TOPIC 1B

FORECASTING THE NEED TO CONTROL PESTS
DISEASES AND WEEDS IN CROPS

CHAIRMEN
SYMPOSIUM. Dr. Y. Robert
WORKSHOP DISCUSSION. Dr. R. Rabbinge
Mr. F. H. Rijsdijk

TOPIC ORGANISER. Dr. D. J. Royle
Dr. B. D. Smith

FORECASTING AND CROP PROTECTION DECISION MAKING - REALITIES AND FUTURE NEEDS

G.A. NORTON, M.J. WAY

Silwood Centre for Pest Management, Department of Pure and Applied Biology, Imperial College, Silwood Park, Ascot, Berks, U.K.

ABSTRACT

Forecasting is important in crop protection decision making, from the farmer to the level of agricultural policy. The need for forecast information, its content and the way it is obtained, will depend on the options and objectives of the relevant decision makers. A distinction is made between short term forecasting of the future incidence of exogenous pest attack; medium term forecasting, concerned with future endogenous pest attack; and long term forecasting, which attempts to assess the effects of political, economic, institutional and technological change on pest development and control. The principles and problems associated with these three types of forecasting are discussed. In particular, attention is drawn to the need for realistic, long term forecasting techniques.

INTRODUCTION

The first principle of good pest management is surely - 'Do not apply unnecessary control measures against pests'. While short term economics, and the problems of induced resistance of pests to pesticides and of environmental pollution, provide the arguments for a more rational use of pesticide, forecasting is often seen as the means of achieving it. Yet, such 'obviously beneficial' practices have had relatively limited success in practice. To discuss some of the reasons for this apparent gulf between ideals and realities at all levels of decision making, this paper sets out to analyse the problem of forecasting and to identify opportunities for improvement, using insect pest problems, in particular, as examples.

ANALYSIS OF THE FORECASTING PROBLEM

The general problem of forecasting in the context of pest control can be stated simply as follows - given a pest population density at a particular point in time, how is that population likely to develop in the future? The problem is to assess in which direction and to what degree changes in the pest population will occur in the future (Fig. 1). However, such a definition is only likely to be of practical value if certain, critical questions can be answered. For example, what time dimension is the forecast attempting to cover? or, for what decision process is information about the future to be used? Thus, the first question that needs to be asked about forecast information is why it is needed. The answer will depend on the level of decision making at which the question is posed, whether it is at the level of the farmer or extension agent, at a research level, or at a policy making level. Consequently, before investigating how forecast information might be obtained, we first need to consider the context in which such information might be used.

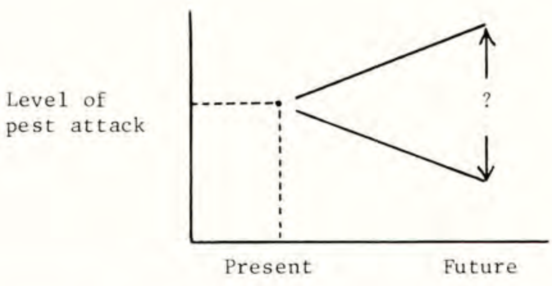


Fig. 1. The forecasting problem.

Although the decision processes mentioned above are obviously different, when viewed in terms of their prinicipal components, they can all be analysed in a similar way (Norton & Mumford 1983). This generalised decision model is outlined in Fig. 2. It starts with the options that are technically possible for the decision maker to adopt. From these, a feasible set can be identified, once the particular contraints under which the decision maker has to operate are considered. The crux of the decision problem is to assess how these feasible options are likely to perform with respect to the decision maker's objectives. Once this assessment has been made, the best option can then be evaluated according to the priorities the decision maker places on these objectives. To illustrate the relevance of this model at different decision levels, some possible options, constraints, and objectives are set out in Table 1.

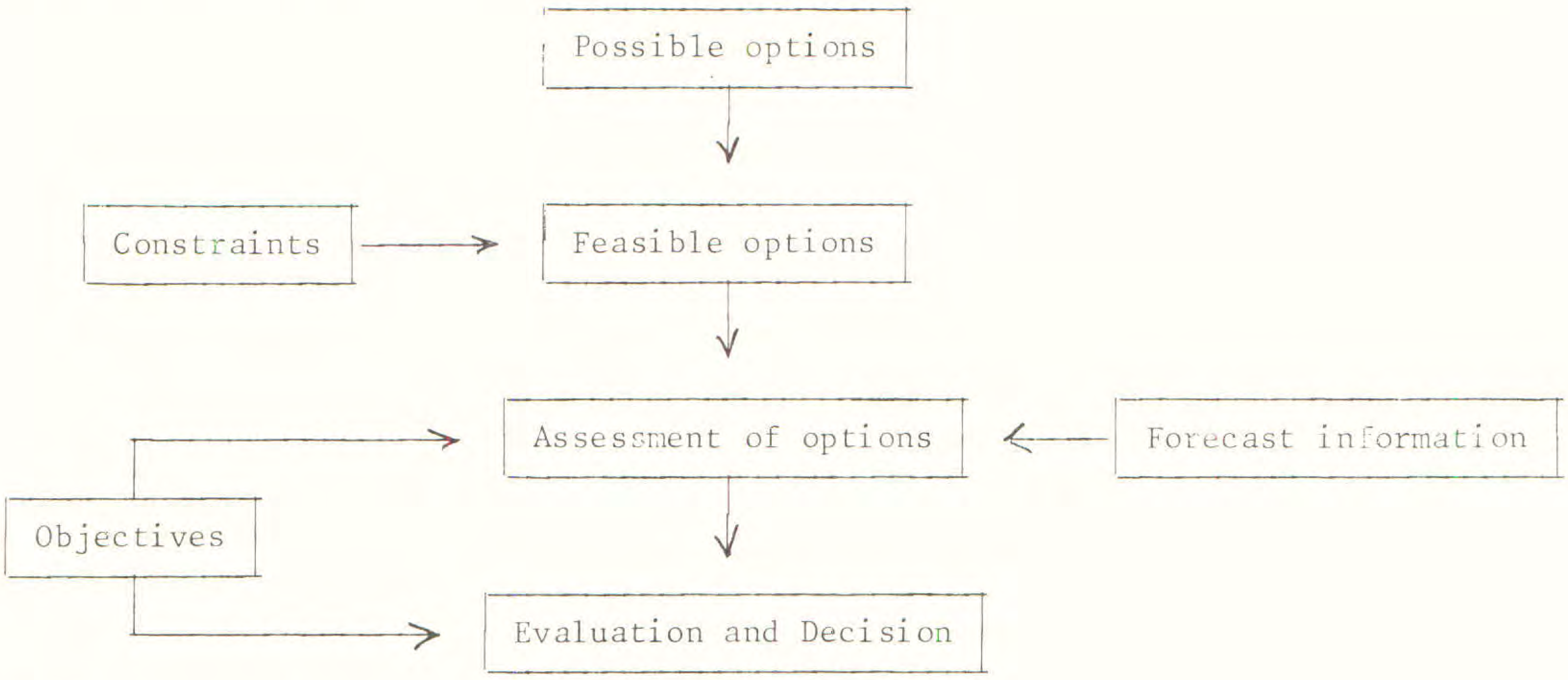


Fig. 2. A generalised decision model.

At each of the decision levels shown in Table 1, the need for forecast information and the time at which it is required will depend on the decision that has to be made. To assess the performance of some options a relatively short term forecast will be required, whereas others will require a much longer term forecast. For instance, if the decision problem is to decide whether to spray a crop or not, the time scale involved may be a week or less, while for other options, such as those concerning agricultural policy, the relevant time scale might be many years. Consequently, the way in which forecasting can be of value in the assessment phase (Fig. 2) will be very different for different decision problems, and in particular, will require different analysis techniques for short term compared with medium and long term situations.

SHORT TERM FORECASTING

The role of short term forecasting is considered here in the context of farmer decision making. Where the time period is a crop season or less, a decision rule used for deciding whether to apply a pesticide treatment or not, or to decide on other control options, is the economic or action threshold. It can be defined as the level of pest attack at which control measures will be justified (cf Stern *et al* 1959), according to the decision maker's objectives (Fig. 2). For example, where the damage relationship is linear and the farmer's objective is to achieve a certain level of profit, the economic threshold can be defined generally (Conway *et al* 1975, Norton 1976, Sutherst *et al* 1979) as where -

$$\underset{\text{(benefit)}}{pd\theta k} = \underset{\text{(cost)}}{c} \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

where p = price per kg of yield
d = the damage caused per unit of pest attack

θ = the untreated level of pest attack
k = the effectiveness of the treatment in reducing the level of pest attack
c = the cost of treatment

That is, the economic threshold level of attack $(\theta^*) = \frac{c}{pdk}$

TABLE 1

Some of the possible options, constraints, and objectives associated with crop protection at five decision making levels in developed and developing countries.

Levels of decision making	Possible options	Possible constraints	Possible objectives
FARMER	Plant resistant variety. Apply granular pesticide. Spray pesticide	Lack of capital, labour, or 'know-how'. Inadequate water supply.	Achieve adequate food supply. Reduce risk of monetary loss.
CHEMICAL INDUSTRY	Increase promotion campaign for certain pesticides. Develop 'package schemes'.	Development of pesticide resistance. Pesticide regulation policies.	Sustain and increase share of market. Avoid bad publicity.
GOVERNMENT RESEARCH	Study population dynamics of particular pests. Conduct pesticide field trials. Undertake farmer surveys.	Lack of expertise, facilities, or finance.	Develop forecasting technique. Understand pest population dynamics and farmer behaviour.
GOVERNMENT EXTENSION	Improve information dissemination. Establish pest clinics. Provide a pest forecasting service.	Lack of scientific knowledge. Poor communication technology.	Reduce losses caused by pests. Be seen to be doing something.
GOVERNMENT POLICY	Improve irrigation and cropped area. Provide guaranteed prices for certain crops. Subsidise pesticides.	Lack of financial resources or 'political will'. Inappropriate institutional structure.	Increase export earnings. Safeguard national food supply. Avoid pest outbreaks.

The role of forecasting in this decision rule may not be immediately clear. On inspection, however, it can be seen that several forecasts are required. First, although the present level of attack may be known, in many situations there is uncertainty about the future development of the population and therefore of the potentially damaging population that treatment is intended to reduce (Fig. 1). Indeed, if natural enemy action or an environmental episode occurs that is damaging to the population, θ may well be reduced without treatment. Similarly, forecasts are required of future damage relationship (d) and of future price (p), in order to forecast potential loss ($pd\theta$) (Way & Cammell 1980). The final variable that needs to be forecast to determine the economic threshold decision rule is the effectiveness of control (k). Weather factors are likely to be the major cause of uncontrollable variation in this variable.

Having noted that all the variables on the left hand side of equation 1 will probably require some forecast information, let us now concentrate on what is usually the most difficult problem, forecasting the level of pest attack. To assess future levels of pest attack, three types of information are likely to be required: fundamental information, concerning the basic ecological processes involved; historical information on past levels of pest attack and damage, and real-time information, obtained by pest, damage, or weather monitoring of the current situation. Real-time information on pest attack can be monitored at sources outside the crop, on entering the crop, or within the crop.

To illustrate how these different categories of information can be combined to produce a forecast of pest attack, consider the case of the black bean aphid, *Aphis fabae*. Fundamental information on the overwintering process provides the basis for forecasting pest attack. Thus, the determination of the overwintering process, and the fact that *A. fabae* overwinters virtually exclusively in the egg stage on spindle, provides the key to the forecasting scheme (Way & Banks 1968). Obtaining real-time information concerning the number of eggs on spindle during the winter, and the number of alates present in the spring, allows an assessment to be made of the numbers of aphids expected in the bean crop, and the time at which they are expected (Way *et al* 1977, Way *et al* 1981). To make the quantitative link between egg numbers on spindle and damaging aphids in the crop, historical information has been used.

While a simple regression enabled monitored information on *A. fabae* egg numbers on spindle to be successfully transformed into a forecast, and provide a basis for decision making, for other pests, a more complex transformation is likely to be required (Way & Cammell 1973). Although the EPI-PRE system, that provides recommendations to farmers on the control of cereal diseases, is essentially based on a regression model (Rijsdijk 1982), a number of other variables, as well as the monitored level of disease incidence, are involved, including information on soil type, planting time, variety, and nitrogen application. In other situations, such as those where natural enemies are important, more complex models may be required. For instance, Croft (1975) has used a simple predator prey model to transform monitored information on mites and predatory mites, on apples, into a decision rule for spraying. For other decision problems the transformation of monitored information to provide a decision rule can be far less complicated. Thus, the detection of pesticide resistant strains of pest in an area (Busvine 1980) is sufficient information for a farmer to change the pesticide he uses. Similarly, the information obtained from the regional monitoring of rice variety resistance to brown planthopper (*Nilaparvata lugens*) attack in Indonesia (Oka 1978) can be immediately interpreted when a breakdown in resistance is indicated.

MEDIUM TERM FORECASTING

The main concern of short term forecasting at the farm level is likely to be with exogenous pests, such as many airborne diseases and migratory insects, that migrate to the crop from outside. Characteristically these pests do not survive within a field from one crop to another, so the farmer is likely to tackle the problem of exogenous pests on a crop to crop, or year to year, basis. The situation is different for endogenous pests, such as some insects, nematodes, soil borne diseases, and weeds, that largely remain within a field, and whose dynamics are determined by factors operating within that field. Since control measures taken against endogenous pests affect both current and future levels of attack, the benefits of control may not only include reduced losses this year but reduced losses in subsequent years. Thus, the benefit (lefthand) side of equation 1 now has to include the likely effects of current control on losses in future years, making forecasting a more complex proposition.

One way of dealing with the problem of forecasting endogenous pest attack is to use a population model. For example, using data on nematode population growth (Jones 1973), Norton (1976) determined how the economic threshold for DD application against potato cyst eelworm (*Heterodera rostochiensis*) changed when 2 years, instead of a single crop year were considered. Such population models can also be useful for assessing the performance of more complex options. For instance, Cussans & Moss (1983) used a population model of black-grass (*Alopecurus myosuroides*) to predict the impact of different rotational cultivation schemes on this weed.

A different approach has been adopted in forecasting the effect that strategic and tactical integrated control options have on the cattle tick (*Boophilus microplus*) in Australia (Sutherst *et al* 1979, Sutherst *et al* 1980, Norton *et al* 1983). In this case, the emphasis is not on precise prediction but on assessing the range of climatic/management situations in which specific strategies can be expected to perform well. On this basis, robust strategies for particular situations can be forecast.

LONG TERM FORECASTING

While the effects of control practices on losses in future years have to be considered for endogenous pests, we have implied that this is not the case for exogenous pests: yet the same principles may still apply. What farmers do in any one season can undoubtedly affect the overall population of many exogenous pests in the next season by affecting between-season populations of the pest in the large and usually ill-defined ecosystem, which extends well beyond the limits of a particular field at risk. This implies that a longer term approach should also be adopted for exogenous species, not necessarily by the individual farmer but at a regional or national level, in order to forecast the effects of changes in agricultural technology on pest incidence and control.

Since traditional cropping practices, such as rotations and mixed cropping, were developed empirically under the pressure of pest attack, they acquired innate, but often unrecognised, pest management properties (Perrin 1980). However, with the drive for higher yields and more specialised production, these practices have been drastically modified, eroding the traditional means of controlling pests, and giving rise to new and increased problems of pest attack. Consequently, pest control strategies and tactics have had to adapt continually to a whirlwind change based on other priorities and, with few exceptions, that takes little account of the needs of pest control.

One result of this development has been a greater reliance on pesticides as the main method of pest control, which in turn has sometimes given rise to other problems of initial and secondary pest resurgence, pest resistance to pesticides, human hazards and environmental pollution. The problems associated with these changed cropping practices, and particularly the use of higher yielding but more pest susceptible varieties, have occurred in developed and developing countries alike, as documented for rice (Kiritani 1979), cotton (Reynolds *et al* 1975), and wheat (Way & Cammell 1979).

Apart from new problems with old crops, the introduction of a new crop to an area can also have undesirable consequences. For instance, following the entry of the U.K. into the European Community, one effect of the Common Agricultural Policy has been to increase the area of oilseed rape from 7,000 has. in 1972 to 175,000 has. in 1982. Apart from the expected pest problems that new oilseed rape growers have had to contend with (Lane 1983), there have been wider implications:

(a) Since present varieties of oilseed rape are tolerant to the disease *Phoma*, the disease has been spread, along with the adoption of the crop, to areas were other, non-tolerant brassica crops are grown.

(b) It has been suggested that the increased acreage of oilseed rape has increased cabbage aphid (*Brevicoryne brassicae*) attack on other crops.

(c) As oilseed rape has spread into other brassica growing areas, cabbage stem flea beetle (*Psylliodes chrysocephala*) from these other crops, has moved on to oilseed rape and become an increasingly widespread problem (Lane 1981).

Similar lessons have been learned in retrospect in the Sudan. Here, the intensification of cropping practices, by introducing groundnuts in rotation with cotton, has bridged a gap in the breeding cycle of the cotton bollworm (*Heliothus armigera*) and escalated its pest status in cotton. As a result of the subsequent control measures used against *H. armigera*, other pest problems were created, contributing to the general decline in the Sudanese economy (Way 1974).

A final example, of changes in sugar beet production in western Europe, provides another perspective. Over two decades ago, two lines of labour saving, but mutually exclusive, production practices were being developed. One was the development of monogerm seed and precision drilling, that allowed growers to drill to the desired, final plant density; the second line of development involved an electronic thinning machine, that enabled the desired plant density to be achieved efficiently after seedling establishment. Partly because selective herbicides necessary for acceptable electronic thinning were not immediately available, the option of drilling to a stand was taken up, creating a more susceptible crop, new levels of pest problem (Dunning 1983), and the need for greater pesticide input, than might be expected with electronic thinning.

The developments described above have two implications for forecasting. First, they can seriously impair the reliability of short term and medium term forecasting. Second, and of more concern here, is the need for long term forecasting of the effects on pest incidence of changes in agricultural practice. Whilst pest control considerations are unlikely to dictate agricultural change, some account should at least be taken of their likely impact on pest development and control. This would not only provide an early warning of the problems to be expected, and enable appropriate research and extension programmes to be initiated, but might also allow modification of design features to reduce pest development (cf Loevinsohn *et al* 1982).

DISCUSSION

The three types of forecasting identified in this paper - short, medium and long term forecasting - cover different decision problems and require different techniques. Short and medium term forecasting, largely associated with exogenous and endogenous pests respectively, not only require forecasts of pest population dynamics but also of revenue loss and the effectiveness of control. The difficulty of forecasting damage and control effectiveness in the British environment, for example, may be largely responsible for the economic threshold decision rule not being more widely adopted.

The problem of forecasting is most difficult when long term decision making is considered. In an ideal world, the planning and execution of agricultural development might be sufficiently comprehensive to account for the complex, dynamic relationships between agricultural development, pest development, and pest control. In the real world, the problems of operating such a comprehensive approach to agricultural planning, as with other planning problems (Norton & Walker 1982), is unlikely to be practicable. A more feasible approach is to identify trends in system behaviour and provide information on how modifications to agricultural change might ameliorate subsequent crop protection problems. Otherwise, the continuation of a process of agricultural evolution, in which the implications for pest development and control are initially ignored, can lead to a continually increasing need for improved pest control becoming accepted practice. This may well produce crop production regimes that become unmanageable or even catastrophic, as in the Ord Irrigation Area in Australia (Wilson 1982), in northeastern Mexico (Reynolds *et al* 1975), and predictably elsewhere.

Having defined the problem, how is long term forecasting to be undertaken? Three assessment stages are involved (Fig. 3): first, identifying relevant political, economic, institutional, and technological change; second, predicting the effect of these changes on crop production; and third, assessing how pest problems and crop protection activities are likely to be affected. We suggest this long term aspect of forecast analysis has been much neglected in the past. It deserves more attention in the future.

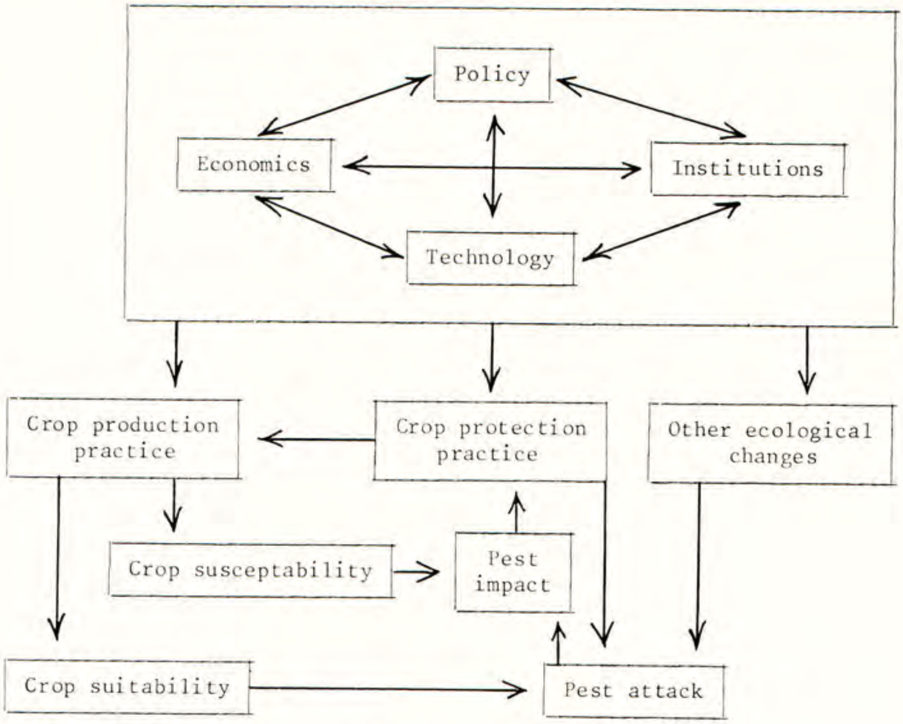


Fig. 3. Factors affecting long term forecasting of pest impact.

