number of characters may follow the text.

(a) How many compounds behave as herbicide safeners?
[KEY IN] SELECT ACTIVITY = herbicide safener
[REPLY] 4 ACTIVITY = herbicide safener
What are these four compounds?
[KEY IN] TYPE FORMAT 1/1-4
[REPLY] Item 1 N,N-Diallyl-2,2-dichloroacetamide
[REPLY] Item 2 Cyometrinil
[REPLY] Item 3 Naphthalic anhydride
[REPLY] Item 4 Oxabetrinil

(b) Does the Databank contain compounds with a molecular formula $C_{10}H_{13}NO_2$?
[KEY IN] SELECT MOLECULAR FORMULA = C10H13NO2
[REPLY] 2 MOLECULAR FORMULA = C10H13NO2
There are two such compounds. What are they?
[KEY IN] TYPE FORMAT 1/1-2
[REPLY] Item 1 Xylylcarb
[REPLY] Item 2 3,5-Xylyl methylcarbamate

(c) Are any 1,4-oxathi-ines included?
[KEY IN] SELECT WISWESSER = T60 DS*
[REPLY] 3 WISWESSER = T60 DS*
Three, using the Wiswesser Line-formula index. What are they?
[KEY IN] TYPE FORMAT 1/1-3
[REPLY] Item 1 Carboxin
[REPLY] Item 2 Oxycarboxin
[REPLY] Item 3 2,3-Dihydro-5,6-diphenyl-1,4-oxathi-ine

```
(d)  What code numbers have the digits 107?
     [KEY IN] EXPAND   Code Index = 107
              A  104   'Velsicol 104'
              B  106   'BAS-107W'
              C  107   'EL-107'
              D  107   'HAG-107'
              E  107   'NRDC 107'
              F  110   'EL-110'
              G  111   'DN 111'
              H  111   OMS 111
     What is (C) 'EL-107'?
     [KEY IN] C
     [REPLY]  1  C of expand
     What is this?
     [KEY IN] TYPE   FORMAT 1
     [REPLY] Item 1  Isoxaben
     Can I have further details?
     [KEY IN] SELECT   NAME = Isoxaben
     [REPLY]  1 Isoxaben
     [KEY IN] TYPE   FORMAT 3
     [REPLY] Item 1
     ENTRY NUMBER
       07585
     ENTRY NAME
       Isoxaben
     COMMON NAMES
       isoxaben (BSI, draft E-ISO, (m) draft F-ISO, draft ANSI);
       the name benzamizole was formally used and is retained in New Zealand
       until isoxaben has passed the ISO letter ballot
     CHEMICAL NAME (IUPAC)
       N-[3-(1-ethyl-3-methylpropyl)isoxazol-5-yl]-2,6-dimethoxybenzamide
     CHEM ABS NAME
       N-[3-(1-ethyl-1-methylpropyl)-5-isoxazoyl]-2,6-dimethoxybenzamide
     CHEM ABS REG NOS
       [82558-53-7]
     DEVELOPMENT
       Its herbicidal properties were described by F. Huggenberger et al.
       (Proc. Br. Crop Prot. Conf. - Weeds, 1982, 1, 47).  Introduced by Eli
       Lilly & Co.
     PATENT NOS
       (GBP 2 084 140) as
     FIRMS CODE NOS
       'EL-107'
     TRADE MARKS
       'Flexidor'
     MOLECULAR FORMULA
       C18H24N2O4
     RELATIVE MOLECULAR MASS
       (332.4)
     WISWESSER LINE NOTATION
       T5NOJ  CMVR  BO1  FO1&  EX2&2&1
```

Example (d) illustrates how more information can be displayed on an entry and the advantage of frequent updates; the name isoxaben, which was adopted by BSI in August 1984, is in The Pesticide Databank now - the 7th edition of The Pesticide Manual listed it under benzamizole.

(e) How many methylcarbamates or dimethylcarbamates are systemic insecticides?

```
[KEY IN] SELECT   ACTIVITY = systemic insecticide AND
                  (NAME = methylcarbamate OR NAME = dimethylcarbamate)
[REPLY] 97 ACTIVITY = systemic insecticide
[REPLY] 40 NAME = methylcarbamate
[REPLY]  4 NAME = dimethylcarbamate
[REPLY] 12 ACTIVITY = systemic insecticide AND (NAME = methylcarbamate
                      OR NAME = dimethylcarbamate)
```

There are twelve such compounds. What are they?

```
[KEY IN] PRINT   FORMAT 4/1-12
[REPLY] PRINTED  FORMAT 4/1-12
```

An alternative to typing the replies on-line is to have them printed and sent by post; this could be cheaper if the entire entries are required for several compounds.

TAPES

It can easily be arranged for customers to buy their own tapes of the entire Pesticide Databank which they can then search on their own computer.

CONCLUSION

The Pesticide Databank complements the information available in The Pesticide Manual and will be updated every three months. It is available on Pergamon Infoline and will shortly be so on several other Hosts. Searches using several concepts can be combined speedily and efficiently. Improvements will, no doubt, continue to be made but already The Pesticide Databank can be searched on-line and it is about to become available on tape.

ACKNOWLEDGEMENTS

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CONVERSION OF RESEARCH MODELS TO MICRO-COMPUTER ADVICE ON CEREAL APHID CONTROL

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ABSTRACT

The development of research on cereal aphid damage to winter wheat is described, from early field-cage work on *Sitobion avenae* through a research simulation model to current development of computer-based on-farm advice on aphid control. Evidence is provided on farmers' spraying strategies from the 1970s and, in more preliminary form, from 1984. Aphid control decisions have frequently been irrational and uneconomic in the past and appear still to be based on inadequate use of available information in the 1980s. The prospects for developing an advisory package based on the economics of insecticide application and the aphid yield loss/growth stage relationship are discussed, with the aid of an outline of farmer inputs and a description of the way the program would work in practice.

INTRODUCTION

Outbreaks of the grain aphid, *Sitobion avenae* (F.) on wheat in the UK have occurred sporadically, at least since the 1960s (Vickerman & Wratten 1979). Their irregular occurrence but high average yield loss (12.5%) caused in outbreak years (George & Gair 1979) have led to comprehensive series of open-field and field-cage experiments aimed at establishing relationships between aphid population levels, crop growth stage and yield loss (e.g. George & Gair 1979, Lee *et al.* 1981). These relationships are now well established and have appeared as simulation models in 'applied' journals (e.g. Watt *et al.* 1984). They have led to the well-known ADAS (MAFF) cereal aphid control recommendations, based on five aphids per ear at flowering and increasing (MAFF 1982). However, there is evidence from farmer surveys carried out in the 1970s and recently that spraying against cereal aphids is still frequently irrational economically, with large proportions of the cereal acreage receiving pesticide inputs. Clearly, research results are not being translated into effective advice to farmers. This paper briefly reviews the relationships on which a simulation model was based. It then describes attempts to convert what is still essentially a research model into a computer-based advisory tool which makes use of aphid data and cereal-growing economics at the individual farm level.

CROP-LOSS WORK LEADING TO THE SIMULATION MODEL

Because of the unpredictability of the outbreaks of *Sitobion avenae*, artificially established populations in field cages (2m x 2m x 2m) have been used at Southampton University. These also permit the use of single-species, clonal, virus-free aphid populations, the levels and timing of which can be manipulated. The cages have no effect on crop yield (Wratten *et al.* 1979) and yield-losses due to aphids match those from open-field spray trials (Watt *et al.* 1984).

The amount of damage caused by grain aphids was shown in the early experiments to depend on the aphid population size and its timing, with the effect of a given number of aphids declining as the crop matures (Lee *et al.* 1981). For example, feeding up to G.S. 71 on the scale of Zadoks *et al.* (1974) reduced mean weight per grain at a rate of 28.4 mg/100 aphid unit days, where one aphid unit equals one fourth instar/adult or three earlier instars. This rate declined to 1.7 mg/100 units by G.S. 71 to 77 and to 0.5 mg/100 units by G.S. 85.

DEVELOPMENT OF THE MODEL

The model used data on yield loss in relation to growth stage and aphid number and aimed to quantify the economic value of control at different stages of outbreaks of various intensities. The model calculated: the aphid population density (A) for each day (j) of the infestation (by interpolation between the aphid counts on particular sample dates), the daily and cumulative (d_j) yield losses

$$d_j = \sum_{i=1}^{i=j} A_i E_i$$

together with the amount of damage saved by an insecticide spray (s_j):

$$s_j = (1-d_t) - (1 - d_j)(1 - W)$$

where E_i is the proportional yield loss per aphid per day on day i; d_t the total calculated yield loss and W the proportional wheeling loss incurred during spraying. The latter, set at 3%, is obviously removed if the use of tramlines is simulated. The model also calculated the cumulative and avoidable damage in monetary terms (D_j and S_j respectively):

$$D_j = TGd_j$$

$$S_j = TGs_j$$

where T is the expected yield (t/ha) and G the grain price (£/t).

Examples are given of outputs from the model, for high (Fig.1) and low (Fig.2) aphid populations. In Fig.1 the financial return from spraying became a net loss one day before the aphid population reached its peak and one week before it declined to zero. If spraying had taken place at the beginning of flowering (7 aphids/stem) a 12.8% gross level of damage would have been avoided. A simulation for a smaller population, reaching 40 aphids/stem (Fig.2) revealed that a profit could be gained for only 4 days after the economic threshold (MAFF 1982) was reached. This comparison of the economics of controlling two different populations in the 1970s emphasises the need for careful matching of the costs involved in growing and spraying cereals to decisions on when to spray, if at all. It is this matching of on-farm economics to a changing need for control as the season progresses which is the aim of the simplified model for farmers' use. Evidence that there is an urgent need for such advice is given below.

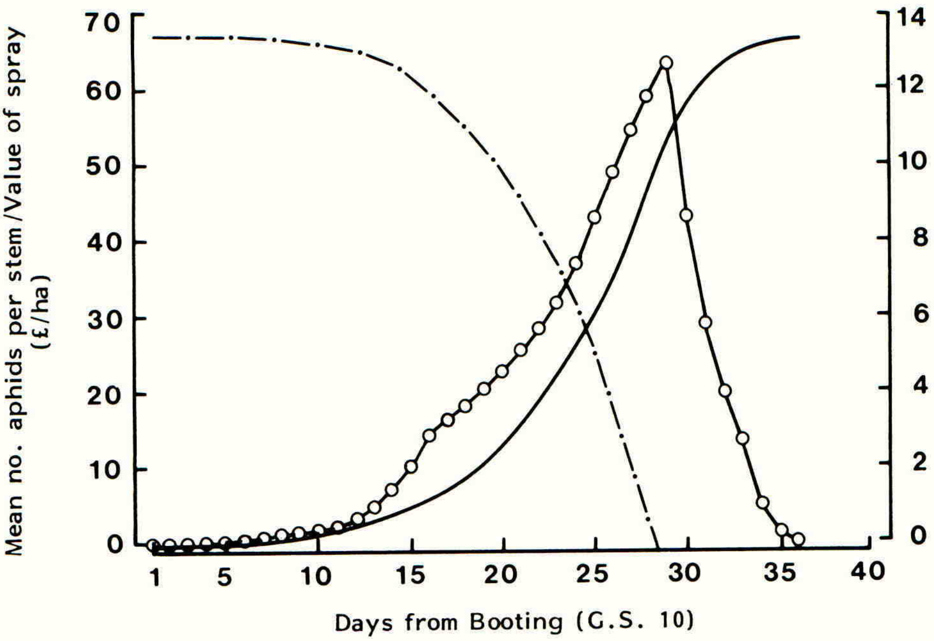

Fig.1. Cumulative percentage crop damage (——) and the value (£/ha) of a crop spray (-·-·) against aphids (o—o). Treatment by tractor-applied insecticide costing £5.9/ha; grain price £117.50/t; expected yield 6t/ha.

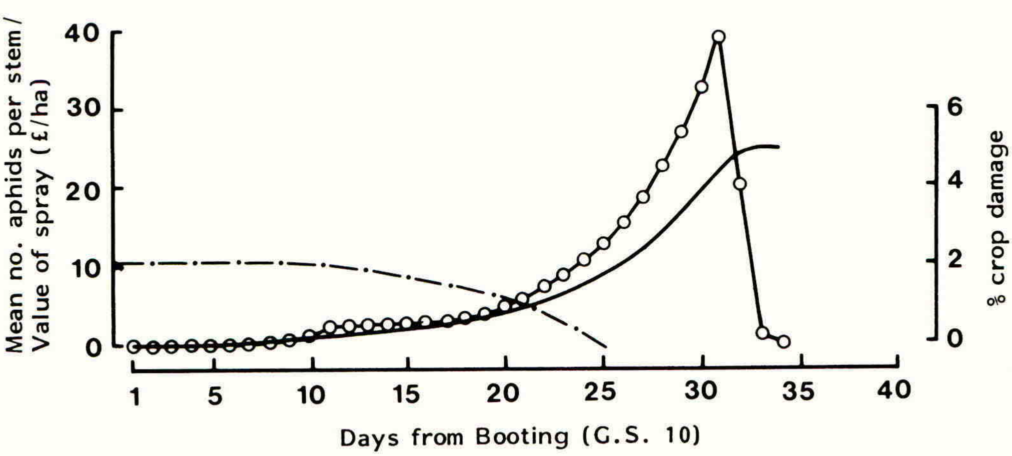

Fig.2. As Fig.1 but based on a lower aphid population

SURVEYS OF APHIDS AND APHICIDE USE IN CEREALS

Details of data collection methods for aphid numbers and insecticide usage are given in Watt *et al.* (1984). For southern and eastern England in 1975-1977, the percentage of the cereal acreage sprayed each week was assessed, together with the profit obtained and the maximum profit obtainable from spraying at its most efficient in terms of date. An example of one of these analyses is given in Fig.3 showing that the average result of farmers' spraying actions in that year was a net loss of £5/ha. In the other cases, although there was large regional and yearly variation, farmers never obtained maximum achievable profit. The average regional 'profits' for treated areas ranged from £14/ha when £58/ha was achievable to a loss of £22/ha when the maximum return was itself a loss of £3/ha. Losses incurred in particular weeks were as great as £29/ha (Watt *et al.* 1984).

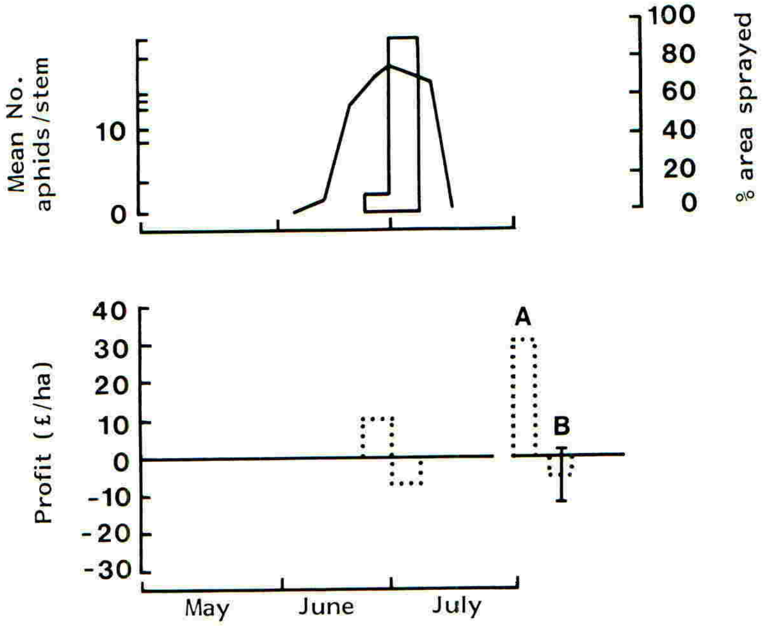

Fig.3. Upper half: mean aphid numbers (———) and percentage area of crop sprayed (of total area sprayed) each week (block); lower half: the profit for each week, the average profit (B) for the whole period of treatment (adjusted according to the area sprayed during each week of the infestation) with an estimate of the range of the average profit obtained, and the maximum profit possible (A). (Grain price and expected yield as Fig.1; control costs based on the range of insecticides and methods of application used by the farmers surveyed).

In the years of the above surveys, it was common for pesticides to be applied at or after the aphid population peak (e.g. Fig.3), when most yield loss had already been incurred (Figs.1 & 2). It is likely that in the 1980s there is a greater awareness of the cereal aphid problem together with an increased use of 'tank mixes' (in this case, insecticides added to fungicides applied at or soon after ear emergence for the control of *Septoria* and *Cladosporium*, among other diseases). These two factors probably increase the likelihood of prophylactic spraying. Preliminary results from a survey of farmers' aphicide use in 1984, returns from which were still arriving at the time of writing, indicate that of more than 7000 ha surveyed, mainly on larger-than-average farms in southern England, 60% received a summer aphicide application, seven insecticides were involved and 40% of the sprayed area was in the form of fungicide tank mixes. The modal spray date was in the week July 2 - 8, which was approximately three weeks after the beginning of flowering. Further analysis will probably confirm that much of this aphicide spraying was of low economic benefit.

CONVERSION OF THE MODEL TO A WORKING ADVICE SYSTEM

The model described earlier does not include an aphid forecasting element, as it uses actual aphid populations as recorded, with interpolations. If a forecasting aspect were not introduced in a practical model, its use would be restricted in that it could indicate only that economic damage had begun, rather than that it was about to begin. The developments described below, therefore, require simple inputs on local weather conditions to assess the likelihood that a population will reach a particular level. This enables the model to calculate the appropriate minimum interval between crop inspections. In outline, the farmer would enter data in the following way onto his data sheet, notebook or his own micro-computer; alternatively, data would be entered onto the consultant's micro:

1. Count percentage of stems with one or more aphid present on flag leaf or ear
2. Assess growth stage
3. Input price/ha of anticipated chemical control (+/- labour costs)
4. Estimate expected yield (t/ha)
5. Estimate or call up expected selling price for feed/milling/seed wheat.

The system then calculates the financial return, if any, from an immediate spray under the above-on-farm conditions. Three recommendations are possible:

1. Do not spray; no further opportunity of making a profit from aphid control that season
2. Spray urgently; recoverable yield loss imminent
3. Do not spray but return n days later and reassess the percentage of stems infested. In this case, the value for n would be determined by growth stage (data already entered) and by the weather (data already entered or added by central computer).

DEVELOPMENT AND MARKETING OF THE ADVICE SYSTEM

The intention is to run the system on a pilot basis in 1985, with the aim of marketing it initially through independent crop consultants. This will be as part of a larger, existing software package which includes fertiliser, herbicide, fungicide and financial advice. This proposal has the advantages of independent advice, and therefore credibility, and the combination of the aphid software with existing packages avoids the unrealistic promotion of an aphid-only program.

The most difficult part of any so-called applied research is to progress to the practical use of the results. The above outline shows how it is intended to make that progression in cereal aphid control; any improvements towards more rational and economically sound spraying decisions should be timely in view of the increasing environmental and economic pressures on U.K. arable farmers.

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A COMPUTERISED DECISION MODEL OF SUGAR BEET INSECT AND DISEASE CONTROL

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ABSTRACT

A computerised decision model is described which presents the user with decision problems and choices for the control of sugar beet insect pests and diseases in eastern England. The model is designed to illustrate the pest control decision making process for students and advisers. Users must obtain information on the crop, its insect and disease problems, and potential solutions before using the model. During play users are given information on weather, crop state, and some advice on pest status, and they make five control choices each season. Output at the end of each season gives a summary of actions taken and outcomes in terms of profit. Alternative strategies can be compared by replaying individual seasons.

INTRODUCTION

One of the most difficult aspects of training pest management students or advisers is to provide an opportunity to practise making real pest control decisions. It is relatively straightforward to describe pests and their biology, their relationships with a crop, and control techniques. However, it is not so easy to get across the problem of interpreting such information, particularly with the degree of uncertainty that a farmer often, or usually, faces when trying to decide if, how, or when to take a control action.

A computer game can be used to simulate such decision problems and can also serve as a focus for learning about pest biology and control. The trainee can be put into the difficult position of a farmer decision maker faced with many choices and little information, making him approach the pest problem as the farmer sees it, a management decision problem, not a biological or ecological process. The use of such a computerised decision model can, therefore, compliment the biological components of pest management training.

Computer models have been used in pest management training in universities (Logan & Fittante 1978, Arneson *et al*. 1978, Troester & Ruesink 1982) for both students and farmers. Much of the emphasis of these models has been on increasing understanding of the biology of individual pests (apple mites (*Panonychus ulmi*), apple scab (*Venturia inaequalis*), and black cutworm (*Agrotis ipsilon*), respectively) and interactions with natural enemies and pesticides, rather than as decision models.

The sugar beet insect pest and disease model described here is primarily designed to demonstrate a decision making problem; the biology is secondary and is taught separately prior to using the model.

MATERIALS AND METHODS

An interactive computer program was developed on a mainframe computer in BASIC. This has been adapted for microcomputers, particularly the Apple //e, with 48k memory capacity.

The program presents the user with five decision points during the sugar beet growing season and offers the choice of applying any of the appropriate pesticides recommended by British Sugar plc for use by sugar beet growers in England (Table 1). At each decision point the user is presented with

TABLE 1

Decision points, pests, and pesticides in the model

1.	March	nematodes, symphylids, pygmy beetles, millepedes, springtails, and wireworms	thiofanox, gamma HCH, bendiocarb, oxamyl, carbofuran, aldicarb, carbosulfan
2.	May	flea beetles	gamma HCH
3.	June	aphids/viruses	pirimicarb, demeton-S-methyl
4.	July	aphids/viruses	pirimicarb, demeton-S-methyl
5.	August	powdery mildew	triadimefon, sulphur, nuarimol

information (weather, crop, or pest presence) that is appropriate to that time of year and that particular season (Table 2).

TABLE 2

Information given at decision points

1.	March	Early or late sowing Seedling pest problem seen/not seen in recent years
2.	April	Good or gappy emergence
	May	Flea beetles seen/not seen
3.	June	Regional aphid warning
4.	July	Regional aphid warning
5.	August	Weather cool, medium, or hot

At the end of each season a summary table of inputs, growth conditions, and profit is displayed (Table 3). Before going on

TABLE 3

Output information given at the end of each season

1. List of chemicals used
2. Total cost of chemicals
3. Estimated potential loss from aphids/viruses for region
4. Beet growing conditions (good, normal, poor)
5. Net profit for sugar beet, other crops, and total

to the next season there is an opportunity to replay the same season using different inputs, in effect to test the outcome of a "neighbour's" control actions. Pest and crop values for 15 seasons are stored within the program, and these seasons can be accessed in different orders so that particular groups of users can gain "experience" of good and bad years in different sequences of play.

Insect pest and disease control on 40 ha of sugar beet is the only management input the user puts into the game. Other management inputs are not controllable and preset variable and fixed costs are subtracted automatically from each year's gross revenue. In addition, the remaining area of the farm is assumed to be in other crops which are not managed by the user. The income from those crops contributes to overall farm income and fluctuates independently of sugar beet pests and income.

Values for pest losses are based on field records. Potential losses from aphids/viruses vary from 1-25%. Use of gamma HCH against soil and seedling pests increases aphid/virus loss by 2% due to killing natural enemies. Losses from soil pests below ground rise each season by 1% from their level after control in the previous year. For simplicity, crop rotation is not considered explicitly. Soil pest control is assumed to take place on the farm as a whole, and so carries over to the next beet crop. Flea beetles appear sporadically (in three seasons) with potential losses up to 8%. Nematodes do not cause any losses in the model (i.e. they are not present on the farm); however, players have the option to apply controls against them anyway. Powdery mildew losses can be up to 10% and are related to weather and crop yield. With a low crop yield (assumed in hot dry weather) powdery mildew is highest, with a high crop (assumed with cooler, wetter weather) powdery mildew losses are lower.

Values for the effectiveness of pesticides were determined from published trials, commercial advertisements, and discussions with sugar beet researchers. Slight insecticide resistance develops to aphicides cumulatively each time an aphid warning is issued. Prices are based on manufacturers' recommended prices for standard application rates.

A pre-game learning session for students takes about 1 h, 15 seasons' play takes about 90 min, and post game discussion takes another hour. "Experts" or farmers could play in much less time.

Trade names are used in the model for teaching purposes to lend a sense of reality, but results using particular named products do not guarantee the true performance of that product in the field. Similarly, some information presented during each season is given as being supplied by British Sugar plc. No criticism or recommendation of any named product or company is intended or implied. Further information on the program can be obtained from the author.

DISCUSSION

This decision model has been used extensively in both undergraduate and postgraduate teaching in pest management at Imperial College. It has also been played with some field staff from British Sugar plc. It has proved popular with students and provides a focus for learning about sugar beet insect pests and diseases.

While the conditions of this decision model are greatly simplified compared to real life, and contain very little biological complexity, students must learn enough about the pests and pesticides to make good decisions. They also experience the problems of limited information and considerable product choice that farmers face. By giving different groups different objectives, for instance to maximise profit, or to obtain a predetermined profit with minimal inputs, users can see the effects that decision makers' objectives have on their pest control choices.

Group discussions after playing the game illustrate the different perceptions players have of pest losses and pesticide performance gained during play. For instance, trial use of a particular product during a year with few pests may dissuade a group from using that chemical for "years" after, while other groups adhere strongly to it. Players, like farmers, often have considerable difficulty in accurately assessing the losses suffered from pests and the effectiveness of the control measures they have employed.

The game could also be used in training courses for technical advisers or for farmer groups to promote discussion on sugar beet pests and their control.

ACKNOWLEDGEMENTS

My thanks to the many students who have played and commented on this game as it has been developed, and to colleagues at British Sugar plc, Broom's Barn Experimental Station, and Imperial College for their help in determining the parameters.

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A MODEL TO AID DECISION-MAKING IN CHOOSING A SUITABLE CROP SPRAYING SYSTEM

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ABSTRACT

A model to aid in selecting ground spraying systems on arable farms is described. Constituent sections of the model are discussed, and the steps taken to validate the sections, using data from farm surveys. Running a computer program of the model demands input data on farm location, expected crop spraying requirements, and necessary spraying system parameters.