REFERENCES

Busvine, J.R. Ed. (1980) *Recommended Methods for Measurement of Pest Resistance to Pesticides*. FAO Plant Production and Protection Division. Paper No. 21. FAO, Rome. 132 pp.

Conway, G.R.; Norton, G.A.; Small, N.J.; King, A.B.S. (1975) A systems approach to the control of the sugar cane froghopper. In *Study of Agricultural Systems*. G.E. Dalton (Ed.) Applied Science Publishers, London. pp. 193-229.

Croft, B.A. (1975) Integrated control of apple mites. Michigan State University Cooperative Extension Service Bulletin 825.

Cussans, G.W.; Moss, S.R. (1982) Population dynamics of annual grass weeds. In *Decision Making in the Practice of Crop Protection*. R.B. Austin (Ed.) British Crop Protection Council, Croydon. pp. 91-98.

Dunning, R.A. (1982) Sugar beet pest, disease and weed control and the problems posed by changes in husbandry. In *Decision Making in the Practice of Crop Protection*. R.B. Austin (Ed.) British Crop Protection Council, Croydon. pp. 143-154.

Jones, F.G.W. (1973) Management of nematode populations in Great Britain. *Proceedings of the Tall Timbers Conference on Animal Control by Habitat Management* 4, 81-107.

Kiritani, K. (1979) Pest management in rice. *Annual Review of Entomology* 24, 279-312.

Lane, A.B. (1981) *Pest Control Decision Making in Oilseed Rape*. Ph.D Thesis. Imperial College, University of London.

Lane, A.B. (1983) A study of the pest control behaviour of oilseed rape growers in the United Kingdom. *Protection Ecology* (in press)

Loevinsohn, M.; Litsinger, J.; Bandong, J.; Alviola, A.; Kenmore, P. (1982) *Synchrony of Rice Cultivation and the Dynamics of Pest Populations: Experimentation and Implementation*. Saturday Seminar. 28th August 1982. International Rice Research Institute, Manila.

Norton, G.A. (1976) Analysis of decision making in crop protection. *Agro-Ecosystems* 3, 27-44.

Norton, G.A.; Mumford, J.D. (1983) Decision making in pest control. In *Applied Biology* 8. T.H. Coaker (Ed.) Academic Press, London (in press)

Norton, G.A.; Sutherst, R.W.; Maywald, G.F. (1983) A framework for integrating control methods against the cattle tick, *Boophilus microplus*, in Australia. *Journal of Applied Ecology* 20 (in press)

Norton, G.A.; Walker, B.H. (1982) Applied ecology: towards a positive approach. I. The context of applied ecology. *Journal of Environmental Management* 14, 309-324.

Oka, I.N. (1978) Quick method for identifying brown planthopper biotypes in the field. *International Rice Research Newsletter* 3, 11-12.

Perrin, R.M. (1980) The role of environmental diversity in crop protection. *Protection Ecology* 2, 77-114.

Reynolds, H.T.; Adkisson, P.L.; Smith, R.F. (1975) Cotton insect pest management. In *Introduction to Insect Pest Management*. R.L. Metcalf; W.H. Luckman (Eds.). John Wiley, New York. pp. 399-443.

Rijsdijk, F.H. (1982) The EPIPRE system. In *Decision Making in the Practice of Crop Protection*. R.B. Austin (Ed.). British Crop Protection Council, Croydon. pp. 65-76.

Stern, V.M.; Smith, R.F.; van den Bosch, R.; Hagen, K.S. (1959) The integrated control concept. *Hilgardia* 29, 81-101.

Sutherst, R.W.; Norton, G.A.; Barlow, N.D.; Conway, G.R.; Birley, M.; Comins, H.N. (1979) Analysis of management strategies for cattle tick (*Boophilus microplus*) control in Australia. *Journal of Applied Ecology* 16, 359-382.

Sutherst, R.W.; Norton, G.A.; Maywald, G.F. (1980) Analysis of control strategies for cattle tick on Zebu x British cattle. In *Ticks and Tick-borne Diseases*. L.A.Y. Johnston; M.G. Cooper (Eds.). The Australian Veterinary Association, Artarmon, N.S.W. pp. 46-51.

Way, M.J. (1974) Applied ecological research needs in relation to population dynamics and control of insect pests. *Proceedings of the FAO Conference on Ecology in Relation to Plant Pest Control*. FAO, Rome. pp. 283-297.

Way, M.J.; Banks, C.J. (1968) Population studies on the active stages of the black bean aphid, *Aphis fabae* Scop., on its winter host *Euonymous europaeus* L. *Annals of Applied Biology* 62, 177-197.

Way, M.J.; Cammell, M.E. (1973) The problem of pest and disease forecasting - possibilities and limitations as exemplified by work on the bean aphid, *Aphis fabae*. *Proceedings of the 7th British Insecticide and Fungicide Conference*. British Crop Protection Council, Croydon. pp. 933-954.

Way, M.J.; Cammell, M.E. (1979) Optimising cereal yields - the role of pest control *Proceedings 1979 British Crop Protection Conference - Pests and Diseases*. British Crop Protection Council, Croydon. pp. 663-672.

Way, M.J.; Cammell, M.J. (1980) Constraints in establishing meaningful economic thresholds in relation to decision-making on pesticide application. *EPPO Bulletin* 10, 201-206.

Way, M.J.; Cammell, M.E.; Alford, D.V.; Gould, H.J.; Graham, C.W.; Lane, A.; St.G. Light, W.I.; Rayner, J.M.; Heathcote, G.D.; Fletcher, K.E.; Seal, K. (1977) Use of forecasting in chemical control of black bean aphid, *Aphis fabae* Scop., on spring-sown field beans, *Vicia faba* L. *Plant Pathology* 26, 1-7.

Way, M.J.; Cammell, M.E.; Taylor, L.R.; Woiwod, I.P. (1981) The use of egg counts and suction trap samples to forecast the infestation of spring-sown field beans *Vicia faba*, by the black bean aphid, *Aphis fabae*. *Annals of Applied Biology* 98, 21-34.

Wilson, A.G.L. (1982) Past and future *Heliothus* management in Australia. In *International Workshop on Heliothus Management*. International Crops Research Institute for the Semi-Arid Tropics, Andhra Pradesh, India. pp. 343-354.

THE ROLE OF FORECASTING IN PLANT DISEASE SUPPRESSION

W. E. FRY, G. R. FOHNER

Departments of Plant Pathology and Agricultural Economics, respectively, Cornell University, Ithaca, New York USA

ABSTRACT

Disease forecasts are potentially useful in enhancing the efficacy of disease suppression. The epidemiological bases of forecasts are reviewed. Weather variables have been emphasized in most disease forecasts, but host, pathogen and time variables can be equally useful. A simulation experiment was done to quantify the benefits of applying fungicide according to a weather-sensitive forecast of potato late blight. On the average, a weekly application of fungicide suppressed disease more effectively than did applications timed according to the forecast. Disease forecasts should be integrated with weather forecasts, host resistance, and other relevant data for determining frequency of fungicide applications.

INTRODUCTION

Disease forecasts are designed to indicate when technology for suppressing plant disease is needed, and when it is not. The potential benefits of forecasts are several: decreased costs, better disease suppression, decreased use of pesticides. Plant pathologists have been actively constructing disease forecasts for more than fifty years. Some forecasts have been readily adopted by growers, while other forecasts have not. It is our goal in this presentation to describe the logical basis for constructing forecasts and to raise questions about why some forecasts are adopted and others are not.

APPROACHES TO FORECASTING

Forecasts are most appropriate for diseases which occur sporadically (Bourke, 1970). If the disease is important during some seasons but not others, then disease suppression technology is not always required, and forecasts can be valuable for identifying those times when disease suppression technology is required, or conversely, identifying those times when it is not. If the disease is consistently important, forecasts are not needed.

Disease forecasts are the plant pathologist's counterparts to the entomologist's action thresholds. Action thresholds based on measurements of disease are unreliable because of the latent period of most plant infections. There are no macroscopic symptoms during the first part of infection, so there is a variable relationship between the amount of visible disease and the total number of infections (Fry, 1982).

Instead of measurements of disease, forecasts use measurements of other variables to determine whether disease suppression technology is needed. Historically, forecasts have used variations in weather as a primary determinant. In a brief survey of twenty-three diseases for which forecasts have been developed, forecasts for only three diseases did not include a consideration of weather (Fry and Fohner, 1983). However, other variables can be equally influential on the occurrence of plant disease. These include host population characteristics (size, susceptibility, location, growth habit, etc.), pathogen population characteristics (size, aggressiveness, virulence, reproduction rate, location, etc.), disease suppression technologies, and the time-interval during which host and pathogen interact.

The epidemiology of the disease provides a guide for developing forecasts. If differences in disease severity are due primarily to differences in the size of the pathogen population at the beginning of the season, then forecasts should be based on size of the initial pathogen population. If differences in disease severity result primarily from differences in host resistance, then forecasts should be based primarily on host resistance. If differences in disease severity result primarily from weather effects on pathogen reproduction, then the forecast should be based primarily on weather. If host resistance, pathogen population size, and weather are all influential, then effective forecasts may require information about all three.

In addition to epidemiological considerations, economic considerations affect the development of disease forecasts. The variables on which the forecast is based must be relatively inexpensive to monitor, and the benefits from the forecast must be large enough to warrant its development and use. An important factor in these economic considerations is the technology available for collecting data and for responding to the forecast of disease.

Although forecasts have been developed for dozens of diseases, some are not widely used. Exceptions are forecasts for apple scab (caused by *Venturia inaequalis*) and Stewart's wilt of maize (caused by *Erwinia stewartii*), which have been widely used by growers in the Northeastern United States, and a forecast for beet yellows in England. The apple scab forecast developed by Mills (1944) assumes that there is a large amount of initial inoculum, and infection is limited by the weather. Mills identified the combinations of temperature and duration of leaf wetness that resulted in severe, moderate, and light infection. In many apple growing regions, temperature and leaf wetness are monitored to detect infection periods based on Mills' forecast, and the results are rapidly publicized via several forms of communication media. If apple foliage was unprotected by fungicide during an infection period, a grower is advised to apply a fungicide with therapeutant (after-infection) activity. *V. inaequalis* remains sensitive to such fungicides for 1-2 days.

Jones and colleagues (1980) at Michigan State University, USA have recently developed an automated apple scab forecasting device. It is a microcomputer linked to weather sensors. The computer is programmed to identify the occurrence of infection periods (Jones, 1980).

The forecast for Stewart's wilt disease of maize has had general application. The forecast identifies indirectly the size of the overwintering pathogen population. The pathogen (*E. stewartii*) overwinters in the corn flea beetle and is transmitted to maize seedlings during subsequent feeding (Elliott and Poos, 1934). Greater numbers of beetles (and therefore *E. stewartii*) survive mild winters than survive harsh ones. Stevens (1934) developed a simple scale to identify the effect of winter temperatures on subsequent disease development. In seasons after mild winters, when the disease is likely to be severe, growers are advised to plant resistant cultivars, or to use insecticides to lower the flea beetle population. The specific relationships have been programmed onto a computer for rapid interpretation (Castor, *et al*. 1975).

A forecast for sugar beet yellows caused by beet yellows virus and beet mild yellows virus has been used by industry fieldmen in England with apparent success (Hull, 1968; Watson, *et al*. 1975). This disease forecast differs from many others in that both weather and insect vectors are monitored for the forecasts. Vector populations (the aphids, *Myzus persicae*, and *Aphis fabae*) increase to important levels earlier in the growing season following warm winters and springs than after cold winters and springs (Watson *et al*. 1975). After a warmer-than-normal winter and spring, industry fieldmen are alerted that aphid populations will increase earlier and virus disease is likely to appear early. The intensity of field observations for aphids can be adjusted on the basis of that alert, and an insecticide application can be applied at the most effective time based on the field observations.

In contrast to the preceding forecasts, those for potato late blight (caused by *Phytophthora infestans*) are not yet used widely by growers in North America. Some intensive extension programs are exceptions, however. Late blight forecasts in these intensive programs have been widely publicized in the potato growing region, and some growers have used the information to adjust their timing of fungicide applications.

Forecasts for potato late blight have probably received more research effort than have forecasts for any other disease. Until very recently, late blight forecasts were based exclusively on weather variables. Techniques to identify the time of the initial fungicide spray of the season or to determine subsequent frequency of sprays have been identified in several countries of Western Europe, in England, and in North America (Beaumont, 1947; Grainger, 1953; Krause et al. 1975; Schrodter and Ullrich, 1966; Wallin 1962). Early forecasting efforts were published nearly 60 years ago (Van Everdingen, 1926).

In an effort to develop a more accurate late blight forecast, our research group at Cornell University has developed a comprehensive forecast technique that includes host resistance (rate-reducing), fungicide effects, and weather as variables for scheduling fungicide applications. We have considered only the frequency of protectant fungicide sprays after the initial one has been applied. The decision rules (Table 1) were derived from analysis of computer models of disease development and of fungicide deposition, redistribution and removal (Bruhn and Fry, 1982a; 1982b; 1981; Spadafora, Fry, and Bruhn, unpublished). Weather

TABLE 1

Decision rules for a potato late blight forecast derived from analysis of computer simulation models[a]

	Cultivars	
	Susceptible	Moderately Resistant
Fungicide should be applied if it has not been applied within 5 days		
AND cumulative blight units[b] since last spray exceed:	30	40
OR cumulative fungicide units[c] since last spray of the fungicide indicated exceed:		
chlorothalonil	15	25
triphenyltin hydroxide	15	20-25
captafol	15	20

[a]From: Fry et al. 1983; Spadafora et al. unpublished results.
[b]Blight units indicate weather favorability for late blight as described in Fry et al. 1983.
[c]Fungicide units describe the amount of fungicide removed since the last application. Fungicide units are defined in Fry et al. 1983, and in Spadafora et al. unpublished results.

effects on disease are quantified in terms of blight units, and a longer period of favorable weather is allowed between sprays for resistant than for susceptible cultivars (Table 1). Fungicide removal is quantified as fungicide units, and fungicide deposits on foliage are allowed to be depleted further between sprays on resistant than on susceptible cultivars (Table 1). Precise characterizations of fungicide toxicity and tenacity are required for inclusion into the scheme. To date, three protectant fungicides (captafol, chlorothalonil, and triphenyltin hydroxide) have been characterized sufficiently well for inclusion in the forecast scheme. The forecast operates well as judged from several field evaluations (Table 2, Fry et al. 1983). For susceptible cultivars, recommendations from this comprehensive forecast are similar to those from Blitecast (Krause et al. 1975), but it recommends fewer sprays to cultivars with greater levels of resistance. In field tests most recommendations for spray in New York State have been generated from occurrence of blight-favorable weather rather than from fungicide depletion.

TABLE 2

Field tests of several fungicide timing techniques for potato late blight suppression[a]

Treatment		Experiment 1[(b)]		Experiment 2[(b)]	
Cultivar Reaction	Timing Technique	No. Sprays	Final Disease	No. Sprays	Final Disease
Susceptible	7-day	7	92%	7	2.1%
Moderately Resistant	7-day	7	44%	7	0.5%
Susceptible	Blitecast[(c)]	8	79%	9	2.2%
Moderately Resistant	Blitecast	8	30%	9	0.2%
Susceptible	Simulation forecast[(d)]	9	74%	8	4.6%
Moderately Resistant	Simulation forecast	6	85%	5	4.1%

[a]Data are from Fry et al. 1983.
[b]Experiment 1 was irrigated daily. Experiment 2 was not irrigated regularly.
[c]Blitecast was applied as described by Krause et al. 1975.
[d]The simulation forecast is described in Table 1.

EVALUATION OF DISEASE FORECASTS

Although initial tests under a limited number of field conditions suggested that late blight forecasts might benefit potato growers in the Northeastern United States, forecasts have not yet been widely adopted by them. We sought to investigate the potential value to growers of late blight forecasts, and identify factors that might affect that value. For this investigation, we used Blitecast (Krause et al. 1975), a late blight forecast which depends on weather variables only. Field experiments to evaluate forecasts over a range of weather conditions and inoculum availabilities were prohibitively expensive, so we turned to computer simulation modeling. The models used were pathogen and fungicide models developed by J. A. Bruhn for potato late blight (Bruhn & Fry, 1982a, 1982b, Bruhn et al. 1980). Late blight suppression via protectant fungicide application at regular intervals was compared to that effected by protectant fungicide applications timed according to Blitecast.

The experiment, which has been described partially elsewhere (Fry & Fohner, 1983), was conducted using 10 seasons of macroclimate data recorded at Geneva, New York. Daily periods of high relative humidity (>90%) within the crop canopy were generated from the macroclimate data using a stochastic function estimated from three seasons of hygrothermograph data (Fohner, White, and Fry, unpublished). The resulting data were representative of relative humidity in microclimates regarded as favorable for late blight. Data for moderately favorable and unfavorable microclimates were generated by subtracting one and two hours, respectively, from each daily period of high relative humidity in the data set for the favorable microclimate.

In addition to evaluating the effect of microclimate on Blitecast and regular intervals, the simulation experiment evaluated the effects of different inoculum pressures. Sporangia (inoculum) were added to the system at low, moderate, or high levels. At each level of exposure, more inoculum was added during weather favorable for late blight than during unfavorable weather (Fohner, White, Fry unpublished).

The degree of confidence placed in the results of this simulation experiment depend on the accuracy of the models and the appropriateness of the models and methodology for comparing Blitecast and regular interavls. Predictions from the two models used in this experiment have been accurate in each of several tests for each model (Bruhn et al. 1980, Bruhn and Fry, 1981; 1982a; 1982b). Additionally, fungicide-timing techniques derived from analysis of these two models have performed well in field experiments (Fry et al. 1983; Spadafora et al. 1983). Consequently, the two models appear to be accurate reflections of reality. The methodology we used to compare Blitecast and regular intervals in this experiment was consistent with the strengths and limitations of the models, and therefore seems appropriate for this experiment.

Results of the simulation experiment were completely unexpected (Table 3). Instead of providing data for quantifying the benefits of using a forecast system, we interpret the results to indicate that Blitecast is not more effective than applying fungicides at regular intervals. Under favorable conditions Blitecast called for more sprays than did the regular weekly application (Table 3). The weekly application tended to suppress disease more effectively than Blitecast at

TABLE 3

Average percent defoliation from late blight and average number of fungicide applications for the simulated seasons for Blitecast and the 7-day interval.[a]

Treatment	Microclimate Favorable	Microclimate Moderately Favorable	Microclimate Unfavorable
	Average % Defoliation		
High Inoculum-Blitecast	40.1 (7.9)[b]	34.1 (8.6)	23.2 (8.9)
High Inoculum-7-day	35.2 (8.2)	21.2 (8.5)	10.9 (5.2)
Moderate Inoculum-Blitecast	16.3 (6.0)	16.5 (9.1)	9.5 (4.6)
Moderate Inoculum-7-day	15.2 (6.7)	10.0 (6.1)	3.9 (3.4)
Low Inoculum-Blitecast	0.2 (0.1)	1.0 (0.7)	0.1 (0.0)
Low Inoculum-7-day	0.4 (0.3)	0.2 (0.2)	0.0 (0.0
	Average No. Sprays		
Blitecast	10.6	8.7	6.6
7-day	10.0	10.0	10.0

[a]Data are from Fohner, White, and Fry, unpublished results.
[b]Values in parentheses are standard deviations of average defoliations.

high and moderate inoculum levels. Under moderately favorable or unfavorable weather conditions, Blitecast recommended fewer sprays than did the weekly sprays, but these resulted in more disease than with weekly fungicide sprays. Other simulation experiments have provided additional evidence that Blitecast provides little if any advantage over regular fungicide applications (Fohner, White, Fry unpublished).

We were initially skeptical about the results of the simulation experiment, but recent field experiments have been consistent with them (Fry et al., 1983). Upon reflection the results seem understandable. The fungicides used in the simulation and field experiments are protectant. They have negligible influence on pathogen development within infected tissues. The weather-sensitive forecasts call for a spray after the weather has been favorable -- after infection has occurred.

Blitecast or some other weather-sensitive forecast might be quite useful if used in combination with reliable weather forecasts. By anticipating impending infection periods as well as responding to previous ones, disease forecasts based on weather might enable more effective use of fungicide than is possible with regular applications.

Predictions from the simulation experiment are restricted to protectant fungicides. Predictions for therapeutic fungicides have not yet been generated, but, conceivably, these fungicides might be very appropriate for use with a weather-sensitive forecast of late blight, just as they are for forecasts of apple scab.