INTRODUCTION

Several methods have been developed to help in farm machinery selection. Reviews of such methods may be found in Smith (1983). Most models tend to be general and abstract in nature; consequently few progress far towards helping farmers select a specific machinery system, such as a spraying system, for their farm. The method in this paper attempts to confront problems of abstraction and generality by using "real-world" data in constructing, validating and running a model to aid selection of a spraying system. The "spraying system" on a British arable farm is composed of the sprayer, refilling arrangements, spraying and ferrying speeds, and application rates.

Constructing and running the model involves three processes. One section involves selection and validation of a suitable sprayer workrate algorithm. A second section examines the influence of weather-related variables on overall spraying system performance, quantifying the number of spray-days available in each month. A third section utilises results from the other two sections in arriving at a list of alternative spraying system options for a given spraying requirement on a farm. A diagram of the model is shown in Fig. 1.

SELECTION OF WORKRATE ALGORITHM

Two main approaches are possible. One is the real-time modelling of sprayer operations, as demonstrated by Nation (1978). Alternatively an algorithm may be used which incorporates all important parameters in giving a single figure for machinery workrates. Examples of such algorithms are in

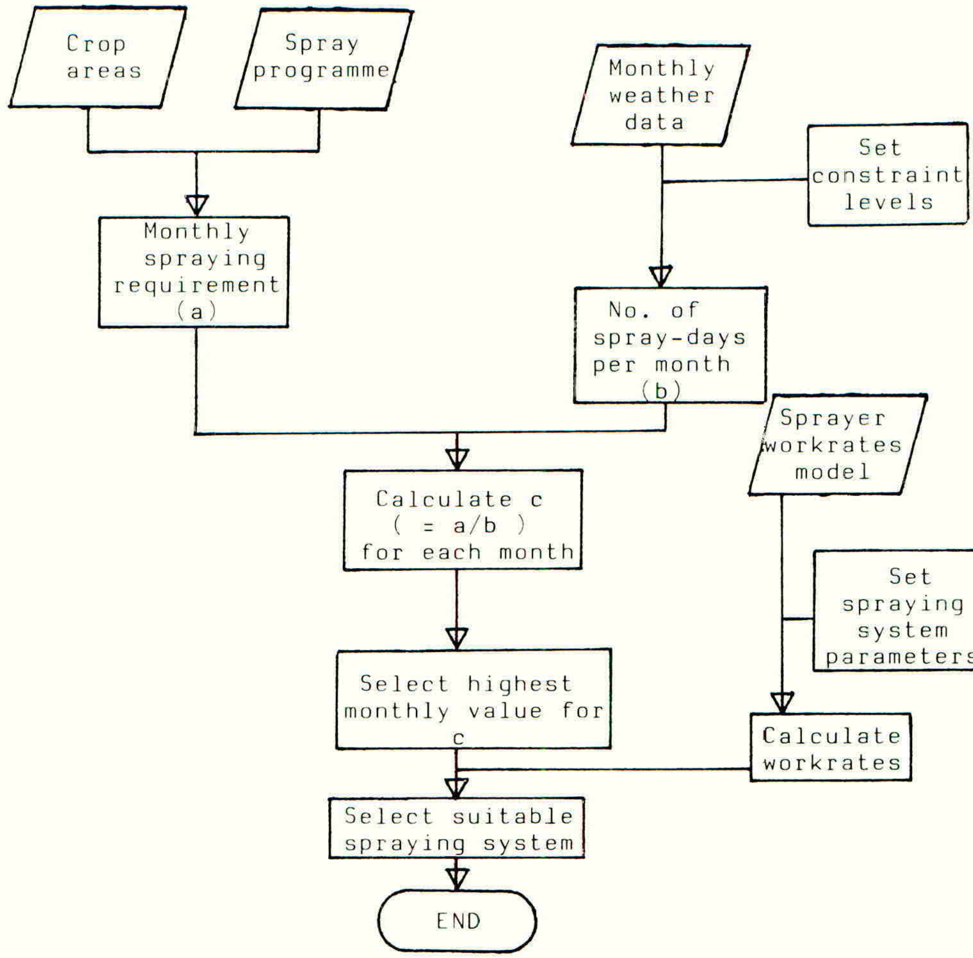

Fig. 1. Flow diagram of model suggesting a suitable spraying system for a farm.

Baltin (1959) and Renoll (1981). The Baltin equation was selected, with modifications for ground crop spraying. A correction factor was superimposed to take account of irregular field shapes. The value was supplied from Sturrock et al.(1977). The values of constants used in the algorithm are in Table 1.

Validation of the algorithm was carried out by comparing predictions with observations on 22 sprayers on different farms in a survey carried out by Smith (1983). Data and algorithm predictions are presented in Table 1. In order to test how closely the algorithm predicts sprayer workrates, a regression was performed on stated farm workrates (y : Table 1, column 7) with model-calculated workrates (x : Table 1, column 8). The regression line obtained was

$$y = 0.996x - 9.10 \qquad (R^2 = 0.62)$$

compared with the "perfect case" of y = x. In carrying out t-tests between these two curves, neither the intercept nor the slope were found to be significantly different at the 5% confidence level.

TABLE 1

Parameters, stated workrates and model-calculated workrates for one hydraulic spraying system on 22 farms. Constants assumed are: time turning sprayer = 10s; distance between fields = 1km; field size = 10ha; ferrying speed = 5m/s; working day = 9h, with 1h idle; average row length = 316.2m.

Dimensions of hydraulic sprayer		Other relevant spraying system variables				Workrates (10h day)	
Tank capacity (l)	Boom width (m)	Average distance to refill (m)	Mean time taken to refill tank and mix chemical (s)	Average volume applied (l/ha)	Normal speed (m/s)	Farmer stated (ha)	Model predicted (ha)
1485	17.7	805	900	180	2.67	60.7	72.7
2000	12.2	1609	1200	225	2.67	80.9	53.0
1600	12.2	402	900	225	2.23	55.0	51.7
2000	12.0	805	600	225	1.78	32.4	47.8
5400	12.0	100	120	202	4.15	101.2	117.2
1575	12.8	805	900	225	2.00	40.5	48.0
2000	12.0	457	600	225	3.57	48.6	78.0
2500	20.0	1073	600	253	2.23	48.6	79.5
2025	12.0	805	600	225	2.67	40.5	63.3
1600	12.0	100	150	100	3.57	121.4	99.8
1350	12.0	100	120	225	2.67	60.7	71.7
1350	12.0	402	750	225	1.78	40.5	43.8
2000	12.0	805	900	225	3.57	48.6	69.6
1500	12.0	805	600	225	1.78	40.5	44.8
2000	15.0	805	600	185	3.57	70.8	91.9
450	12.2	100	180	84	1.78	34.4	51.4
1500	12.2	1207	300	150	3.10	48.6	74.6
675	12.2	403	1200	225	2.20	20.2	32.6
1800	12.0	403	600	225	2.23	28.3	56.5
1125	12.0	100	600	225	2.23	48.6	51.5
1000	12.0	100	1200	200	2.67	50.6	47.3
4500	18.0	100	180	152	2.23	121.4	101.7

THE INFLUENCE OF WEATHER ON SPRAYING OPERATIONS

The weather can influence spraying by affecting droplet behaviour and chemical efficacy; in addition indirect effects may arise, such as wet soil impeding vehicular access. Certain chemicals may be sensitive to elements of the weather, e.g. differential rainfast properties. Several authors have compiled generalized guidelines on the weather conditions under which it is safe to spray, in defining "spray-days". Table 2 provides threshold values quoted by Spackmann & Barrie (1982) for the main environmental parameters influencing ground spraying. However, there is some evidence that farmers may be prepared to disregard guidelines, particularly for windspeeds (Smith, 1983).

TABLE 2

Threshold values quoted by Spackmann & Barrie (1982) for major environmental parameters influencing ground spraying, which must be satisfied for at least five successive hours. An LGPV (Low-Ground Pressure Vehicle) is a ground-based spray rig with design features enabling access onto wetter soils than is possible with a tractor-pulled spray rig.

Parameter	Threshold at which spraying is constrained
Hourly mean windspeed	$\leq$ 4.6 m/s (hydraulic pressure sprayer) $\leq$ 6.2 m/s (controlled droplet sprayer)
Soil moisture	Days when soil moisture deficit (SMD) $<$ 5mm (conventional tractors), with no SMD constraint for LGPVs.
Daylight	Daylight, but not earlier than 0600h or later than 2100h.
Temperature	$>$ 1.0 C during spraying, with the air temperature $>$ 7.0 C sometime during the day.
Precipitation	None for at least 1h beforehand, or at the time of spraying.

How closely are weather conditions experienced and recorded at one site (e.g. a weather recording station) typical of the locality? In a survey Smith (1983) found that the most commonly quoted source of weather forecasts by farmers was from the nearest weather station. Consequently it would seem reasonable to extrapolate estimated spray-day values over a locality, using observations from a local weather recording station. Spackmann & Barrie (1982) have calculated spray occasions in each month using 10 years of weather data from 15 weather stations around the U.K.

SUGGESTING SUITABLE SPRAYER SYSTEMS

The components described in the previous two sections have been placed in a computer program to suggest suitable sprayer systems. The program requires input data on location and monthly area spraying requirements. Data on the monthly spray-days available at a number of weather stations (using criteria such as those in Table 2) are program-resident. The program identifies the critical month in which the ratio of: spray area requirement/spray-days available in a locality is highest, to give the minimum daily spraying requirement that the spray system must achieve. The workrate algorithm is then used to generate possible solutions, i.e. sprayer system combinations to fulfil the daily workrate requirement. Further input is required on which factors in the algorithm are to be regarded as constants, and which are to be varied in the output suggesting alternative sprayer system options. Values for field size, shape and distance between fields are constants, as a sensitivity analysis showed that varying these factors do not substantially influence overall workrates.

Program output consists of a table of spraying systems which will match the stipulated workrate requirement. The format is similar to Table 2, except that columns 7 and 8 are absent. Output from the model may be viewed in Smith (1983).

DISCUSSION

Computerization of the model allows a rapid investigation of alternatives. A BASIC program will fit into the memory of most business micros. Such a program could be utilized frequently by consultants, representatives or computer bureaux. As with most programs, expert help is desirable, particularly with input values and the interpretation of output.

Risk aversity can be incorporated by stipulating high expected spraying requirements through the year, or by using "worst-weather" data in estimating monthly spray-days available. It is assumed in the model that no costs are incurred due to untimely applications, as all monthly spraying requirements must be carried out within that month. This monthly division is arbitrary; it may be necessary for some chemicals, e.g. aphicides, to be applied within the space of a few days. However, a much finer division of time periods may reduce the representative nature of spray-day values for a locality.

Although data are not available to compare directly model predictions with farm sprayer systems, it does appear that many smaller farms are heavily stocked with sprayer machinery (Smith 1983). This may be explained by risk aversity, or the relatively low cost of sprayers compared to chemicals. High spray machinery levels may try to compensate for inefficient spraying system components, e.g. poor refilling facilities.

New crop spraying technology may relax some weather constraints, e.g. controlled droplet applicators (machines with nozzles producing droplets of a predictable (and usually controllable) size, with a low vmd/nmd (volume median diameter/number median diameter) ratio) may permit spaying in higher windspeeds,and LGPVs may allow vehicular access on wetter soils. The model may be used to evaluate and quantify benefits from the use of such new technology. Sprayers embodying relevant new technology can have smaller boom and tank dimensions, and still maintain the necessary performance.

CONCLUSIONS

The model outlined in this paper has three main possible uses. Firstly, to evaluate the relative performance of different spray systems; secondly, to suggest alternative spray systems for individual farms; and thirdly, to evaluate the impact of new technology on sprayer systems performance.

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MONITORING WETNESS OF DEAD ONION LEAVES IN RELATION TO BOTRYTIS LEAF BLIGHT

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ABSTRACT

Electrical impedance probes were used to monitor hydration and dehydration of dead onion leaves exposed to cycles of alternating high and low humidity at 18°C. The probes effectively monitored wetting patterns and duration of wetting but gave only a rough indication of leaf moisture content. Leaves initially dried to brittleness hydrated more rapidly and absorbed more moisture during successive humid periods. The rate of moisture loss during successive dry periods of 60-70% r.h. also increased. After probe readings stabilized during the third dry period the leaves were pliable and contained about 12% moisture (dry wt basis). These leaves rehydrated rapidly. The humid period required for sporulation of _Botrytis squamosa_ was 40 h when the leaves were dry and brittle at the onset of high humidity, but only 23 h and 16 h after the leaves were immersed in water for 0.5 or 10 min, respectively.

INTRODUCTION

Leaf wetness is an important variable influencing foliar diseases and is frequently utilized in disease forecasters and models. Wetness duration usually is measured by instruments calibrated against the appearance and disappearance of dew on green leaves. Instruments for monitoring wetness on leaves utilize either string-type sensors, or electrical resistance sensors in the form of artificial leaves or wetness clips connected to microprocessor-based data loggers (Sutton _et al_. 1984a). Sensors for monitoring wetness on green leaves may not be suitable for monitoring wetness of dead leaves. Unlike living leaves, dead leaves do not regulate water exchange with the atmosphere and absorb large amounts of moisture when the ambient humidity is high or free water is deposited upon them. Water in dead leaves is in a state of dynamic equilibrium with atmospheric moisture, and flows as vapor into and out of the dead tissues while maintaining that equilibrium. Water relations of dead leaves are of major importance in the epidemiology and management of diseases caused by necrotrophic pathogens which may colonize, sporulate and survive in association with dead foliage.

Botrytis squamosa is a necrotrophic pathogen of onion foliage and causes spotting and dieback of the leaves. The pathogen sporulates on the dead leaves shortly after they die back. In field studies we observed that _B. squamosa_ often failed to sporulate at night when wet periods, monitored according to dew on green leaves, appeared favorable for sporulation (Sutton _et al_. 1983). Because lack of sporulation usually correlated with dry conditions on the preceding day, it appeared possible that the moisture status of dead leaves before the humid period may influence the ability of the pathogen to sporulate during the humid period. In the present study we examined hydration characteristics of dead onion leaves using electrical impedance sensors, and relationships of hydration to sporulation of B. squamosa.

MATERIALS AND METHODS

An electrical impedance probe was designed for monitoring moisture of dead onion leaves. The probe, a modification of a clip-type impedance sensor used for monitoring surface wetness of leaves (Sutton et al. 1984a), consisted of two nickel wires (0.25 mm diameter) mounted parallel to each other and 1 mm apart on a plastic clothes peg. The wires protruded 15 mm beyond the front of the peg. Electrodes were formed by removal of insulated sheathing from the terminal 8 mm of each wire. When the probe was in use, the peg was clamped onto a support rod and the pair of electrodes was inserted into a dead onion leaf. Changes in electrical resistance between electrodes were recorded with a data logger (model CR-21 'micrologger', Campbell Scientific Inc., Logan, UT 84321, USA). To shape the output signal of the probe to conform with specifications of the micrologger, two variable resistors (0-100 kohm) were used in accordance with the CR-21 Operator's Manual. Because the sensors were in electrical contact with the earth through the onion plants, a 10-microfarad capacitor was used in each probe lead to prevent polarization.

Hydration of dead onion leaves was examined by exposing the leaves to alternating high and low humidity in a moist chamber located in a growth cabinet. Hydration was monitored with a wetness probe inserted in each leaf. Probe responses were scanned at 1-min intervals and averaged over 15-min intervals by the data logger. Air temperature in the moist chamber was 18 $\pm$ 1.0 °C and was monitored with a shielded thermistor connected to the data logger (Sutton et al. 1984a). Relationships of electrical impedance and moisture content of dead leaves were studied in samples of dead leaves exposed to three or more cycles of alternating humid periods (14 h at $\geqslant$95%) and dry periods (10 h at 60-70% r.h.). Moisture contents of leaf samples were determined gravimetrically at various times in the successive cycles. Patterns of hydration and dehydration of dead onion leaves were studied in a series of experiments in which leaves were exposed to three cycles of alternating humid and dry periods. Leaves in these studies were still attached to pot-grown onion plants and were dried to brittleness before each experiment.

Relationships of moisture content of dead onion leaves immediately before the humid period and time required for B. squamosa to sporulate on the leaves during the humid period were examined in controlled environment. Onion leaves were inoculated with B. squamosa and allowed to die back. The dead leaves were detached, dried at 40°C for 2 h, weighed and then immersed in water for various periods of time. After immersion, surface moisture was removed with tissue paper and the leaves were reweighed, placed in gauze-bottomed aluminium dishes, and exposed to continuous high humidity. The leaves were observed hourly for sporulation of the pathogen and weighed again after sporulation was observed.

Wetness of dead leaves was studied in relation to surface wetness of green leaves and atmospheric r.h. in onion field plots between 8 July and 3 Aug. 1983. Internal moisture was monitored with four probe sensors connected in parallel. Surface wetness was recorded with five clip-type sensors mounted in parallel and with electrical resistance sensors (artificial leaves) with electrodes wound in dual spirals on an acrylic tube (Sutton et al. 1984a). R.h. was monitored with a hygrothermograph positioned in an instrument shelter.

RESULTS

Response of the electrical impedance probes increased with moisture content of the dead onion leaves but there was considerable variability in the data (Fig. 1). Probe response varied with different leaves and also in the same leaf when the probe was inserted in different positions or at different times. The leaves were brittle when % moisture was near 0 and probe readings were 0, but pliable when at 12% moisture and probe readings were 0.020-0.029. At 100% moisture content (probe reading 0.784) the tissues were visibly wet.

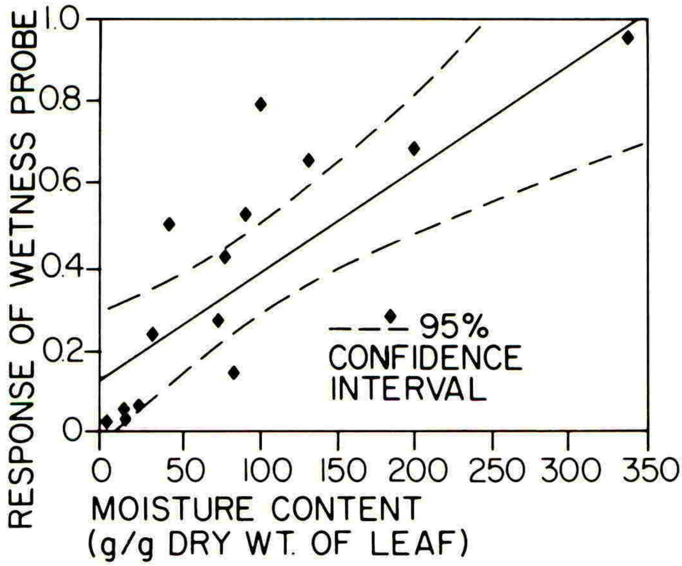

Fig. 1. Response of electrical impedance probes positioned in dead onion leaves in relation to moisture content of the leaves.

The rate of hydration of the dried onion leaves usually increased during successive humid periods (Fig. 2). In the first humid period probe response resulted in a plateau at only 30-60% of the maximum response observed, indicating that the dead leaves became only partly wetted. During the second humid period, the leaves attained 75-100% of maximum wetness, but only after 12-15 h of high humidity. Hydration of the dead leaves during the third humid period was always rapid and attained near-maximal values during 6-9 h. An abrupt upward inflection was observed in some curves after a trend towards a plateau. Decline in sensor readings usually began within 1-3 h after humid periods ended. Drying was delayed markedly when moisture films were present on the dead leaves. The rate of drying after initial decline in sensor readings increased during successive dry periods. During the third dry period, probe readings stabilized just above zero (0.002-0.003). The leaves at this stage contained 0.12 g water/g dry wt and were pliable.

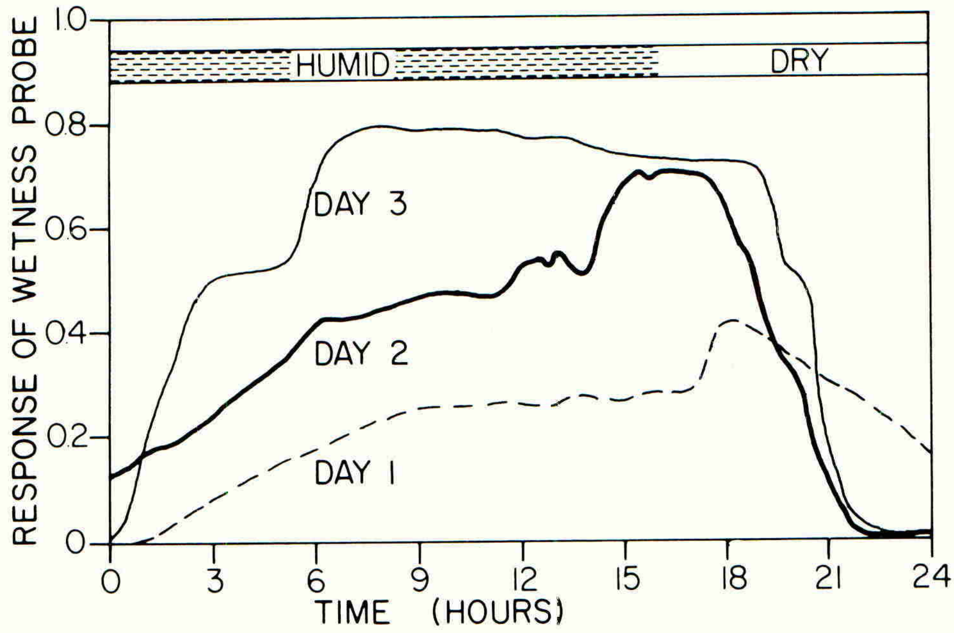

Fig. 2. Patterns of hydration and dehydration of dead onion leaves dried to a state of brittleness and exposed to alternating humid and dry periods on three successive days.

The humid period required for sporulation of B. squamosa was 40 h when the dead leaves were dry and brittle at the onset of high humidity but only 23 h and 16 h respectively, when the leaves were immersed in water for 0.5 min or 10 min before the humid period. Immersion of dead leaves for 0.5 or 10 min, respectively, increased the water content to 40% and 100% of the maximum observed in the study. Leaves immersed for 0 or 0.5 min attained 50 and 65% of the maximum water content at the time of sporulation.

TABLE 1

Relation of water content of dead onion leaves after various periods of immersion in water to the humid period required subsequently for sporulation of B. squamosa and mass of water imbibed by the leaves during the humid period.

Immersion period (min)	Water content after immersion (g/g dead leaf)	Humid period (h) before sporulation	Water imbibed during humid period (g/g dead leaf)
0.0	0.0	40	2.8
0.5	2.1	23	1.5
10.0	5.3	16	0.3
30.0	5.3	16	0.1

Patterns of hydration and dehydration of dead onion leaves in field plots were generally similar to those of increasing and decreasing r.h. However, changes in response of the impedance probes often lagged behind changes in r.h., especially when humidity initially declined from saturation. On successive nights, readings from wetness probes often plateaued at different levels. Daily periods of hydration and dehydration ranged from 1-10 h and 1-11 h respectively (means 4.1 h and 3.9 h). Duration of surface wetness of green leaves and of hydration of necrotic leaves (probe output above dry baseline) frequently differed by 1-5 h.

DISCUSSION

The electrical impedance probes were effective for monitoring patterns of hydration and dehydration of dead onion leaves, but gave only a rough indication of the moisture content of the dead tissues. The observed variation in probe response associated with different leaves, or with the same leaf at different times, may have been a function of electrolyte concentration of structural differences in tissues near the electrodes, or of varying electrical contact between the probe and the tissue. For example, a reduction in electrolyte concentration or collapse of the tissues may increase electrical impedance. Differential effects of these variables on impedance and hydration may account for the lack of precision of the probes in monitoring water content. Similar difficulties may be encountered in attempts to relate probe output to water potentials of the tissues. Nevertheless the probes appear to have value for monitoring periods when leaves are hydrated sufficiently for growth of pathogens. The field data indicated that instruments which monitor surface wetness are generally unsuitable for monitoring wetness of dead leaves. A possible exception is the artificial leaf, which responded to humidity as well as to free water.

The slow wetting and drying of the dead leaves which initially were dry and brittle, and the low moisture content of these leaves after equilibration in a moist chamber, indicated that extreme drying changed the hydration and dehydration properties of the tissues. Collapse of dead leaves when dried may reduce fluxes of water vapor through the tissues and thereby reduce the rates of absorption and desorption. The dried leaves also may have a reduced affinity for moisture. Restoration of rapid rates of wetting and drying and of high plateaux of hydration required exposure of the leaves to two or three successive humid periods. During the intervening dry periods the leaves retained some moisture and remained pliable. The pliable leaves hydrated more rapidly than leaves which were dry and brittle. The observations indicate that wetting of dead leaves may be slower after dry weather than after humid weather.

The long humid period required for sporulation of B. squamosa on leaves which were initially dry and brittle was associated with slow moisture increase in the leaves. Slow hydration of extremely dry leaves may explain lack of sporulation in the field during humid nights following dry days (Sutton et al. 1983). Interrelationships of water content, water potentials and pathogen development in dead leaves, however, remain unclear.

The impedance probe has applications in the implementation of BOTCAST, a forecaster for timing fungicides to control botrytis leaf blight of onions (Sutton et al. 1984b). The probe would facilitate the prediction of sporulation by B. squamosa on dead leaves and obviate the need for a hygrothermograph at each monitoring site, thereby reducing costs. An output value indicating threshold moisture for sporulation is required for application of probe data in BOTCAST. Similar applications of wetness probes may be visualized in the management of other diseases caused by necrotrophic pathogens.

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A COMPARISON OF WETNESS SENSORS FOR USE WITH COMPUTER OR MICROPROCESSOR SYSTEMS DESIGNED FOR DISEASE FORECASTING

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ABSTRACT

The performance of six designs of wetness sensor were compared above and within a wheat crop. The sensors often dried faster than leaves at similar heights and the indicated wetness period could vary between sensors by up to 4.5 h . The behaviour depends on local environmental conditions and on the way the sensors intercept and hold water.

INTRODUCTION

Wetness on the leaves of crops has particular epidemiological significance because many fungal and bacterial pathogens require free water at some stage in their life cycles. The duration of leaf wetness is of value in the prediction of specific diseases or their progress, and a number of disease forecasting schemes have been proposed which use an estimate of leaf wetness duration as one of the weather variables to define a critical period.

Schemes such as these have been used to aid decisions on the timing of fungicide applications, but as economic and environmental constraints on the use of fungicides become stronger, there is a need for improved forecasting accuracy and in some cases good measurements of wetness duration are appropriate.

Surface wetness on leaves in field crops can result from rain, dew, fog, mist, irrigation or guttation. The persistence of surface water depends on the amount intercepted and the length of time it takes to evaporate. Intercepted water from rain or sprinkler irrigation is commonly in the form of drops of many different sizes. In contrast, water on leaves from dew, fog or mist is usually much more uniform. Surface water may either be shaken from the leaves, evaporate or be absorbed by the plant, though the amount absorbed is very small. In strong winds substantial movement may dislodge some water from leaves, thereby reducing the amount of intercepted water in the canopy. The remaining surface water evaporates from the leaf at a rate which depends primarily on the total absorbed radiation and the wind speed. Some evaporation may occur during rain. Evaporation of dew and rain drops will normally proceed at different rates because of differences in the distribution of surface water, both on individual leaves and within the canopy.

Various designs of printed circuit grids with two interspersed electrodes are in current use for detecting wetness and are mounted either outside the canopy as part of an automatic weather station, or deployed as mock leaves within the canopy itself (e.g. Davis & Hughes 1970; Gillespie & Kidd 1978; Sparks & Wass 1983). Information on the relative performance of these sensors is sparse, and the development of computer or microprocessor-based apparatus for disease forecasting which incorporate wetness sensors of this type seems premature without further investigation. Printed circuit sensors are frequently used with such apparatus because they are cheaply produced and easily replaced, however no standard design exists. Here we compare a number of designs with each other and with actual leaf wetness in a cereal canopy and consider the effects of sensor exposure.

MATERIALS AND METHODS

Description of sensors

The major differences between the sensor designs summarised in Table 1 are in the shape, size and nature of the sensing surface.

TABLE 1

Characteristics of the wetness sensor designs tested

Sensor	Electrodes	Size (mm)	Surface	Electrode separation (mm)
1 CDEM	Exposed, rhodium plated	77×30	Semi-cylindrical	0·15
2 Gillespie and Kidd	Painted, (white latex)	80×30	Flat	3·0
3 Fine	Exposed, tinned	86×14	Flat	0·3
4 Fine, silicone	Exposed, tinned	86×14	Flat	0·3
5 Coarse	Exposed, tinned	86×14	Flat	0·5
6 Flexible, silicone	Exposed, tinned	86×14	Flat, flexible	0·3

Sensor 1 was developed by the Meteorological Office, has been used on the Crop Disease Environment Monitor (CDEM) weather stations (Painting & Pettifer 1981; Sparks & Wass 1983), and is described by Wass (1982).

Sensor 2 is described by Gillespie & Kidd (1978) and consists of a grid of copper fingers on a fibreglass board. The sensing surface is covered with two coats of white latex paint.

Sensors 3, 4, 5 and 6 were developed at Long Ashton Research Station and are of similar shape and dimensions to a cereal leaf. Each unit was etched from copper-clad PCB material and tinned with solder to minimise oxidation of the bare metal. Sensor 6 is identical to Sensor 4 except that a flexible PCB material was used; the device is mounted at the base and allowed to move in the wind in a similar way to a real leaf. Sensors 4 and 6 are coated with silicone (applied as a spray) which causes water to form discrete drops on the sensing surface but which does not affect the electrical sensitivity to the presence of surface water.

Components of wetness sensor performance

The total wetness period indicated by any sensor may be divided into three phases: the initial wetting of the sensing surface, the duration of rain or dewfall, and the subsequent evaporation of the intercepted water. The behaviour of an ideal sensor during each of these phases should match that of a typical leaf within a canopy at the same height.

The way in which water is held differs between sensors with painted surfaces, sensors with bare electrodes and real leaves. In the former, the first intercepted raindrops are partly absorbed by the porous layer and form an almost continuous film with subsequent interception completely wetting the surface. Water held on the surface of sensors with exposed electrodes often forms drops, which may coalesce to form large, irregularly shaped wetted areas. However, on young, green cereal leaves, intercepted water is held as discrete drops whose size distribution is usually well-defined. Sensors with a silicone coating have a similar distribution of water on their surface to that on cereal leaves. The evaporation from the wetted surface will depend on the way water is held.

Sensors with porous painted surfaces are extremely sensitive to small quantities of moisture, whereas the response of sensors with exposed electrodes depends on the probability of a drop bridging the gap between the electrodes, and therefore on the electrode spacing. The optimum spacing for a sensor treated with silicone was calculated as 0·3 mm by considering drop size distributions on green leaves after rain. Sensors with a smaller separation require more frequent cleaning to remove foreign matter which settles in the narrow gaps between the electrodes.

During the drying phase, the indicated duration of the wet period depends on the volume of water per unit sensing area, V, and the evaporation rate for the sensor. The value of V at saturation may be measured directly for any sensor, but the evaporation rate depends both on sensor characteristics and environmental conditions. The two most important determinants of relative drying times between fully wetted sensors are the interception capacity per unit area and the radiative properties of the surface.

Measurements

Estimates of the persistence of wetness related to a canopy of winter wheat were made using different designs of printed circuit wetness sensor. These were mounted horizontally above the crop (2 m above the ground), at the mean height of the uppermost leaves, and within the canopy itself.

For each design, the presence of surface wetness was detected as a change in electrical resistance, and the energising circuit (Gillespie & Kidd 1978) was identical for all sensors. Outputs were recorded continually every 15 minutes from April-July 1983 when for the majority of the time, one of each sensor type in Table 1 was mounted at the same location both above the crop and at crop height. No inconsistencies in performance for any sensor type were observed when sensors were replicated at a single height; the indicated wetness periods always agreed to within ±15 min.

Canopy wetness was assessed at the same height as the sensors. Frequent observations of a sample of six leaves were made using a five point scale from dry (1) to saturated (5). The canopy was assumed dry when the total score for an observation fell below 9.

RESULTS

Wetting-up times between sensors after rain never varied by more than 3 min which is negligible when compared to the total wetness period usually observed as a result of rain. Differences in wetting-up times in response to dew as compared to rain were more marked between sensors at the same height, occasionally reaching and sometimes exceeding 2•5 h. However, agreement was better when the onset of dew was well defined and the total dewfall was heavy. Table 2 shows the mean differences between the indicated times of dew formation by the various sensors and its initial detection obtained from a total of 25 nights when dew persistence exceeded 4 h.

The response from sensors mounted at 2 m was usually later than those at crop height, and the CDEM sensor was generally the first to indicate wetness. Sensor 2 generally began to respond quickly, but took longer to reach the threshold voltage used to differentiate wet and dry

TABLE 2

Mean differences (h) between the indicated time of dew formation by the various sensors and its initial detection, obtained from a total of 25 nights.

Sensor	At 2 m	At crop height
1	1•6	0•1
2	1•9	0•3
3	2•7	1•2
4	2•2	0•6
5	2•6	n/a
6	2•0	1•2

conditions. For dew formation, the speed of response of the CDEM sensors in comparison to the other unpainted units may be attributed to the narrow electrode spacing, but is more probably caused by their cooler surface temperature. On clear nights all sensors will cool below air temperature, and less heat will be convected to the surface of the larger sensors maintaining a lower surface temperature and promoting earlier formation of dew.

The initial respose of sensors 1, 3 and 5 to dew was up to 2 h later than the mean values in Table 2 when the sensors were new. These differences became significantly less after exposure for a few days. The performance of sensors 1, 3 and 5 for dew may therefore be expected to improve with a short period of 'weathering'.

The total wetness periods indicated by the various sensors following the onset of rain or dewfall are compared on three separate occasions in Fig. 1. These results were selected to illustrate differences in the relative behaviour of the sensors from day to day. Agreement between sensors at the same height to within 2 h was obtained on 24 July with an extended period of light, intermittent rain at night (Fig. 1a) and on 9 June following dewfall (Fig. 1b) in broad agreement with the mean values in

Table 2. However, the indicated wetness period on 7 June during and after heavy morning rain varied by as much as 4•5 hours (Fig. 1c). The sensor behaviour on different occasions, as illustrated in Fig. 1, is apparently inconsistent but no variation in the relative sensor performance was ever observed while rain was falling; thus differences between the indicated wetness periods during and after rain must be attributed to differences in the drying times between sensors.

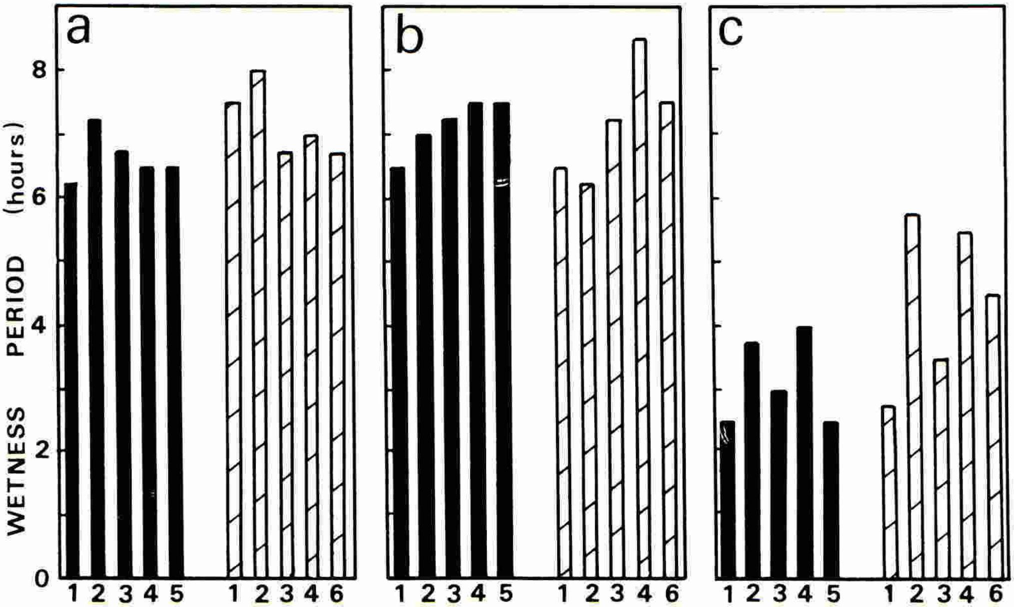

Fig. 1. Total wetness periods indicated by the various wetness sensors following the onset of (a) rainfall at 0330 on 24 July, (b) dewfall at 0345 on 9 June and (c) rainfall at 1045 on 7 July. Results from sensors at 2 m (solid bars) are differentiated from those at crop height, and the key to sensor design in given in Table 1.

Under conditions when subsequent evaporation was great and a sensor had intercepted little water (Fig. 1a), or when the period of dewfall had formed a significant part of the total wetness period (Fig. 1b), good agreement between sensors was generally obtained and differences in evaporation rate were of minor significance. In these conditions the sensors has all intercepted similar amounts of water. However, when all sensors were saturated and the potential evaporation was slow (Fig. 1c) marked differences in the indicated wetness periods were obtained.

Values of V at saturation varied markedly between sensors. Sensor 2 generally held the most water per unit sensing area, and Sensor 1 the least. Sensors with bare electrodes has saturation capacities which lay between these extremes and were roughly similar to those obtained for green leaf tissue. The addition of a silicone coating increased the value of V by about 30% (although this was still less than for sensor 2). The saturation capacity of the flexible device (sensor 6) became less when the sensor was moved, mimicking the behaviour of real leaves in wind.

All sensors mounted at 2 m dried faster than leaves at crop height, probably because they were exposed to greater wind speeds. At the top of the canopy, most sensors also underestimated the wetness duration on real leaves, especially after heavy rain; this difference was occasionally as great as 3·5 h.

The behaviour of sensor 4 generally matched that of real leaves to within 1·5 h, although it was inferior to the flexible design in windy conditions. Sensor 2 showed less consistent performance, but was usually dry within 2 h of the observed drying of the top of the crop.

These trends were most marked when the sensors were saturated after heavy rain. They were ill-defined when the crop was not saturated, although under these conditions the indicated wetness period varied less between sensors, and the drying time of those at crop height was often within 1 h of observed leaf wetness.

CONCLUSIONS

At the top of a wheat canopy, wetness periods indicated by sensors of various designs may differ significantly from each other and from visual observations of water on leaves at the same height. The differences become less when the sensors intercept little water (after light rain or dewfall) and when subsequent evaporation is great; they are greatest when the sensors are saturated and the evaporation slow.

Sensors exposed above the crop were slower to indicate the formation of dew and dried more quickly than those at crop height, and even the latter often underestimated the drying time of leaves. However, the performance of sensors with bare electrodes was improved by the application of a silicone film. As microprocessor based weather monitoring systems for crop protection are developed, the correct use of wetness sensors should be carefully considered. It is clear that the design, the degree of saturation, and the drying conditions strongly affect the performance of a sensor. To interpret measured wetness periods correctly it is necessary to differentiate between night rain and dew and to assess the degree of saturation of the sensor. This could be achieved with a monitoring system which incorporates a computer or microprocessor, and the appropriate software could be included to calculate the likely rate of evaporation using standard formulae. This information would allow the degree of confidence in wetness periods indicated by a sensor to be established, and may significantly improve the accuracy of a forecasting system which incorporates wetness duration.

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A MICROCOMPUTER BASED WEATHER STATION FOR PEST AND DISEASE FORECASTING

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ABSTRACT

The design and operation of a weather station based on the Commmodore 4000 series computer are discussed.

INTRODUCTION

Weather conditions play an important part in many aspects of crop production not least in the area of crop protection. They are of particular importance in the prediction of the crop pests and diseases. A number of predictive models are now available which could assist the farmer with his spray programmes if meteorological data were available to him. At present his main source of information is the national meteorological network. The main problems with this source is the slow dissemination speed and the relationship between weather recorded at the various meteorological sites and those in the farmers fields. The Prestel network will help to speed up the information distrbution but the basic difference between the climate of weather station and farm cannot be overcome. In order to take advantage of the potential improvements in spraying efficiency from pest and disease forecasting techniques, the farmer requires the capability of recording meteorological information on his own site. For management it is desirable also that the recording system is capable of carrying automatic calculation.

The arrival of low cost computer systems and the subsequent development of periferal equipment enabling environmental sensors to be linked to them has made it possible to construct a relatively low cost computer based weather station capable of handling many pest and disease prediction programmes simultaneously.

This paper gives an outline of a weather station developed at Wye College. The system uses the Commodore 4000 series personal computer, but in concept and basic architecture it could easily be adapted to other systems.

WEATHER STATION DESIGN

There are three major parts to the system: meteorological sensors (temperature, humidity, radiation etc.), analog to digital interface (A/D), 32 channel, 12 bit, ±5.0 V, and computer and peripherals (CBM 4000, 32K).

The development of sensors suitable for use in a low cost weather station has been somewhat slower than microcomputer development. It is now possible to obtain almost the complete range of sensors fom variouse commercial sources. The output from the sensors must be within the ±5.0 V range of the A/D. The various sensors are erected on a mast and linked to the A/D via a multicore cable.

The A/D converts the analogue signals from the sensors to the digital code of the computer. It has a 12 bit resolution (1 in 4096) giving a high level of definition in measurement of weather data, e.g. temperature measurements can be made to an accuracy better than 0.1 C with a suitable sensor. The A/D interface also houses a 32 channel multiplexer allowing up to 32 sensors to be read into the computer in sequence. The computer controls the frequency with which the sensors are scanned and this can be altered at the keyboard to suit specific requirements. In practice sensors are usually scanned every minute and readings converted to engineering units. These values are added to a running mean and at hourly intervals the data is stored in the computer memory. The data may be recorded on disc or tape if it is required for further analysis or as hard copy on the printer for a visual record. The A/D is interfaced to the computer via the microprocessor buses at the memory expansion connector. Additional information,for e.g. plant growth stage, insect count etc., may be fed in at the keyboard.

The video monitor displays recent data, or with a few keyboad operations, data for previous preset periods may be displayed graphically.

The main programme is in BASIC enabling easy addition and modification of the programme. Various simple pest and disease models may be programmed into the system and modified as appropriate.

Recently Spa Micrographics have introduced a weather station with disease forecasting capability for use by farmers. The basic design of the system is similar to that of the Wye station (sensors - A/D - computer). It is designed as a stand alone unit capable of recording data from 8 sensors at 6 minute intervals for a period of 4 days. An on board computer programmed with several simple disease warning criteria provides an alarm facility of disease periods. The computer may be reprogrammed by the manufacture to add additional models or to introduce more comprehensive programmes. Through a RS232 data link the data from the weather station can be accessed by the farms main computer, increasing the analysis capability of the system.

CONCLUSION

A microcomputer based weather station can provide accurate onfarm weather data. It can carry out the necessary calculations and give pest and disease forecasts based on epidemiological models. The provision of accurate and reliable data relating specifically to his farm reduces considerably the uncertainty that a farmer has in operating a pest or disease control programme. The weather data may be used also to assist in the management of other weather dependant operations such as irrigation scheduling and frost protection.

EXPERT COMPUTER SYSTEMS AND VIDEOTEX AS AIDS TO CEREAL DISEASE CONTROL

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ABSTRACT

Careful use of agrochemicals is vital for the continuing success of the farmer and agrochemical industry. It also minimises possible adverse effects on the environment. The problem was to find a way to combine masses of data and individual experiences, making them easily available to the farmer in a usable form. Expert Systems can manage complex knowledge, such as that concerning cereal disease development, in a fashion not too dissimilar from the human expert. Making this type of system available in videotex and operated through the telephone network provided a solution.

INTRODUCTION

Correct and rational decision-making on agrochemical usage is fundamental to the continuing success of the farmer and the agrochemical industry. For the farmer it is essential that money invested in agrochemicals is cost effective and a continuing viable agrochemical market depends upon this. Rational chemical usage also minimises possible adverse environmental effects and helps create a public atmosphere more conducive to efficient use of all available resources for maintenance and improvement of profitable crop yields.

THE PROBLEM

The problem is to have the right information available at the right time in order to make the right decisions. A vast amount of valuable information is continually being produced and is being used as effectively as possible by farmers and advisors. As this information filters down, so the number of crops, the number of times at which decisions are being made and advice sought is increasing. Yet sheer economics means that the number of people with sufficient expertise to be able to sift and utilise the information at the same rate does not exist. At peak periods at least, the ratio of advice seekers to advice givers is out of balance and the quality of many of the decisions could be questioned.

Computers have for some time been used as an aid in this area but have been hampered by their lack of ability to provide reasoning to back up the advice and recommendations given, normally done by the scarce and expensive human expert. In addition, the cost involved of a true multi-user system would have been enormous and also the presentation of data unacceptable to the non-computer specialist. A cheap and simple-to-use system was therefore required, which was available over a long period and gave results which were not only readily understandable but could be questioned and backed up with reasoning. The system needed to be flexible and capable of rapid incorporation of new information.

A SOLUTION

At least partial answers to these problems have been provided by recent software developments and have been utilised by ICI Plant Protection Division to devise a crop management program, initally concentrating on wheat disease control. The program is registered as Counsellor and is an Expert System running on videotex. Videotex is now becoming widely used both in the UK and the rest of the world. It is best known in the UK as Prestel, the public system, but over 200 private systems are also in use, primarily in the holiday and motor trade. ICI Plant Protection Division has a private system, code-named Grapevine, which is regularly accessed by its field staff in the UK and a number of distributors. The great virtue of videotex is that it has the potential of bringing the power of the main frame computer into every home at relatively low cost. Using the ordinary telephone and, at the lowest level an adapted television set, access can be made to a videotex system. While most videotex systems allow you to look at static pages of text, connection can be made to interactive programs. Videotex's use of colour and very simple commands makes it a truly 'user-friendly' system.

The big break-through with Counsellor is the interfacing of videotex to an Expert System which is at the leading edge of software development, being based on artificial intelligence. Expert Systems add a new dimension to the way a program is set up and in its presentation to the user.

EXPERT SYSTEMS

So what is an Expert System?. All computer programs embody some knowledge about solving particular problems, but while conventional programs hold their knowledge in the form of program steps and data, Expert Systems do so in a more human-like fashion. Instead of doing calculations, they perform a simple type of reasoning and can often handle uncertainty and contradictory information in a natural way. Like us they can concentrate on one thing at a time and avoid considering irrelevant details. Instead of working with data, they work, as we do, with things, concepts etc and the relationships between them. The knowledge held in an Expert System is usually referred to as a'Knowledge Base',in order to distinguish it from databases and conventional computing.

Of course, that describes a "pure Expert System". In practice, many Expert Systems will also do a certain amount of conventional calculation and can access conventional databases. These features give rise to a number of advantages over conventional computer systems which were found particularly relevant in the construction of Counsellor:

a. Ease of expressing knowledge. The language used by Expert Systems for expressing knowledge, although still a computer language, is more comprehensible to the non-computer person. This means that an Expert System can be built more quickly than a conventional program to do the same job, and that subsequent modification is easier. This is particularly important in areas like fungal disease, where the knowledge is continually changing due to scientific innovation or practical changes in the field, e.g. introduction of new crop varieties or a change in their resistance to disease.

b. Flexibility of expression. While conventional scientific programs often work at a level of great detail, Expert Systems offer the flexibility of working at several levels, from the deep science of fungi to the rules of thumb that rarely get written down in textbooks but which farmers nevertheless use on a day to day basis. This is discussed later.

c. Explanation of reasoning. While conventional programs give an answer, Expert Systems can additionally explain how they arrived at that answer or why they are asking a particular question. This is particularly useful where unexpected advice is given and the response may be "no computer is going to tell me what to do". In addition, such explanations can have an educational side effect.

d. Human-like reasoning. In real life we often reason thus "because this field has heavy soil the crop is likely to suffer from damp conditions and so eyespot is more likely", which is a long way from the precise calculations performed by conventional computers. Expert Systems, because they operate with items and relationships, and can handle uncertainty, can perform reasoning very similar to this.

In short, Expert Systems offer a more human-like type of computing. They are thus more able to tackle some areas of real life where more judgement is required than conventional programs.

THE KNOWLEDGE BASE DESIGN

Counsellor is based on Expert System software known as Savoir (ISIS System 1984) which works by using an 'Evidence Net' consisting of boxes and arrows. Fig. 1 shows part of the net which is used to predict the risk of powdery mildew.

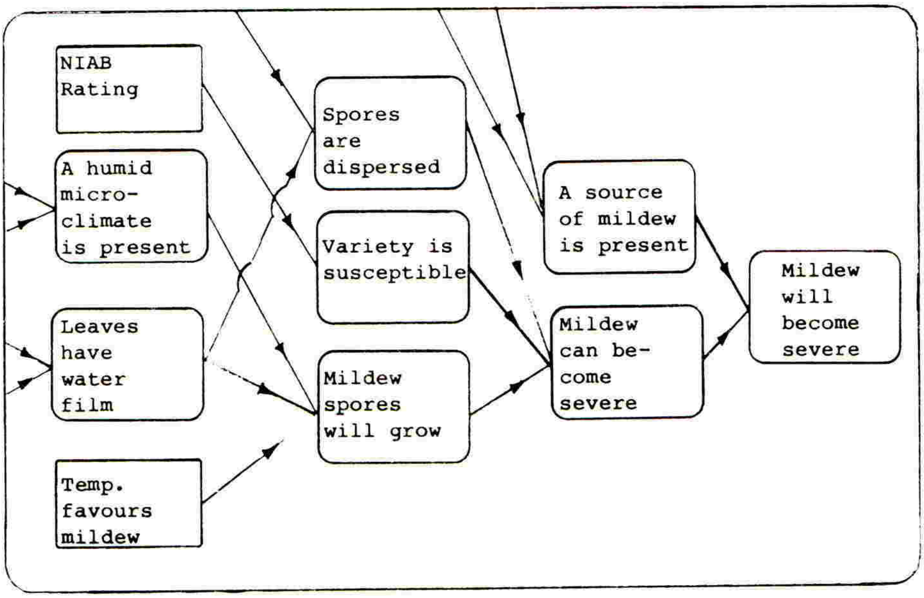

Fig. 1. Part of Counsellor evidence net for wheat powdery mildew

The evidence nets for other diseases are similar but incorporate different factors. The boxes represent meaningful concepts which must be clearly defined and understood. Each box represents the risk of something occuring, eg "mildew becomes severe" which is dependent on the other boxes within the evidence net. The arrows indicate the causal links. For instance "spores are dispersed" is one of the evidence factors for "mildew can become severe". That is, if spore dispersal is likely, we can increase our belief that "mildew can become severe" which in turn increases our belief that "mildew will become severe".

Counsellor investigates each disease in turn by tracing the paths from right to left until it finds a box with no arrows feeding into it. Such a box is derived, not from other evidence, but by putting a question to the farmer. This ensures that only relevant questions are asked. The answers thus received are propagated through all the appropriate causal links. The result is that after all the relevant questions have been answered the right-most boxes attain a degree of belief in the facts they represent being true, i.e. that disease will be severe. Propagation of evidence is carried out in accordance with Bayesian updating mechanisms. (Duda et al 1979).

Whilst Fig. 1 is part of an evidence net for predicting the risk of disease, Counsellor also has evidence nets which are used for optimising treatment recommendations.

The evidence for each box is weighted according to its importance and each starts with an initial degree of belief. Both the weights and initial degrees of belief are based on probabilities calculated from research work and expert judgement. Sources used so far include, MAFF Surveys of Foliar and Stem Base Diseases 1978-82, NIAB Guides to Cereal Varieties, Gair et al 1983, Cook 1982, and ICI experience from development work.