CONCLUSIONS

The predictions developed from the simulation experiment and the results of our recent field experiments have caused us to revise our recommendations for suppressing late blight. We now suggest that if growers monitor the environment, they use the resulting data only as one of several factors in determining spray frequency, rather than as the sole criterion. Cultivar resistance and weather forecasts are recommended as additional criteria for determining spray frequency. Differences in cultivar resistance in our experiments during the past 3-4 years have been more influential on variations in disease development than have been differences in weather (Fry et al., 1983). For upstate New York we have developed recommended spray frequencies for cultivars of diverse resistances. On the average, susceptible cultivars should be sprayed every 6-7 days. Moderately susceptible and moderately resistant cultivars should be sprayed every 8-9 and every 10-12 days, respectively.

Our results with potato late blight may be applicable to forecasts for diseases of other crops. Forecasts based exclusively on weather to determine frequency of protectant fungicide sprays may provide negligible benefit. Data on host characteristics or pathogen characteristics may be equally or more important in determining the need for fungicide applications.

References

Beaumont, A. (1947) The dependence on the weather of the dates of outbreak of potato blight epidemics. Transactions of the British Mycology Society 31:45-53.

Bourke, P. M. A. (1970) Use of weather information in the prediction of plant disease epiphytotics. Annual Review of Phytopathology 8:345-370.

Bruhn, J. A.; Bruck, R. I.; Fry, W. E.; Arneson, P. A.; Keokosky, E. V. (1980) Lateblight, a plant disease management game. User's Manual. Mimeo 80-1, Plant Pathology Department. Cornell University, Ithaca, New York. 49 pp.

Bruhn, J. A.; Fry, W. E. (1981) Analysis of potato late blight epidemiology by simulation modeling. Phytopathology 71:612-616.

Bruhn, J. A.; Fry, W. E. (1982a) A statistical model of fungicide deposition on potato foliage. Phytopathology 72:1301-1305.

Bruhn, J. A.; Fry, W. E. (1982b) A mathematical model of the spatial and temporal dynamics of chlorothalonil residues on potato foliage. Phytopathology 72:1306-1312.

Castor, L. L.; Ayers, J. E.; MacNab, A. A.; Krause, R. A. (1975) Computerized forecasting system for Stewart's bacterial disease on corn. Plant Disease Reporter 59:533-536.

Elliott, C.; Poos, F. W. (1934) Overwintering of Aplanobacter stewartii. Science 80:289-290.

Fry, W. E. (1982) Principles of Plant Disease Management. Academic Press. New York. 378 pp.

Fry, W. E.; Apple, A. E.; Bruhn, J. A. (1983) Evaluation of potato late blight forecasts modified to incorporate host resistance and fungicide weathering. Phytopathology 73:(in press).

Fry, W. E.; Fohner, G. R. (1983) Disease Prediction. In C. A. Gilligan, D. S. Ingram, and P. H. Williams (eds.). Advances in Plant Pathology. Volume IV. Mathematical Modeling. Academic Press, Lond. (in press)

Grainger, J. (1953) Potato blight forecasting and its mechanization. Nature 171:1012-1014.

Hull, R. (1968) The spray warning scheme for control of sugar beet yellows in England. Summary of results between 1959-66. Plant Pathology 17:1-10.

Jones, A.; Lillevik, S. L.; Fisher, P. D.; Stebbins, T. C. (1980) A microcomputer-based instrument to predict primary apple scab infection periods. Plant Disease 64:69-72.

Krause, R. A.; Massie, L. B.; Hyre, R. A. (1975) Blitecast: a computerized forecast of potato late blight. Plant Disease Reporter 59:95-98.

Mills, W. D. (1944) Efficient use of sulfur dusts and sprays during rain to control apple scab. Cornell Extension Bulletin 630. January 1944. 4pp.

Schrodter, H; Ullrich, J. (1966) Further research on the biometerology and epidemiology of Phytophthora infestans (Mont.) de By. A new proposal for the solution of the problems of epidemiological prognosis. Phytopathology Z. 56:265-278.

Spadafora, V. J.; Apple, A. E.; Bruhn, J. A.; Fry, W. E. (1983) Evaluation of simple and complex potato late blight forecasts. Phytopathology 73:375. (abstr.)

Stevens, N. E. (1934) Stewart's disease in relation to winter temperatures. Plant Disease Reporter 12:141-149.

Van Everdingen, E. (1926) Het verband tusschen de weergesteldheid en de aardappelziekte Phytophthora infestans. Tijdschr. Pl. Ziekt XXX11, 129.

Wallin, J. R. (1962) Summary of recent progress in predicting late blight epidemics in the United States and Canada. American Potato Journal 39:306-312.

Watson, M. A.; Heathcote, G. D.; Luackner, F. B.; Sowray, P. A. (1975) The use of weather data and counts of aphids in the field to predict the incidence of yellowing viruses of sugar-beet crops in England in relation to the use of insecticides. Annals of Applied Biology. 81:181-198.

1B—S3

TOWARDS A RATIONALE FOR THE PREDICTION OF WEED INFESTATIONS AND THE ASSESSMENT OF CONTROL STRATEGIES

A. M. MORTIMER and L. G. FIRBANK

Department of Botany, University of Liverpool, U.K.

ABSTRACT

The objective of weed control is the maximisation of desirable biological production for the least cost. This necessitates forecasting long and short term changes in weed populations and relating these changes to interference with production. Appropriate strategic models are presented which describe long term weed population flux and its impact on production. Short term effects of weed control are insufficiently understood to allow the development of tactical forecasting methods as yet.

Weed ecology; forecasting; competition; models.

INTRODUCTION

Pest control has an historical lineage heavily drawn from the subject disciplines of entomology and pathology. A glance at the literature reveals a wealth of empirical study in these areas that has led to theoretical understanding of the ecology of pest control, the application of forecasting techniques and the design of control strategies (for example Waggoner and Horsfall, 1969; Croft et al. 1976; Hassell, 1982). The same cannot be argued for plant biology and weed control, where the major botanical emphasis has been placed with plant biochemistry and physiology and the mode of action of herbicides. In 1968, looking forward over the next 20 years, Sagar saw three issues confronting weed scientists - that of 'living' with weeds ; the development of technologies for the control of pernicious ones ; and assessment of the consequences to agroecosystems of the disappearance of weeds. He viewed the then imminent weed-free cropping environment as technically possible given appropriate economic conditions. Today it is an environment which is defined not necessarily in the same literal sense, containment of weeds (as well as pests) to acceptable levels being the desirable goal rather than eradication (Huffaker et al. 1978; Attwood, 1980). These issues remain central to weed science and weed management today for they focus directly on the objectives of integrated management practices, the design of weed control strategies and decision making. In different ways they have been addressed by many authors. For example Fryer and Chancellor (1970) have assessed the interspecific response in the weed flora to changing husbandry practice as have Way and Cammell (1981) for invertebrate pests. Moreover intraspecific change, both ecological and evolutionary, is evident in weed populations (Putwain et al 1982) whilst economic and technological constraints demand careful long term planning (Jarvis, 1981).

Forecasting techniques in weed management systems therefore can be applied at three levels - the weed community, the species population and individuals within populations. They may also be made at strategic and tactical levels, the distinction being one of temporal scale. Strategic forecasting looks to long term prediction of weed infestations, whilst tactical forecasting applies to events within a cropping season. This review examines the current status of techniques for forecasting weed infestations and their effects, and the research needs for their development. The definition of a weed is limited to a plant interfering with those grown for food production.

THE OBJECTIVES OF WEED CONTROL - THE EQUATION OF COST-BENEFIT

The declared aim of crop protection is the maximisation of desirable biological production for the least costs - in essence a process of optimisation subject to both internal and external constraints (Norton and Conway, 1977). Southwood and Norton (1973) have argued that the underlying objective of insect pest control is to maximise the cost–benefit relationship $Y[A(S)].\ P[A(S)] - C(S)$. As a conceptual tool it is equally applicable to weed control, describing the interface between the concerns of population ecology and economics. The control function, $A(S)$, is the weed infestation resulting from a strategy of control (S). It determines through the damage functions of quantity (crop yield), $Y[A(S)]$ and quality (price) $P[A(S)]$ the value of the crop which is produced for the cost $C(S)$ of the control strategy.

Working in financial units it becomes an equation of cost-effectiveness.

Discerning the components of crop damage, the causal agents and measuring their effects is more readily achieved for crops which require whole plant destruction at harvest and are grown as monocultures. At the opposite end of the spectrum (Snaydon, 1980), in rangelands and grassland pastures the transition between trophic levels makes evaluation complex. Weeds in these agroecosystems may have lethal effects on the production units with considerable financial penalties (Nielsen, 1978) but the effect of non-toxic indigenous species on livestock production is a matter of debate (Snaydon, 1978). It is pertinent therefore on both methodological and conceptual grounds to differentiate forecasting techniques that relate to homogeneous cropping systems on the one hand against those appropriate to heterogeneous ones.

HOMOGENEOUS CROPPING SYSTEMS

Homogeneous cropping systems are characterised by uniformity of crop species, defined planting arrangements and resource additions to maximise yield. Crops with annual life cycles typify such systems but so do perennial tree and shrub crops in which the range of influence of weeds may be just as great (Atkinson and White, 1981).

In achieving the broad objective of weed control - cost-effective crop yield maximisation - the dimensions of weed infestations that are of crucial importance in crop monocultures are

1) the size of the biological reservoir from which the weed infestation is recruited;
2) the size, duration, distribution and density, and timing of occurrence of the actual weed infestation and the effects on crop yield; and
3) weed infestation rate.

Concerns with 1) and 3) are strategic and with 2) tactical.

Within a cropping cycle (planting, growth and harvest) damage to the crop occurs through loss of yield and a lowering of harvesting efficiency (quantity damage components) and by determining the price of the crop (quality damage). Table 1 illustrates the easily envisaged relationships for a cereal crop. The nature of this damage to the 'current' crop will depend on the components of yield that are harvested and their response to interference from weeds. The occurrence of damage to 'future' cropping will in return relate to quantity damage components - reflecting in fitness parameters (survivorship and fecundity) of weed species. Where weed control is practised, frequently the above-ground injurious plant community is a poor reflection of its dormant reserves below ground. Disregarding economic considerations, the heart of forecasting rests therefore on descriptions of the population dynamics of weed species. It is an area that has not been seriously worked.

Table 1. Causes and relationships in the damage function for weed infestations in a cereal crop. See text for further details.

	Cropping cycle	
Damage	Current	Future
Quantity (Causes of crop yield loss)	1. Competition for resources for growth. 2. Predation from animal pests and pathogens migrating from host weeds. 3. Harvest inefficiency. 4. Application of control measures.	1. Contamination by reproductive propagules. 2. Survival of adult plants. 3. Maintenance of hosts for pests and pathogens.
Quality (causes of commodity price loss)	Grain and straw contamination.	

POPULATION MODELS

The primary aim of modelling is the prediction of quantity damage components. Rates of change in weed population size (and hence future potential damage) and yield loss (damage to the current crop) due to competition for limiting resources are the most important factors.

Rate of change

A variety of difference equations have been proposed for monocarpic species with discrete generations involving density dependent and independent regulation. The magnitude of regulatory components during the life cycle has been measured for some grass weeds using essentially equation 1, Table 2 (Cussans and Moss, 1982). This focusses on gains and losses to the seed bank, which if seed recruitment is excluded decays in an exponential manner (equation 2, Table 2), decay rates being determined by management practice (Roberts and Feast, 1973). Equation 3 illustrates the expansion for inclusion of cohorts and a seed bank (Manlove et al. 1982). To incorporate density dependent effects recognises mortality and fecundity as functions of plant density and equation 4 describes the relationship between seed bearing plants for species with discrete generations and no bank of persistent seeds (Watkinson, 1980).

Perennial weed populations which display overlapping generations and semelparity are most conveniently handled by difference equations in matrix form, $A_{t+1} = T A_t$ where the vector A describes the population structure at t and t+1 and T the transitions between elements of the population. The dominant latent root of T gives the finite rate of increase of the population. This methodology is well researched (Usher, 1972; Caswell and Werner, 1977) and the work of Sarukhan and Gadgil (1974) and Law (1975) provide illuminating examples of their utility to

Table 2. Some difference equations used in the description of weed populations. Terms remain consistent amongst equations subject to indicated constraints. See text for details.

1. A general equation ignoring density dependence

$$S_{t+1} = S_t (1-g)(1-n) + S_t g e F$$

- S_t, S_{t+1} - seed population at times t, t+1
- g - proportion of seeds germinating, $0 \leq g \leq 1$
- n - proportion of seeds dieing, if not germinating, $0 \leq n \leq 1, g + n \leq 1$.
- e - proportion of seedlings that survive to seed set
- F - mean seed production per plant

2. Dynamics of a seed population where gains from seed production are zero.

$$S_{t+1} = S_t \exp(-d\,T)$$

d - decay constant

T - time span from t to t+1

3. An equation incorporating cohorts and a seed bank.

$$S_{t+1} = S_t \sum^{z} K_i\, p_i\, F_i + S_t h . \qquad 1 \geq \sum^{z} K_i + h$$

- z - no of time periods in a growing season (cohorts)
- i - i'th time period of growing season
- K_i - proportion of seeds germinating in i'th time period
- p_i - proportion of plants in the i'th cohort that survive to maturity
- F_i - mean seed fecundity of individuals of the i'th cohort
- h - proportion of seeds surviving, if not germinating

4. A difference equation incorporating density dependence

$$N_{t+1} = S_{max} N_t ((1 + a N_t)^b + m S_{max} N_t)^{-1} q$$

- N_t, N_{t+1} - seed bearing-plant population at times t, t + 1
- a^{-1} - density of plants at which mutual interference amongst individuals becomes appreciable
- b - the efficiency of resource utilisation
- q - density independent mortality $0 \leq q \leq 1$
- m - the reciprocal of the asymptotic value of N_{t+1} as $N_t \rightarrow \infty$
- S_{max} - seed production per plant in an unrestricted environment

plant population dynamics and the usage of secular transition matrices and density dependent regulatory functions. Perennial species present particular problems to demographers since there are important ecological distinctions between populations described by age as opposed to stage (Gatsuk et al. 1980). This is especially true in the prediction of weed infestations since the targets of chemical control measures are more often defined according to physiological stage rather than absolute age. Hubble and Werner (1979) give a method of measuring rates of increase of populations with heterogeneous life histories and Law (pers comm) has shown that the dynamics of a population classified simultaneously by age and stage can be considered as an extension of standard population theory.

Yield loss

Functions describing the relationship between yield at harvest and weed infestation density have been examined extensively by weed scientists in an empirical manner (e.g. Dew, 1972). Watkinson (1980) in extending the work of Bleasdale and Nelder (1960) has shown that in crop monocultures mean yield per plant, $\bar{w}$ may be described by the function,

$$\bar{w} = W_m (1 + a N)^{-b}.$$

W_m is the mean yield of isolated plants grown in an unrestricted environment, a is the area giving resources to achieve growth to W_m, b is the efficiency with which resources are utilised and N is surviving plant density. W_m and a are time (season) dependent. When b = 1 yield per unit area becomes constant at high N and the law of constant final yield is observed. This model may be extended to describe the impact of a weed species on crop yield to give

$$\bar{w} = W_m (1 + a (N + \alpha N_w))^{-b} \qquad .5$$

in which N_w is the density of weed species at crop harvest and α represents the intensity of interference by the weed or the equivalence value of an individual weed plant to a crop plant (Watkinson, 1981). This equation has equal relevance in predicting weed biomass which may interfere with harvesting.

THE UTILITY OF MODELS

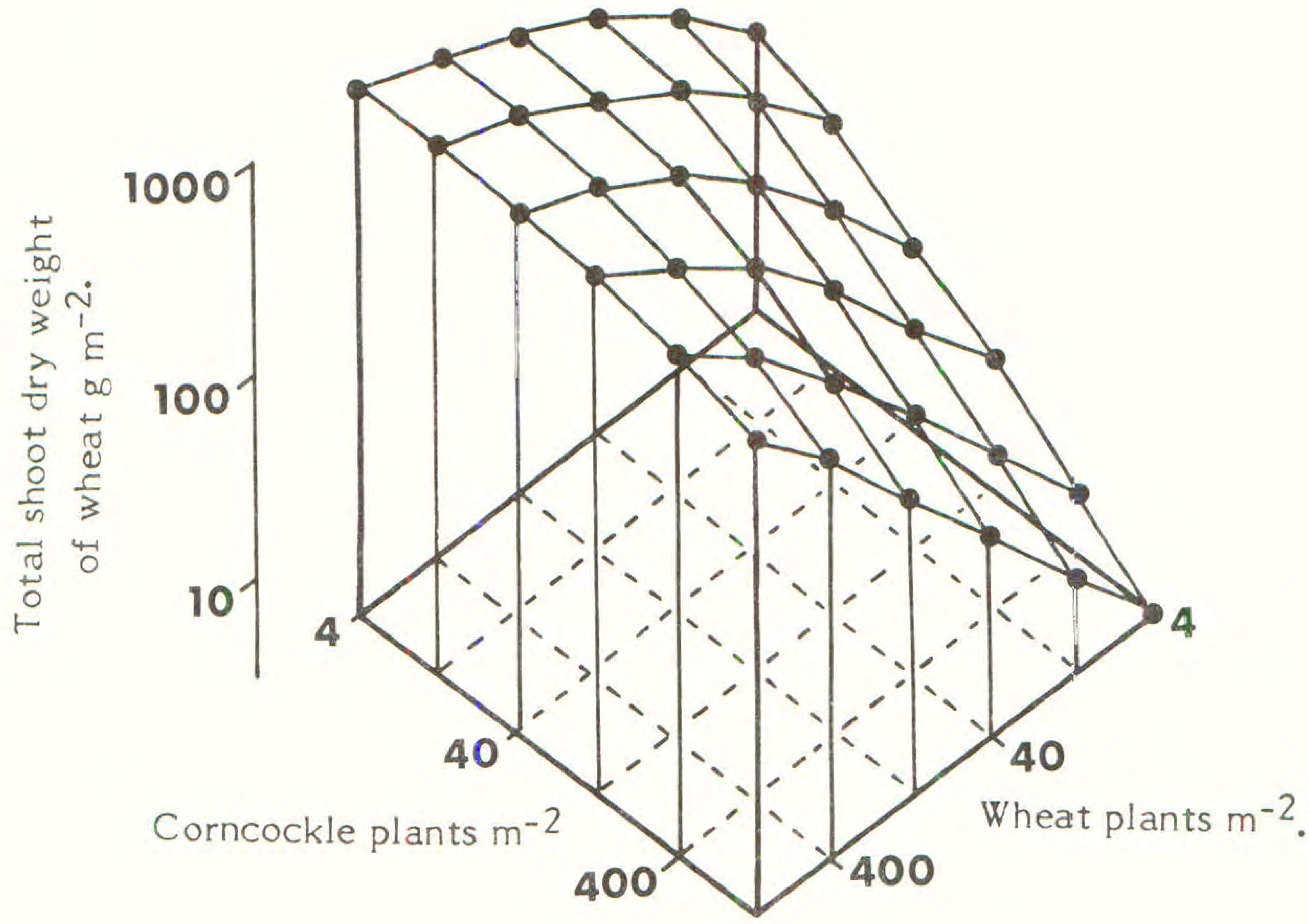
The application of the models outlined above have led to initial attempts by simulation to explore the consequences of alternative management policies and also provide a means for assessing competition.

Following equation 5, Fig. 1 (Firbank, unpublished) illustrates yield interrelationships between spring wheat and corncockle and its application as a tool for strategic assessment of competitive interactions. It is strategic in the sense that it relates weed and crop density at harvest to crop yield. Moreover it demonstrates the reciprocity of interspecific competitive effects. The greatest crop yield loss per weed plant occurs at the lower densities of weed infestation since at the higher densities of Agrostemma intraspecific interference becomes of increasing and disproportionate importance. Scragg and McKelvie (1976) have documented similar findings for Avena fatua. There is clearly no threshold density of Agrostemma required to cause loss of yield, but a continuum of effect - whilst there is a threshold density required to ensure noticeable yield loss. The model obviously has utility in assessing the comparative outcome of two-species interactions for prescribed environmental circumstances and for making comparative assessments of competitive ability amongst crop cultivars.

Preliminary attempts to predict weed infestation rates have been made by Manlove et al, (1982) and Cussans and Moss (1982) ignoring density dependent regulation of seed production and plant survivorship. Inclusion of this demographically important concept has not been attempted to date and the paucity of available data and the reluctance of weed scientists to examine crop-weed interactions at high weed infestation densities precludes any generalisation. Yet in homogeneous cropping systems with high inputs of resources for crop growth, intra and interspecific density dependent regulation of weed fecundity rather than survivorship may be of greatest importance. McMahon (1982) has demonstrated the intensity to which this may occur in rhizome bud production in Elymus (Agropyron) repens and Manlove et al. (1982) have confirmed the nature of the response for Avena fatua in Triticum aestivum. An important adjunct to considerations of density dependent phenomena in the light of forecasting is the morphological unit in the plant population that must be assessed. In Elymus repens shoot complexes (tillers arising from orthotropic rhizome apices) appear more responsive recipients of density-mediated stress than easily observable tillers (Mortimer and McMahon, unpublished). This same consideration is of importance when using models to explore the dynamical properties of weed populations and the sensitivity of rates of change to alteration of flux within elements of the population. Mortimer (1983) for instance employed 'adults' (sensu shoot complexes) in a sensitivity analysis for a population of E. repens experiencing minimal tillage.