The risk of each disease is firstly determined independently of the other diseases. They are then combined to estimate a resultant yield loss. Aswe were unabletofind much published literature on combined effects of diseases on yield, wehad to develop a method ourselves, which is based on probabalistic logic. We took into account the risk of getting a severe attack of each disease, the maximum potential yield loss from each disease and the likely effect of disease on individual plants. This is giving reasonable results, i.e. when we have carried out consultations the predicted losses due to disease were well accepted by farmers and also compared well with data obtained from fungicide experiments. However, we are still evaluating and modifying the methodology as new facts become available. This sort of modification is easy to implement with the Savoir type of Expert System.

As the knowledge in this type of Expert System is held as meaningful boxes, it is also easy to provide the farmer with information to support the main recommendations by displaying some of the boxes in the middle of the net. It is the ability to give supporting information that is so important in aid- ing decision-making, particularly where judgement or prediction is involved. The art of constructing Expert Systems is still in its infancy. During the construction of Counsellor a number of issues were encountered (Attarwala and Basden 1984). A major issue was the level of detail to which the evidence nets should be taken. At one extreme we could go down to the minutest biological mechanisms of fungi but this level of detail is unnecessary for most farmers. At the other extreme there is no detail at all but this does not allow the generation of supporting information. The most appropriate level of detail was considered to be one level deeper than that with which most farmers are fully familiar. Expert System software like Savoir allows us to choose our level of detail.

WHAT WHEAT COUNSELLOR DOES

Counsellor can operate in two modes. Firstly, it can help to plan the fungicide programme for the season ahead based on knowledge of the farm/field situation and past history. Secondly, immediate in-season problems can be identified and recommendations offered for the rest of the season. This may seem fairly conventional but much more in-depth information is available to explain the reasoning behind the recommendations. A typical consultation could take the following form:

1. Identification of user, farm and field.
2. Retrieve available information from a database, e.g. field history, wheat variety susceptibility.
3. Ask the farmer relevant questions concerning information not already in the database, e.g.seed rate, fertiliser usage.
4. Evaluate the risks from the diseases. Justify the evaluation if required by displaying some of the more in-depth information and reasoning (Fig.2).
5. Make treatment recommendations (including no treatment if this is appropriate).
6. Display cost/benefit analysis for treatment recommendations.
7. If required, display cost/benefit analysis of alternative treatments.

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              ICI PPD WHEAT COUNSELLOR
        Phase 3: Report Disease Assessment
        Farm 1: Field 2: Variety 2: Aut. Plan

           The Risk factors and variety
        susceptibility (based on NIAB) are on
        the scale (0 to 1)

        Risk of Mildew becoming severe
          and causing Yield loss...... 0.88
        Due to:-
        .Risk of Source............... 0.65
        .Risk of Spore dispersal...... 1.0
        .Risk of Suitable conditions.. 0.86
        .Variety Susceptibility....... 0.30

    Key # to continue

         COMMAND<               >
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Fig. 2. Counsellor example display of mildew risk assessment

The whole consultation is carried out in the form of a dialogue close to the situation in real life with both the computer and user asking and answering questions and challenging statements made. Counsellor is able to recall previous consultations and, therefore, will only ask for information that may have changed, e.g. observed level of disease in the crop, crop growth stage.

PROGRESS TO DATE

The decision to mount a full scale project to develop a wheat management aid was taken in July 1983; work in earnest started in September 1983. The first public viewing in videotex form took place in February 1984 in front of a group of influential agrochemical distributors. Its advantages were immediately obvious to those present.

Further development and viewings to a considerable number of people occurred in the following months. It was formally launched at the Royal Agricultural Society Show in July 1984. Over 4 days it was demonstrated live to farmers, consultants, government officials and members of the agricultural trade with great success. It is now available to farmers through ICI Plant Protection distributor customers. Counsellor will continue to be developed and other crop management aids introduced.

CONCLUSION

Our experience shows that Counsellor, if correctly used, will be beneficial to growers, the agrochemical industry and the environment. Growers will benefit not only from appropriate fungicide advice which is tailored to their specific situation, but also from the supporting information that Counsellor offers. The agrochemical industry will benefit from increased use of fungicides where they are appropriate. The environment will benefit from the avoidance of wasteful or inappropriate over-application of fungicides that is not uncommon at present. In addition a number of people have suggested that it would be useful in an educational setting.

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AUTOMATIC ACQUISITION OF METEOROLOGICAL DATA FOR CROP PROTECTION

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ABSTRACT

Developments in environmental monitoring, improvements in data transmissions, storage and processing, and new systems which can be used for the widespread dissemination of a variety of meteorologically-based information will all lead to substantial improvements to information and advice available to the farming community in support of decisions in crop protection. Automation lies at the root of these anticipated advances, allowing a substantial increase in the range of information and advice available without a prohibitive increase in cost to the user.

INTRODUCTION

Meteorological requirements for operational crop protection schemes are often not met by the information available from the National network of meteorological observing stations. Even data obtained within 10 km of a crop's location can be inappropriate for the prediction of disease development within a crop, particularly in regions with large topographical variability (Schroedter 1983). Where the meteorological station and the crop are close together, or where horizontal gradients of the meteorological variables of interest are small, it is still necessary to apply corrections to the observations in order that they should better represent the microclimate to which pests and pathogens in the crop are exposed.

Increasing automation in the measurement, processing and communication of meteorological observations is beginning to provide the means of overcoming many of the shortfalls in the present systems. This paper discusses how such developments are likely to lead to a much more satisfactory application of meteorology to crop protection in the future.

THE REQUIREMENTS FOR METEOROLOGICAL MEASUREMENTS IN CROP PROTECTION

The pests and diseases to be controlled include soil-based insects and pathogens, organisms which reside largely on plants and have a local origin, and those which can be spread over long distances by larger-scale atmospheric flows; weeds must also be included. The development or spread of many of them is determined not by average meteorological conditions over a day or so, but rather by the integration of the values of a number of interacting variables, with the relative importance of variables changing as the pest or disease cycle progresses. Therefore, a proper understanding of the influences of meteorological factors requires, in addition to biological data, meteorological data from below soil surface, through the plant canopy and into the lower atmosphere, on horizontal scales determined chiefly by variations related to local topography and the general variability of rainfall, and on time scales down to small fractions of a day.

Meteorological elements required, and their accuracy

These elements will vary with the pest or disease being considered, but a comprehensive list would include air and soil temperature, vapour pressure, solar radiation, wind speed and direction and rainfall rate and duration. To these should be added plant surface wetness which, though not a conventional meteorological variable, is sometimes estimated along with other meteorological elements by environmental monitoring systems (e.g. Sparks & Wass 1983).

Different organisms will show widely different responses to meteorological factors. This, and the form of the meteorologically-based schemes used to predict organism development (e.g. whether very detailed, or simple and empirical), make it impossible to provide here brief, useful guidelines on the required accuracy of meteorological data. Although data from the standard observing network will usually have sufficient accuracy, the loss of accuracy in extrapolating to the locations and microclimates of the organisms being considered may be unacceptably large.

THE AVAILABILITY OF METEOROLOGICAL DATA, AND SHORTFALL FROM REQUIREMENTS

The National synoptic (i.e. operational) meteorological observing network provides a measuring system which in many respects is completely automated, and which forms the basis of an automated scheme to link to warnings of plant disease development (Roe 1984). However, such networks have usually been designed with the needs of general, rather than agricultural meteorology in mind and have substantial shortcomings in the context of operational crop protection.

The meteorological stations which participate in the scheme for the United Kingdom are shown in Fig. 1. Approximately 55 manned stations make hourly observations of temperature, humidity and wind speed and direction, but none of them at present includes surface wetness. They also report weather (e.g. raining/dry) at the time of observation. Thus, although hourly information on rainfall is not available from all the sites, it is still possible to use the observations to make estimates for those diseases whose warning criteria include a period of surface wetness (for example, by relating leaf wetness duration to rainfall and the duration of the subsequent period of humidity (Smith 1962)). Although the observations themselves are made manually, transmission and archiving of the observed data is entirely automatic.

A further 40 manned stations make a more restricted range of observations (e.g. less frequently than hourly, or hourly, except at night or weekends) which can be used to estimate pest or disease development for a more limited range of organisms. Additionally, there are a number of fully-automatic stations observing a restricted range of meteorological variables.

For weather-based pest and disease warnings there are two major shortcomings in the synoptic network: first the lack of full geographical coverage (many important agricultural areas have no synoptic station), and second because the meteorological data are obtained over short grass and not within or over field crops. Many of the 55 full synoptic stations are located at sites which are not representative of agricultural areas, or are in coastal regions. The numbers actually located in important areas of field cropping or horticulture are small. This would not be a serious drawback in operational crop protection provided the meteorological variables showed only small horizontal variations away from coastal regions. Unfortunately this is not the case for rainfall (and by inference leaf or surface wetness).

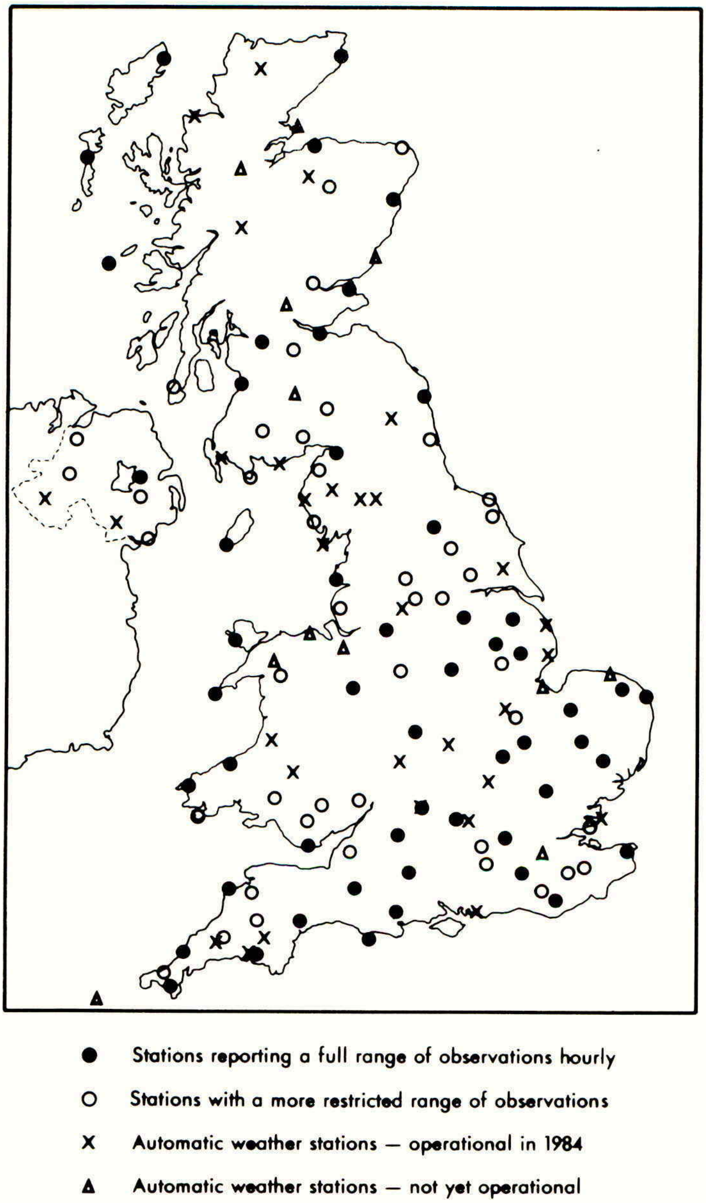

Fig. 1 The location of synoptic meteorological stations providing observations used in the preparation of operational advice on plant disease development, and the network of automatic weather stations

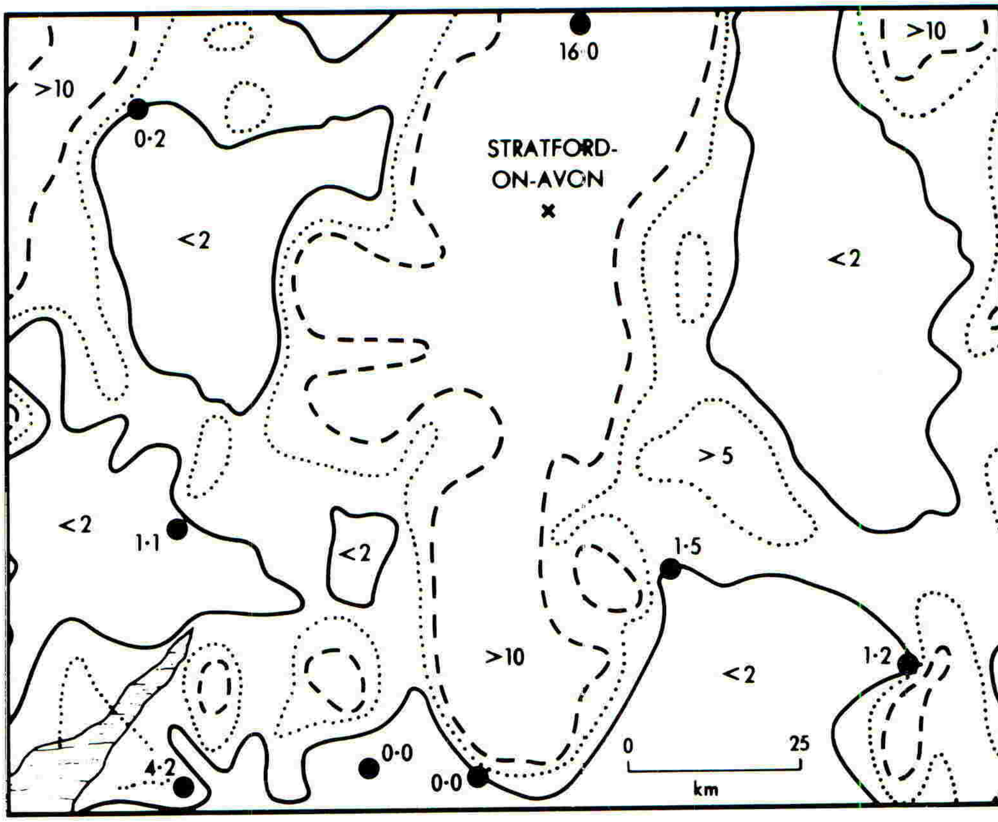

Fig. 2 Daily rainfall in mm (09-09, 1-2 June 1982) as measured by the full climatological network of raingauges (isopleths), with values from the synoptic raingauges (●) superimposed: the synoptic raingauge network has missed almost completely substantial rainfall over large areas.

Rainfall often shows large spatial variability, not only hourly or daily (Fig. 2) but even weekly or monthly. Thus, estimates of pest or disease development from data from the standard synoptic network can be misleading if applied to places remote from the synoptic stations. Automatic weather stations, now being installed, will fill some biologically important gaps in the monitoring networks. These will eventually be equipped with surface wetness sensors, and this is expected to enhance the value of the observations for crop protection. Nonetheless, the sort of meteorological variability demonstrated by Fig. 2 usually prevents any national network of meteorological stations from giving other than a broad-based picture of likely pest and disease development in response to weather. However, where organisms develop only slowly, and integrate the effects of weather over weeks rather than hours, then the use of meteorological data interpolated between the observing stations may give acceptable guidance. The role of rainfall in controlling soil moisture and hence indirectly soil temperature might be noted here. Dry soils become warmer by day than moist ones, particularly on sunny days with light winds, so affecting the rate of development of pests which spend at least part of their life cycle in the upper soil layers.

The problem of standard meteorological observations not representing the environment within which the insect or pathogen is developing, is an important one also, but here at least a theoretical basis ("micrometeorology") exists for deriving an indication of in-crop conditions from the standard observations; empirical methods can also be used for the same purpose.

THE USE OF AUTOMATIC METHODS TO IMPROVE METEOROLOGICALLY-BASED CROP PROTECTION SCHEMES

Enhancement of the synoptic meteorological network

The cost of purchasing and installing a standard synoptic automatic weather station (SAWS) is similar to the annual running costs of a fully-manned synoptic station, and so enhancements currently being made to the UK network are almost exclusively the introduction of automatic stations. Although these automatic stations are unable to provide the visual records of the human observer they are well-suited to gathering data of value in operational crop protection, including frequent (at least hourly) observations of surface wetness, solar radiation and near-surface soil temperature; at present none of these measurements is made regularly at the manned stations. The SAWS network is being provided to meet a variety of operational needs, and so only about a dozen of the proposed c.50 stations will be located in agriculturally important areas: even so some major gaps in the present network will be filled.

The radar rainfall network

Raindrops partially reflect electromagnetic radiation, with the reflection coefficient a function of drop size. Hence, the strength of a radar return signal from falling rain may be interpreted as a rate of rainfall provided the raindrop size spectrum is known. In practice the size spectrum is a function of the type of rain (e.g. frontal, showery) and so operational radar rainfall systems are calibrated at regular intervals by data from a limited number of ground gauges. The data obtained by such systems become increasingly qualitative as distance increases, with a maximum useful range of 150-200 km.

The United Kingdom network (Palmer *et al* 1983) now has 5 radar sets which between them cover almost all of England and Wales. Their data are now in use operationally for short-term weather forecasting and within the next year radar estimates of hourly rainfall in 5 x 5 km squares will become available operationally at Bracknell.

For a variety of reasons radar estimates of rainfall are substantially less accurate than gauge estimates but nonetheless can be used to infer useful values of the *duration* of rainfall. As a result, it will become possible to relate disease and pest development to weather with much greater geographical resolution than is possible using data from synoptic weather stations alone, provided quantities such as temperature and vapour pressure measured only at synoptic stations are assumed to vary smoothly in the horizontal.

Relationships between standard meteorological measurements and in-crop values

The standard observations from the National synoptic network are stored automatically in an easily-accessible computer database and so are readily used for weather-based warnings of possible pest and pathogen activites, employing suitable algorithms. Account, however, must be taken of differences of environment within the crop from that measured by conventionally-exposed meteorological instruments. Of particular interest is the duration of leaf wetness. Smith (1962) demonstrated that a simple criterion based on the size of the standard measurement of dew-point depression gives useful estimates of leaf wetness duration for a tall, sparse canopy. Wass (1982) has produced only slightly less simple criteria, also based on dew point depression, which give a good indication of the onset of dew, and evaporation of surface moisture for a short crop. A more fundamental approach, based on simple micrometeorological theory, and applicable in principle to most crops, has been described by Pedro and Gillespie (1982). Such schemes, or suitable modifications of them might readily be used in automated systems for relating pest and disease development to standard meteorological data.

Unfortunately, all of these schemes have shortcomings when a fairly dense crop canopy is thoroughly wetted by rain since then the upper layers in the canopy may dry out several hours earlier than leaves nearer the ground (Thompson 1981). For reasons such as this, and because until now the National meteorological network has been unable to provide other than a very sparse geographical coverage, interest has increased in the employment of specialized in-crop environmental monitoring systems on individual farms.

On-farm monitoring of pest and plant disease environment

Off-site meteorological data must always run second to reliable observations obtained at the optimal height within the crop to be protected. The increasing interest in local monitoring has been encouraged by the need to avoid unnecessary sprays because of the threat of sharply reduced prices for cereals, especially, in the future. This interest has been encouraged by the developing use of computers on the farm which can provide the required processing facilities for the acquired data, and by recognising that advances in instrumental design and especially electronics are reducing the likely cost of such systems, and increasing their reliability.

Portable, self-powered, microprocessor-based systems, such as that described by Sparks and Wass (1983), can be placed within or over the crop and may be programmed to estimate disease or pest development over the previous day or so. However, their output indices then apply strictly to one crop and uncertainty enters when the same environmental data are used to provide disease development information for various crops at other locations on the same farm. Additionally the output indices of disease development may require further interpretation in the light of current disease levels, crop growth stage and forecast weather over the next few days before spray scheduling can be carried out. Furthermore, since a deterioration in the performance of such devices may not be readily detectable by the non-meteorologists using them, they must be very well engineered and so will never become very cheap.

An alternative strategy is to expose the appropriate range of meteorological sensors over a well-exposed grassland site on the farm and connect their outputs directly to a computer system in the farm office. Simple empirical relations can then be used to infer from the observations the expected environment within any crop on the farm, and thus likely disease development rates; forecast weather inputs can also be used to indicate likely development rates some way ahead. However, these results still have to be interpreted before the decisions to spray are taken, and it therefore appears essential for plant pathologists to play an active role in the development of the necessary computer program packages. Such instrumental systems also have the advantage of providing meteorological data which can be used for other purposes, such as irrigation scheduling or the timing and amount of fertiliser application.

The use of weather forecasts

The most effective crop protection schemes use not only current or recent information on pest and disease development, but also note the likely influence of future weather. The accuracy of weather forecasts has improved considerably over the last two decades, largely through automation in the form of computer-based forecasting models. Of particular interest to crop protection is the prospect of using directly the outputs of these models to provide probability forecasts of, for example, rainfall amount and duration, and temperature. Probability forecasts have been issued for some years in North America (e.g. Glahn 1980) and are under investigation by the Meteorological Office. Such forecast information (which can even be used to produce written forecasts entirely automatically (Glahn 1980)) is well suited to dissemination by modern automated communication systems (see below) and is likely to provide an important input to crop protection schemes in the next few years.

The spraying of herbicides is an area of crop protection in which detailed conventional weather forecasts are required in order to decrease the risk of damaging spray drift incidents, or reduced efficacy. Such forecast information is neither widely nor cheaply available at present through conventional channels and this aspect of crop protection will be materially improved by use of the new communication systems.

The demand for more precision in forecast data, and the possibility of using these data in local computer-based systems for a host of on-farm activities suggest that the provision of forecast information as a matrix along the lines of Table 1, with up-dating perhaps two or three times daily, will become a standard practice. Local processing of such a matrix using suitable algorithms could provide all the forecast information needed by a farm enterprise. Similar matrices, but with the forecast elements given in probability terms, will also become available in the next few years.

Automation in the dissemination of meteorological information

The system for collecting, storing and processing the basic weather information from the UK synoptic observing network is already almost completely automated. The need now is to improve access by the farming community at large to the increasing range of meteorological information which this automated system is able to produce for applications in crop protection. Television and regional radio will remain of little value here and although local radio gives more scope it seems certain that teletext transmissions, either serving specialist "closed user groups", or through the open Prestel system, will become the major mechanism for providing a wide range of timely and relatively inexpensive information to the user. Telex, which is used at present to provide organizations like ADAS with a broad range of computer-based agrometeorological information from Bracknell, will be superseded by direct computer-to-computer links allowing the transmission cheaply of large quantities of data. Interactive systems may also become widespread where the user can feed his on-farm data to a central processing facility, and receive back more comprehensive information than could be supplied by carrying out the processing solely on the farm.

TABLE 1

Example of a matrix of forecast meteorological data for on-farm application

Element	Time ahead (hours)									
	0-4	4-8	8-12	12-18	18-24	24-36	36-48	48-72	72-96	96-120
Wind speed	*	*	*	*	*	*	*	*	*	*
Wind direction	*	*	*	*	*	*	*	*	*	*
Max. temperature	*	*	*	*	*	*	*	*	*	*
etc.										

CONCLUSIONS

Political decisions are likely to lead to falling returns from a whole range of field crops in the next few years. It is fortunate therefore that we are now entering an era when expected developments in meteorological observing networks, in-crop monitoring systems, on-farm computers, weather forecasts for agriculture and data dissemination methods will all contribute to more cost-effective schemes for crop protection.

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ENVIRONMENTAL MONITORING FOR CROP PROTECTION: A SURVEY OF COMPUTER NEEDS ON U.K. FRUIT FARMS

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ABSTRACT

The growers among 180 responders to a questionnaire represented c. 20% of the U.K. total fruit acreage. Personal attitudes to office computing and decision-based crop protection strategies influenced replies. Overall, however, a field-based, battery-driven microcomputer is wanted on the farm (by 70% of responders) or in the district (31%) for 9 months each year, to monitor weather and indicate when conditions are favourable to scab, powdery mildew, caterpillars and mites on apple. Sensors recording temperature, r.h., surface wetness and rainfall would provide inputs for pest and disease predictive models; the temperature data could also be used for predicting crop yield, harvest date, certain storage disorders and for frost warnings, all mentioned by the responders. Information should be displayed digitally on the field monitor and stored in memory for several weeks. A printing facility seems worthwhile. The survey indicated that direct access to the field monitor from the farm office will become necessary as business computers become more popular. At 1982 values, the maximum price acceptable was £400 (45%), £800 (32%), £1200 (16%) and £1600 (8%).

INTRODUCTION

Biological and environmental monitoring and data interpretation are necessary for rational crop protection decisions and have been discussed for U.K. orchards (Butt & Jeger 1982). Instruments designed for monitoring the environment in or near apple orchards include a chart recorder (MacHardy 1979), an electronic device (Richter & Häussermann 1975) and a microprocessor-based system functioning as a microcomputer (Jones *et al.* 1984). This paper reports the findings of a survey of the U.K. fruit industry to discover the need for microprocessor-based monitoring and computing systems in the field.

MATERIALS AND METHODS

Questionnaire

A questionnaire was sent in 1982 to c. 1000 members of the East Malling Research Association, which includes most leading growers and advisers. Recipients were asked to study the description of a hypothetical monitoring system before answering the questions. In summary this read: "Electronic sensors monitor temperature, r.h., surface wetness and perhaps rain, wind and other variables in the vicinity of crops. A monitor, which may be placed a short distance from the sensors, logs the data. Information called for by the user could be weather summaries, leaving the user to interpret the data for effects on diseases and pests, and/or indications of conditions favourable to certain diseases and pests. Information can be displayed directly on the field monitor, possibly equipped with a printer, or accessed from an office computer."