The methods discussed above provide vehicles which in general are not appropriate for

Fig. 1 The influence of weed and crop density on crop yield. The graph shows the model of equation 5 (see text) fitted to data from a field experiment in which spring wheat (cv Sicco) and corncockle (Agrostemma githago) were planted simultaneously. The competition coefficient, α, for the effect of A. githago on wheat was 1.63 and for wheat on A. githago was 0.41. All scales are logarithmic.



tactical forecasting procedures. The requirement here is the ability to be able to predict the short term trajectories of populations in relation to functional driving variables (notably climate and fertilisers) and their response to control practices (chemicals) within the wider context of damage functions. Orwick et al.(1978) have approached the former using continuous simulation procedures. However the literature reveals a dearth of information needed to predict the relative contributions to damage components that individuals in a weed population make. It is possible however to make some notional qualitative statements on the lines proposed by Elliott (1982). By example, for a monocarpic weed species with a stage distributed population in an annual cropping system, individuals at a similar or greater stage than the crop are likely to cause disproportionate damage in terms of crop yield loss in comparison to smaller (later emerging or suppressed) members of the weed infestation. Conversely these individuals may make the largest contribution to inefficiency at crop harvest (Elliott, 1980) being delayed in maturity and in consequence comprising proportionally the bulk of living biomass at harvest to interfere with harvesting operations. Discriminatory control procedures against weeds may also interact with their age or stage distribution. Those individuals which by virtue of appropriate size and physiological stage of development become the targets of control, may protect suppressed individuals in a hierarchy who are released only with the demise of those elements of the population conspicuous to the control measure. Contributions to future damage may also be distributed disproportionately according to age-state. The act of harvesting may prohibit late developing individuals from dispersing reproductive propagules to the ground through death or removal with the crop at harvest.

Whilst some proposals exist for predicting the outcome after selective removal of components of a weed infestation (Lefkovitch, 1967, Mortimer, 1983), the nature and magnitude of compensating processes in the survivor population of weeds and in the crop through competitive release have not been substantially investigated. A part exception to this are the studies of critical periods of competition (Roberts, 1976) but this empirical approach, subsuming differences in weed flora, belies the understanding of competitive interactions that may occur. Firstly the act of weed removal may or may not release resources for crop utilisation. Secondly, if weed removal becomes substantially delayed crop recovery can never be complete either because of insufficient time left in the growing season or because yield components have been already determined or because of resource exhaustion. In some crops there is therefore an ideal period of weed removal invariably site and season specific, beginning before the critical time for full compensation and ending when crop growth is sufficiently well developed that later recruits to the weed infestation cause no yield loss. This period is not however a critical period of competition - competition begins when plants are at growth stages sufficient to interfere with one another in the process of resource capture and ends only in death or removal of plants or when resources are no longer limiting growth.

The methodologies outlined so far are applicable to single species and are most pertinent to persistent weeds in otherwise clean crop monocultures. Expression in stochastic form leads naturally to risk analysis. Furthermore their extension to distinction between genotypes within populations is a logical application to analysis of mixures of susceptible and resistant individuals to herbicides (see Gressel and Segel, 1982).

HETEROGENEOUS CROPPING SYSTEMS - GRASSLAND AND RANGELAND

Weeds in pastures and rangelands fall into two categories - those which are toxic or physically harmful and those which are neither but indigenous to the agroecosystem. The former represent a group amenable to single species analysis as discussed above. For the latter however, the chain of relationship - prehension, palatability, digestibility and conversion efficiency - between plant biomass on offer and herbivore weight on 'hoof' represents considerable complexity. It has not been fully considered for indigenous weed (?) species (Snaydon, 1978). Whilst 'grazing' models are well established (Van Dyne and Abramsky, 1975), analytical methods (Noy-Meir, 1975) are still in a juvenile state. Sufficient data now exist to emphasize that the flux of individual plants in grassland pastures and their neighbour relations are of crucial importance (Turkington and Harper, 1982). This dynamic nature of populations in heterogeneous crops that show long term compositional stability has much to do with localised spatial heterogeneity and environmental variance (Harper, 1978). It is only with descriptions of patchiness that the door to forecasting with precision will begin to open for these systems.

FUTURE NEEDS AND CONCLUSIONS

A common assertion of 'pest' ecologists is that additional data is needed for successful forecasting. This is undoubtedly true for the prediction of weed infestations and their control. Yet amassment of demographic data is an expensive process and must be conducted towards rigorously defined objectives. These are defined importantly by end-user requirements and economic considerations. Shoemaker (1977) has pointed to the weakness of taking strategic models (sensu Table 2) and using them to seek cost effective solutions. But the 'bottom-up' approach discussed here represents the important first step towards forecasting in weed science. Until the realised niche of weed species (Mortimer, 1983) is described and the likelihood of phenological and evolutionary change under alternative management practices assessed, crop production will be vulnerable to adventive species - new or old weeds! One of our future concerns must be with the population ecology of weeds.

Another future concern must be the development of tactical forecasting methods. The location of weed infestations in a crop may be observed from previous growing seasons and future ones predicted with some certainty, as short-distance dispersal of reproductive propagules tends to be the rule. "Size of inoculum" may be measured by soil sampling. Whilst this starts to define action thresholds and gives justification to prophylactic control, translation of the inoculum into injurious plant communities is at present a poorly forecastable event (but see Roberts and Ricketts, 1979). We lack Bayesian probability matrices for decision making purposes based on a fundamental understanding of competitive interactions when components of the total plant community are differentially selected against by chemical control. It is here that forecasting weeds has common meteorological ground with other pests. The ability to predict spray days on the one hand and subsequent allometric change in growth of plant parts as a consequence of weed suppression by spraying on the other, are central to developing a rationale to integrating herbicide use with the intrinsic biological control of weeds by crop competition (see Hawton, 1980). This is the central and formidable challenge to forecasting and the assessment of therapeutic control methods for the containment of weed infestations. We must be equally concerned with crop yield and weed yield to future infestation potential.

A last concern comes with putting theory into practice. It would seem wise to wait a little on 'theoretical' gestation before attempting practical implementation even bearing in mind the pressing needs of current circumstances.

ACKNOWLEDGMENTS

Several of the ideas given here are re-expressions of thoughts presented by AMM at a conference in centennial commemoration of Darwin's death at UNAME, Mexico in 1982 under the title "Population ecology and weed science". We are also grateful for valuable discussion with Roy Snaydon, Philip Putwain and Glen Sampson.

REFERENCES

ATKINSON, D. & WHITE, G.C. (1981). The effects of weeds and weed control on temperate fruit orchards and their environment. In Pests Pathogens and Vegetation. Thresh J.M. (Ed.) AAB Pitman pp 415-428.

ATTWOOD, P.J. (1980). Strategic planning for weed control : eradication or containment - an advisors view. Proceedings (1980) British Crop Protection Conference - Weeds, 3, 833-838.

BLEASDALE, J.K.A. & NELDER, J.A. (1960). Plant population and crop yield. Nature, 188, 342.

CASWELL H. & WERNER, P.A. (1977). Transient behaviour and life history analysis of Teasel (Dipsacus sylvestris Huds.). Ecology, 59, 53-66.

CROFT, B.A., HOWES, J.L. & WELCH, S.M. (1976). A computer based extension pest management delivery system. Environmental Entomology, 5, 20-34.

CUSSANS, G.W. & MOSS, S.R. (1982). Population dynamics of annual grass weeds. In Decision making in the practice of crop protection. Austin R.B. (Ed.) Croydon BCPC pp 91-98.

DEW, D.A. (1972). An index of competition for estimating crop loss due to weeds. Canadian Journal of Plant Science, 52, 921-927.

ELLIOTT, J.G. (1980). The economic significance of weeds in the harvesting of grain. Proceedings (1980) British Crop Protection Conference - Weeds, 3, 787-797.

ELLIOTT, J.G. (1982). Weed control in cereals - strategy and tactics. In Decision making in the practice of crop protection. R.B. Austin (Ed.), Croydon BCPC, pp 115-119.

FRYER, J.D. & CHANCELLOR, R.J. (1970). Evidence of changing weed populations in arable land. Proceedings (1970) British Weed Control Conference, 3, 958-964.

GATSUK, L.E., SMIRNOVA, O.V., VORONTZOVA, L.I., ZAUGOLNOVA, L.B. & ZHUKOVA, L.A. (1980). Age states of plants of various growth forms : a review. Journal of Ecology, 68, 675-696.

GRESSEL, J. & SEGEL, L.A. (1982). Interrelating factors controlling the rate of appearance of resistance : possible reasons and implications. In Herbicide Resistance in Plants. Lebaron, H.M. & Gressel, J. (Eds.), Wiley pp 325-348.

HARPER, J.L. (1978). Plant relations in pastures. In Plant relations in pastures. J.R. Wilson (Ed.) CSIRO, pp 3-16.

HASSELL, M.P. (1982). What is searching efficiency? Annals of Applied Biology, 101, 170-175.

HAWTON, D. (1980). Yield effects of herbicides on competition between crop and weed communities. Australian Journal of Agricultural Research, 31, 1075-1081.

HUBBLE, S.P. & WERNER, P.A. (1979). On measuring the intrinsic rate of increase of populations with heterogeneous life histories. American Naturalist, 113, 277-293.

HUFFAKER, C.B., SHOEMAKER, C.A. & GUTIERREZ, A.P. (1978). Current status, urgent needs, and future prospects of integrated pest management. In Pest Control Strategies. Smith, E.H. & Pimentel, D. (Eds.) Academic Press, pp 237-259

JARVIS R. (1981). The integrated effect of herbicides and cultural methods on grass weed control at Boxworth E.H.F. In Grass Weeds in Cereals in the U.K., AAB Reading, pp 367-376.

LAW, R. (1975). Colonisation and the evolution of life histories in Poa annua. Ph.D., University of Liverpool, 211pp.

LEFKOVITCH, L.P., (1967). A theoretical evaluation of population growth after removing individuals from some age groups. Bulletin of Entomological Research, 57, 437-445.

McMAHON, D.J. (1982). The population dynamics of Agropyron repens (L.) Beauv. Ph.D. thesis, University of Liverpool, pp 94.

MANLOVE, R.J., MORTIMER, A.M. & PUTWAIN, P.D. (1982). Modelling wild oat populations and their control. Proceedings (1982) British Crop Protection Conference - Weeds 2, 749-756.

MORTIMER, A.M. (1983). On weed demography. In Recent advances in weed research. Fletcher, W.W. (Ed.). In press.

NIELSEN, D.B. (1978). The economic impact of poisonous plants on the range of livestock injury in the 17 western states of U.S.A. Journal of Range Management, 31, 325-328.

NORTON, G.A. & CONWAY, G.R. (1977). The economic and social context of pest, disease and weed problems. In Origin of Pest, Parasite, Disease and Weed Problems. Cherrett, J.M. & Sagar, G.R. (Eds.), Blackwells, pp 205-226.

NOY-MEIR, I. (1975). Stability of grazing systems : an application of predator-prey graphs. Journal of Ecology, 63, 459-481.

ORWICK, P.L., SCHREIBER, M.M. & HOLT, D.A. (1978). Simulation of foxtail (Setaria viridis) growth : the development of Setsim. Weed Science, 26, 691-699.

PUTWAIN, P.D., SCOTT, K.R. & HOLLIDAY, R.J. (1982). The nature of resistance to triazine herbicides : case studies of phenology and population studies. In Herbicide Resistance in Plants, Lebaron, H.M. & Gressel, J. (Eds.), Wiley, pp 99-116.

ROBERTS, H.A. (1976). Weed competition in vegetable crops. Annals of Applied Biology, 83, 321-324.

ROBERTS, H.A. & FEAST, P.M. (1973). Changes in the numbers of viable weed seeds in soil under different regimes. Weed Research, 13, 298-303.

ROBERTS, H.A. & RICKETTS, M.E. (1979). Quantitative relationships between the weed flora after cultivation and the seed population in the soil. Weed Research, 19, 269-275.

SAGAR, G.R. (1968). Weed biology - A future. Netherlands Journal of Agricultural Science, 16, 155-164.

SARUKAHN, J & GADGIL, M. (1974). Studies on plant demography : Ranunculus repens L., R. bulbosus L. and R. acris L. III. A mathematical model incorporating multiple modes of reproduction. Journal of Ecology, 62, 921-936.

SCRAGG, E.B. & McKELVIE, A.D. (1976). The effect of certain species of weeds on the grain yield of spring barley. Annals of Applied Biology, 83, 335-338.

SHOEMAKER, C.A. (1977). Pest management models of crop ecosystems. In Ecosystem modelling in theory and practice. Hall, C.A.S. & Day, J.W. (Eds.), Wiley, pp 545-574.

SNAYDON, R.W. (1978). Indigenous species in perspective. Proceedings (1978) British Crop Protection Conference - Weeds, 3, 905-914.

SNAYDON, R.W. (1980). Plant demography in agricultural systems. In Demography and Evolution in Plant Populations. Solbrig, O.T. (Ed.), Botanical Monog., 15, Blackwells, pp 131-160.

SOUTHWOOD, T.R.E. & NORTON, G.A. (1973). Economic aspects of pest management strategies and decision. In Insects : Studies in Pest Management. Ed, Geier, P. et al. (Eds.). Memoirs of Ecological Society of Australia, Canberra, pp 168-184.

TURKINGTON, R. & HARPER, J.L. (1982). The growth, distribution and neighbour relationships of Trifolium repens in a permanent pasture. IV. Fine scale biotic differentiation. Journal of Ecology. 67, 245-254

USHER, M.B. (1972). Developments in the Leslie matrix model. In Mathematical models in Ecology. Jeffers, J. N. (Ed.). British Ecological Society Symposium, 12, Blackwells, pp 29-60.

VAN DYNE, G. & ABRAMSKY, Z (1975). Agricultural systems models and modelling : An overview. In Study of Agricultural Systems, Dalton, G.E. (Ed.) Applied Science Publishers, pp 23-105.

WAGGONER, P.E. & HORSFALL, J.G. (1969). Epidem, a simulator of plant disease written for a computer. Conneticut Agricultural Experimental Station Bulletin No. 698.

WAY, M.J. & CAMMELL, M.E. (1981). Effects of weeds and weed control on invertebrate pest ecology. In Pests, Pathogens and Vegetation. Thresh, J.M. (Ed.), AAB Pitman, pp 443-458.

WATKINSON, A.R. (1980). Density-dependence in single-species populations of plants. Journal of Theoretical Biology, 83, 345-357.

WATKINSON, A.R. (1981). Interference in pure and mixed populations of Agrostemma githago. Journal of Applied Ecology, 18, 967-976.

1B—S4

INTEGRATING ECONOMIC ANALYSIS WITH POPULATION MODELLING IN PEST MANAGEMENT PROBLEMS

CHRISTINE A. SHOEMAKER

Department of Environmental Engineering, Cornell University, Ithaca, N.Y. 14853 U.S.A.

ABSTRACT

This paper reviews the various types of models created to aid in the development of pest management programs. Studies are categorized by their purpose and by the techniques used in their construction and computation.

INTRODUCTION

Developing effective pest management programs depends not only upon understanding pest population dynamics but also upon being able to evaluate the economic impact of various management policies. Mathematical models have been an important tool in this endeavor. Management models are an attempt to describe the crop ecosystem in sufficient detail so that the impact of alternative management strategies can be evaluated. Building upon our understanding of the fundamental ecological and physiological processes involved, models can be used to estimate what will occur if environmental conditions or management decisions vary from those for which empirical field data is available. Since it is not economically or physically feasible to test for every possible weather and management condition, models are an important tool in evaluating the likelihood of success of a range of management alternatives under a range of environmental conditions. Models can be used to screen for the best alternatives for each set of environmental conditions. Those policies selected by the screening procedure can then be the focus of field experimentation. Hence models do not replace the need for field and laboratory experiments -- instead they are a procedure by which we can increase the amount of information obtained from empirical studies.

There are a number of different types of management models developed to answer different questions. Factors distinguishing models include their scale of application (e.g., single field versus a region or entire country), the degree of economic and biological detail incorporated, the techniques used (e.g., simulation, optimization or mathematical analysis) and whether randomness in variables is incorporated (e.g., deterministic versus stochastic models).

STUDIES FOCUSING ON ECONOMIC ANALYSIS RATHER THAN ON POPULATION DYNAMICS

Some of the models developed to assess pest management alternatives have had little or no description of pest population dynamics either because the information was not available or because it is not computationally possible to incorporate given the scale of the problem. For example, models which attempt to evaluate economic impacts of pest management on a regional or country-wide scale usually cannot incorporate a detailed description of pest dynamics. Pimentel and Shoemaker (1974) used an econometric model to evaluate the impact of changes in pest management practices on the spatial distribution of crop production throughout the United States. This study was later expanded to include a wider range of integrated pest management practices including scouting, diapause control, plant variety and trap cropping (Pimentel et al. 1979). The model utilized a linear programming formulation in which the decision variables are the number of acres planted in each crop in each geographic location. Changes in pest management cause changes in production costs and in yields which in turn change the optimal location for growing crops.

To incorporate the impact of quantity produced on the price, it is necessary to utilize a nonlinear optimization procedure. Rovinsky et al. (1980) developed an optimization procedure which could be used for this kind of a problem. Rovinsky and Shoemaker (1981) applied it to an analysis of the effect of changes in pest management practices on cotton production throughout the United States.

Even for problems on the farm level, it is possible to develop a useful economic model of pest management without a detailed description of pest dynamics. Carlson

(1970) and Norton (1976) both used decision analysis to determine the best procedures for management of disease pests, relying upon a predetermined probability distribution of the likelihood of disease severity. They did not attempt to model the dynamics of the disease populations because information was not available to develop such a model. Shoemaker et al. (1979) utilized a similar approach to consider the management of a complex of disease and insect pests with a combination of cultural, biological and chemical control methods.

The work of both Carlson and Norton evaluated the impact of a farmer's aversion to risk on his decisions. Feder (1979) extended this type of analysis to consider the general pest management problem. He showed that more pesticide will be used if it reduces variability in yields and incomes. Although he did not consider a specific pest population, his approach is mathematically general enough to apply to a range of population models including those which are quite detailed.

DETAILED SIMULATION MODELS OF PEST ECOSYSTEMS

In contrast to the economic models discussed above, there have been a large number of simulation models developed which have very detailed descriptions of the population dynamics of the pest ecosystem. Such models typically include variables to describe the number of individuals in each pest age class and the amount of biomass stored in leaves, stems, fruit and roots. Ruesink (1976a) gives an extensive review of such models. More recent work, like Reichelderfer and Bender (1979), combines a detailed population model with a more complete economic analysis. For example, Wedberg et al. (1977) used a simulation model to determine economic thresholds for Hypera postica. With the simulation model they were able to develop thresholds which depend upon crop height as well as on pest density. These thresholds have been incorporated into extension recommendations made in Illinois. Troester and Ruesink (1982) developed an interactive version of their simulation model of Agrotis ipsilon to enable farmers to evaluate the alternative control strategies based upon information relevant to their local conditions of weather and pest infestation level.

The effect of pest damage on crop quality can have a substantial impact on the economics of pest management. Onstad and Shoemaker (1983) utilize a simulation model which describes the dynamics of alfalfa weevil and alfalfa growth to predict the impact of pest damage and management strategies (insecticide applications and harvest timing) on alfalfa quality and quantity. Since alfalfa in Northeastern United States is consumed primarily on the farm where it was grown, it was necessary to utilize a separate model to compute economic value of the crop as a function of its tonnage and quality. Their analysis indicated that alfalfa should be harvested earlier than is currently the general practice. With an early harvest, weevil populations should not require an insecticide treatment for most weather patterns, even when initial population densities are quite high.

Choristoneura fumiferana has been the focus of several intensive modelling efforts. The simulation models developed by Jones (1979) and Stedinger (1977) differ from those discussed above in several respects: they describe population dynamics over a large region, they consider very long time periods (about one hundred years), and they include a random number generator to describe stochastic variation in weather patterns. The reasons for these differences are intrinsic to the differences between chronic agricultural pests and epidemic forest pests. The forests experience spruce budworm outbreaks only about once every forty years. When outbreaks do occur they tend to spread by migration over large areas, and management decisions are usually made at a state or provincial level. Because of the scale of this pest management problem, the Jones model has been expanded to include an analysis of the effects of alternative management practices on a range of socio-economic variables including income and unemployment (Holling, 1978).

PHENOLOGY MODELS

Rather than publish an entire simulation model of an ecosystem, it is more common for subcomponents of ecosystem models to be reported. Components include models describing factors such as oviposition, predator-prey interactions or phenology.

In recent years, much more emphasis has been placed on the development of phenology models for pest management. Phenology models attempt to predict the occurrance of events (usually different life stages) without attempting to predict density. Hence, they differ from more complicated simulation models in that they do not consider mortality factors affecting the pest population nor do they consider the dynamics of the crop or natural enemy populations. The advantage of phenology models is that because they are simpler and do not include hard-to-measure factors like mortality, they are easier to construct and have a higher rate of success than do their more complicated cousins. Phenology models are useful in helping to determine the best timing for control actions, especially applications of microbial or chemical pesticides.

A major concern in phenological modelling is how to incorporate variability in development rates among individuals. Welch et al. (1978), deWit and Goudriaan (1978) and Ruesink (1976b) utilize procedures by which the number of age classes in the computer model is manipulated to achieve the desired level of variability. The fewer the age classes, the greater is the variability simulated by the model. A different approach is used by Kempton (1979), Birley (1977) and Osawa et al. (in press), who use procedures which incorporate variability by mathematically describing the form of the probability distribution function. In this way the number of age classes can be chosen more naturally, usually to represent the number of stages which can be observed in experiments. The procedures of Kempton (1979) and Osawa et al. (in press) also differ from earlier studies in that they use maximum likelihood procedures to estimate directly from field data the parameter values which give the best fit to the whole data set considering all life stages simultaneously. The procedure of Osawa et al. has been expanded by Stedinger et al. (1983) to estimate phenology based on samples with spatial correlation. This procedure was applied to data on C. fumiferana development. Shoemaker et al. (in preparation) have also used this data to demonstrate the use of Kalman filtering to update and improve phenology model estimates as monitoring data becomes available during the growing season.

STATISTICAL MODELS OF REGIONAL POPULATION DYNAMICS

Most detailed population models used in management are based upon data collected in a few locations. It is very seldom that adequate data is available to validate a detailed population model over a large region. In order to be certain that the major processes incorporated in detailed management models are correct over a wide area, it is advisable to try to do some exploratory data analysis on the regional information available. Studies by Fleming et al. (in press, a and b) are examples of this type of an approach. Using six years of C. fumiferana data taken from hundreds of sites in Maine, they studied the impact of egg densities, defoliation and insecticide spraying in one year on egg densities and defoliation in the subsequent year. The results in some cases conflicted with generally held theories about this insect. For example, neither high population density nor insecticide applications appear to be as effective in reducing population growth as had been conjectured. Current work (Fleming and Shoemaker, in preparation) indicates that two of the simulation models developed to describe the spruce budworm ecosystem do not appear to be able to qualitatively mimic the regional Maine data.

OPTIMIZATION MODELS

Another approach to the analysis of pest management is the use of optimization methods. These procedures have the advantage that they select the optimal policy without evaluating every possible alternative management strategy. With simulation methods it is necessary to recompute the model for every different alternative considered. For example, if we want to consider whether or not an insecticide should be applied at each of eight time periods, there are a total of 2^8 or 256 different alternatives. This is very expensive in computer time. An optimization method can be used to find the most economical alaternative without exhaustive evaluation of every alternative.

There are a wide variety of optimization techniques available. The optimization technique most widely used in economic applications is linear programming. Unfortunately, pest population management problems are usually nonlinear because the effect of the decision variable (e.g., pesticide) usually needs to be represented by a function involving the product of the decision variable and the state variable (e.g., the pest density). Shoemaker (1973) used a nonlinear optimization method, dynamic programming, to evaluate the management of a predator-prey system in which the insecticide killed some of the predators as well as the pest. Regev et al. (1976) used a reduced gradient optimization method to consider the management of alfalfa weevel. Their analysis included a simple but dynamic description of both the pest and crop.

Optimization methods have limitations, and frequently it is necessary to simplify the biological model in order to facilitate the use of an optimization model. For example, the model by Regev et al. contained only three age classes and the 1973 model by Shoemaker contained only one age class. A later paper by Shoemaker (1979) developed a method by which a much larger number of age classes could be incorporated into a dynamic programming model. Talpaz et al. (1978) utilized a nonlinear optimization procedure to compute the best policy for managing cotton boll weevil. The optimization procedure worked in conjunction with a detailed simulation model of cotton and boll weevil population dynamics.

All of the optimization models discussed above have been deterministic. Because of the importance of random events like weather it is important to incorporate this uncertainty into models used in management. Dynamic programming is the only optimization method which can both incorporate the uncertainty associated with random events and can correctly recommend decisions based on observations taken during the decision process. For example, in a study by Shoemaker and Onstad (1983) the weather in the future is not assumed to be known exactly. Instead several weather patterns are possible and there is a specified probability distribution for each (Shoemaker, 1982). However, information about the weather patterns and pest densities is incorporated into the model recommendations as this information becomes available. The model utilizes stochastic dynamic programming and considers biological control by a parasite and cultural control by early harvesting as well as pesticide control. In another application of dynamic programming, Shoemaker (in press) extends the earlier 1979 paper to incorporate the effects of stochastic events like rainfall on pesticide toxicity.

ACKNOWLEDGMENTS

Confronted with the dilema of a very broad topic and a short page limit, I have chosen to focus this review on the research with which I am most familiar, namely that done by myself, my students and close colleagues. Although the references indicate the contributions made by each individual, I would like to give special thanks to David Onstad, Jery Stedinger, Richard Fleming, and Robert Rovinsky for their contributions to our co-operative research. There are a number of excellent related studies which I have not been able to include in this short review. Interested readers can find references to related work in the papers already cited and in reviews by Feldman and Curry (1982), Conway (1977) and Shoemaker (1981).

REFERENCES

Birley, M.H. (1977) The estimation of insect density and instar survivorship functions from census data. J. Anim. Ecol. 46:497-510.

Carlson, Gerald A. (1970) A decision-theoretic approach to crop disease prediction and control. Amer. J. of Agri. Econ. 52(2):216-223.

Conway, Gordon R. (1977) Mathematical models in applied ecology. Nature 269:291-297.

deWit, C.T. and J. Goudriaan (1978) Simulation of Ecological Processes. John Wiley and Sons, New York.

Feder, G. (1979) Pesticides, information and pest management under uncertainty. Amer. J. Ag. Econ. 61:97-103.

Feldman, R.M. and Guy L. Curry (1982) Operations research for agricultural pest management. Oper. Res. 30:601-618.

Fleming, R.A. and C. A. Shoemaker (in preparation) Validation of spruce budworm models using regional Maine data.

Fleming, R.A., C.A. Shoemaker and J.R. Stedinger (in press a) A statistical analysis of regional dynamics of unsprayed spruce budworm (Lepidoptera: Tortricidae) populations. Environmental Entomology.

Fleming, R.A., C.A. Shoemaker and J.R. Stedinger (in press b) Assessment of the impact of large-scale spraying operations on the regional dynamics of spruce budworm populations. Canadian Entomologist.

Holling, C.A. (ed.) (1978) Adapative Environmental Assessment and Management, John Wiley & Sons.

Jones, D.D. (1979) The budworm site model, in Pest Management, G. A. Horton and C. S. Holling, Eds. Oxford, England: Pergamon.

Kempton, R.A. (1979) Statistical analysis of frequency data obtained from sampling an insect population grouped by stages. In Statistical Distributions in Ecological Work. J.K. Ord, G.P. Patil and C. Taille (eds.) pp. 401-418. International Co-operative Publishing House, Fairland, MD.

Norton, G.A. (1976) Analysis of decision making in crop protection. Agro-Ecosystems 3:27-44.

Onstad, D.W. and C.A. Shoemaker (1983) Management of alfalfa and the alfalfa weevil (Hypera postica Gyll.): An example of systems analysis in forage production. Technical Report. School of Civil & Environmental Engineering, Cornell University, Ithaca, N.Y.

Osawa, A., C.A. Shoemaker and J.R. Stedinger (in press) A stochastic model of balsam fir development and its use in spruce budworm control. Forest Science.

Pimentel, D., C.A. Shoemaker, E.L. La Due, R.B. Rovinsky and N.P. Russell (1979) Alternatives for reducing insecticides on cotton and corn: Economic and environmental impact. Environmental Protection Agency, EPA-600/5-79-007a, August.

Pimentel, D.P. and C.A. Shoemaker (1974) An economic, and land use model for reducing insecticides on cotton and corn. Environ. Ent. 3:10-20.

Regev, U., A.P. Gutierrez, and G. Feder (1976) Pests as a common property resouce: A case study of alfalfa weevil and control. Amer. J. Agr. Econ. 58:188-196.

Reichelderfer, K.H. and F.E. Bender (1979) Application of a simulative approach to evaluating alternative methods for the control of agricultural pests. Amer. J. Agr. Econ. 61:258-267.

Rovinsky, R.B. and C.A. Shoemaker (1980) The optimal distribution of crop production under differing levels of farmer cooperation: An example using cotton. In Operations Research in Agriculture and Water Resources, D. Yaron and C. Tapiero (eds.), pp. 217-247, John Wiley & Sons, Inc.

Rovinsky, R. and C.A. Shoemaker (1981) Operations research: Applications in agriculture, in Operations Research: Mathematical Models, A. Goldman (ed.), American Mathematics Society.

Rovinsky, R.B., C.A. Shoemaker, M. and M.J. Todd (1980) Determining optimal use of resources among regional producers under differing levels of cooperation. Operations Research 28:859-866.

Ruesink, W.G. (1976a) Status of the systems approach to pest management. Annu. Rev. Entomol. 21:27-44.

Ruesink, W.G. (1976b) Modeling of pest populations in the alfalfa ecosystem with special reference to the alfalfa weevil, in Modelling for Pest Management, R. L. Tummala, D. L. Haynes, and B. A. Croft, Eds., Michigan State Univ. Press.

Shoemaker, C.A. (1973) Optimization of agricultural pest management III: Results and extensions of a model. Math. Biosci. 18:1-22.

Shoemaker, C.A. (1979) Optimal timing of multiple applications of pesticides with residual toxicity. Biometrics 35:803-813.

Shoemaker, C.A. (1981) Applications of dynamic programming and other optimization methods in pest management. IEEE Trans. Automatic Control 26:1125-1132.

Shoemaker, C.A. (1982) Optimal integrated control of univoltine pest populations with age structure. Operations Res. 30:40-61.

Shoemaker, C.A., C.B. Huffaker and C.B. Kennett (1979) A systems approach to the integrated management of a complex of olive pests. Envir. Ento. 8:182-189.

Shoemaker, C.A., and D. Onstad (1983) An optimization analysis of the integration of biological, cultural and chemical control of alfalfa weevil. Envir. Ent. 12:286-295.

Shoemaker, C.A. (in press) Deterministic and stochastic analyses of the optimal timing of multiple applications of pesticides with residual activity. In Pest and Pathogen Control: Strategy, Tactics and Policy Models, G. R. Conway (ed.), Wiley-Interscience Pubs., Chichester.

Shoemaker, C.A., J.R. Stedinger and E. Clinger (in preparation) Use of a Kalman filter for predicting insect phenology.

Stedinger, J.R. (1977) Spruce budworm management models, Ph.D. dissertation, Div. of Eng. & Appl. Phys., Harvard Univ.

Stedinger, J.R., C.A. Shoemaker and R.F. Tenga (1983) A stochastic model of insect phenology for a population with spatially variable development rates. Technical Report, School of Civil & Environmental Engineering, Cornell University, Ithaca.

Talpaz, H. et al. (1978) Optimal pesticide application for controlling the boll weevil on cotton. Amer. J. Agr. Econ. 60:469-475.

Troester, S.J. and W.G. Ruesink (1982) Avoiding black cutworm (Lepidoptera: Noctuidae) losses in corn through education: Evaluation of a grower oriented manual/computer model instructional package. Bull. of Ent. Soc. Amer. 28:349-353.

Wedberg, J.L., W.G. Ruesink, E.J. Armbrust, and D.P. Bartell (1977) Alfalfa weevil pest management program. University of Illinois Coop. Ext. Serv. Circ. 1136.

Welch, S.M., B.A. Croft, J.F. Brunner and M.F. Michels (1978) PETE: An extension phenology modeling system for management of multi-species pest complex. Environ. Entomol. 7:482-494.

PHEROMONE MONITORING OF THE PEA MOTH, CYDIA NIGRICANA (F)

A.J. BIDDLE[1], J. BLOOD-SMYTH[2], J. COCHRANE[3], B. EMMETT[4], D.G. GARTHWAITE[5], J.C. GRAHAM[6], A.R. GREENWAY[5], T. LEWIS[5], E.D.M. MACAULAY[5], J.N. PERRY[5], M.C. SMITH[5], D.M. STURGEON[5], C. WALL[5]

1 Processors and Growers Research Organisation, Thornhaugh, Peterborough, U.K.

2 Ministry of Agriculture, Fisheries and Food, A.D.A.S., Cambridge, U.K.

3 Meteorological Office, A.D.A.S., Cambridge, U.K.

4 Ministry of Agriculture, Fisheries and Food, A.D.A.S., Leeds, U.K.

5 Rothamsted Experimental Station, Harpenden, Hertfordshire, U.K.

6 Department of Pure and Applied Biology, Imperial College, London, U.K.

Background and objectives

Dry harvest peas for human consumption or seed in the U.K. were valued at £19.5 M in 1982. Peas damaged by the pea moth must be removed as waste at harvest; penalties represent a loss of 1 - 1.5% of the gross value per 1% damage. To be effective, insecticidal sprays must be timed to kill newly hatched larvae before they enter pods; the critical period varies from year to year and field to field. The objective of this work was to produce a monitoring system, operated by the farmer, to determine when moths migrate into individual fields and, thereby, the first date to spray for optimal control.

Materials and Methods

Two sticky traps, each containing 3 mg E-10-dodecen-1-yl acetate (an analogue of the moth's natural pheromone), are placed in each pea field. Traps are examined every two days. When 10 or more moths are caught in either trap on two consecutive occasions, calculations are started for egg development rates to predict first larval hatch. These calculations are done either by the farmer (using local temperature records and a simple calculator), or by computer at A.D.A.S. Cambridge, using data from the Met. Office. Farmers can obtain a spray date prediction based on their trap records and the computer model, by telephoning a pre-recorded tape at A.D.A.S., Cambridge or P.G.R.O.

Results and conclusions

Approximately 40% of dry harvest pea growers in the main U.K. pea area (East Anglia) used the traps in 1982. The traps are cheap, simple to use, species specific and can be used in individual fields to provide local warnings of attack. Specialist interpretation of trap catches is available through a 'phone-in' service provided jointly by A.D.A.S. and P.G.R.O. Some growers run traps but do not use the 'phone-in' service whilst others 'phone-in' without running traps - this must be discouraged.

References

Perry, J.N.; Macaulay, E.D.M.; Emmett, B. (1981) Phenological and geographical relationships between catches of pea moth. Annals of Applied Biology 97, 17-26.

Wall, C.; Greenway, A.R. (1981) An effective lure for use in pheromone monitoring traps for the pea moth, *Cydia nigricana* (F.). Plant Pathology 30, 73-76.

1B—R4

POPULATIONS OF SITONA LINEATUS L. ON FIELD BEANS

N. HAMON

The Hatfield Polytechnic, College Lane, Hatfield, Hertfordshire, England

R. BARDNER

Rothamsted Experimental Station, Harpenden, Hertfordshire, AL5 2JQ, England

Almost all crops of field beans (Vicia faba L.) in Britain are infested by the Pea and Bean Weevil, Sitona lineatus. The pest has one generation a year, adults invading the crop in spring, mainly by flight. They can be found on foliage throughout most of the summer, although overwintered adults are most abundant in May and June. Their feeding results in the characteristic U-shaped notches in the edges of leaves. Each female lays several hundred eggs and on hatching the larvae infest and destroy the nitrogen-fixing root nodules, populations of larvae being highest about the time of pod set. After pupation in the soil the new generation of adults emerges in the late summer and feeds on a variety of leguminous crops and weeds before winter quiescence.

Controlling Sitona larvae will increase the yields of beans, but insecticides which control both adults and larvae are more effective, and recent simulation experiments suggest that feeding by adults may also cause yield loss. A correlation has been established between the numbers of larvae per root of spring-sown beans and subsequent effects on yield. Average populations of larvae are likely to be associated with losses of about 0.5 t ha^{-1}.

The flight activity of adults can be monitored by suction traps of the Rothamsted Insect Survey, but this information is of limited use in predicting the risk of attack. Flight can occur throughout April and May, and by the end of May large numbers of eggs have often been laid, but it is then too late to apply insecticides. Another complication is the large numbers of eggs laid. Mortality of eggs and young larvae is very high, competition for root nodules being intense.

Adult numbers on bean plants are greater the earlier the sowing and fewer the more dense the crop. There are indications that they are also positively related to field size and the intensity of pea and bean growing within a district, although adults seem to have little difficulty in locating isolated crops. Up to 62% of adults can be parasitized by the braconid Dinocarpus rutilus Nees but this is only after most eggs have been laid. Predation of adults by Carabids is low in the spring, but can account for 12% of newly emerged adults in the summer.

Larval numbers are positively related to the amount of root nodulation, but negatively to plant density. Predation and parasitism of larvae and pupae seem unimportant.

Although it is not practical to define economic threshold levels in terms of the number of adults invading bean crops it is possible to define crops whose yields are most likely to be decreased by attacks.

References

Bardner, R.; Fletcher, K.E.; Griffiths, D.C.; Hamon, N.C. (1982) Sitona lineatus on faba beans in Britain. Fabis 4, 48-50.

Bardner, R.; Fletcher, K.E.; Griffiths, D.C. (1983) Chemical control of the pea and bean weevil, Sitona lineatus L., and subsequent effects in the yield of field beans, Vicia faba L. Journal of Agricultural Science, Canbridge (in press)

A MODEL FOR THE IMPACT OF SOYBEAN MOSAIC VIRUS IN SOYBEAN

W. G. RUESINK, M. E. IRWIN

University of Illinois, Urbana, Illinois, U.S.A., and Illinois Natural History Survey, Champaign, Illinois, U.S.A.

Background and objectives

Soybean mosaic virus (SMV) occurs wherever soybeans are grown. It is transmitted through soybean seed and, under field conditions, by aphids. SMV is already a serious production problem in some parts of the world and could become serious in others if and when factors favor its early-season spread (Irwin & Schultz 1981). These factors are primarily the density of aphid vectors early in the season and high levels of infection in the seed sown. We sought a method of forecasting the impact of SMV on yield and on seed transmission that would work in most of the soybean producing regions of the world.

The model

A dynamic simulation model of SMV was written in Fortran. It uses observed daily aphid landings, soybean planting date and soybean varietal characteristics as inputs. Harvest time outputs are percentage yield reduction and percentage infected seed; daily outputs include percentage infected plants and percentage source plants.

Aphid landings are measured using horizontal green pan traps at canopy height. The model calculates a daily "vector intensity" by weighting the catch for each genus of aphid by its efficiency as a vector then summing over all genera. Two crop phenology parameters are required: days from planting until the plant is no longer susceptible to infection, and days from planting to leaf senescence. Yield reduction and percentage of harvested seed carrying virus are computed on a plant by plant basis, with both of these being determined solely by the age of the plant at the time it becomes infected.

The model assumes that immigrant aphids do not bring virus into fields and that aphids do not reproduce on soybeans.

Results and conclusions

Model accuracy was evaluated using 1982 data from 4 states plus 3 years of Illinois data. In most cases forecasted levels of infection and yield reduction were within 20% of the observed, but less accuracy was obtained on forecasts of seed transmission levels. The shape of the observed disease progress curve always agreed closely with the forecast.

The model predicts that geographic regions that regularily have very low vector intensities early in the season can safely tolerate planting seed that is up to 1% infected with SMV. In these regions the level of seed infection will decline year after year, eventually reaching very low levels. Regions with high vector intensities will experience major yield losses if more than 1 seed in 10,000 is infected. These latter regions cannot safely produce their own seed, because virus levels will increase year after year, regardless of initial levels. Regions that have years of low vector intensity intermixed with years of high vector intensity will experience occasional outbreaks of SMV unless precautions are taken to insure that relatively clean seed is planted every year.

If aphid landing rate information is obtained for several years from a region, and if immigrants are virus free and do not colonize soybeans, this model can be used to compute the safe level of infection in planted seed.

Reference

Irwin, M. E.; Schultz, G. A. (1981) Soybean mosaic cirus. FAO Plant Protection Bulletin 29, 41-55.

1B—R6

POSSIBILITIES OF FORECASTING PRIMARY INFECTION OF POTATO LATE BLIGHT

I. CUPSA[1], V. IGNAT[2], G. PAMFIL[1]

[1]Research Potato Institute, Brasov [2]Agricultural Faculty, Bucharest, Rumania.

Background and objectives

The prophylactic protection of the potato crop against late blight (Phytophthora infestans) is necessary even if post-infectional fungicides are used. An economic preventive control strategy could be implemented if the occurrence of primary inoculum from infected seed tubers could correctly be predicted. Several authors, e.g. Hirst & Stedman, 1960, and recently Easton, 1982, referring to arid central Washington State, have argued for forecasting this real start of the epidemic. Current forecasting methods make assumptions about this initial stage without actually taking it into account. Our work partially fills this gap.

Materials and Methods

16,352 artificially infected tubers were planed in Brasov (540 m altitude) in 1969-82, and 4,910 tubers in Slobozia M (90 m) in 1974-82. The occurrence and incidence of primarily infected plants were correlated with climatic conditions and soil properties in order to detect possible determinants/predictors. For data processing a stepwise discriminant analysis and simple polynomial/multiple regression analysis were used.