Sorting the replies

Replies were transferred to punched cards, sorted and expressed as the number (n) of replies to each answer and the percentage of replies based on the total number (N) of responders to each question. Apparent discrepancies in numbers are due to some responders not answering every question or giving more than one reply to a question. Several people were, for example, both growers and advisers.

Tests for dependence of replies on personal factors

Questions 1.1-1.4 were used to group the responders according to occupation, land area and attitude to chemical control and office computing: replies to questions (except 1.5, 3.2, 3.3 and 3.4) were examined for dependence on these four personal factors using a chi-squared test.

RESULTS

Overall result

Replies were received from 180 people. It is estimated that growers i.e. farm owners and managers in this sample, represented c. 20% of the total top- and small-fruit acreage in the U.K. The overall result is shown in Table 1.

TABLE 1

Overall replies to a questionnaire on an environment monitoring system for use on fruit farms

Question/Answer	Replies (n)	$\frac{100n}{N^*}$
Personal information		
1.1 Your interest in fruit farming is as:		
farm owner or manager	162	(93%)
adviser or teacher	36	(21%)
1.2 Area farmed, advised or supervised:		
<100 ha	104	(63%)
100-1000 ha	55	(34%)
>1000 ha	5	(3%)
1.3 To avoid risk, I prefer to spray routinely and regularly	77	(43%)
To be cost effective, I prefer to time sprays in relation to weather and other factors	108	(61%)
1.4 Do you use or expect to use in the next three years an office computer?		
Yes	34	(20%)
Probably	64	(37%)
No	73	(43%)
1.5 What weather data do you collect?		
rainfall	117	(65%)
temperature	94	(52%)
other	32	(18%)
none	42	(23%)

TABLE 1 (cont.)

Question/Answer	Replies (n)	100n/N*
Interest in an environment monitoring system		
2.1 Do you need a system:		
on your farm(s)?	125	(70%)
in your co-operative/group/district?	55	(31%)
not at all	7	(4%)
2.2 Excluding an office computer (if needed), the maximum I would pay is:		
£400	65	(45%)
£800	47	(32%)
£1200	23	(16%)
£1600	11	(8%)
Role of an environment monitoring system		
3.1 A system should:		
summarise weather	26	(15%)
give pest/disease warnings	50	(29%)
do both the above	99	(57%)
3.2 If a system gives warnings suggest diseases/ pests keeping all your crops in mind:		
apple scab	162	(96%)
apple powdery mildew	155	(92%)
caterpillars	88	(52%)
fruit tree red spider mite	73	(43%)
aphids	52	(31%)
Botrytis	50	(30%)
cereal diseases	41	(24%)
hop downy mildew	25	(15%)
3.3 Suggest uses other than disease/pest control:		
irrigation	64	(52%)
frost warning	31	(25%)
crop and fruit size prediction	23	(19%)
harvest date prediction	13	(11%)
fertilizer needs	11	(9%)
forecasting storage life and monitoring stores	7	(6%)
various minor applications	38	(31%)
3.4 When could a system be switched off?		
January	127	(99%)
February	107	(84%)
March	18	(14%)
April-August	0-2	(0-2%)
September	22	(17%)
October	65	(51%)
November	119	(93%)
December	126	(98%)

TABLE 1 (cont.)

Question/Answer	Replies (n)	$\frac{100n}{N^*}$
Design of an environmental monitoring system		
4.1 A system should be powered by:		
mains electricity	61	(36%)
a power pack with long-life batteries	113	(67%)
4.2 Cost in mind, information produced should be:		
limited (e.g. simple summary of weather)	94	(55%)
comprehensive (e.g. warnings with weather details)	79	(46%)
4.3 Cost in mind, a system memory should last:		
4 days	69	(41%)
4 weeks	98	(59%)
4.4 The number of diseases/pests programmed into a system for warnings should be:		
none/few	116	(69%)
many	53	(31%)
4.5 A disease warning displayed on the monitor should be:		
a single warning light	24	(14%)
several lights to indicate risk	22	(13%)
a number from 1-5 to indicate risk	132	(76%)
4.6 Should warnings be audible?		
Yes	25	(15%)
No	146	(85%)
4.7 Information should be available to the user:		
on the field monitor	87	(51%)
on a portable printer	59	(35%)
on an office computer	34	(20%)
4.8 How important is it to have direct access to monitored information from the office?		
very important	56	(32%)
desirable	78	(44%)
not important	44	(25%)

* N = number of responders to each question

Influence of personal factors on an environment monitoring system

Tables 2-5 show the number of replies grouped according to personal factors.

Professional occupation in fruit growing (question 1.1)

Answers were independent of occupation.

Area of land (question 1.2)

The maximum price proposed (question 2.2) depended upon ($p<0.05$) the farm area (Table 2).

TABLE 2

Dependence of maximum price proposed for a system on land area

Monitoring system Maximum price*(£)	Land area (ha) <100	100-1000	>1000
400	45	14	2
800	26	16	1
1200	11	11	1
1600	3	8	0

* omits any office computer

TABLE 3

Dependence of a) need for and b) role of a system on attitude to strategies of chemical crop protection

Monitoring system	Chemical control strategy	
	Routine	Decision-based
a) Needed:		
on farm	43	84
in district/group	27	29
not wanted	7	0
b) Role:		
weather data	6	22
pest/disease warnings	25	25
both the above	41	61

Chemical control strategy (question 1.3)

Attitude to decision-based crop protection strategies influenced interest in a system (question 2.1, $p<0.01$) and views on its role (question 3.1, $p<0.05$) (Table 3). Interest in audible warnings (question 4.6) also depended on ($p<0.05$) this personal factor, being least popular among those least averse to taking risks.

Use of office computer (question 1.4)

This factor had the largest influence of the personal factors, with answers to questions 2.1 ($p<0.001$), 2.2 ($p<0.001$), 4.4 ($p<0.05$) and 4.7 ($p<0.01$) dependent on attitude to office computers (Tables 4,5).

Affinities between personal factors

Table 6 shows associations between factors used to group responders to the questionnaire.

TABLE 4

Dependence of a) need and b) maximum price proposed for a system on attitude to office computers

Monitoring system	Office computer Yes	Probably	No
a) Needed:			
on farm	28	53	39
in district/group	8	13	32
not wanted	0	0	5
b) Maximum price (£)			
400	8	15	40
800	8	21	17
1200	7	15	2
1600	3	5	3

TABLE 5

Dependence of a) capacity for pest/disease warnings and b) information delivery method of a system on attitude to office computers

Monitoring system	Office computer Yes	Probably	No
a) P & D warnings:			
none/few	19	40	54
many	15	23	13
b) Delivery method:			
on logger	4	32	48
by printer	12	25	20
via office computer	21	11	1

TABLE 6

Associations between four personal factors known to influence views on an environment monitoring system

	Occupation (1.1)*	Land area (1.2)	Control strategy (1.3)	Computer use (1.4)
Occupation	-	xxx	NS	x
Land area		-	NS	xx
Control strategy			-	x

Chi-squared test of dependence: x $p<0.05$; xx $p<0.01$; xxx $p<0.001$; NS-not significant

* Number of pertinent question in questionnaire (Table 1)

DISCUSSION

Profiles of the sampled population

Table 1 shows that 93% of replies were from farm owners and managers, 63% were from people responsible for areas <100 ha, 61% favoured decision-based strategies of chemical control and 57% were from people owning or expecting to own an office computer. These four personal factors were mutually associated (Table 6). In comparison with people not intending to buy an office computer, for example, the 'computer-minded' remainder had a greater (64% c.f. 50%) interest in decision-based control strategies, a greater (50% c.f. 20%) responsibility for areas >100 ha and comprised more (22% c.f. 12%) advisers and teachers. Three points to note are that 'computer-minded' people were associated equally with areas < and >100 ha; half of the people who were not 'computer-minded' and 70% of people who indicated a probable future purchase of an office computer showed interest in decision-based control strategies; advisers and teachers were responsible for areas >100 ha (24%) rather than <100 ha (11%).

Interest in an environment monitoring system

Only 4% of responders had no use for a monitoring system; 70% of replies indicated that a system is wanted on farms and 31% indicated a need in the district (Table 1). Opinions depended, however, on attitudes to office computers and to risk in pest and disease control. For example, 78% of those with office computers said they needed a system on the farm, compared to 51% of those with no interest in office computers, but in this latter group 42% were in favour of a district siting (Table 4). Also, 74% of those interested in decision-based chemical control indicated the need for a system on the farm, compared to 56% of those who favoured routine control (Table 3). Regarding the cost of a system, 45% overall suggested a maximum of £400 (1982 price) but 56% were prepared to pay £800, and 24% £1200. Again, these opinions depended upon personal factors: of those who had or were likely to buy an office computer, 39% and 36% respectively were willing to pay £1200, whereas of those with no intention of having an office computer, 35% did not wish to exceed £800 (Table 4). Of those responsible for areas <100 ha, 48% were willing to pay £800 compared to 71% of those in the group responsible for 100-1000 ha (Table 2).

Role of an environment monitoring system

Overall, 57% wanted a system to provide both weather data and pest and disease warnings. The replies to this question (3.1) depended, however, on attitude to risk in crop protection; more people interested in decision-based control strategies asked for weather information than did those satisfied with routine spray programmes (Table 3). In each of these groups, however, 57% asked for both weather data and pest and disease warnings. Of the pests and diseases, apple scab (*Venturia inaequalis*) and apple powdery mildew (*Podosphaera leucotricha*) were by far the most frequently mentioned (Table 1), reflecting expensive spray programmes (Butt & Jeger 1982): predictive models may also be justified for orchard moth (*Cydia pomonella*, *Archips podana*, *Operophtera brumata*, *Adoxophyes orana*) and mite (*Panonychus ulmi*) control. More than half the responders suggested that a monitoring system should be used to determine irrigation needs. The necessary data - in particular evapotranspiration - are probably best obtained, however, from available sources at district or regional level. More pertinent to the on-farm role of a monitor would be other suggestions made by the responders, namely predicting crop yield (Jackson *et al*. 1983) and harvest date (Luton & Hamer 1983), assessing risk of storage disorders such as low temperature breakdown, core flush and superficial scald (Sharples 1975) and giving frost warnings in spring.

Design of an environment monitoring system

On the basis of overall majority views (Table 1), a battery-powered monitor is needed in the field from February (for crop yield prediction) to October. It must generate relatively simple information and data should be retrievable from memory for several weeks. In addition to providing summarized environment data, warning is needed of conditions suitable for scab, mildew, certain caterpillar species and mites on apple. It is noteworthy that 44% of people with office computers want warnings of many pests and diseases, whereas 81% of those without a computer would be satisfied with a system programmed to give few or no warnings (Table 5). Users without an office computer want information to be displayed digitally on the field monitor (Table 5) and there is a definite preference for warnings of critical conditions to be similarly displayed and to indicate risk levels; no audible warning is needed. The majority of people who have a business computer would prefer information to be delivered at the office computer. It seems likely that as office computers become more widely used on fruit farms, a demand for this means of accessing data will increase; this is indicated by the replies to question 4.8 in which only 25% of responders thought it unimportant to have access to an environment monitoring system from the farm office. Clearly, in this type of system the monitor needs to function as a data logger only, because the processing and interpretation of data can be performed on the office microcomputer after the raw data have been transferred. Meanwhile, the survey indicates that at present the majority of users would require the output of information on the monitor itself, but preferably with an option for printing: with this type of delivery system the monitor is a dedicated microcomputer.

The system will require sensors to measure temperature (wet and dry bulb), surface wetness (state and duration) and probably rainfall. These variables will drive models to predict apple scab and powdery mildew; the temperature data can also be used in the control of orchard moths and mites, for frost warnings (using both screened and exposed sensors), and to predict crop yield harvest date and certain storage disorders.

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DEVELOPMENTS IN DETECTION OF AIRBORNE APHIDS WITH RADAR

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ABSTRACT

Although radar has been used since the mid 1960's to measure the numbers and movement of insects such as locusts and moths, most studies have concentrated on academic aspects and the tool has not been developed for routine monitoring and pest forecasting. With the availability of modern high speed electronics and micro-computers it is now possible to process the radar signals immediately. This ability both improves the radar performance, allowing small insects such as aphids to be detected, and provides the opportunity to design a fully automatic system that can be used for pest monitoring.

INTRODUCTION

Aphids are the major agricultural insect pest in the U.K. causing direct feeding damage to crops and also transmitting viruses. Over the past 20 years a network of 12.2 m high suction traps has been developed to monitor the changing aphid aerial population and currently 23 traps are operated throughout Great Britain (Taylor 1974, Taylor et al. 1981). The insects caught in the traps are identified by teams of specialists and the information is collated centrally at the Rothamsted Experimental Station and used to produce pest warnings (Woiwod et al. 1984).

The present suction trap network samples insects only from a single height at 12.2 m and provides no information on the diurnal variation of insect numbers with height or on the speed and direction of movement. Measurements by Johnson and Taylor (1955) using suction traps attached to large balloons showed that aphids are regularly carried up to heights of 330m and that the average profile of insect density with height depends upon the atmospheric stability (Johnson 1957). Taylor and Palmer (1972) stressed the importance of measuring this height/density profile if the numbers of insects landing on crops is to be determined. However the use of balloon mounted suction traps would be impractical in a routine monitoring system. An alternative technique is to use a remote sensing instrument such as radar.

The developments in radar entomology over the past 20 years have now made it possible, at a relatively low cost, to detect radar echoes from small aphid sized insects at ranges in excess of 500 m (Schaefer et al. 1979). The further challenge is to analyse automatically the radar echoes to produce information useful for agricultural pest forecasting. With the recent availability of low cost, high speed, microprocessor-based computers, such a system tool is now realisable.

This paper describes the developments in the detection of aphids by radar and the work currently being undertaken at the Rothamsted Experimental Station to develop a fully automatic, computer controlled monitoring tool.

DEVELOPMENTS IN RADAR ENTOMOLOGY

As early as 1949 it was recognised that individual insects could produce radar echoes (Crawford 1949). However, although a number of qualitative radar studies of insects were made (Rama Murty et al. 1964, Schaefer 1970), it was not until the late 1960's that quantitative observations of airborne insect activity were undertaken (Glover et al. 1966, Schaefer 1976). Most of these studies, initially on larger insects such as locusts and moths, used high power, pencil beam, pulsed radars, scanning in azimuth and elevation and displaying the return echoes on plan position indicator screens. These screens were analysed manually and the numbers of insects at the different heights were measured together with their speed, direction of flight and body orientations (Schaefer 1976). Entomological radars of this type are now used widely for scientific investigations (Riley et al. 1983, Wolf 1979, Greenbank et al. 1980, Drake 1982).

At an early stage in the development of radar entomology it was recognised by Schaefer (1976) that when sampling electronically the return echoes from a fixed range, a large proportion of insects flying through the beam produced signals whose amplitude is modulated at frequencies apparently associated with their beating wings. This provided a means of broadly categorising the insect types. Similarly Riley et al. (1983) also reported attempts to distinguish African Armyworm moths (Spodoptera exempta) from wingbeat patterns alone. These results often prove to be inconclusive due to the wide spread of frequencies within and between species, indicating that identification is not always possible from this parameter alone.

A number of radar systems using and extending the electronic sampling technique have been developed over the past few years, including an airborne radar for moth detection (Schaefer 1979, Greenbank et al. 1980), and a vertically pointing ground-based radar (Riley & Reynolds 1979). Both these systems utilised the polarisation properties of the radar beam which was used to measure insect flight headings and to study the collective orientation of night flying moths.

The application of radar to measurements of the agriculturally important small insects, such as aphids, was first reported by Schaefer et al. (1979). Their results, obtained by electronically sampling a fixed volume of space that could be scanned in elevation, were obtained by measuring the average return echo on occasions when many insects were in the monitoring volume. Advantage was also taken of an unusual situation when large numbers of a single aphid species were in the air during an outbreak of the rose grain aphid (Metopolophium dirhodum Walk.) in July 1979 (Dewar et al. 1981). Fig. 1 shows the diurnal variation of insect density with height on 26 July 1979, when 96% of insects with weights above 100 µg caught in nearby suction traps were cereal aphids. The data show clearly that the highest aphid densities are in general found near the ground but that the profile changes continuously, showing layers of aphids at various heights with, from time to time, the aphids being carried up to heights in excess of 300 m by convection currents. The radar results emphasise the importance of measuring the insect density/height profile if accurate predictions of deposition into crops are to be determined.

Although the technique described above works well for situations where many insects of a single type are in the sample volume simultaneously, the more usual monitoring situation is during periods of low density when individual insects of different types fly through the radar beam at the different heights. In this situation an alternative approach is required.

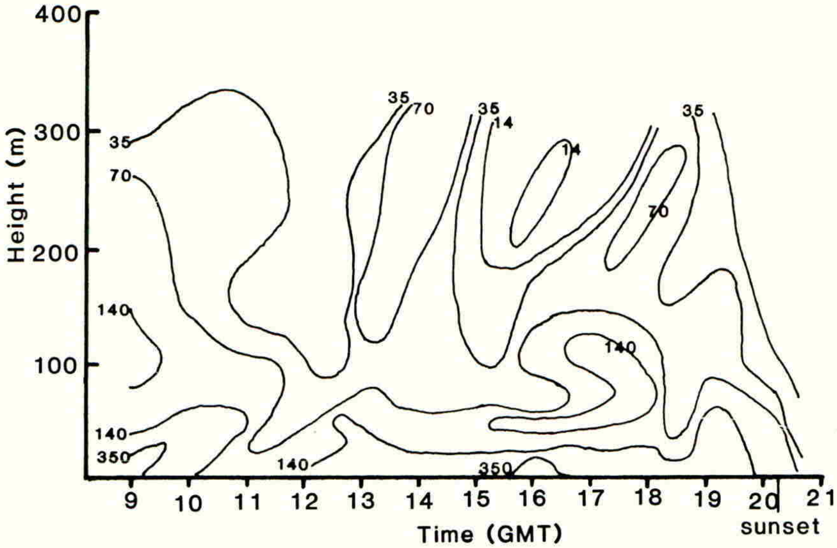

Fig. 1. Radar measurements of the diurnal variation of aphid density with height. The countours give the numbers of aphids per 10^3 m^3 of air. (Reproduced by kind permission of Professor G.W. Schaefer)

THE ROTHAMSTED INSECT RADAR

The radar system currently under development at Rothamsted aims to monitor insects, particularly aphids, flying at low density at heights of 12-250m and at greater densities to beyond 500 m. The system is also required to determine the height, speed and direction of flight and to categorise the signals to allow identification of various insect types.

The prototype radar is a vertically pointing dual antenna system and uses a high power 25 KW transmitter operating at a frequency of 9.4 GHz(3.2 cm wavelength), a pulse length of 50ns and a pulse repetition frequency of 5KHz.The transmitter is connected directly to one of the two parabolic antennas via a centre fed dipole aerial to produce a 3.6 degree wide pencil beam. The second parabolic antenna, also with a centre fed dipole, is mounted close to the transmitter antenna and offset at a small angle to the horizontal. This antenna is then rotated mechanically about the vertical dipole axis, conically scanning the receiver radiation patterns as shown in Fig. 2.

As an insect flies over the radar site and traverses the region in which the transmitter and receiver radiation patterns overlap, the intensity of the radar echo produced depends upon the target's range, its position within the beams and the radiation scattering properties of the target which are defined by the radar cross-section.

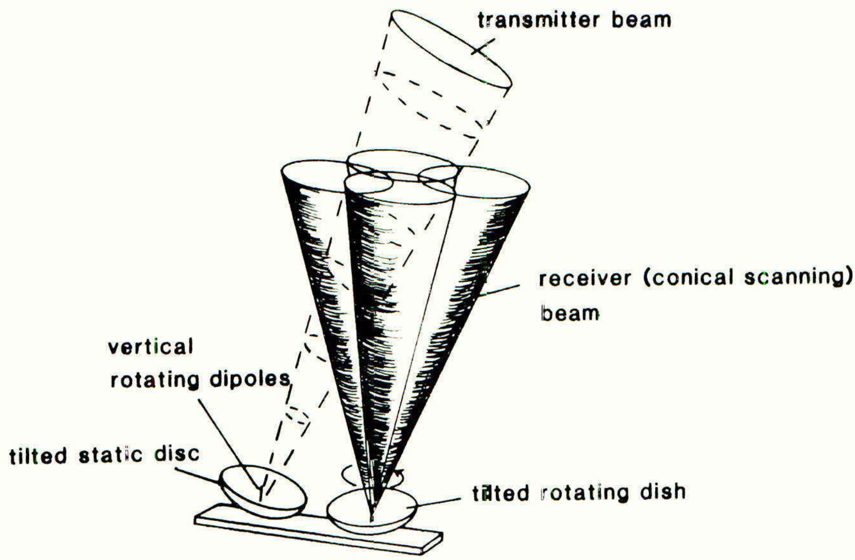

Fig. 2. Schematic diagram of the dual dish radar.

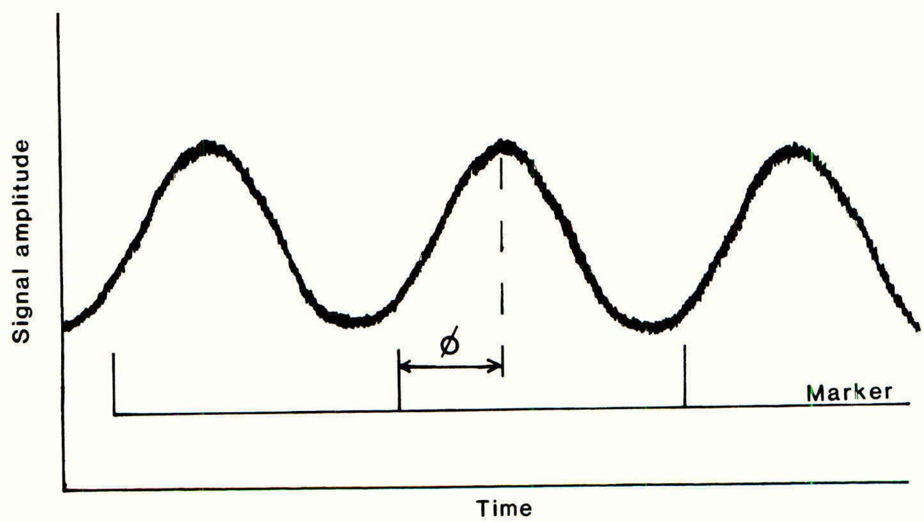

Fig. 3. Radar signal from a small metal sphere located in the concial scanning beam. The signal amplitude and phase angle, Ø, are a measure of the spheres position and radar cross-section.

Echo intensity is highly dependent on range, varying inversely as range to the fourth power for small targets. In the present system, target range is determined by sampling electronically the return echoes from fixed height intervals of 12-250 m with each height range covering a depth of 7.5 m.

The signal intensity variation due to target position is a function of the two-way radiation pattern, which in the overlap region changes in a predictable way at the conical scanning frequency. Target position can be determined by measuring the amplitude and phasing of the return echo at this frequency. This is illustrated in Fig. 3, which shows the return signal measured from a small metal sphere positioned in the overlap region at a range of 12 m. The position markers, shown in the figure, indicate when the conical scanning beam is at zero degrees in the reference frame of the system and the phase Ø, between the marker and the signal peak, measures the angular position of the target. The amplitude of the signal, measured from maximum to minimum, is directly related to the radial distance of the target from the vertical dipole axis and therefore the two measurements give the target position. By rotating the receiver antenna at a high frequency and

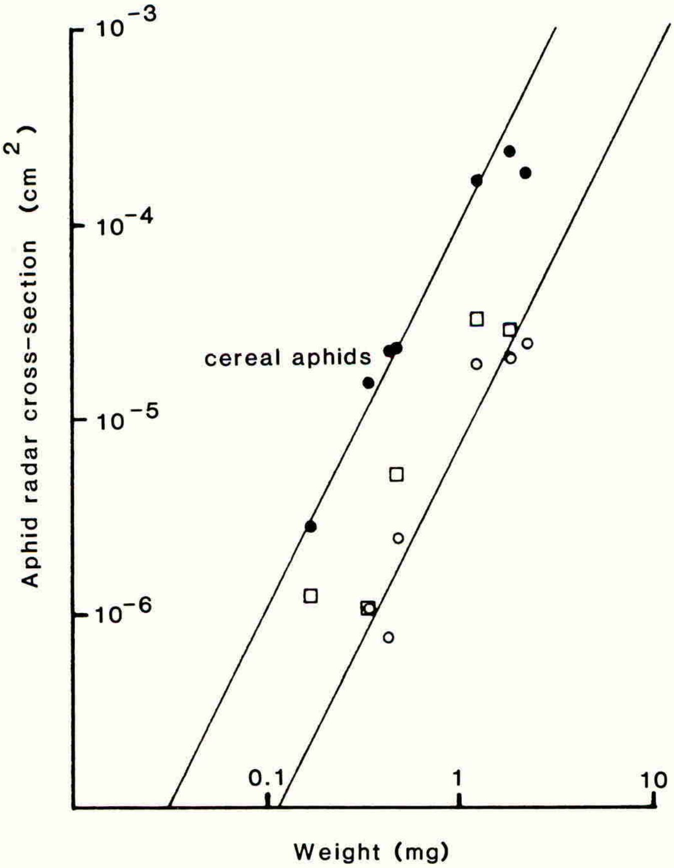

Fig. 4. Measured radar cross-sections of aphids of different mass, at three polarisations. a) Along body axis ● ; b) Across body axis ○ ; c) Head or tail on □ . Solid lines are the theoretical predictions for an equivalent dilectric spheroid of axis ration 3 : 1.

measuring the signal amplitude and phase many times per second as the overlap region is traversed, the insect speed and direction is obtained.

Insect radar cross-section is a function of the body weight and shape and the polarisation and frequency of the radar signal with which it is detected (Schaefer 1976, Riley 1973). Laboratory measurements of the radar cross-section of aphids have been made on an instrument developed by Dr. J. Riley at the TDRI Radar Unit, Malvern. The results are shown in Fig. 4. At the chosen radar wavelength of 3.2 cm radar targets of aphid act as Rayleigh scatterers, with radar cross-sections proportional to the square of the target mass. The measurements were made at three different polarisation angles - a) polarisation along the body axis, b) polarisation across the body axis, and c) polarisation head or tail on. These results agree well with theoretical predictions for dilectric spheroids with a major to minor axis ratio of 3 : 1 (Schaefer 1976). For the cereal aphids the average radar cross-section is approximately 10^{-5} cm² at this wavelength. Calibration of the prototype radar has been undertaken using metal spheres of known radar cross-section. The results indicating that targets of cereal aphid size are detectable at 200 - 250 m range.

In the prototype system the polarisation of the radar signal is rotatable through 360 degrees by synchronously rotating the dipole aerials.

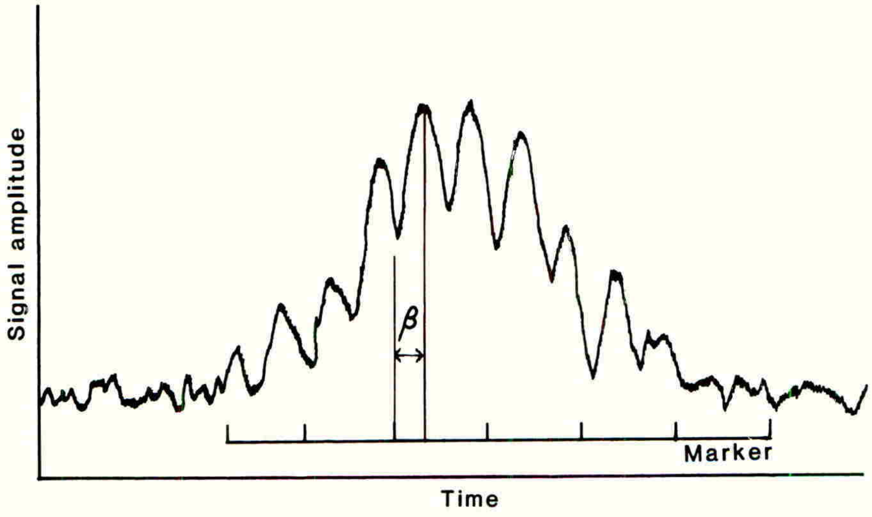

Fig. 5. Radar signal from an insect flying through the beam, with dipole rotation only. The depth of the modulation is a measure of the insect's body shape.

Since all the insects are being viewed from below, the polarisation will be aligned along and across the body direction twice per dipole rotation. Therefore by measuring the amplitude and phasing of the return echo modulation at twice the dipole rotation frequency and using the information about the target position, the body weight, shape and orientation can be determined. Fig. 5 shows a typical example of the signal modulation produced by dipole rotation only as an insect with a length to width ratio of 3 : 1 traverses the beam. Again a position marker is used to determine the signal peak relative to some fixed reference angle from which the body orientation (ß) is measured.

The combination of a conical scan to determine target position and body weight with dipole rotation to obtain body shape and orientation produces a complex signal as an insect flies through the beam (Fig. 6). The higher frequency signal modulations that are associated with the wingbeating of the insect are also shown in Fig. 6. Some or all of this information may be needed to classify the insect target and in a routine monitoring system must be determined immediately. This would be impossible without the aid of a high speed dedicated computer to perform signal recognition.

COMPUTER PROCESSING OF RADAR SIGNALS

Sampling and processing the radar signals must be undertaken by a dedicated computer whose tasks also include control and monitoring the radar operation. This requires a machine that is capable of performing a large number of calculations per second, approximately 100 000, of performing many tasks simultaneously (multi-tasking), and one that is flexible and expandable as more refined processing techniques are introduced. As the cost of

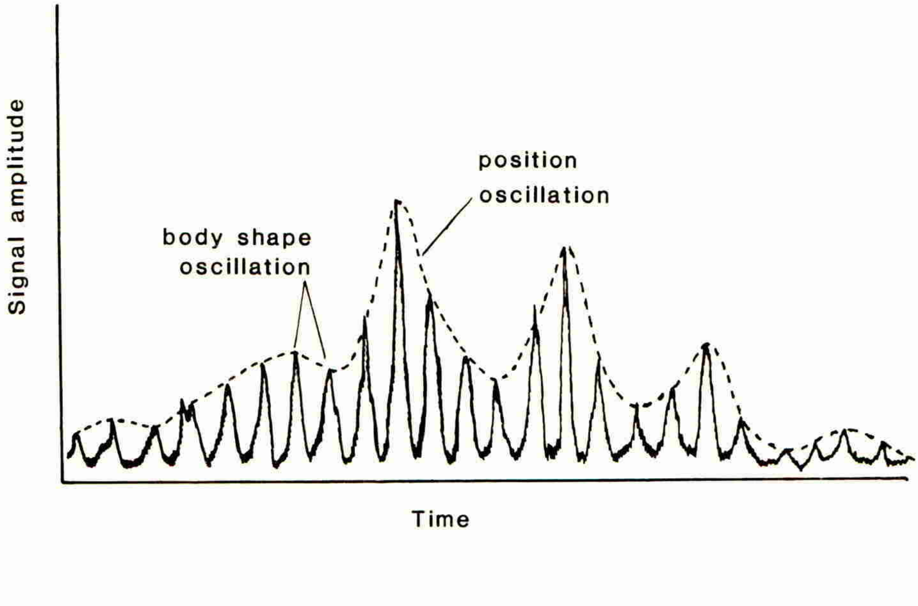

Fig. 6. Complex radar signal from an insect flying through the beam, with both dish and dipole rotation.

microprocessors decreases it is becoming more cost effective to design such systems with multiple processors sharing the data processing load and the resources of the system. This requires some method of interconnecting the processors and system resources and of controlling communication and access (arbitration) between them.

The recently introduced VMEbus concept (Anon 1982), allows the design of such closely coupled systems using 8, 16 or 32 bit microprocessors communication via a 32 bit data transfer bus. Bus arbitration, allocating the bus to each microprocessor in turn, can be configured either on a priority basis, the highest priority processor requesting the bus being granted bus mastership, or in a round robin configuration in which each processor is granted the bus mastership for a fixed period of time. The VMEbus specification also defines seven levels of priority interrupts and a variety of system utilities.

Physically a VMEbus system comprises a series of modules each constructed on double height eurocard boards and interlinked via two 96-way backplanes. The dedicated radar computer consists of four such modules. The first two modules are the processor units which are identical. Each of these contains a 16 bit MC 68000 microprocessor, operating at 8 MHz; a 256KB dual ported random access memory (RAM), accessible either from on the board via a local bus or from the VMEbus; 32 KB of EPROM and 16 KB of SRAM accessible from the local bus only and used to initialise the system; a multiprocol communications controller interface, which on one module is used as a modem link and on the other as a terminal interface when required; a 24 bit parallel interface, used to monitor the dipole and dish rotation angles; a 24 bit programmable timer and real time clock which are used to control the firing of the radar and the rotation rates of the dish and the dipole aerials. Also on each module is a floppy disc controller but this is not used at present. The third system module is a memory card configured to hold 128 KB of EPROM and SRAM which contain the system software. The final module is a 32 channel 12 bit analog to digital converter, with a conversion time of 45 μs per channel and interrupt generation when a conversion is completed. On the module is also a 2 channel, 12 bit digital to analog converter.

The computer system operates by controlling the firing of the radar and reading the output of the radar's sampling circuits via the A/D converter channels. These data are then stored in the memory and averaged to determine the presence or absence of a target in any of the height ranges. If a target is detected further processing of the stored data is undertaken to determine the parameters described above which are then stored for further processing. These initial operations are performed by one of the two MC68000 microprocessors, whose module is given priority in the bus arbitration scheme to ensure that the time critical functions are performed efficiently. The tasks of the second microprocessor will include the further analysis of the stored parameters and the categorising of the various targets. This second processor is also responsible for communicating the information to the outside world. The development of software to perform these tasks is a current area of research. Communications to and from the radar computer are via a CASE 440/12 data modem which is connected between the multiprotocol communications controller interface and a telephone line. The modem has a data transfer rate of 1200 baud and includes autodial and autoanswer ciruitry, makings it incorporation into the system relatively simple.

Software to perform the required data analysis and radar control is currently being developed in 68000 assembler language on a separate VMEbus development system and then blown into EPROM for use in the radar computer. Future software development will also use the 'C' language and operate under a real time executive operating system which is being investigated at present.

A RADAR MONITORING NETWORK FOR INSECTS

The radar, together with its electronic sampling circuits and dedicated computer, is housed in a mobile trailer. It is envisaged that a number of these automatic systems will be strategically sited throughout the U.K. and be linked directly to Rothamsted over the telephone system. In operation each radar will collect information about the numbers of insects in different categories flying at the various monitoring heights, together with speeds and directions, and the totals in each category will then be stored in the computer's memory bank. At suitable times the radar computer will be contacted via its modem and the stored information relayed to a host computer sited at Rothamsted. This host machine will also contact the other radar sites and collate the information from them all. The data will then be used in conjunction with the information already available from the suction trap network to produce up to the minute pest warnings and for improved forecasts. Some of the computer techniques already developed for handling the large amounts of data that will be collected are discussed in the following paper by Woiwod and Tatchell.

CONCLUSION

This paper has described the automatic radar system currently being developed at the Rothamsted Experimental Station to monitor airborne insects and the possibility of using such a tool in a future radar network. The system's reliance on the use of sophisticated computers and computer techniques, without which such a network would be inconceivable, serves to illustrate the impact that computers are making in this area of agricultural crop protection.

ACKNOWLEDGEMENTS

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COMPUTER MAPPING OF APHID ABUNDANCE

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ABSTRACT

Computer mapping has been used for some years to display the data on aerial aphid abundance from the Rothamsted Insect Survey suction trap network. The processes involved in the production of computer maps from irregularly spaced sample data are described and examples of different types of map are presented. The Insect Survey uses such maps for the analysis and interpretation of its large database for research purposes and has recently begun to produce maps for displaying information for advisory purposes. Such mapping techniques can be adapted readily for displaying a wide range of pest and disease sample data.

INTRODUCTION

The spatial dimension of insect pest population dynamics is often ignored, with population changes only being monitored in a limited area on a crop during a short period of the insects' life cycle when damage is caused. However, for many insect pests, population redistribution occurs at some stage of the life cycle and only if this movement is monitored adequately can the ecology of the pest be understood fully and useful forecasts developed. This is true particularly for aphids, which are the most important insect pests in Great Britain due to the direct damage they cause and their ability to transmit plant virus diseases. Aphids have complex life cycles and many species are particularly well adapted to migrate into and exploit annual crops, and when the crop becomes unsuitable their offspring move to other host plants.

The Rothamsted Insect Survey (RIS) was established to monitor continuously these changes in aphid distribution and abundance throughout the British Isles. It uses a network of 40-foot (12.2m) high suction traps so that the relevance of such migrations can be assessed and forecasting systems developed (Taylor 1974). The network at present consists of 23 sites, with similar traps now operating in a number of other countries in Europe (Taylor 1983). Details of the daily operations of the network, forecasting methods, the dissemination of information and other aspects of the Survey's work can be found elsewhere, e.g. Tatchell 1982, Taylor 1974, 1977a, 1979, Taylor *et al*. 1981, Woiwod *et al*. 1984. Here we are concerned with one particular technique, which plays an important role in the analysis and interpretation of the spatial data collected, that of computer mapping.

WHY COMPUTER MAPPING?

Computers can be used for a wide variety of mapping tasks ranging from simple maps of the position of features of interest (e.g. county outlines or the presence/absence type of data produced in many biological surveys (Tatchell *et al*. 1983)), to sophisticated multi-coloured cartographic maps of a standard suitable for direct publication. The final result will depend on the sophistication of the available hardware and software. However, our particular interest lies in the mapping of quantitative data of the type commonly produced in sampling programmes, such as the aphid aerial abundances obtained by the network of Insect Survey suction traps.

There are two main processes involved in producing maps from such irregularly spaced data. Firstly, values are interpolated from the sample data, usually to form a matrix based on a regular spatial grid. Secondly, this grid is displayed in a way which enables the information to be quickly and easily assimilated by the user, often after some form of contouring.

Although casual users of large computer mapping packages often do not need to separate these processes as they are linked together in the programs, mapping becomes a much more powerful technique if each process can be controlled independently. The interpolated matrices can then be manipulated to provide useful secondary information, e.g. by dividing or subtracting matrices to produce maps showing rates and areas of change or by adding or multiplying matrices to produce mean maps. Also, a range of options to control the final form in which maps are displayed enables the most appropriate choice to be made, often at a late stage in map production. The choice may be determined by the use to which the map is to be put, e.g. whether for preliminary assessment, detailed analysis or display for publication. It also enables gridded data produced or manipulated by other programs to be mapped in the same format, making comparisons between different data sets easier.

INTERPOLATION

Many methods for the interpolation of irregularly spaced data have been suggested. The two methods used widely are, firstly, to fit a polynomial to the sample data which is then used to calculate interpolated values, or secondly, a distance-weighted mean is used to calculate values at a point in the data matrix by taking a number of the nearest sample values and weighting them, often as the inverse square of the distance from that point, to determine a mean value.

Fitting a polynomial appears attractive as the number of terms in it may be increased until a very good statistical fit is obtained. However, the resulting surface can have a very strange shape making interpretation unrealistic and any form of extrapolation very unreliable. For this reason the interpolation method used most commonly is that of distance weighted means, and weighting samples by the inverse square of their distance has been found empirically to give reasonable results (Rhind 1971).

A third method of interpolation known at 'Kriging' has been developed for the mining and geological sciences. In this method an empirical model is fitted to sample data to describe the spatial relationship between samples. The model can then be used to produce the best unbiased estimates, with their associated errors, at each point in the data matrix. Although the method is very appealing in theory, in practice the amount of extra effort and computing time required probably limit its usefulness in the agricultural sciences, except for very detailed studies (Woiwod 1982).

CONTOURING AND PLOTTING

Having produced a matrix of interpolated values from the original sample data the final step is to display it. This often involves contouring, that is threading lines of equal value through the matrix and then displaying these lines on the final contour map. This is not a trivial computer problem, but algorithims are now available and most large mapping packages have an inbuilt contouring facility.

The final form in which the map appears depends on the program used and computer peripherals available. Shaded maps can be produced quickly and cheaply by overprinting characters on a line printer (Fig. 1) or by the use of a suitable dot matrix printer (Fig. 2). High quality graph plotters can produce contour maps (Fig. 3) or perspective block diagrams (Fig. 4) suitable for scientific publication and either of these can be readily displayed on graphics VDU's for quick appraisal. Finally, colour is becoming available on many computer systems and can be a very useful aid to interpretation, although reproduction of colour maps in scientific publications can only be managed occasionally due to cost (e.g. Taylor 1973, Taylor & Taylor 1979).

THE PROGRAMS

It was realised at an early stage in the development of the Insect Survey that some form of mapping would be required to aid our understanding and analysis of changes in the distribution and abundance of insect species. By 1968 sufficient sites were operating to make mapping worthwhile. Fortunately, one of the first large computer mapping packages became available at this time and it served our initial requirements well (Woiwod 1979, 1982). This was the SYMAP V program developed by the Laboratory of Computer Graphics, Harvard, originally for the analysis of geographical census data.

Like most mapping programs SYMAP is large, because of the need to handle a large data matrix, and therefore requires a mainframe or large mini computer on which to run. It was developed at a time when most computer input was by punched cards so that input was normally in fixed format and interpolation is only by distance weighted mean (Shepard 1968). Although the program has many options controlling the exact form and labelling of the output, only overprinting on a line printer is available as a means of displaying this output, probably because at the time the program was developed this was often the only device available. Fig. 1 shows a typical output obtained from SYMAP using Insect Survey aphid data.

As computing technology advanced, these deficiencies in SYMAP became more apparent and so recently we began using the SURFACE II program developed by the Kansas Geological Survey (Sampson 1975), which overcomes many of these problems. This has major advantages over SYMAP in its flexibility of data entry, wide choice of algorithms for interpolation, including 'Kriging', ease of manipulation of data matrices and high quality contour or perspective plots as output (see Figs. 3 and 4). Other output formats are possible on the SURFACE II produced grid matrix using suitable post-processors, e.g. shaded dot matrix maps (Figs. 2 and 5) and full colour (not illustrated) which is now available at Rothamsted on a high resolution Sigma 5000 colour VDU with a Sigmex ink-jet colour plotter.

COMPUTER MAPPING APPLICATIONS

The large volume of data obtained from the RIS suction trapping network poses many problems of analysis and interpretation which, in many instances, computer mapping can assist in solving. These problems fall into two main categories, longer-term research, using the historical database, or the interpretation of current data for advisory purposes. These two activities differ mainly in time available for analysis, time often being more critical in advisory interpretation (Tatchell 1982, Woiwod et al. 1984).

The simplest maps represent the density distribution of a migrant aphid species for a single sampling period, usually 1 day. A series of such maps provides a visual indication of the changes in density and distribution from one sampling period to the next. However, the numbers of migrant aphids may

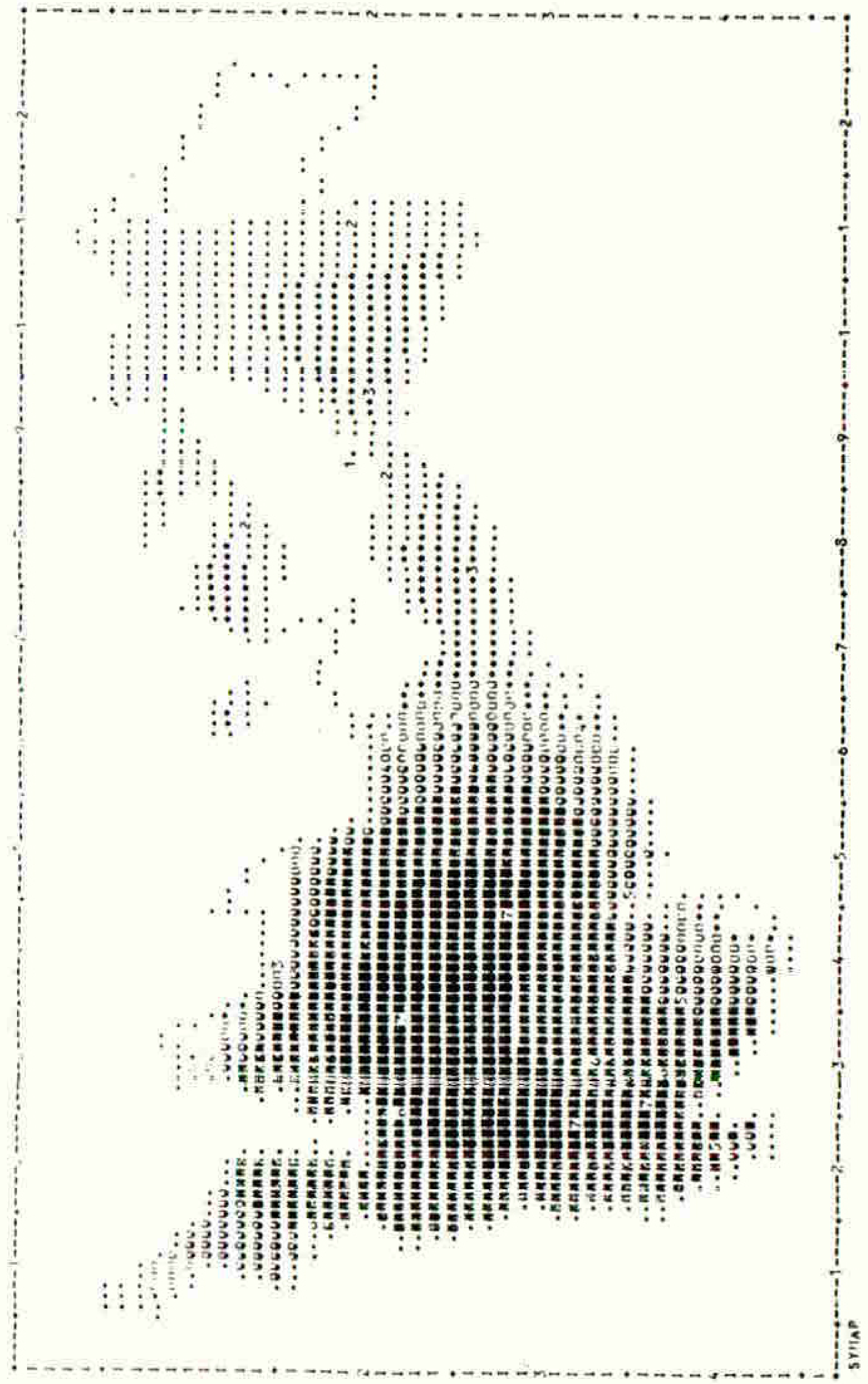

Fig. 1. Map of total number of Sitobion avenae for the week 11-17 June 1984 using the SYMAP program. Darker areas represent higher densities on a logarithmic scale (x 3 intervals). Numbers on output show position of sample sites with corresponding level.

Fig. 2. Difference map showing the increase in aerial density of Myzus persicae between 29 and 30 July 1982, when a possible invasion occurred in East Anglia. The darker the shading the larger the increase in aerial population. The map was produced using the matrix manipulation facilities in the SURFACE II program run through a post-processor to produce shaded output on a dot matrix printer.

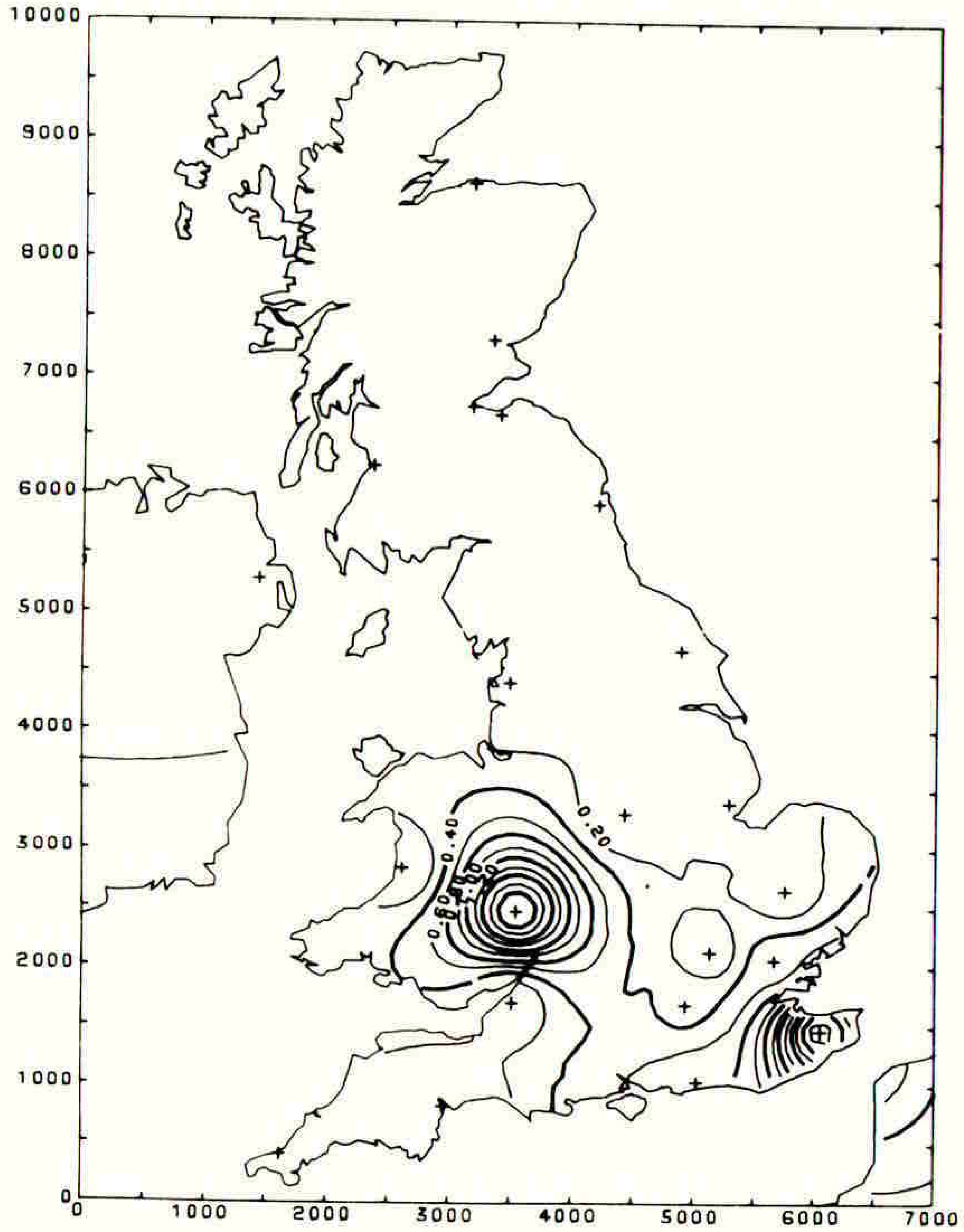

Fig. 3. Contour map of the aerial density of Phorodon humuli for the week 26 September to 2 October 1983. The map was produced by SURFACE II with typical output on a high-quality graph plotter. Sample sites are marked with a '+'. Logarithmic intervals.