Results and conclusions

The factors allowing possibilities of yes or no occurrence of PI (primary infection) to be significantly distinguished are soil temperature and precipitation in Brasov but only the latter in Slobozia M. The variation of PI incidence, between 0.69 - 11.25% in Brasov, was governed by precipitation and also influenced somewhat by soil clay content. The occurrence of PI was influenced by the time of planting: the first appearance of PI varied from 27-29 days in Brasov, and was dependent mainly on soil temperature, and from 40-77 days in Slobozia M, when it was influenced both by soil temperature and precipitation. Based on these relationships, descriptive and predictive mathematical models have been constructed. A preliminary model for the prediction of PI occurrence has a standard error of estimation of 8.3 days in Brasov and 5.5 in Slobozia M.

References

Hirst, J.M.; Stedman, O.J. (1960) The epidemiology of Phytophthora infestans. II The source of inoculum. Annals of Applied Biology 48, 489-517.

Easton, G.D. (1982) Late blight of potatoes and prediction of epidemics in arid central Washington State. Plant Disease 66, 452-455.

BIONOMICS AND SAMPLING METHODS FOR THE NORTHERN CORN ROOTWORM IN QUEBEC.

W. N. YULE, C.R. DOMINIQUE, M.A. MATIN

Macdonald College of McGill University, Ste. Anne de Bellevue, Quebec, Canada

Background and objectives

The Northern corn rootworm (NCR), Diabrotica longicornis (Say)(Coleoptera: Chrysomelidae) is a recently-arrived pest of corn in Quebec , where its establishment is being encouraged by the modern practice of growing continuous monocultures of corn. It has been known for a much longer time as a very serious pest in the corn belt states of mid-west U.S.A., and in S. Ontario. The larval stages cause most of the direct damage to corn plants by eating the roots, but adults may also reduce grain yields by eating the ear silks at pollination time and affecting seed development . As a basis for scientific management of this potential pest, and in order to develop local economic threshold, population prediction, and control decision data for this recently-invaded area, basic studies on bionomics and sampling methods for the various stages of this pest have been made over the past four years.

Materials and Methods

Observations and measurements of life cycle stages and habits were made in commercial corn fields in S. Quebec, experimental field plots, and on caged populations in glasshouse and laboratory cultures. Sampling methods for the various stages of the pest were developed with field populations using standard ecological and statistical techniques ; practical conclusions and recommendations for sampling procedures were formulated, and a partial life table and information on population dynamics of the species under Quebec conditions were developed from the results of these studies.

Results and Conclusions

The threshold temperature for development of NCR eggs was estimated at 9.7°C. The mean thermal constant for first hatching in the laboratory was 326 degree days above 9.7°C. Eclosion occurred in the field when average soil temperature conditions at the 5 - 10 cm depth reached 331 - 334 degree days. Pupation occurred in the soil from late June to early July. Adults emerged from mid-July to August, and oviposition occurred during the same period. Oviposition preferences of NCR beetles were studied in relation to local soil types, soil moisture, and soil surface conditions, both in the laboratory and in the field under free choice conditions. In both cases, a clear preference was shown for moist, cracked, clay soil. The behaviour of adults held under controlled environmental conditions (12L:12D diel light 23 ± 2°C temperature, 60 - 80 per cent RH) was investigated, and emergence, locomotor activity and sexual behaviour were recorded. The duration of larval stages reared in the laboratory on natural diets were compared with those for field-collected larvae. Natural enemies and mortality factors for the species were investigated in the field. A simple method for rearing NCR in the laboratory was developed.

Horizontal distribution of NCR eggs around plants was random in three Quebec cornfields. Vertically, 72% and 24% eggs occurred in the surface 10 cm soil before and after fall plowing, respectively. A 5 x10 cm x 15 cm (deep) sampling unit was appropriate for estimating egg populations before plowing. Thereafter, 20 cm depth was needed. Larvae and pupae were concentrated around the root system and a soil quadrat 20 x 20 cm x 10 cm (deep) was an easily reproducible sampling unit. Direct counting on corn plants in early morning was the most efficient method for adult sampling. Sample sizes for all stages were calculated for different precision levels. Spatial distributions of eggs and larval field populations were contagious, and a stratified random sampling is appropriate for density estimation. Spatial distribution of adults changed with corn phenology. Average mortality of overwintering eggs was 66% and of spring larvae 89%. The field population density of beetles did not change significantly during 1979-82.

References

Guibord, M.O'C. (1976) La chrysomele des racine du maïs, Diabrotica longicornis (Say) (Coleoptera: Chrysomelidae), au Québec. Ann. Sociétié Entomologique du Québec 21(1): 49-51.

Chiang, H.C. (1973) Bionomics of the northern and western corn rootworms. Annual Review of Entomology 18: 47-72.

Southwood, T.R.E. (1978) Ecological methods with particular reference to the study of insect populations. 2nd edition. ELBS and Chapman and Hall, England. 524 pp.

1B—R8

ROTHAMSTED INSECT SURVEY CEREAL APHID MONITORING SCHEME - "RISCAMS"

A.M. DEWAR

Rothamsted Experimental Station, Harpenden, Hertfordshire, AL5 2JQ, England

Background and objectives

The Rothamsted Insect Survey (RIS) suction traps give early warning of cereal aphid migration and arrival into crops. Subsequent development of aphid populations on cereals is strongly correlated with later trap catches in some years, e.g. 1979, when their development in different fields was synchronised. In other years, however, correlations between trap catches and field populations are more diffuse due to large differences in aphid population development between fields, e.g. in 1980 and 1981. RISCAMS was designed to investigate the extent of the variation in aphid populations between fields within and between different regions in the country, and to identify factors which contribute to that variation, thus enabling more accurate and discretionary interpretation of RIS trap data in the future.

Materials and Methods

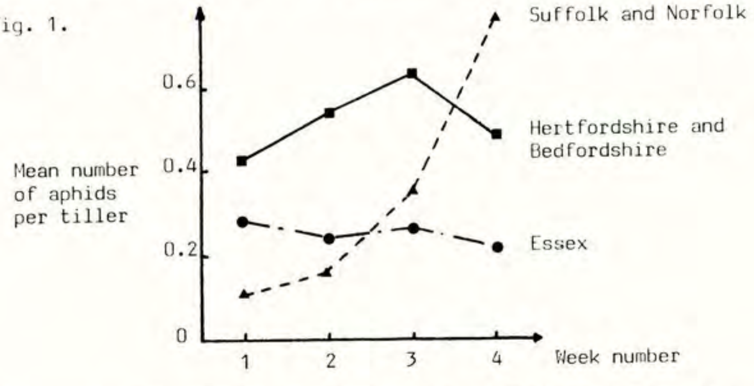
In 1982, a total of one hundred wheat fields, comprising 37 fields in Hertfordshire and Bedfordshire, 30 in Suffolk and Norfolk, and 33 in Essex, were sampled weekly for four weeks in June. All the fields lay within a 35 km radius of the RIS suction traps at Rothamsted, Brooms Barn and Writtle respectively. Crops were monitored by three non-entomologists trained in aphid identification, sampling procedures and data recording at Rothamsted. Aphid numbers were estimated using Rabbinge's method of counting the proportion of tillers infested with aphids, and converting this to actual density using established regression equations. Records were also taken of the cultural and chemical history and the topography of each field to investigate the effect of various agricultural practices on aphid abundance. Observations of the more common natural enemies, such as coccinellids, syrphids and lacewings, mummies and diseased aphids were also noted.

Results and conclusions

Aphid numbers were generally low in all three regions in 1982. Both *Sitobion avenae* and *Metopolophium dirhodum* were present in approximately equal numbers, but their populations never rose above two per shoot in any of the fields examined due largely to the activities of natural enemies, especially syrphid and lacewing larvae. The only factor to have a significant effect on aphid numbers was the use of insecticides, which, although unnecessary, were usually applied as part of a spraying programme irrespective of aphid density. In unsprayed fields there were small differences between regions, which changed through the sampling period. In the beginning of June there were more aphids on average in Hertfordshire and Bedfordshire than in either Essex or East Anglia, but, by the end of June, numbers in the latter region had increased to almost 0.8 aphids per shoot, while populations in the other two regions remained approximately constant throughout (Fig. 1).

The variation between fields within a region in 1982 was slight, but may be greater in other years when natural enemies are less abundant. Predators reduced variation by preying on the densest populations, thus masking the effects of other agricultural practices such as sowing date or variety. This first year of RISCAMS showed that large scale sampling was feasible and it will be expanded to other regions in future years.

Fig. 1.



Reference

Rabbinge, R.; Ankersmit, G.W.; Carter, N.; Mantel, W.P. (1980) Epidemics and damage effects of cereal aphids in the Netherlands. *Bulletin SROP/IOBC III/4*, 99-106.

FORECASTING OUTBREAKS OF THE GRAIN APHID

N. CARTER, A.M. DEWAR

Rothamsted Experimental Station, Harpenden, Hertfordshire, AL5 2JQ, England

Background and objectives

Outbreaks of grain aphid, Sitobion avenae, occur sporadically depending on interactions between (i) the timing and number of alate immigrants entering a crop, (ii) weather during and after immigration and (iii) the abundance of natural enemies. The effects of adverse weather such as heavy rain on aphid population development have not been quantified but more information is available on natural enemies and aphid immigration. This paper describes an attempt to simulate and quantify interactions between aphids and their natural enemies with the long-term aim of predicting in which years the latter are likely to prevent aphid outbreaks.

Materials and Methods

Aphid and predator numbers per square metre were estimated from samples taken in wheat fields at Rothamsted from 1978-1982, and at Norwich in 1976, 77 and 78 and were used to validate a simulation model. At Rothamsted samples were collected using a vacuum sampler when aphid densities were less than one per tiller and direct visual counts made at higher densities (Dewar, et al. 1982); at Norwich visual counting was used exclusively.

The simulation model was initiated by the first field sample with aphids present and updated by subsequent immigration, as measured by suction traps, until the end of flowering. The expected daily logistic population growth of S. avenae was calculated, with temperature as the main driving variable, though the effect of the developmental stage of the crop on the aphids was also considered. The rates of increase at the minimum, maximum and mean temperatures were calculated and the average of these three rates was used in the model. The developmental stage of the crop was updated using a two-factor polynomial equation with day degrees, above a threshold temperature of 6°C, as the independent variable. Predation rate was calculated from the observed numbers of predators in the field and their consumption rates measured at various temperatures in the laboratory.

Simulations were made using data from several years to show examples of (i) low numbers of immigrants resulting in no outbreak (1978) (ii) high numbers of immigrants leading to an outbreak (1977) and (iii) high numbers of immigrants failing to produce an outbreak (1980).

Results and discussion

The predicted population growth curves were similar to the observed field situations for all three examples indicating that, with knowledge of the numbers of aphids migrating into the crops and the effects of natural enemies, the model gives a reasonable description of the population dynamics of S. avenae.

Both the timing and, to a limited extent, the size of the spring migration of this species as measured by suction traps can be predicted from the weather, especially temperature, during the winter, with mild conditions encouraging early migrations of many alates and vice versa. However, while late migrations of few aphids never result in an outbreak, the converse is not always true and to predict outbreaks following large early migrations good estimates of the potential for natural enemies to control aphids below the economic threshold are needed early in the season. Unfortunately no practical method of estimating this potential is yet available, and current research is directed towards this end.

References

Carter, N.; Dixon, A.F.G.; Rabbinge, R. (1982) Cereal aphid populations; biology, simulation and prediction. Wageningen, The Netherlands, Pudoc, pp. 94.

Dewar, A.M.; Dean, G.J.; Cannon, R. (1982) Assessment of methods for estimating the numbers of aphids (Hemiptera : Aphididae) in cereals. Bulletin of Entomological Research 72, 675-686.

Walters, K.F.A. (1982) Flight behaviour of cereal aphids. Unpubl. Ph.D. Thesis, University of East Anglia, Norwich.

1B—R10

FORECASTING OUTBREAKS OF THE GRAIN APHID SITOBION AVENAE IN EAST ANGLIA

K.F.A. WALTERS, S.J. WATSON, A.F.G. DIXON

School of Biological Sciences, University of East Anglia, Norwich. NR4 7TJ

Background and objectives

The grain aphid (*Sitobion avenae*) is a serious pest of cereals in England but its abundance varies from year to year. Cereals in East Anglia are colonized in spring when aphids fly from their overwintering sites and both the size and timing of this migration are important in determining the likelihood of a cereal aphid outbreak. Techniques have been developed for forecasting the size (Watson and Carter 1983) and the timing (Walters 1982) in East Anglia and this report describes recent attempts to combine the two methods into a single forecasting scheme.

Materials and methods

A simulation model of cereal aphid population dynamics (Carter *et al*. 1982) was used to quantify the effect of changing the time and the size of the colonization of cereal crops on the subsequent development of aphid populations. Initially, data collected during routine sampling of wheat fields in the Norwich area for the last eight years were used in the model. Subsequent simulations used either different initial crop developmental stages or different numbers of immigrant aphids. Population development after colonization is dependant on factors such as weather and natural enemies which are incorporated into the model.

Results and conclusions

As aphids have rarely been found to overwinter in cereal fields in the Norwich area, the results of this study (Fig. 1) indicate that it is possible to accurately forecast the

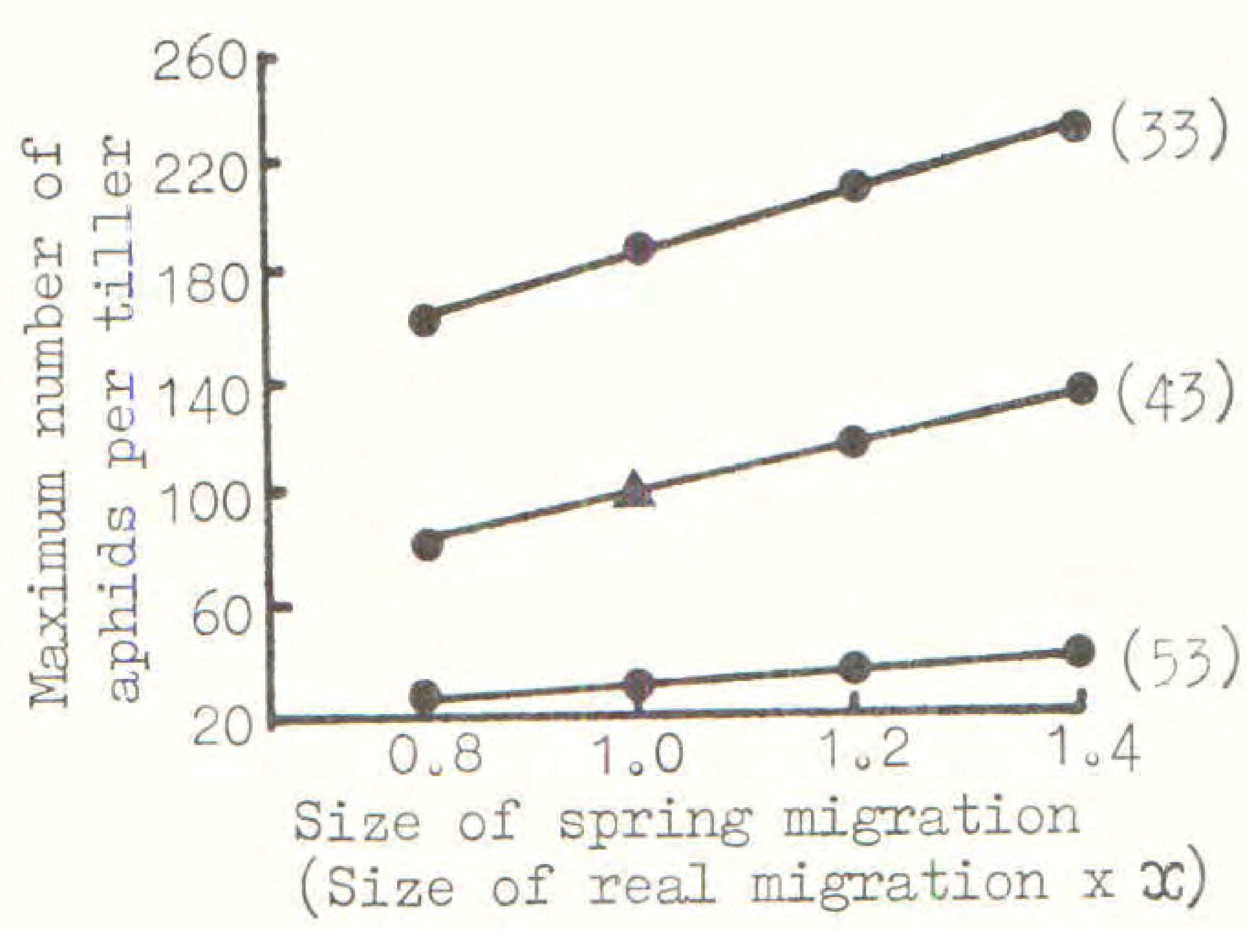


Fig. 1. The simulated effects on populations of *S.avenae* of changing the size and timing of the spring migration. Numbers in parentheses represent the crop developmental stage at which the migration occurred. ▲ = result of the simulation using the real size and real time of the migration.

likely outbreaks of *S.avenae* in the region, using data which is readily available. As our knowledge of the factors affecting the development of aphid populations on cereals improves it will be possible to identify the major variables with more certainty and this approach is currently being used in Norwich to develop and test the technique. In addition, when assessing the importance of other factors in determining outbreaks, the size and timing of the spring migration must be a central consideration.

References

Carter, N.; Dixon, A.F.G.; Rabbinge, R. (1982) Cereal aphid populations: biology, simulation and prediction. Simulation Monograph. PUDOC, The Netherlands.

Walters, K.F.A. (1982) Flight behaviour in cereal aphids. Unpublished PhD thesis, The University of East Anglia.

Watson, S.J.; Carter, N. (1983) Weather and modelling cereal aphid populations in Norfolk (UK). EPPO Bulletin 13 (2), 223-227.

THE INTERPRETATION AND DISSEMINATION OF APHID MONITORING DATA

G.M. TATCHELL, I.P. WOIWOD

Rothamsted Experimental Station, Harpenden, Hertfordshire, AL5 2JQ, England

Aphids are the most important group of pests in Britain causing both direct feeding damage and transmitting plant virus diseases. Annual crops are infested by alatae (winged aphids) flying in after emergence of the plants. These migrant aphids have been monitored continuously since 1968 by the network of up to 23 suction traps of the Rothamsted Insect Survey distributed throughout Britain sampling at a height of 12.2 m. Currently vertically looking radar with high-speed signal processing is being developed to monitor aphid density profiles to be used to supplement the suction trap samples.

Aphids from the English traps are identified to a tight weekly schedule at Rothamsted by a team of trained assistants using instant visual recognition and visual keys. Data are entered into an MSI/77 hand-held data logger using bar codes for speed and accuracy. The aphid data are down-loaded from the data logger onto a MIDAS 3HD 8-bit microcomputer where a suite of programs validates them and produces the 'Aphid Bulletin' (a table issued weekly with the numbers of 30 pest aphids recorded from each trap during the previous week).

For some species forecasts have been developed to predict the timing or the size of aphid infestations from suction trapping data. For example if five or more black bean aphids (Aphis fabae) are recorded in a trap by mid-June, spring-sown field beans (Vicia faba) in that area are likely to be damaged. Other examples are the timing of the start and finish of the migration of the damson-hop aphid (Phorodon humuli) from its winter hosts to hops (Humulus lupulus) which can be predicted from the preceding weather, and the risk of infection of winter-sown cereals planted on different dates by barley yellow dwarf virus which can be determined from the number of migrant vector aphids in the autumn in relation to the proportions transmitting the virus. Such forecasts are combined with information obtained by computer mapping and other rapid quantitative computer comparisons between the current situation and the historical data-base. These comparisons are made weekly for each of 10 regions of Britain for the 9 pest aphid species that infest cereals, potatoes, sugar beet, field beans, hops and apples. These comparisons and forecasts are combined in a second weekly report, the 'Aphid Commentary'.

The two weekly reports are sent by first class letter post to over 200 representatives of crop consultants, Agricultural Development and Advisory Service (ADAS), pesticide companies, and farmers. A survey of these people revealed that there is a secondary dissemination to about 100,000 individuals, especially in the arable areas of eastern Britain, through newsletters, farm visits, telephone information services, Prestel, the agricultural press and word of mouth.

The provision of such information from a large scale monitoring network is very cost effective and provides considerable benefit to British agriculture by determining the need for and timing of insecticide applications.

References

Tatchell, G.M. (1982) Aphid monitoring and forecasting as an aid to decision making. Proceedings 1982 British Crop Protection Symposium. Decision making in the practice of crop protection. Monograph No. 25, 99-112.

Taylor, L.R. (1973) Monitor surveying for migrant insect pests. Outlook on Agriculture 7, 109-116.

Taylor, L.R. (1979) The Rothamsted Insect Survey - an approach to the theory and practice of synoptic pest forecasting in agriculture. In: Movement of highly mobile insects: concepts and methodology in research R.L. Rabb and G.G. Kennedy (Eds), Raleigh, North Carolina, USA: North Carolina State University, pp. 148-185.

Woiwod, I.P. (1982) Computer mapping of Insect Survey data. In: Euraphid Gembloux 1982 J. Bernard (Ed), Brussels: Commission des Communautés Européennes, pp. 83-91.