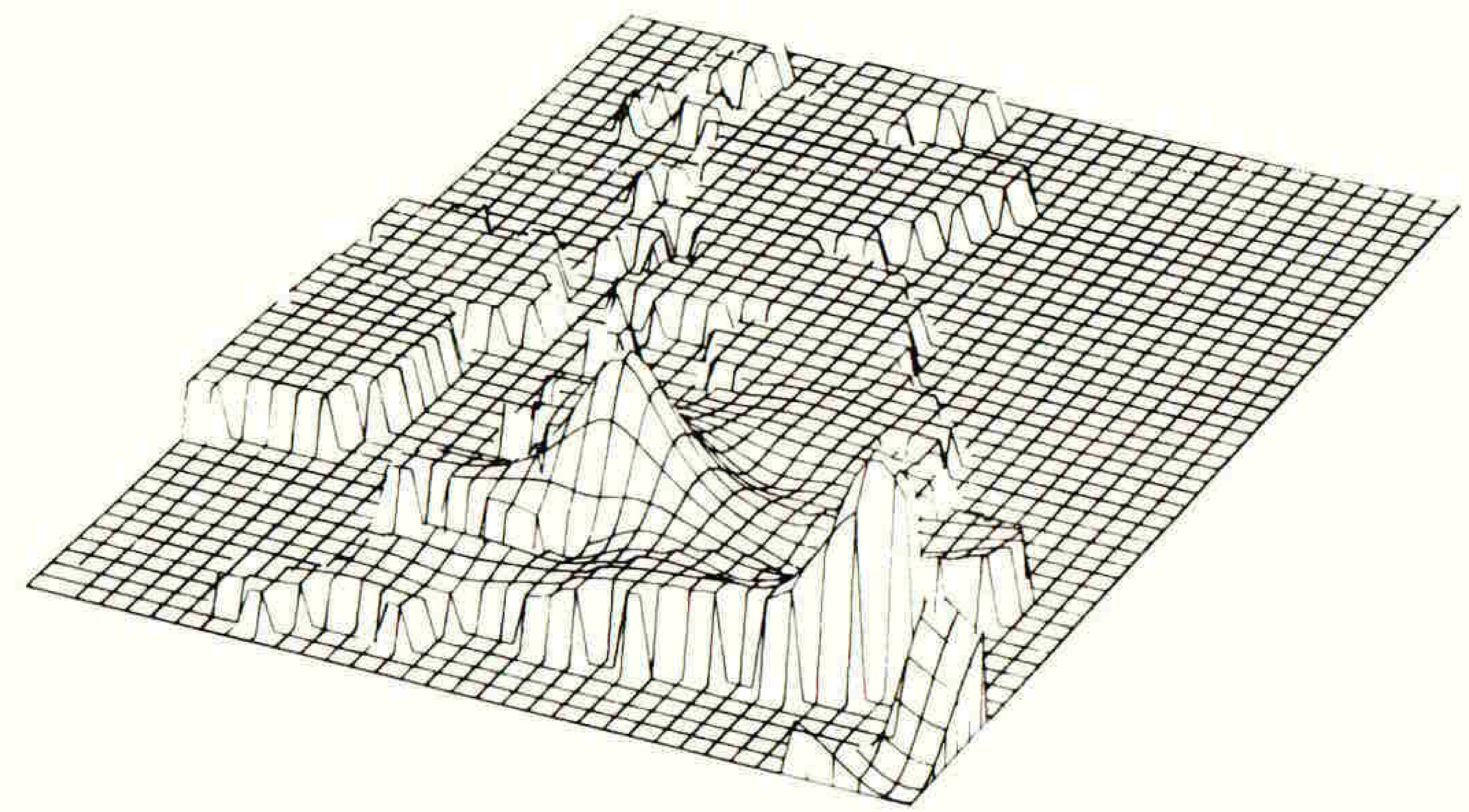

Fig. 4. Three dimensional perspective block diagram using the same data as Fig. 3. Such plots can sometimes reveal features not apparent in two-dimensional plots and are useful for display purposes. They can be produced as a simple option in the SURFACE II programs and plotted on a high quality graph plotter.

fluctuate greatly from day to day, depending on the prevailing meteorological conditions (Taylor 1985), and therefore daily samples are often accumulated for periods of 1 wk (Fig. 1), 4 wk or even 1 yr (Taylor 1974). Such maps may indicate areas in which initial crop colonization is occurring, or areas of greatest infestation.

For many animal species changes in distribution and abundance are understood more readily if samples are accumulated for a period of biological significance, such as a generation. Aphids reproduce rapidly, having many generations a year, and they have up to three periods each year during which population redistribution occurs (Taylor 1985). Each period is known as a migration and has a different spatial pattern for each species (Taylor *et al.* 1981). For example, the migration of the damson-hop aphid, *Phorodon humuli*, from *Prunus* spp. to hops in early summer occurs extensively throughout southern Britain where *Prunus* spp. grow, but in autumn the return migration is concentrated in the hop growing regions of the south east and west Midlands (Fig. 3) (Taylor *et al.* 1979).

More complex maps, produced by manipulation of the interpolated data matrix, often help in the biological interpretation of spatial changes of population density. The map produced by the subtraction of the matrix for one day from that for the following day provides a quantitative picture of the change in population during this period. This is illustrated well by what appeared to be a sudden immigration of the peach-potato aphid, *Myzus persicae*, into East Anglia, possibly from the continent, on 30 June 1982 (Heathcote 1984) and was confirmed by the resulting difference map (Fig. 2). Similarly, the matrices for whole migrations may be compared. For example, the distribution and abundance of *M. persicae* is very different during its three periods of redistribution but if the matrix for the distribution in spring is subtracted from that for the previous autumn it is found that this species overwinters most successfully in an area bounded by the Chilterns and the South Downs (Taylor 1977b).

'Kriging' provides not only estimated values but also gives errors of these estimates. These errors can be mapped separately to show how well interpolated values are estimated over the whole mapped area, and can therefore be used to decide from where additional samples should be taken (Woiwod 1982).

The examples described above are from some of our research activities using our historical database. The requirement to provide the agricultural industry with current information for pest aphids to strict deadlines creates different mapping problems. Currently two reports are issued each week to the industry. The "Aphid Bulletin" provides the numbers of pest aphids recorded from each suction trap, while the "Aphid Commentary" provides an interpretation of these data for the major aphid problems (Bardner *et al.* 1981, Tatchell 1982, Woiwod *et al.* 1984). Maps of pest aphid distribution, or changes in distribution, would assist interpretation greatly and could be issued with the "Aphid Commentary". However, until recently the program size, and hence turn-around time for map production, has prevented this happening on a routine basis. Our recent transfer to a computer using a virtual memory system, the VAX 11-750, in which program size is less critical, may make the rapid production of current aphid density maps a possibility in the near future.

Perhaps the most useful maps for people having to control, or advise on the control of insect pests are those indicating areas in which crops might be at risk from damaging infestations or infection by insect-transmitted virus

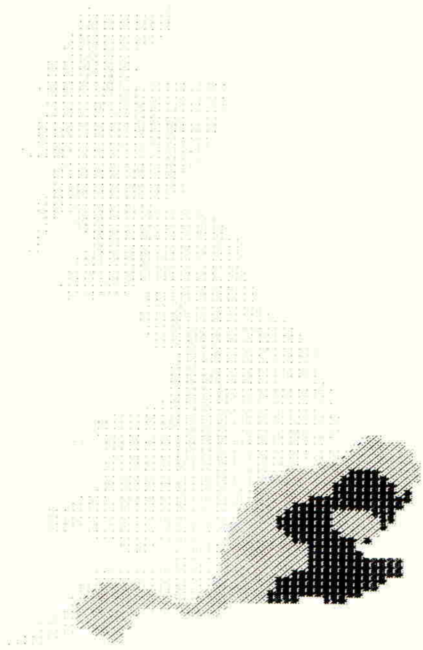

Fig. 5. Risk map of Aphis fabae for 1984. The map is based on accumulated suction trap catches up to 17 June and is produced in a similar way to Fig. 2 except that only three levels are displayed.

diseases. However, this is only appropriate where damage thresholds have been established. This year, for the first time, we issued such a map with the "Aphid Commentary" indicating the areas in Britain where spring-sown field beans were at risk from damaging infestations of Aphis fabae (Fig. 5). This was only possible because extensive host plant sampling over many years had been related to suction-trap samples (Way et al. 1981). It indicated that if five or more A. fabae (Fig. 5, darkest shading) were recorded in a single trap by mid-June, damage was probable in that area. If fewer than five (Fig. 5, medium shading) were recorded then damage was unlikely, and in yet other areas (Fig. 5, lightest shading) no A. fabae were recorded. In future it is hoped to develop the criteria for producing risk maps for other pest aphid species.

The examples presented here relate to the analysis of aphid data from suction-trap samples, but mapping techniques can be applied equally well to any quantitative sample data for pests or diseases where a visual representation might aid analysis, interpretation or presentation. Colleagues at Rothamsted have already been helped to map diverse data ranging from the distribution and abundance of Spodoptera littoralis in pheromone traps in Cyprus (Campion et al. 1977) to slug damage in field plots (Airey 1984). As computer technology advances our use of mapping to provide advisory information is likely to increase dramatically.

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RECENT EXPERIENCES IN COMPUTERISED PEST AND DISEASE CONTROL IN THE NETHERLANDS

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ABSTRACT

A brief description is given of the EPIPRE system, a computer based pest and disease management system for winter wheat. Recommendations are given on the timing of field observations, the decision to treat or not and the choice of the chemical to be used. Field observations and recommendations are made on an individual field basis. The farmer uses a standardised observation method to inspect his field.
Results show that the EPIPRE-recommendations did not change the net grain yields from the participants' fields. EPIPRE increases the knowledge of the participants on disease symptoms, the method to observe them in the field and the way to combat them. Participants who strictly follow the EPIPRE recommendations tend to spray less frequently and use less chemical per spray. Work is underway to extend this system to a computer-based comprehensive crop management system. Some future developments of computerised advice systems are discussed.

INTRODUCTION

Winter wheat is one of the largest arable crops in the Netherlands. The total area covered by this crop fluctuates between 100,000 and 150,000 ha, which is 15 - 20% of the arable land. One half to three quarters of the cereal area is occupied by winter wheat. Computerised disease control in wheat started in 1978 when, after some years of severe stripe rust (*Puccinia striiformis*) attack, researchers of the Department of Phytopathology of the Agricultural University decided to make their knowledge on stripe rust available for farmers by means of a computer-based disease management system.

The name they chose for this advisory system was EPIPRE, an abbreviation for PREdiction and PREvention of EPIdemics. Soon after its introduction in 1978 it became clear that treatment decisions for just one disease are not practical, as a farmer deals with more than one disease, and also cereal aphids must be considered. A decision about spraying against one disease may be influenced by the severity of other diseases in the crop.

From 1979 - 1983 all of the main diseases of wheat for which a chemical treatment is available and useful were incorporated in the advice model. Furthermore, recommendations are given for cereal aphids, the main pest in wheat (Rabbinge & Rijsdijk 1983).

Since 1982, EPIPRE has been operated by the Research Station for Arable Farming and Field Production of Vegetables in Lelystad. Each year some 600 farmers make use of this service. Other EPIPRE versions have been in operation from 1982 in Belgium, Switzerland, Sweden and Great Britain.

DESCRIPTION OF THE EPIPRE SYSTEM

Recommendations are made for the following diseases and pests: stripe rust (Puccinis striiformis), leaf rust (Puccinia recondita), mildew (Erysiphe graminis), leaf spot (Septoria tritici), glume blotch (Septoria nodorum), eyespot (Pseudocercosporella herpotrichoides) and cereal aphids (Sitobion avenae, Metopolophium dirhodum and Rhopalosiphum padi).

Farmers are expected to make a number of standardised observations in every field with which they participate. Observations are made by incidence counting. Leaves are scored as attacked or not by a particular disease; tillers are scored in the same way for aphids and eyespot. A mean of 4 - 5 observations per season are made in every field. The timing of the observations is regulated by the computer programme. The results of each field observation are posted to a central computer where the data are processed.

In deciding whether a spray might be profitable the results of the observations are combined with field data which were fed into the computer at the beginning of the season (crop variety, soil type, expected yield, labour costs) and data about previous sprays and nitrogen applications. Pesticide application is only considered profitable when the value of anticipated yield benefit exceeds the costs of spraying. Each field is considered individually. The advantage of looking at each field separately is that none of the peculiarities of each field are overlooked, thus the recommendation is more apt to meet specific needs. The recommendations are sent by post to the participants. The final decision to spray or not is taken by the farmer. He is free to follow the advice or not. An example of a recommendation is given in Fig. 1.

A summary of the disease situation is sent to the Regional Extension Services, interested scientists and the agricultural press every 2 weeks. In Table 1 a summary of recommendations in the past 3 years is given.

EXPERIENCES WITH THE EPIPRE PEST AND DISEASE MANAGEMENT SYSTEM

In 1982 Dr K. Blokker (Blokker 1984) of the Department of Extension Education of the Agricultural University, Wageningen, interviewed 232 EPIPRE participants and analysed their responses. Some of his results, which were much in agreement with our experiences and the results of verification trials, will now be discussed.

FIELD NAME: Behind Rosegarden FIELD NUMBER: 1312 VARIETY: Arminda

Lelystad, June 8th 1984

Based on your field observation of June 7th 1984:

Decimal code 47,

Disease	score	Damage and costs in kg/ha expected damage	labour costs	wheeltrack damage	chemical costs
stripe rust	16	more then 500	40	101	107
leaf rust	0	0	40	101	138
mildew	0	0	40	101	107
leaf spot	17	253	40	101	210
aphids	2	0	40	101	43

we advise you to spray this field before June 13nd.
The application is aimed at:

LEAF SPOT and YELLOW RUST

The ultimate date for the next observation is June 27th.

We recommend you to use one of the below mentioned chemicals:
Bayleton, Corbel or Tilt in combination with Captafol.

Fig. 1. An example of an EPIPRE recommendation

TABLE 1

Number of spray recommendations per disease in the past 3 years

Treatment against	1982	1983	1984
eyespot	-	77	126
stripe rust	0	104	33
leaf rust	0	241	42
mildew	141	866	1099
septoria	117	512	402
aphids	548	435	420
Total	4328	5306	5266
Number of fields	1069	1380	1100

Users often deviate from the EPIPRE advice. Fig. 2 shows the results for 1982. In this year, with extremely low disease severities, the EPIPRE recommendation was strictly followed during the whole season on 30% of the fields (Reinink & Drenth 1982). A majority failed to follow the recommendations at least once. The main deviations are to spray more often than recommended or to use more chemicals per treatment. The practice of standard spraying at ear emergence is particularly adopted contrary to recommendations.

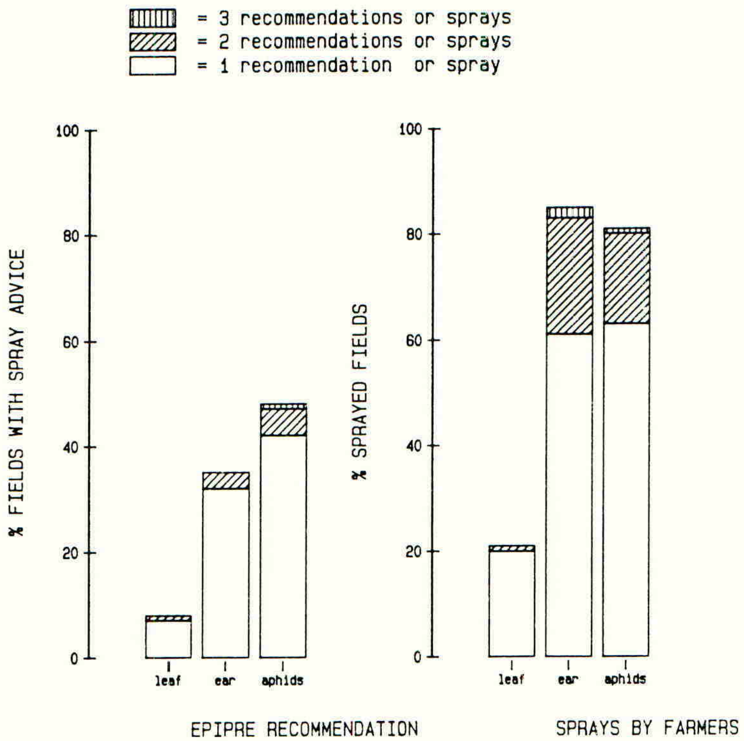

Fig. 2. EPIPRE recommendations and sprays by farmers.
Leaf: fungicides before eary emergence, ear: fungicides after ear emergence, aphids: aphicides.

Most farmers participate for two or three years. Some reasons to leave the system are lack of time to do the field observations properly, the tendency of EPIPRE to advise fewer sprays than some farmers would like, and the waiting period before a recommencation reaches the farmer. Although for disease management purposes it is not always necessary to have an immediate answer to a field observation, for psychological reasons the waiting period must be as short as possible.

In 1983 and 1984 this problem was dealt with by sending the farmers in advance the thresholds above which they were sure to get a spraying advice (Reinink & Drenth 1984). In 1985 direct telephone communication will be used. In future the farmer will have to feed the results of his observations to his own microcomputer or terminal and these communication problems will be solved.

An important reason for leaving the system, mentioned by many farmers, was that they felt they had learned enough. The training in making field observations and diagnosing pests and diseases in their wheat crop was very much appreciated.

Spraying to EPIPRE recommendations had no significantly beneficial effect on the net grain yield. Both farmers' data and field experiments in the Netherlands gave the conclusion that when the EPIPRE recommendations are strictly followed the tendency is for less spraying to be done and less chemical per treatment to be used. In so doing the yield will mostly be lower, but the costs are also reduced, so the net yield will be about the same.

Although a positive net result would have been more encouraging it was decided that there were enough educational and environmental reasons to continue this computer-based advisory system. Work continues on the improvement of recommendations and the broadening of the system to a computerised crop management system.

IMPLICATIONS OF THE INTRODUCTION OF MICROCOMPUTERS ON FARMS

Many Dutch farmers consider buying a microcomputer for their farm and many will do so in the next few years. At the moment the lack of useful programmes is in many cases still a reason to postpone buying a micro. However, the introduction on a substantial scale of micros in farmers' practice seems to be only a question of a few years. In this situation it has to be decided whether a specific programme can be run on the farmer's own micro or if it is still necessary to use a central computer. The connection between the farmer's micro and the central computer could be made by means of a viewdata system. The more updating of a programme and the more external data necessary, the less a programme will be suitable for installation on a farm microcomputer. For software dealers this type of programme will be unattractive. They will concentrate first on programmes which require little updating, like registration and financial programmes and simple calculations.

Most crop protection programmes will have to be updated at least every year because of new scientific results which improve recommendations, new chemicals, changes in effectivity of chemicals etc. With advisory systems like EPIPRE, running a decentralized programme would also mean the loss of valuable information on the disease and pest situation in farmers' fields. For these reasons it seems probable that most crop protection advisory systems will remain in the hands of research institutions or extension services and a viewdata system will be used as an intermediary between the farmer's microcomputer and the central computers.

CROP MANAGEMENT SYSTEMS

Only part of the financial return of the wheat crop is influenced by pest and disease management. Other important factors are timing and amount of fertilizer, weed combat, variety choice and the use of growth regulators. It can be expected that when recommendations for these crop measures are also given by a computerised advice system, the system will be more attractive to farmers. A condition for making such a system attractive is to keep small the total time the farmer invests in it. The value of EPIPRE-recommendations per se will not change by incorporating EPIPRE in a comprehensive crop management system, but the possibilities of offering background information or connecting with programmes for pesticide information will make the EPIPRE system more valuable.

A crop management system will have to contain the following elements:

- decision models to support farmers decisions (e.g. EPIPRE)
- warning signals: depending on date, crop growth stage and previous cropping measures the farmer's attention is drawn to certain decisions that have to be considered
- background information, e.g. about disease symptoms, observation methods, variety and pesticide information.
- registration: input, output and update of crop data and financial data.

A crop management system will offer the farmer an up-to-date insight into recent developments in various areas of crop growing. Saving money by high input of knowledge will be an important feature of these systems.

From the evolution of EPIPRE the development of computerised systems for agriculture can be deduced, initially with recommendations for one disease (stripe rust), then all important wheat diseases, then a crop management system including all important cropping measures. In future there will be farm management systems including all important crops, mechanization and financial programs.

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COMPUTERS IN CROP PROTECTION: A COMMERCIAL POINT OF VIEW

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ABSTRACT

Under commercial pressure computer aids in common with any other product must meet the demands of the user or perish in obscurity. In a new field of computerised techniques the system provider plays a role in shaping the user's response and attitude to the services offered. The objectives and style of commercial computer aids for crop protection are examined and some opportunities and constraints for both users and suppliers are highlighted. The future of computer-based crop protection services independent of state funding will be dominated by commercial imperatives and the benefits they offer farmers as an integral part of crop management.

INTRODUCTION

The development of computer aids for decision making in crop protection has been in the hands of organisations with access to massive quantities of data on crop production under trial conditions. These are either state funded research bodies, universities, state extension services, or the manufacturers responsible for testing their own agrochemicals and devising recommendations for use. Due to the centralised nature of computer resources until very recently, the services on offer have largely been administered for the farmer or his supplier directly by and under the control of the system builders. Farms, in common with other businesses, now have access to computer facilities on-line via viewdata equipment, or locally on portable or office computers of their own as well as by joining bureau services.

Since the introduction on farm of microcomputers in 1978, there has been a brief honeymoon period, during which the farmer was almost entirely dependent on the computer service supplier who dictated the goods available. As farmers and their advisors gradually gain a degree of computer literacy they begin to appreciate what is to be gained from information processing. This paper examines the interaction between the farmer and the supplier of decision aids and how the need for rationalisation of crop protection policy may affect system design and use of crop protection products in the future. As nationwide, commercially available crop protection computer advisory services are confined in the U.K. to winter cereals, at the time of writing, (BASF CASP system, BAYER Wheat Prediction Scheme, COMPUT-A-CROP EPIPRE system, ICI COUNSELLOR system) examples will be confined to winter wheat pest and disease control.

A small number, amounting to no more than 4% of U.K. farmers have their own stand-alone computers (Anon 1984a).

COMMERCIAL CROP PROTECTION OBJECTIVES - THE ROLE FOR COMPUTER AIDS

Sources of crop protection advice are subject to change due to opportunities created by telecommunications and information technology. With the introduction of innovative techniques, initially the new methods are offered as concurrent alternatives to old established ways. Then as new methods are proven in terms of efficacy and improved efficiency, old methods are relinquished. Finally the new methods perform tasks not possible within the constraints of the system which has been replaced.

Progress in the supply of crop protection advice and in research into improved strategies is no exception. Advice to farmers and growers has conventionally been supplied through contact with technical support staff of merchants, manufacturers, and ADAS. Journals, manufacturers' literature, government publications and textbooks are supplementary sources.

The majority of crop protection decisions in wheat at farm level have been based on the presence or suggested threat of disease. The decisions have been largely confined to a choice between materials to be applied, based on efficacy against the nominated disease,and short term financial considerations of price. "Conventional wisdom" of routine sprays of particular types of material at particular crop growth stages has been promulgated and widely accepted in an economic environment where high cash returns from wheat grown under less than ideal conditions have masked the room for improvement.

This advisory climate has enabled manufacturers to reduce farm and merchant visits without losing market share. It has enabled farmers to embrace a belt and braces prophylactic, insurance spray strategy. Despite the training efforts of the extension service, farmers have not acquired disease recognition skills and have often confined their decision making to which product to spray, rather than first assessing the need to spray. On-farm, subjective, individual field assessment has to an extent been replaced by remote or written sources of advice, based on largely prophylactic crop protection programmes. These have developed from a deterministic base of past experience, and have been vigorously promoted by manufacturers. Why are strategic changes necessary or desirable?

The farmer's objectives - profitability, survival, environmental safety

Farmers' overriding business objectives are to stay in productive farming, profitability being achieved without jeopardising the long term farming prospects of their successors. Crop protection measures to safeguard current production and margins are favoured in place of the once fond hope of total eradication of pests and diseases. Growers of earlier years, who had no agrochemical armoury, were dependent on rotation, cultivation and seasonal weather for the crop's survival and their prosperity. Local surpluses are increasing the economic pressure exerted on farmers by the E.E.C. Common Agricultural Policy. Breakdown of varietal resistance to disease and new pathogen resistance to pesticide still occur.

Since 1970 the proportion of net farm income in the U.K. paid out to service borrowings has increased from 8% to a projected 24% for 1984. It is anticipated that the relationship between income and interest will continue to deteriorate to the detriment of the farmer (Pettitt 1984). Borrowings by U.K. farmers from the London Clearing Banks over the last five years have increased at an average annual rate of 23.8%

An increasingly active conservationist lobby is drawing attention to environmental effects of spraying, highlighting possibilities of reducing unwarranted sprays where use is not justified by economic returns.

Confronted by these economic, social and biological factors, today's British growers need to develop financially sound crop production strategies appropriate to the circumstances of each farm business. One of the means within their grasp is to reduce chemical bills whilst preserving margins. Where there are heavy borrowings to run the farm and high volume, high quality cereal yields are routinely obtained which service the debt, then there is less potential for cash savings to be made. However, there is perhaps greater need for crop monitoring than where the farmer owes a minor amount, or regularly anticipates only moderate cereal yields. (Keene 1984, Rijsdijk 1982, Thompson 1984). Some 30% of prophylactic sprays of cereal crops are likely to be uneconomic, amounting to half a million hectares per annum in the U.K. (Cook 1983). Although stringent quality controls may be imposed or demanded by the market, an increase in the acreage of milling wheat will probably reduce the return from quality premiums which farmers may expect, so crop protection costs cannot be considered alone. Disease control objectives for the grower cannot be isolated from market prices and the overall plan for production, including weed control, fertiliser regime, and the timing of cultivations and drilling. (Lilley 1983). Computer-based advisory services can be key factors in identifying where savings on spray costs are to be made as part of an integrated approach to crop management, more finely attuned to potential yield under given conditions and to individual financial circumstances.

The merchant's objectives - profitability, survival, diversification

Agrochemical distributors and dealers have experienced a reduction in margins in some cases to as low as 2-4%, due to declining profitability for the manufacturers and fierce competition. Firms are struggling to increase overall turnover in a market where demand is no longer expanding. Some merchants still supply spray advice to their customers but as an advisory service which can be charged for in addition to sprays supplied. The merchants are therefore able to move, to an extent, away from promoting the use of chemical towards gaining a proportion of their income from advice charged per acre, regardless of whether a spray application is recommended or not. Some agrochemical manufacturers, have begun to make their own computer services available strictly through distributors, in order to retain dealer loyalty, to sustain market share and to obtain market intelligence from their distributors' information processing on farms. Some merchants intend to remain independent of manufacturer influence over spray advice and are promoting independent computer based services (Anon 1984b), or devising their own subscriber or customer only services.