1B—R12

DAMAGE THRESHOLDS IN THE FORECASTING OF BARLEY YELLOW DWARF VIRUS

D.A. KENDALL, B.D. SMITH

Long Ashton Research Station, University of Bristol, Long Ashton, Bristol, England

Background and objectives

Barley yellow dwarf virus (BYDV) is the most important virus disease of cereals affecting wheat, barley, oats, maize and most species of grass. In the U.K. the disease is usually carried to autumn-sown cereals in September to November by winged migrant aphids and subsequently spread to adjacent plants by their wingless progeny. Patches of infected plants show in fields in spring and early summer.

The spread of BYDV in autumn-sown crops can be controlled by correctly timed insecticide sprays in the autumn. However, the incidence of disease is irregular and differs between regions from year to year. To avoid unnecessary spraying a system is being devised to forecast infection risk. Part of this work has been to study the relationship between yield and disease incidence and so define a threshold above which control becomes economically worthwhile.

Materials and Methods

Data for winter barley and winter wheat have been obtained from a series of spray timing trials done at Long Ashton and elsewhere in S.W. England between 1978 and 1981. All experiments included 2 to 5 sowings at intervals from early September to mid-November. Treatments with demeton-s-methyl (244 g a.i./ha) or cypermethrin (25 g a.i./ha) were replicated within each sowing. BYDV infection was assessed in May-June by counting tillers showing symptoms in 1 m^2 sample areas. All plots were taken to yield. Only results from single sprays applied between late-October and mid-November have been used here, since treatments during this period gave the greatest yield increases (Kendall et al. 1983).

Results and conclusions

Yield increases from either insecticide treatment in winter barley correlated well with the amount of BYDV in untreated plots ($y = 0.70\ x + 1.61$, $r = 0.946$; where y is the yield increase calculated as a % of the unsprayed yield, and x is % tillers infected with BYDV). The intercept of this regression is not significantly different from zero so the relationship can be simplifield to $y = 0.73x$. This correlation has been revised from that reported earlier (Kendall & Smith 1981a) with the inclusion of more data.

A similar analysis for winter wheat indicates that BYDV infection is slightly less damaging ($y = 0.49x + 0.87$, $r = 0.791$; or simplified to intercept the origin $y = 0.53x$).

These regressions can be used to estimate the economic value of insecticide treatment, and hence a disease threshold where spraying becomes worthwhile. For example, assuming insecticide cost (including application) of £15/ha and average values for wheat and barley crops to be £600/ha and £500/ha respectively, then the minimum yield increases to offset insecticide cost would be about 2.5 and 3.0% respectively. Substituting these values in the above equations suggests that insecticide treatment becomes cost-effective when crop infection is $\ngtr$ 4% in barley and about 5% in wheat. Hence, a forecasting system for BYDV must aim to identify situations where crop infection is likely to exceed these thresholds. This becomes increasingly important as crops are sown earlier; in our experiments with sequential sowings BYDV infection has exceeded these thresholds in 11 out of 21 crops sown before mid-October, but has remained below in all 18 crops sown after mid-October.

Improvements in the forecasting of BYDV are expected to come from current work on aphid infectivity and dispersal, crop monitoring to predict local aphid population changes and virus spread, and from work on sources of aphids and virus (Kendall & Smith 1981b).

References

Kendall, D.A.; Smith, B.D.; Burchill, L.G.; & Chinn, N.E. (1983) Comparison of insecticides in relation to application date for the control of Barley Yellow Dwarf Virus in winter barley. Tests of Agrochemicals and Cultivars No 4 Annals of Applied Biology 102 Supplement 22-23.

Kendall, D.A.; Smith, B.D. (1981a) Yield benefit from autumn control of aphids and Barley Yellow Dwarf Virus on winter barley. Proceedings 1981 British Crop Protection Conference - Pests and Diseases 1 217-221

Kendall, D.A.; Smith, B.D. (1981b) The significance of aphid monitoring in improving Barley Yellow Dwarf Virus control. Proceedings 1981 British Crop Protection Conference - Pests and Diseases 2 399-403.

THE INFECTIVITY INDEX AND BARLEY YELLOW DWARF VIRUS

R. T. PLUMB

Rothamsted Experimental Station, Harpenden, Herts., AL5 2JQ, U.K.

Introduction

Aphid vectors of barley yellow dwarf virus (BYDV) are especially common in the suction trap catches of the Rothamsted Insect Survey in September and October. In consequence cereals sown in the autumn are exposed to these potential vectors for a time dependent upon crop sowing date and emergence. Counting aphids, either those caught in suction traps or those on crops, does not give a reliable forecast of the risk of virus infection because of differences and changes in aphid biology and, consequentially, behaviour in the autumn. To supplement data from the Rothamsted Insect Survey, which monitors the numbers of migrant aphids, the infectivity of aphids, i.e. those carrying BYDV and able to transmit it to host plants, has been determined at Rothamsted since 1969 and subsequently at the Welsh Plant Breeding Station (1970), Long Ashton Research Station (1976) and Shardlow (ADAS) (1982).

Materials and Methods

Aphids caught alive in a suction trap from 1 September to the end of the autumn migration early in November are identified and potential vectors of BYDV placed individually on test seedlings (1-leaf stage) of the oat cv. Blenda for a minimum of two days. Infected plants are identified by symptoms, which are confirmed by serology, 3-4 weeks later. The Infectivity Index (II) (Plumb et al. 1981) is calculated each week by multiplying the proportion of aphids of each species transmitting BYDV by the number of the appropriate species caught in the closest suction trap of the Rothamsted Insect Survey.

Results and Conclusions

Weekly calculation of the II takes account of three of the most important influences on crop infection by BYDV; aphid number, the proportion transmitting virus, and crop sowing date and emergence. The data can be displayed as a matrix, of the II each week against crop sowing date, which allows the determination of the II for any crop at anytime. At Rothamsted, experiments on time of sowing and autumn pesticide treatments have shown that significant increases in yield are only obtained when treated crops have an II of 50 or more. It is not known for what area the II obtained at any one site applies, however, it seems probable that regional forecasts will be required based upon local measurements of the II and the threshold value at which treatment is required. For the 1982/3 crops the maximum II at the four sites was Rothamsted (145), WPBS (0), Long Ashton (892) and Shardlow (1763).

The II is intended to be a guide to which crops will benefit from treatment and should be interpreted in the light of experience and by reference to crop infection and II for previous years. The scheme should allow more rational use of insecticides to control the vectors of BYDV thus minimising losses caused by the virus and ensuring that insecticides are used only when necessary. Evidence to date (Barrett et al. 1981; Kendall et al. 1982) suggests that the optimum time for treatment with insecticide is late October/early November. The present, direct feeding method of testing for infectivity gives the II for crops emerged up to the end of the first week in October by the end of this month. In our experience only rarely do crops sown, or emerged, after this date require treatment. Quicker methods of indirect, serological testing for infectivity may shorten the time required to obtain the Index but, so far, those tested have not proved sufficiently reliable to replace the existing procedure. However, indirect methods may be of value for other crops damaged by insect and especially aphid-transmitted viruses where counting vectors, either in traps or on the crop, does not give a reliable forecast of infection.

References

Barrett, D.W.A.; Northwood, P.J.; Horellou, A. (1981) The influence of rate and timing of autumn applied pyrethroid and carbamate insecticide sprays on the control of barley yellow dwarf virus in English and French winter cereals. Proceedings 1981 British Crop Protection Conference - Pests and Diseases 2, 405-412.

Kendall, D.A.; Smith, B.D.; Lyons, C.H.; Hazell, S.; Mathias, L.; Chinn, N.; Frape, C. (1982) Cereal aphids and spread of barley yellow dwarf virus (BYDV). Report of Long Ashton Research Station for 1980 pp. 128-132.

Plumb, R.T.; Lennon, E.A.; Gutteridge, R. (1981) Barley yellow dwarf virus. Report of Rothamsted Experimental Station for 1980, Part 1, 182.

1B—R14

FORECASTING BARLEY MILDEW DEVELOPMENT IN WEST SCOTLAND

A.G. CHANNON

The West of Scotland Agricultural College, Auchincruive, Ayr, Scotland.

Background and objectives

Mildew (*Erysiphe graminis* f.sp. *hordei*) is the most prevalent fungal disease of spring barley in West Scotland, but varies in severity from year to year. Golden Promise, the most widely grown variety in Scotland, is highly susceptible to mildew and can suffer severe attacks. Where the risk of mildew is high, treatment of the seed is recommended. Where the risk is lower, reliance may be placed on a fungicidal spray applied before escalation of the disease. A method of forecasting the likely development of mildew would help in deciding whether or not to spray (Channon, 1981).

Materials and methods

In 1973-79, sticky rod traps were placed in plots of untreated Golden Promise barley during May-July. On each rod the trapping surface was a cellophane strip with a sticky outer surface which could be peeled off and mounted on a microscope slide for spore counting. The trap rod was normally changed each day.

Disease development was assessed at intervals during the same period as percentage mildew cover on the top 3 leaves of sample plants.

Daily records from the College Climatological Station at 0900 GMT indicated when the levels of weather factors considered by Polley & King (1973) to favour mildew spore production were attained. The requisite daily levels were:-
(1) max. air temperature > 15.6°C, (2) sunshine > 5 hr, (3) rainfall < 1 mm, (4) run-of-wind > 246 km. Periods of high risk (Polley periods) as stated by Polley & Smith (1973), were identified and the incidence of these was compared with the 3-day running means of numbers of Polley factors satisfied and the numbers of mildew spores trapped. Daily relative humidity (R.H.) values at 0900 GMT were computed from wet and dry bulb thermometers at the weather station.

Results and conclusions

Mildew development varied considerably over the seven years. Whilst severe mildew developed in 1976, little disease occurred in 1975 and 1977. In the remaining years, mildew was moderate, with the disease building up late in the life of the crop in 1978 and 1979.

Although very few mildew spores were trapped in those years when mildew was very low (1975, 1977), there was no direct relationship between the concentration of spores detected and the amount of disease in the other years. There was, however, an indication that once mildew had begun to develop in the crops, the pattern of the 3-day running mean values of spores trapped and those of numbers of daily Polley factors satisfied, were similar. Furthermore, where a threshold value of 2.2 was placed upon the 3-day running mean of Polley factors satisfied, the length of the periods where this value was exceeded and the duration of high risk as defined by Polley & King, were very similar.

In each year, high risk periods occurred frequently and there was no indication that their occurrence invariably heralded upsurges of mildew. When, however, for each year the number of Polley factors satisfied was summed for those days when the R.H. at 0900 GMT was 78% or more during 15 May - 14 June, the accumulated values at the end of the period were later reflected in the relative severity of mildew developing in the plots in mid- to late July.

Thus the studies showed that by using Polley & King's criteria, modified by incorporation of the R.H. factor, it was possible during the period of stem extension growth to predict the likely severity of mildew in the crop a month or so later.

The success of this forecasting technique depends on the situation in the West of Scotland where mildew on spring barley does not generally start to develop until late May or early June. With the increasing popularity of winter barley, however, and the threat of early infection that it can pose to spring-sown crops, it is clear that due allowance will have to be made for such sources of infection in any forecasting system.

References

Channon, A.G. (1981) Forecasting barley mildew development in West Scotland Annals of applied Biology 97, 43-53.

Polley, R.W.; King, J.E. (1973) A preliminary proposal for the detection of barley mildew infection periods. Plant Pathology 22, 11-16.

Polley, R.W.; Smith, L.P. (1973) Barley mildew forecasting. Proceedings of the 7th British Insecticide and Fungicide Conference 2, 373-378.

A EUROPEAN APPROACH TO FORECASTING SEPTORIA IN WINTER WHEAT

D.J. ROYLE[1], R.J. COOK[2], A. OBST[3]

[1]Long Ashton Research Station, University of Bristol, Long Ashton, Bristol BS18 9AF UK; [2]Agricultural Development and Advisory Service, Cambridge, UK; [3]Bayerische Landesanstalt für Bodenkultur und Pflanzenbau, München, Federal Republic of Germany.

Background and objectives

Septoria diseases are major causes of yield reduction in winter wheat throughout Western Europe. Of two common species, S. nodorum occurs most frequently and is most consistently damaging, whilst S. tritici appears geographically to be more localised and is usually active only early in crop growth. However, in some countries recently, S. tritici has built up late in the season and has reached the upper leaves and occasionally the ears.

Although in general, Septoria develops in some crops in most years, economically damaging attacks are sporadic and fungicidal control may not always be justified. Means of forecasting initial outbreaks and the rate of increase would enable more confident decisions to be made on the need for and timing of control measures. Of several short-range, weather-based forecast methods only a few have become operational, and because these sometimes are unreliable a working group of the International Organisation for Biological Control (IOBC)‡ considered that a broadly-based approach to be problem through collaborative research was needed. In 1981, we started a 3-year project to examine afresh relationships of Septoria development to crop, weather and pathogen factors at sites across W. Europe chosen to embrace a wide range of conditions influencing Septoria attack.

Procedures

Data have so far been collected from 18 site/years and 13 susceptible cultivars from the UK, W. Germany and the Netherlands. In 1983, sites in Belgium and France are being included. At each site information is obtained on general risk factors, e.g., previous cropping, soil characteristics and fertiliser history, and on the current crop, e.g. sowing density, height and yield. Systematic crop records are taken weekly from April (GS 30) until July (GS 75-82). In order to ensure comparability of data, much attention is given to defining variables explicitly. The intensity of disease is assessed separately for S. nodorum and S. tritici in relation to the degree of leaf senescence and prevalence of other diseases. Spore yield, a pathogen measure of disease, is also recorded. Interpretation of spatial disease spread is aided by measurements of crop growth and density; at Long Ashton the effects of different crop densities are being compared. Weather factors (temperature, humidity, rain) are monitored at standard meteorological stations within 2 km of the crop.

Results and discussion

Much analysis awaits complete data acquisition. At this interim stage, attention is focussed on comparing overall disease progress between site/years and on interpreting pathogen events, e.g. dispersal, infection, in distinct weather situations. This has allowed hypotheses to be defined which are relevant to forecast options. The following are some examples. (1) Irrespective of whether there is resident inoculum, disease spread is sometimes not explained by the weather criteria stipulated in several forecast rules for S. nodorum, e.g. those based on a sequence of rain days. (2) When source inoculum (as pycnidia) resides in the basal, senescent leaves of a crop in spring, the amount appears not to be a major factor determining the magnitude of an outbreak or subsequent disease progression. Thus, from similar source strengths, either S. nodorum and S. tritici can each become epidemic in the same crop, (as at some UK sites in 1981), or one species only can develop to a severe degree, (as S. nodorum at Long Ashton in 1982). Weather characteristics may at least partly explain different behaviour of the two species. (3) Significant outbreaks of S. nodorum can develop when sudden, heavy rain falls within 24h during an otherwise lengthy dry weather spell These conditions are common in southern Germany and were also encountered in the UK in 1982. (4) The rate at which rain falls interacts with crop density in determining the vertical progression of S. nodorum inoculum. Dispersal is impeded and less disease results when dense canopies prevent a proportion of high velocity raindrops from reaching inoculum sources within a crop stand. In relatively open canopies a high rate of rainfall can elevate inoculum 30-50 cm through the crop stand in one step.

Hypotheses are being validated in separate experiments at Long Ashton and serve both as an aid in the construction of mathematical models, which aim to identify key components of Septoria development, and also to provide numerical estimates of linkages to weather and crop variables. Such models are the precursors of new forecast methods.

Reference

King, J.E.; Cook, R.J.; Melville, S.C. (1983) A review of Septoria diseases of wheat and barley. Annals of applied Biology 103, in press.

‡IOBC (W. Palaearctic Region) Working Group: The use of models in integrated crop protection.

1B—R16

POPULATION MODELS IN STRATEGIC PLANNING FOR CONTROL OF AVENA FATUA

B.J. WILSON, G.W. CUSSANS
ARC Weed Research Organization, Begbroke Hill, Yarnton, Oxford, OX5 1PF

Background and objectives

Weed populations are powerfully influenced by systems of tillage and other husbandry methods. In practice, these effects cannot be considered in isolation from the potential kill by herbicides.

A model for *Avena fatua* in winter cereals can be used to describe such interactions. The model is based on the life cycle of *A. fatua*, consisting of five pathways:

1. seed multiplication within the crop.
2. seed losses from the field in contaminated grain or straw.
3. seed losses from the stubble (natural or by straw burning).
4. seed losses within the soil.
5. mortality of seedlings.

Viable seeds (or seed equivalents) are used as the basic unit of population, and average probabilities of seed increase or decrease for each pathway have been derived from field experiments.

Materials and Methods

Four systems of growing continuous cereals are considered. These are annual tine cultivations or mouldboard ploughing, with or without straw burning. Starting with an introduction of one plant, the population increase in the absence of herbicides can be shown for each system. If complete control (say herbicides + hand roguing) is introduced to prevent an arbitrary threshold being exceeded, the rate of population decline under the four systems can be predicted. The minimum level of control needed to stabilise the population and contain it below this threshold has been calculated for each of the four systems.

Results and Conclusions

Type of cultivation and straw burning influence the rate of increase of an uncontrolled population. The model shows that *A fatua* increases most rapidly (x 3 annually) with tine cultivation without burning, and least rapidly (x 1.6 annually) with ploughing and straw burning. It follows that to prevent a threshold plant population being exceeded, control measures have to be introduced in an earlier year of the build up in systems favouring most rapid increase.

With tine cultivation systems seed reserves of *A. fatua* are less persistent. Tine cultivation, as well as favouring increase of an uncontrolled population, also results in a faster population decline than ploughing, when control of seeding is complete. Seeds in the soil decline by 75% annually with tine cultivation, and by 65% annually with ploughing. Control measures which prevent seeding will be needed for more years with ploughing than with tine cultivation systems to reach a low population.

The model also shows that the minimum level of annual control needed to stabilise and contain a population of *A. fatua* has to be higher for systems of tine cultivation (85% without burning, 75% with burning) than for ploughing (80% without burning, 70% with burning).

Rates of population change predicted by this model for continuous cereal growing accord fairly well with those found in practice in long term population experiments (Selman 1970).

References

Cussans, G.W. (1976) Population dynamics of wild-oats in relation to systematic control. *Rep. Weed Res. Org.* 1974-75.

Selman, M. (1970) The population dynamics of *Avena fatua* (wild-oats) in continuous spring barley. Desirable frequency of spraying with tri-allate. *Proceedings 10th British Weed Control Conference* 1176-1184.

CHOICE OF HERBICIDES AND FUNGICIDES FOR CEREALS IN FRANCE: COMPUTER PROGRAMMES TO AID DECISION MAKING

L. LESCAR, R. DUHAUBOIS, J. TRANCHEFORT

Institut Technique des Céréales et des Fourrages (I.T.C.F.), Boigneville, F 91720 MAISSE, France.

I.T.C.F., a farmer's organisation for cereals and fodder crops, proposes two micro-computer programmes to aid decision making about choice of herbicides and fungicides in a conversational way. These programmes have been tested by farmers and technicians since autumn 1982. The aim is to help them to take account of all technical data available in order to prevent routine applications which are generally neither adapted nor profitable, and which may favour the development of resistant strains or the appearance of new diseases.

DESERB-ITCF works for all autumn and spring cereals: wheat, barley, oat, rye and triticale. The farmer may choose six of the most important weeds he has in his crop from a list of 12 grasses and 50 broad leaved species. After having answered questions about cultivar, growth stage and type of soil, the computer gives him a choice of solutions: (1) a list of wide spectrum herbicides to destroy all the weeds chosen, and/or (2) possibilities of including different timing of sprays with a succession of herbicides. The products are selected according to (a) selectivity on the crop at the growth stage chosen (b) efficacy on grasses and dicotyledonous weeds.

This programme can also give advice on resowing a spring crop after a winter cereal sprayed with herbicides in the autumn according to the delay between spraying and drilling, rates applied and soil types.

FONG-ITCF makes it possible to determine, for each wheat plot, whether it is necessary to treat and, if so, when and with which fungicide. The questions which the farmers have to answer are simple and deal solely with disease development and crop conditions. Some climatic data of that particular year, at the beginning of stem extension and at heading, are introduced into the programme. The principle of this programme is: (1) to determine the basic risk which is linked to a range of more or less easily observed diseases. This risk is determined from crop conditions (previous crop, soil preparation, cultivar, date of sowing). The basic risk may be low (score < 10), moderate (score 10-13) or high (score > 13). (2) to evaluate the specific risk from one or several diseases which are developing significantly in the particular plot (eyespot, *Septoria*, Rusts...)

The need to treat and the choice of product depends on the replies given to these two groups of questions. In the case of low basic risk, no treatment is advised except if the threshold is reached for one or more diseases. A product is then chosen which is efficient only against these particular diseases. If the basic risk is moderate, two treatments are recommended (1 - 2 nodes and heading) with a fungicide which is fairly efficient against this basic risk (e.g. benzimidazol + dithiocarbamate). If, however, the threshold is reached for one or more diseases, a product which is also very effective against these particular diseases will be chosen. If the basic risk is high, two treatments are recommended with chemicals which are not only very effective against the basic risk but also against diseases which may be observed on the field. In that case, the choice is made from the fungicide with the widest range.