State Objectives - maximum production for the least cost, safety

State funded research, education and extension services in the U.K. have declared objectives of maximising production for the least cost. One of the roles of the extension service is to evaluate and compare programmes for disease and pest control promoted by commercial enterprises. Research efforts have resulted in the publication of advisory booklets and now of computer programs and models supplying growers with a non-commercial source of crop protection advice. Managed disease control is recommended as a complementary management technique to the proper use of varietal resistance and cultural factors, to limit the need for chemical control measures.

INTERACTIONS BETWEEN FARMER AND SYSTEM SUPPLIER - THE COMMERCIAL PROSPECTS

Product constraints

The uptake of computer-based decision aids by farmers will be promoted or deterred by a number of key product features in addition to the perceived need for advice: a) The users will need a positive attitude to the value of the advice generated and will have to be able to understand it readily. b) Its presentation must be simple and to the point, with sufficient information displayed or printed out for the users to validate that the correct information has been analysed and if necessary make corrections to the input (Cope 1980). Farmers must know that the originators of the system can also run checks on accuracy, backed up by personal contact where necessary. c) Users must have verifiable objectives, e.g. target yields and budgets per crop or field. Those who stand to benefit the most are growers who have weighing devices of some sort, ranging from `Yield per Field' meters to full weighbridges. Records of input costs and output values are necessary adjuncts to the system. d) Users must have a source of weather data which relates to the site to be monitored. An on-farm weather station can provide automatic weather recording directly into the computer-based advisory system, although for the foreseeable future, the majority of growers will rely on their own rainfall and temperature records taken manually on a daily basis, or on those of a local weather station or weather service via viewdata. e) If on-farm hardware forms the basis of the advisory service, then it must be able to run management programs to justify its place in the farm business.

User Constraints

A common criticism of the farmer's ability to make independent crop protection decisions is a limited knowledge of disease recognition, and limited understanding of disease incidence significance. None of the systems for rationalising the use of fungicides developed by chemical companies in the U.K. moves completely away from the routine use of chemicals, or a deterministic approach, to decision making where a "wait and see" disease assessment approach is adopted (Lilley 1983).

The limitation of farmers' ability to recognise disease is overcome in a number of ways. Firstly, farmers doubting their ability can monitor their crops together with merchant or extension service staff, and use aids to recognition provided as disease illustrations such as the ADAS disease recognition cards. Secondly, computer aids when supplied direct to the grower will, to be of any use, include an educational element (Cope 1982). Computer models can be used as training aids to teaching the principles of a system as well as to give experience of computers per se. Computer assisted education radically enhances the possibility of diversity, permitting each individual to advance at a purely personal pace. Computers permit users to follow a custom-cut path, built upon on-farm information towards increasing farmers' own knowledge, rather than a rigid syllabus, limited by data from external sources extrapolated from regional, historical averages (Toffler 1970).

Growers must know they can now take an active part in crop monitoring, not merely living within a computer model based on regional averages and determined by historical comparisons, but to grasp direct experience of individual crop assessment. This can be by tackling simply the measure of disease incidence in relation to growth stage, date and weather records, as in the case of EPIPRE (Rijsdijk 1982) or measuring disease severity by assessing leaf area affected as in the case of COUNSELLOR (Anon 1984c).

Experience of commercialising EPIPRE

EPIPRE was developed as part of a programme of applied research on behalf of the Dutch government extension service (Zadoks 1981). The system is available commercially to farmers in the U.K. and has been amended and developed both to attain normal commercial standards of presentation and to meet U.K. farming conditions and disease control requirements.

Changes to EPIPRE, a product of Dutch government funded applied research to suit the U.K. farm market - lessons for workers in applied research

In addition to the inevitable translation of the documentation from the Dutch original, a number of cosmetic changes to the system's documentation, input and output were necessary to attain the consistency of presentation demanded by a commercial product. Users are provided with a field observation pack comprising ADAS disease recognition cards for relevant diseases, rainfall recording chart, a growth stage recognition chart, and field recording cards, together with a full operator or subscriber manual. Field recording cards have been improved for the user to see at a glance the level of each disease recorded.

Field histories are requested early in the season to allow users plenty of time to validate the information and to enable computer records to be set up for each field, ahead of the first training meeting of the growing season.

Field sampling procedure has been modified, to reduce sampling time where possible, without any apparent loss in sampling effectiveness and to divert the sampler's route through the field away from the diagonal, to include observations representative of all areas of the field. The original sampling procedure was developed with relatively small fields in mind. Field size was not expected to exceed 10 ha. Field size monitored by EPIPRE in the U.K. commonly exceeds 15 ha. Where conditions vary widely from one part of the field to another it is still recommended that the areas which differ in character are treated as separate fields for the purposes of disease control. Crop sampling procedure has also been modified so that a total sample of 40 tillers per field sampled serves the needs of all disease assessments.

The forecasting model for Septoria nodorum and S. tritici has been modified to take account of rainfall in the 14 day period before field observation and to interpret incidence in the light of regional risk criteria.

These changes have reduced the demands made by the system on management time ade recording simpler and improved the quality of in-field recording. It is anticipated that the revision of the Septoria spp. forecast will meet U.K. conditions more closely. (At the time of writing 1984 harvest figures and seasonal summary are not available to the writer for analysis.)

Although EPIPRE was produced to high programming and operational standards, its transfer from academic to commercial hands, from one language and country to another, from one style of computer to another (from DEC-10 mainframe to Z80 microcomputer) and from one pattern of wheat husbandry to another offers an opportunity to assess and anticipate lessons which may be useful in the future transfer of product from the hands of workers in applied research to those of farmers and their advisors.

If research projects produce software for commercialisation as a computerised crop protection aid, then:
1) Documentation must be directed at the intended user, whether consultant or farmer, in non-scientific language.
2) Documentation of programs must be explicit, in order to accomodate continuity of product maintenance, despite changes in the product support team.
3) Sampling techniques, recording and reporting procedures should be tested by the intended users and such techniques should be considered an integral part of any system design.
4) The system's data requirements must be assessed in the context of other data that the user is likely to want to record, so that system specific data can be analysed together with data from external systems, without jeopardising the integrity of either set of data.
5) Precise data input requirements should be specified as it is increasingly likely that much of the data required will already be available to the user in computer readable form where computer systems already exist
6) Summary programs should be provided with the facility where possible for comparison between one user's data with another.

THE EFFECT OF RATIONALISATION OF CROP PROTECTION POLICY ON SYSTEM DESIGN

Spraying only when needed can be achieved if decision aids are based on real crop conditions. All systems ask for some account of current cropping and relevant background information, but data collected should be interpreted against a disease development forecast and not against a deterministic prediction.

For rationality, disease control advice must be relevant to individual fields. In the past, for instance, the effect of weather on disease development has been predicted from weather data supplied at regional or local level. The advent of on-site automatic weather recording devices will enable disease forecasts to take into account site specific weather conditions and probably improve the quality of disease control advice.

Future system design will increasingly take into account a body of data about individual recognisable sites to which the decision making process applies. This systematic development will lead to expert systems which can learn from their own data, but will also be able to correlate results and crop, disease, product and farmer behaviour between sites.

The information about any site will, therefore, be of value to the system builders in terms of both potential contribution to program development for disease management, and of market definition for chemical producers. A more definitive description of product behaviour and customer response to manufacturers' efforts would be hard to imagine.

One of the commercial spinoffs of computerised decision aids is the possibility that, if any one company or group of companies can corner the market in interactive computer based decision tools, it can also obtain a stranglehold on market information. This will give an immense competitive advantage, which may be to the customers' benefit through cheap advice in the short term, but be detrimental to farmers' long term choice of product.

Just as manufacturers could opportunistically exploit farmers' information to their own commercial ends, so can farmers, through their consultants and other independent companies amass and pool on farm information for their own use and retain their traditional aura of independence. Increasingly, demand for pesticides will be decided by farmers and their advisors, based on needs during the current and forthcoming forecast periods. As rationalisation of pesticide usage will reduce prophylactic applications (often a tank mix of low levels of active ingredient, at low cost, which is inclined to encourage pathogen resistance to otherwise effective products), farmers will be more inclined to accept recommendations to spray effective pesticides at biologically effective dosage rates. This will benefit both the grower and the research based agrochemical manufacturer.

Inevitably companies who recognise the tremendous opportunities for market development must make a first step into this new market area with relatively unsophisticated systems. Their market presence and commercial strengths will lend credibility to relatively simple predictive, deterministic and generalised systems of disease control advice. These initial systems will provide many widely different commercial advantages. They will enable the companies to cream off direct sales promotion opportunities whilst farmers still have little computer experience. They also provide the means whereby system builders can accumulate sufficient site specific data, to develop fully interactive expert systems in order to retain customer dependence later.

State funded, independent research projects to develop and validate forecast techniques which can be used by individual farmers, must proceed with due recognition that to sustain the policy of maximising production for the least cost the growers' commercial considerations must remain supreme. With the low level of farmer organisation in the UK, state funded research, independent consultants and companies are their only safeguard.

The dynamic economic climate, new crop varieties and changing pathogen resistance will stimulate both multinational manufacturers and independent companies to introduce new crop protection programmes and disease forecasting techniques. The AFRC and ADAS will have a continuing role to play in developing and screening these techniques and products to serve the national interest. It is, therefore, of paramount importance that state funded research be given the opportunity to develop centres of excellence in forecasting procedures for the major UK crops. Information systems will enable them to develop a strategy of rapid response to farmers' needs for information.

CONCLUSIONS

Manufacturers have been forced to concede that in many cases their programmed approaches, especially those using protective sprays of broad spectrum fungicides at specific growth stages can be questioned by the need to rationalise pesticide use and also to maintain profitability. Their role as information providers and producers of crop protection decision aids will always be viewed by the grower as coloured to an extent by a makers' vested interest.

Farmers recognise that a number of short and long term farm business objectives can be met by lower pesticide use or by improved application timing. These include better socio-economic relationships with non-farmers, the long term stability of the environment and the prospect of survival during a period of economic stringency through the thrifty use of resources, both chemical and financial. The forward looking farmer will be able to influence the course of development of computer aids for farm management by espousing recording and crop monitoring techniques and feeding farm information into the computer designer's pot, but should recognise the market value of his data. The farmer's safeguard continues to be vested in companies independent of the agrochemical industry and in state funded research and extension services.

The only automatic machine on which man depended which pre-dates the computer is the clock. Time keeping by clock created a new reality, one in which for the majority the feeling of hunger was replaced as a stimulus for eating; one ate when an abstract model had achieved a certain state, i.e. when the hands of a clock pointed to certain marks on the clock's face, and similarly for signals for sleep and rising (Weizenbaum 1976). The farmers and consultants who embrace computer aids will fall into two categories - those who use the manufacturer's `clock' to reinforce the conventional reality of outside abstract crop protection advice, and those who want to grasp the direct experience of becoming better informed and more attuned to the biological and economic factors which point to optimum disease control on their own crops, in other words to exercise more self-determination in the choice of crop protection measures and timing.

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COMPUTER AIDED CEREAL DISEASE MANAGEMENT: PROBLEMS AND PROSPECTS

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ABSTRACT

Trends in UK cereal growing are encouraging the adoption of a more flexible attitude to disease management. In assisting farmers to utilise control measures circumspectly and according to changing crop and economic needs, the development and testing of schemes which utilise the capacious and fast-delivery properties of computers is to be encouraged. However, for a time such schemes will inevitably be imperfect. In applications to environmental monitoring and disease forecasting, computer technology is supported with inadequate biophysical knowledge. No computerised, complete disease management schemes are currently available for on-farm use. As research supplies the knowledge to construct them it is likely that the needs for continual refinement will limit their use to centralised systems.

INTRODUCTION

Cereal producers have recently experienced an unprecedented boom the end of which has been associated with a remarkable full circle in attitudes. The advent of relatively cheap effective fungicides in the early 1970s coincided with a realisation that diseases were causing substantial yield losses. At this time the cost of fungicides was relatively high in comparison to prices. It was difficult to persuade growers that fungicide treatment would be cost effective. Since that time grain prices have increased to a plateau. Indeed there is every likelihood that prices will drift downward relative to current costs.

Growers have become used to relatively disease free, high yielding crops. The availability of effective fungicides and improved machinery has enabled them to adopt practises, e.g. early sowing and intensive cultivation, which in the past have not been feasible because of increased disease risk. The developments have increased the role of chemicals in disease control and, although farmers may not have realised it, have made them dependent on fungicides. In 1984, for the first time in almost 10 years, farmers became more aware of input costs and consciously attempted to reduce the cost of disease control. This was a response to the relative decline in prices, which presents the serious challenge of maintaining profitability. Therefore, there can be little doubt that there will be much effort to reduce pesticide inputs, wherever this is possible.

Pressure also arises from increasing public awareness of environmental factors and from problems of pathogen resistance. As a result, there will be an increased demand on advisers and consultants for precise, high quality advice on spray selection and timing at minimum cost. This depends on developing sound adaptive disease management strategies, harnessed to the opportunities now given by computers and their attendant devices for environmental monitoring and equipment control, computer modelling, data recording and management and information delivery (Teng & Rouse 1984).

Some of the firms developing this technology for agriculture now provide a wide range of hardware and a comprehensive selection of software for farm business use. Naturally, they wish to extend their applications to the tactics of disease control. Growers may assume that because much appears to be offered at low cost it will be of immediate value in improving the precision of disease control. Our aim in this paper is to examine the scientific justification and relevance of these developments.

DISEASE MANAGEMENT STRATEGIES

Disease management is based on the maintenance of diseases at a level below that at which economic damage is likely to occur (Zadoks & Schein 1979). Reasoned sets of guidelines describe how to use the methods available for regulating diseases within an agricultural system. Frameworks for disease control are now provided by several companies and by ADAS. We recognise two categories:-

1. The simplest, prophylactic, in which treatment is specified on a calendar basis usually at fixed crop growth stages. This does not qualify as part of disease management since there is little opportunity to manipulate control measures according to need.

2. Based on risk assessment; subdivided into:

(a) Non-adaptive - which provides a strategic plan for the individual farm by considering, ahead of the growing season, agronomic factors that influence seasonal disease levels, e.g. the use of resistant cultivars, manipulation of sowing date and the general disease risk of an area. This allows farmers to make judgements of their own risk and to plan strategically the sprays which may be needed.

(b) Adaptive - in most cases farmers will wish to modify their strategic considerations in (a) by evaluation of disease during the growing season. They may also include interpretation of the influence of weather, i.e. biometeorological forecasts. These then allow tactical day-to-day decisions on the application and timing of sprays. These most comprehensive frameworks aim to give flexibility, allowing response in cost-benefit terms to changing conditions.

Computers can aid both strategic and tactical decision making, but since this last, adaptive area is of greatest importance it is here that we must evaluate their particular value and potential. The Table classifies some cereal disease management schemes.

Risk Assessment

Points systems attempting to predict treatment need have been developed for cereal diseases in Europe. These enable the grower to estimate disease risk, as in the Bayer Wheat Prediction Scheme (Kelly 1982). They are based on data from field experiments as well as experience and attempt to provide objective guidance. All disease management or spray warning systems are essentially forms of risk assessment. However, we regard the simplest, non-adaptive schemes as distinct from those which include estimates of disease development during the growing season. The simple schemes can be used to provide a strategic plan of spray need and are thus relatively inflexible to changing conditions. In general they do not attempt to provide a budget from which the probability of economic yield response can be calculated, although the provision of fungicide costs does allow the grower to make some estimations if he wishes.

TABLE

Computer-related cereal disease management schemes

Type	Example	Computerised?	Cost-benefit embodied?
Non-adaptive:	FUNGIPLAN (Ciba-Geigy)	Yes	Yes
	SPRAYTEL (Ciba-Geigy)	Yes	No
	Wheat Prediction Scheme (Bayer)	No	No
Adaptive:			
Subjective disease assessment:	CASP (BASF)	Yes	Yes
	Counsellor (ICI)	Yes	Yes
	FONGITCF (ITCF, France)	Yes	No
	Managed Disease Control (ADAS)	No	No
Objective disease assessment:	EPIPRE (University, Wageningen & Comput-A-Crop, UK)	Yes	Yes

Computerising such essentially simple schemes may be judged unnecessary for operational use. Thus, The Bayer Scheme and the ADAS Managed Disease Control (MDC) Scheme (Anon, 1984) are presented in booklets. The decision grids developed to guide French growers have been programmed for a micro-computer as FONGITCF (Lescar et al. 1983) with lists of fungicides and comparative costs as a standard part of the screen output. In many ways it is comparable to the MDC scheme and both are suited to access through viewdata, for example.

In FUNGIPLAN, Ciba-Geigy use a plotter to estimate progress of selected diseases given fungicide treatment in specified situations. It is based on results of experiments, subjectively amended if necessary and has the advantage of gross margin calculation for instant appeal. The system may have predictive potential.

Each of these probability systems ignore detail of disease development in the crop although simple presence or absence observations are included.

DISEASE DEVELOPMENT

Risk assessment schemes become adaptive disease management systems when they provide timely advice relative to changing needs of individual circumstances. In attempting to couple risk assessment with observations on disease development Counsellor, (Jones et al. these Proceedings) EPIPRE, (Zadoks, 1981) and to a limited extent also CASP (Walker, 1982) are first attempts at providing computer-based, commercial schemes. They have been developed to provide a tactical decision aid. Whilst the concepts of their programs differ, they each require similar inputs to generate estimates of disease risk. Thus, details of field history, crop and husbandry factors, soil type, and either anticipated yield or data on previous yields are all used to compute a base level of risk in cost/benefit terms. As in all strategic determinations of risk the precision required is not great and the quality of information now available is probably adequate. A difference between these schemes and those of the points system type is that they rely on complex computerised data bases to sort feature effects relevant to the individual crop.

Incorporation of disease development into such schemes is far more problematical. Guidance of day-to-day disease control decisions requires knowledge of the current state of disease and estimates of future development. These are supplied from disease observations, which optimally are from within individual fields. In addition, since diseases are critically dependent on the environment, there is also need for relevant weather records together with suitably accurate and reliable biometeorological disease forecasts. Are our resources and expertise adequate to meet these needs?

Disease monitoring

The dependence on disease monitoring of the commercial schemes differs substantially. CASP at present operates with no specific monitoring demands; up-dating of risk levels is made purely from representatives' observations in a local area. At the moment Counsellor stipulates no standard protocol for monitoring but requires subjective estimates of disease intensity. Disease monitoring is central to EPIPRE which was developed on the basis that successive disease observations integrate the total environmental impact on pathogens. Its conceptual level is at that of the disease population and much effort is therefore given to educate farmers to recognise individual diseases and to record and report incidence objectively, according to specific guidelines. EPIPRE translates observations of incidence into intensity and uses them to project disease progress according to the classic concept of disease growth rate (Sensu Vanderplank). The outcome is not only to advise of the need for treatment but also of the need for further assessments. The protocol has been simplified for UK conditions, however there remains no meaningful method for monitoring diseases like septoria whose precence may be confined to basal, senescent or withered leaves. This biological problem cannot be solved by computers!

Improvements in disease management will result from solutions to these problems and from widespread recognition of the need for objective monitoring within individual crops. However, if requirements are too detailed farmers may be reluctant to expend time on monitoring especially if their perception of the importance of a given disease is low.

Weather monitoring

The advances in electronics which have facilitated sophisticated crop and management records have also enabled precise measurement of physical information to describe weather on farms and in crops. Thompson (these Proceedings) has given some reasons for the growing interest in on-farm, automatic meteorological monitoring equipment. Commercial firms are likely to issue equipment either as straightforward weather stations, or devices dedicated to crop protection by linking sensors to programmed disease warning models. Both the ADAS/Met. Office Crop Disease Environment Monitor (CDEM), a research tool, and the recently launched Spa Micrographics Ltd. Weather Station are of the dedicated type, information from sensors driving weather-based warning models for several diseases.

So far, no disease management scheme incorporates weather information derived from individual farms. CASP is independent of weather, whilst Counsellor utilises information from the nearest local weather station. Developed originally for wheat rusts and mildew EPIPRE was claimed to be satisfactory without weather data. However, diseases like septoria and eyespot, epidemics of which are often monocyclic, cannot be predicted purely from growth rate projections. So there is a need to identify weather conditions influencing disease development. In several countries EPIPRE now incorporates empirical, weather-based criteria for estimating septoria. It is a matter of time before schemes like this utilise the opportunities offered by automatic on-farm recording equipment. Certainly, the inherent value of local weather records to inform why things happen and why they go wrong is to be encouraged. But there can be no assurance that because on-farm monitoring improves the geographic resolution of weather data, at low cost, it will be of immediate value in disease management. The increased precision with which the physical environment can now be recorded is not matched by an equivalent precision either in basic biological knowledge or in applying it to forecasts. Scant attention has been given in the past to the meteorological information required to serve as parameters of forecast criteria, and the degree of meteorological precision needed for satisfactory estimation of disease development is not known.

Of the disease warning criteria being used in dedicated monitoring devices, many were derived using synoptic weather. Others were drawn up from controlled environment experiments and still others express empirical relationships of disease to microclimatic factors. There is doubtful value in operating all these with modern electronic sensors, with which they are untested. Although sensors can be placed anywhere on a farm, at present there can be NO justification whatsoever for placing them within a crop.

Problems attend the selection of sensors, e.g. those which measure wetness. Records of wetness duration vary greatly according to sensor characteristics and to the sources and intensity of wetness (see Huband & Butler, these Proceedings). Is the direct measurement of wetness too problematic for practical use; is this important condition better calculated instead? Until we can modify or standardise existing warning criteria, or develop new ones to suit the new technology, how can we expect better disease warnings from on-farm weather equipment? Warning criteria need to be developed alongside the intended monitoring technology, such as in the development in the USA of dedicated weather monitors for apple scab (Jones _et al_. 1984) and potato blight, the BLITECAST system, (MacKenzie 1981).

Forecasting models

A serious limitation in optimising disease management schemes is in providing accurate and robust means for forecasting changes in disease. Before computers became of general use, there were many attempts to define criteria to predict outbreaks, increases, infection periods, final severity or damage of individual diseases. Nowadays the fashion is to include such criteria within the term 'disease modelling'. We now have a number of simple, general 'models' for most of the important cereal diseases. They have traditionally been used in isolation and without computers, and until recently there have been few attempts to integrate them into farming practice. Many are based on empirical relationships with synoptic weather and have no explanatory base. The approach has sometimes been useful in aiding control decisions, as in ADAS regional warnings. But most have never been judged for their value in guiding treatments and so have never been thought to be appropriate for use on individual farms.

Of 58 crop protection models in central and western Europe which were identified in an inventory organised by a working group of the International Organisation for Biological Control, 33 concerned cereals (Jeger & Tamsett

1984). Most were for forecasting and although over half were claimed to be for managerial use (i.e. control strategy or tactics) only three were of value to farmers and practitioners. It was concluded that few models were being developed to practical ends in crop protection, but of these forecasting was the main objective. How can we therefore expect forecast models to play a serious role in disease management with its reliance on electronic technology and committment to farm-based operations? New efforts are needed, and are now underway at Long Ashton, to develop soundly-based models with realistic expectations of their application. They must recognize that several diseases occur at a time and also the relationships of disease onset to crop development, so that disease and treatment warnings can be interrelated.

Much attention has been given in the last 15 years to developing elaborate, mechanistic models, many describing the intricacies of pathogen life cycles. As far as we are aware no such models have ever been used in practical forecasting and we still do not know if it is possible or appropriate to reduce them to simple rules. The problem of what kind of information needs to be included in computer-operated schemes is unresolved. It is likely that elements of empiricism will always be necessary and useful. It is certain that their development must be based on knowledge of the plant/disease system and the interactions of the various stages of disease development with weather.

PROSPECTS

There is pressure by growers and their consultants to be provided with guidance on what factors should be recorded, how to record them and how they relate to disease as well as crop development. It is clear that we do not yet possess the requisite knowledge to meet this demand. For example, there is little tradition of incorporating a biological dimension into disease warnings based primarily on weather. The lack of a measure of inoculum (the current state of disease) is a serious limitation. Farmers now seem more prepared to assess their crops but methods need to be developed to enable relevant information to be obtained simply and reliably.

Our initial attempts to meet the needs are therefore empirical and also somewhat subjective. They must offer results in a simple form to help the farmer make a rational decision. Most importantly, we should understand that as scientists our natural inclination is only to provide guidance on firm incontrovertible evidence. Too often we forget that in purveying advice we make subjective estimates of what we think will happen because we do not have precise information. There will probably always be a place for subjective estimates in predictive programs.

There is another cause for concern. Although many schemes or weather criteria have been developed, few have been subject to careful validation. This is not surprising. Validation is difficult and not always possible because the pressure from our customers for guidance means we do not always have the opportunity. Also, there has been little investigation so far into the methods and opportunities needed for this difficult task.

This scenario implies that disease management systems must not be considered complete. For a time they will therefore be unsuitable for growers' use on their own farm computers. Improvements will be more easily achieved if systems are maintained and developed centrally. It is important to remember that there will be, and it is desirable that there should be more than one approach. The various computer-based systems currently being developed exploit quite different decision making methods, with the sophisticated facility of Counsellor to exploit viewdata and the comprehensive attempts to predict disease development in EPIPRE as the extremes. Growers and consultants may wish to subscribe to more than one scheme. It would help, therefore, if they could be offered alongside one another.

We should recognise, however, that the best schemes will survive, and be used, because they meet growers' needs, NOT because they are computerised. Use of computers for the wrong reasons will destroy the credibility of disease management as a concept. Our aim must be to harness computers to augment what is already possible. There is some danger that this is not the way current developments are moving.

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