The weak point of the present system is that climatic conditions are not taken into account very accurately. Studies of models are in progress to improve this programme.

Materials

The two programmes have been written in 'Basic 80' by microsoft and compiled. They work at present on three types of micro computers: (a) Sil'z from Leanord; (b) Micral 80-21 C2 from R2E; (c) Alcyane A 6 from MBC.

Hardware is logical size 6 HK bytes; exploitation system is CP/M; screen 24/80 dots; 2 x 5 1/4 inches floppies 600 K bytes each formated; printer speed 120 signs per second.

Software: FONG-ITCF holds with files on one floppy; DESERB-ITCF needs two floppies.

A Cobol rewriting of FONG-ITCF is planned to be used through the French TELETEL system.

1B—R18

UTILIZATION OF WEED SURVEYS FOR COTTON MANAGEMENT PROGRAMS

R.E. FRANS, K. KHODAYARI

University of Arkansas, Fayetteville, Arkansas, U.S.A.

Background and objectives

Pests in the United States cause reduction in crops, livestock, forests, and aquatic resources of over 30% of their value. Weed pests, for example, cause annual losses of about 10% in agricultural production and, in 1980, amounted to about $12 billion in the United States alone. Producers spend about $3.6 billion each year for chemical weed control and about $2.6 billion for cultural, ecological, and biological control. Thus, the losses caused by weeds and the costs of their control are estimated at more than $18.2 billion annually.

In Arkansas, cotton growers lost more than $14.5 million to weeds in 1974. Because of the influence of such pests on crop production, Arkansas is one of many states in the U.S. that is initiating integrated pest management (IPM) schemes to improve systems of pest management. An integral part of such programs involves determination of weed species present and their infestation levels, in order to devise appropriate control strategies that are economically feasible. Among the objectives of our involvement in IPM were to determine weed population densities and species present early in the growing season in cotton, to evaluate weed control program effectiveness at the end of the season, and to predict potential weed infestations for the succeeding year.

Materials and Methods

Weed surveys were conducted in ten cotton fields, comprising 177 hectares, in the Mississippi River delta region of Arkansas from 1980 to 1982. Twenty random samples from each field selected were taken both early and late in the growing season. The sample size was a quadrat of 0.33 by 6.0 m placed over the row (longest sides parallel to the row). The number of each weed species per each m^2 was computed for all fields.

Results and conclusions

Sixteen weed species were identified with *Digitaria sanguinalis*, *Eleusine indica*, *Sida spinosa*, *Cynodon dactylon*, and *Euphorbia maculata* being the most prevalent. We assumed that a weed density of less than one plant/m^2 was negligible, and we concluded that all species were satisfactorily controlled by the herbicide practices used in the fields samples in 1980. *Cynodon dactylon* was the only species that increased in infestation during the growing season in one field, and then only slightly. Good weed management practices resulted in excellent control of all weed species in four of five fields in 1981. However, our surveys in two fields, one in 1981 and one in 1982, indicated the employment of less than satisfactory management strategies because of uncontrolled weeds at the end of the season. These results suggest that weed surveys were a reliable procedure for assessing population dynamics, for advising procedures as to need for control programs, for evaluating effectiveness of herbicide programs currently in use, and for predicting weed infestations for the following season.

References

Hurst, Harold R. (1974) Economic losses due to weeds. *Research Report, Southern Weed Science Society* 27, 196.

Khodayari, K., L.R. Oliver, and R.E. Frans. (1981) Weed survey techniques for cotton and soybeans. *Proceedings, Southern Weed Science Society* 34, 253.

Shaw, W.C. (1982) Integrated weed management systems technology for pest management. *Weed Science, Supplement* 30, 2-12.

TACTICAL USE OF COMPUTERS IN COTTON PEST CONTROL

A.G.L. WILSON

C.S.I.R.O. Cotton Research Unit, P.O. Box 59, Narrabri, N.S.W. 2390 Australia

Background and objectives

The 1972-73 season marked a watershed for the Australian cotton industry with development of resistance to DDT by *H. armigera*. Spray frequency increased to 16-20 per season and pollution caused problems to the cattle industry and wildlife. Increased research improved action thresholds, and knowledge of pest biology but it was difficult to translate such information into reduced on-farm pesticide usage because conventional extension services were thinly spread and could not be greatly expanded for economic reasons.

SIRATAC (CSIRO and Department of Agriculture Tactics for growing cotton) was conceived as an on-line, on-farm service working through portable terminals connected by telephone to the central computer situated at Narrabri. A major objective of the program was to minimise use of "hard" insecticides, without affecting yield.

Operational procedures

Inputs

The crop checker records standardised field observations on cards, and inputs these to the computer as follows:

1) Numbers of insects, counted and entered every third day.
2) Numbers of flower buds and fruits, counted and entered weekly.
3) Pheromone trap catches which indicate the proportion of *H. armigera* and *H. punctigera* moths in the fields.
4) Details of previous sprays.

Separately gathered temperature and rainfall data are inputted to the computer daily.

Data processing

The data are fed through the remote terminal to the central VAX 750 computer by a simple question and answer program. The program first predicts the development and mortality of pests in order to predict the numbers likely to be present tomorrow and the next day. The effects of weather, beneficial insects and the residual effects of previously applied sprays are taken into account to estimate mortality.

Past and present fruit numbers and estimated damage from surviving pests are used to predict the number likely to survive to harvest and to determine whether the target yield will be reached by the nominated target date if a spray is not applied.

The next step is a decision tree through a series of yes/no answers in order to decide the most appropriate action to be taken.

Output

A comprehensive set of reports can be accessed through the remote terminal about 4 minutes after data input; including the recommended pest options.

Results and conclusions

Initially the program resulted in reductions of 50% in number of sprays, compared with normal commercial crop checking. Savings in costs are partially offset by the increased annual cost of the system of $5 per hectare over the normal annual scouting charge of $25/ha.

In the past two seasons the margin has tended to narrow because of light infestation, use of pyrethroids and a tightening up in commercial scouting, partly attributed to farmer comparison with SIRATAC results. In the past season about 5 sprays were applied in the computerised system and about 7 commercially.

A non-profit making company SIRATAC Limited, has been set up to market and service the system initially funded by a voluntary levy of 25¢/bale paid by farmers. The system has now been adapted for use in all cotton growing areas.

Further extension of the program has been made more urgent by the development of field resistance by *H. armigera* to pyrethroids in one small production area - Emerald in central Queensland.

Acknowledgement

A large number of people have collaborated in development of SIRATAC. Initial programming was by P.M. Room and A.B. Hearn, current program modifications are made by A.B. Hearn and K. Brooks.

1B—R20

MONITORING AND FORECASTING MAJOR MIGRANT PESTS : ECOLOGY AND TECHNOLOGY

R.C. RAINEY

c/c Tropical Development and Research Institute, London W8 5SJ

Recent exchange of experience through the Academia Sinica and the Royal Society has emphasised the close agreement of findings by different methods on the nature of migration in five major pests - Oriental armyworm (Mythimna separata), brown plant-hopper (Nilaparvata lugens), rice leaf-roller (Cnaphalocrocis medinalis), Desert Locust (Schistocerca gregaria) and African armyworm (Spodoptera exempta).

Among ecological factors common to all these pests are the monsoon winds with seasonal reversals with which the main northward and southward migration take place, such significant changes in vegetation as the use of higher-yielding rice varieties and of extensive double-cropping, and the clearance of tropical forest to savanna and grassland which has massively augmented the gramineaceous food supplies of the armyworms.

In a unique series of field experiments in China, marked insects have been recaptured at distances up to 1480 km for Oriental armyworm moths, up to 720 km for brown plant-hoppers, and up to 1260 km for rice leaf-roller moths. These distances were confirmed for the small insects of the two latter species by using thin-layer chromatography to identify a fluorescent marking material. Also, some thousands of brown plant-hoppers have been caught by extensive aircraft-trapping, at heights up to 2500 m, including catches made by unmanned radio-controlled target aircraft. Complementary evidence on the extent and scale of flight of the African migrants has been provided by aircraft tracking of Desert Locust swarms, and by radar observations of the height, density and ground-speed of night flying Desert Locusts and armyworm moths.

All five pests show characteristic sudden, simultaneous appearances of migrant insects in large numbers over areas previously clear and of the order of 10^5 km^2 in extent. They appear within periods of a few days and in China sometimes at more than a hundred observation points. Sequences of such appearances of each species constitute quasi-regular seasonal patterns of migration over distances of several thousand kilometres.

Successful monitoring and forecasting services for these pests have developed on two different lines. In China the arrival of the adult pests, and oviposition, are monitored by a range of very effective trapping devices, at many thousands of recording points. These observations are used immediately, at local (county) level, to provide inferences of the expected dates of appearance of the subsequent larval or nymphal stages. For Desert Locust and African armyworm, on the other hand, forecasting has developed at central units, each monitoring day-to-day changes in the overall distribution of the main populations of one pest on an international scale (over the entire Afro-Asian range of the species in the case of the Desert Locust), and providing detailed forecasts up to a generation ahead as well as short-term warnings.

References

Li Guangbo; Chou Chong-Keng; Chang Shao-she; Betts, E.; Lewis, T.; Rainey, R.C.; Shaefer, G.W. (1981) Proceedings Airborne Pest Symposium Beijing, in press.

Riley, J.R.; Reynolds, D.R.; Farmery, M.J. (1981) Radar observations of Spodoptera exempta: Kenya, March-April 1979. COPR Miscellaneous Report 54, 43 pp.

MIGRATION AS A FACTOR IN FORECASTING BROWN PLANTHOPPER OUTBREAKS

J.I. MAGOR, L.J. ROSENBERG, D.E. PADGHAM

Tropical Development and Research Institute, College House, Wrights Lane, London W85SJ, UK

Background and objectives

The brown planthopper, Nilaparvata lugens, a rice pest, is found in Asia and Australia. Large numbers feeding cause hopperburn (the wilting and death of rice plants) and it transmits three diseases. Virulence to rice cultivars, resistance to insecticide and the presence of disease vary both within and between populations. Windborne migrations lead to the seasonal colonisation of temperate areas where rice is grown only in summer. Damage to this crop can be predicted from immigrant numbers and occurs only after a population has built up through two or more generations. In the tropics, population development is unpredictable and immigrants sometimes cause damage. As rice is grown throughout the year in the tropics, immigrants were assumed to be solely of local origin. This study establishes the potential for long distance migration in brown planthoppers originating in the tropics and examines their windborne dispersal. The implication of long-range migration for plant protection services is discussed.

Materials and methods

Probable times and heights of migration were obtained from field observations. The potential flight duration of insects originating in the tropics was estimated directly in flight experiments and indirectly from the rate at which their fuel reserves were utilised.

Trajectories drawn downwind for a distance equal to windspeed X flight time were used to simulate brown planthoppper migratory flights. Weather maps of observations at 10m and at 1.5km were analysed by the direct streamline-isotach method to estimate wind direction and speed between observation sites.

Results and conclusions

Brown planthoppers in the tropics took-off at dawn and dusk and dusk flights lasted considerably longer. Post-flight fuel resynthesis suggested that only one major migration occurs. Maximum potential flight durations were 14-16h for insects reared on a resistant rice IR36 and were 24-26h when a susceptible rice IR20 was used. These results are similar to those obtained in temperate areas. There, back-tracks from ships in the East China Sea to source areas in central China and Taiwan lasted up to 30h.

Trajectories starting at dusk and simulating 30h downwind flights varied with height. Those from the same site had different tracks on successive days. Trajectories in July, September and November illustrated the seasonal shift in wind direction and showed deviations from the dominant wind direction as disturbances moved through an area. The restriction of migration during cold surges in the winter was also apparent.

The trajectories suggested that immigrants come from a variety of local and distant sources and that movements occur between countries. Such movements might be important in two ways: as the initiators of populations leading to outbreaks or as vectors of disease and carriers of insecticide resistance.

Planthopper population development varies with the variety of rice grown, local farming and pest management practices and impact of natural enemies. Consequently in Japan, forecasts and control warnings are prepared locally in each Prefecture with the service and improvements to it being co-ordinated nationally. In the tropics, immigrants are not exclusively from distant sources and at times they cause damage. Thus control may need to be initiated much more quickly than in Japan; an additional reason for preparing forecasts locally.

The situation is different with respect to disease transmission and insecticide resistance. Here a knowledge of likely sources could alert plant protection services to the possibility of new diseases or resistant insects being introduced. Trajectory analysis is being used to define the regions within which brown planthopper information should be exchanged.

References

International Rice Research Institute (1979) Brown planthopper: threat to rice production in Asia. Ed and Publ, Los Banõs: International Rice Research Institute.

Padgham, D.E. (1983) Flight fuels in the brown planthopper (Nilaparvata lugens. Journal of Insect Physiology 29, 95-99.

Padgham, D.E. (1983a) the influence of the host-plant on the development of the adult brown planthopper, Nilaparvata lugens (Stål) (Hemiptera: Delphacidae), and its significance in migration. Bulletin of Entomological Research 73, 117-128.

Rosenberg, L.J.; Magor, J.I. (1983) Flight duration of the brown planthopper, Nilaparvata lugens (Homoptera: Delphacidae). Ecological Entomology 8(3) (in press).

1B—R22

TDRI - DLCOEA - KARI ARMYWORM PROJECT : 1. FORECASTING SERVICES

D J W ROSE*, E BETTS*, P O ODIYO+ and C F DEWHURST*

*Tropical Development and Research Institute, London W8 5SJ.
+Kenya Agriculture Research Institute, P O Box 30148 Nairobi

A major problem in controlling African Armyworms, Spodoptera exempta, Noctuidae, arises from the sudden appearances of larvae at high density, often 100 sometimes a few thousand per square metre, over areas of a few hectares up to about 50,000 ha , with similar closely contemporary infestations scattered across 1000 km. Such sudden, dense infestations devastate cereals and grasses within a few days of their discovery, so that control must be organised rapdily if it is to be effective.

To meet this, a system for forecasting armyworm infestations was developed in eastern Africa from 1969 (Betts 1976, Odiyo 1979), based on an hypothesis of downwind moth migration, typically 100 to 500 km between successive generations at intervals of 1 to 1½ months, and the concentrating effect of such downwind transport of moths into wind-convergence zones (Brown, Betts and Rainey, 1969). Reports of larvae indicate the location of the major S. exempta populations, estimates of expected dates of emergence at these infestations and moth catches indicate when emigration is beginning, wind and rainfall charts show areas likely to be reached by airborne moths, and moth catches elsewhere show areas actually reached where infestations of the next generation are imminent. Moth monitoring, initially by light-traps, was later supplemented by pheromone traps (Campion et al 1976), which allowed moths to be caught in areas without electricity supply, avoided loss of information at full moon and cut moth sorting costs. A grid of light-traps for monitoring S.exempta and other pests was developed in southern Africa in the early seventies, a few light-traps in Malawi were supplemented from 1977 by some 70 pheromone traps and pheromone traps were set up in Yemen Arab Republic from 1974 and are currently being established in Guinea under the auspices of FAO.

In eastern Africa, forecasts are issued weekly to indicate districts where farmers should look for imminent infestations, for, in the main, the system functions only one generation ahead. Some longer-term warnings based on analogues with past armyworm history have been provided. Sequences of infestations spread from central and eastern Africa northwards into Yemen Arab Republic and PDR Yemen and southwards into southern Africa, but there is much variation from year to year with the sequences extending through the more northern countries only in some years, more southern countries in others, or infestations may be very sparse everywhere (e.g. 1977-78). Thus infestations are likely to appear in Ethiopia in March-June only if populations on a moderate to substantial scale have occurred earlier in Kenya or Uganda and infestations are likely in Yemen Arab Republic only if large populations have reached Ethiopia or Somalia. Exchanges of information between national or regional agricultural offices seem likely to provide an appropriate balance between the needs for rapid collection and dissemination of information and the need for a continental view of the situation.

First infestations of the season occur between Kenya and Zimbabwe during October to January and can be forecast reliably only when sudden rises of moth catch indicate that infestations are imminent. Such infestations may arise by concentration of local low density populations (Rose 1976) or by immigration. An empirical association between heavy armyworm seasons following droughts and lighter seasons following heavy rainfall, long recognised by local entomologists in eastern Africa, Zimbabwe and South Africa has been demonstrated in respect of Kenya and Tanzania to be statistically significant (Tucker, in press) but its cause remains to be determined.

References

Betts, E. 1976. Forecasting infestations of tropical migrant pests: the Desert Locust and the African armyworm. Symposia roy. ent. soc. 7: 113- 134

Brown, E.S., Betts, E. and Rainey, R.C., 1969. Seasonal changes in distribution of the African armyworm, Spodoptera exempta (Wlk.) (Lep., Noctuidae), with special reference to Eastern Africa. Bull. ent. Res., **58**: 661-728.

Campion, D.G., Odiyo, P.O. Mushi, A.M., Hall, D.R., Lester, R. and Nesbitt, B.F. 1976. Field Tests with the synthetic sex pheromone of the African armyworm. Centre for Overseas Pest Research, Miscellaneous Report 25. pp4.

Odiyo, P.O. 1979. Forecasting infestations of a migrant pest: the African armyworm, Spodoptera exempta (Walk.) Phil. Trans. R. Soc. Lond. B 287, 403-413.

Rose, D.J.W. 1976. The synoptic weather in relation to an outbreak of the African armyworm, Spodoptera exempta (Wlk.). J. ent. Soc. Sth. Afr. **39**: 125-130.

TDRI*-DLCOEA-KARI AFRICAN ARMYWORM PROJECT. 2. RECENT STUDIES ON MIGRATION

D.J.W. ROSE, W.W. PAGE, C.F. DEWHURST, J.R. RILEY, D.R. REYNOLDS, D.E. PEDGLEY

Tropical Development and Research Institute, London W8 5SJ, U.K.

Background and objectives

Understanding the migration of this insect pest is essential to the development of a regional control strategy. There is strong circumstantial evidence that adult moths move up to several hundred kilometres between generations. This evidence comes largely from biogeographical studies of seasonal redistribution and from back-tracking the parent moths of caterpillar outbreaks to known or likely sources by means of windfield maps. Direct evidence is provided for very short ranges by eye observations, and for ranges up to at least 20km by radar. Long-range movement is best demonstrated by mark-and-recapture.

Materials and methods

165,000 moths (34% males) were marked on 1 May 1982 with neutral red dye sprayed with molasses as a bait on to 430 trees, scattered over about 1km² of a 20km² outbreak site 30km south-east of Nairobi, Kenya, and just before peak emergence from pupae in the soil. A network of about 100 sticky pheromone traps had been laid out along roads in a 90° sector towards which winds were expected to blow with 0.8 probability, and to a range of 150km. Further traps were set out in other directions. A 3cm radar, set up at the edge of the site, followed emigration and was used to calculate 2h trajectories by extrapolation. Wind records were used independently to calculate trajectories by assuming downwind movement.

Results and conclusions

Six marked male moths were recaptured in the 90° sector, the furthest at 140km, but none in other directions. Distances and directions from the marking site are consistent with downwind movement, starting soon after dusk and in winds of 8-10 m/s. This unique combination of techniques shows unequivocally that African armyworm moths can move at least 140km, probably in one night, and in a downwind direction when wind speeds are much stronger than their air speed (2-3 m/s).

References

Brown, E.S.; Betts, E.; Rainey, R.C. (1969) Seasonal changes in distribution of African armyworm with special reference to East Africa. Bulletin of Entomological Research 58, 661-728.

Rose, D.J.W.; Dewhurst, C. (1979) The African armyworm - congregation of moths in trees before flight. Entomologia Experimentalis et Applicata 26, 346-348.

Tucker, M.R.; Mwandoto, S.; Pedgley, D.E. (1982) Further evidence for windborne movement of armyworm moths in East Africa. Ecological Entomology 7, 463-473.

* TDRI, Tropical Development and Research Institute, London, U.K.
DLCOEA, Desert Locust Control Organization for Eastern Africa, Addis Ababa, Ethiopia.
KARI, Kenya Agricultural Research Institute, Muguga, Kenya.

1B—R24

DETECTION OF STORED PRODUCT PESTS : PHEROMONES AND FOOD ATTRACTANTS

P.M. COGAN, M.R. STUBBS, D.B. PINNIGER

MAFF, Slough Laboratory, London Road, Slough, Berks, UK.

Introduction

Stored product insect pests can cause serious problems in food processing, transport and storage and because of high standards, even very small numbers of pests can cause financial loss. Therefore, detection of insects at low infestation levels is of paramount importance.

Pheromones

Although attraction or aggregation (arrestant) pheromones have been identified for a number of stored product beetles the greatest success in the UK has been achieved with sex pheromones of stored product moths. All major pest species of moths may be detected or monitored by TDDA (Z,E)9,12 tetradecadienyl acetate)incorporated as a lure in traps.

In a number of long-term flour stores with a zero tolerance of moths, use of plastic funnel TDDA traps has resulted in the detection of all infestations of *Ephestia kuehniella* over a period of 4 years. Infestations of *E. kuehniella* in 2 flour mills have been effectively and economically monitored using funnel traps for 4 years and the trap catch was directly related to extensive visual inspections both before and after fumigations.

Laboratory evaluation of TDDA traps currently available indicates that one large sticky trap design is most suitable for non-dusty environments and/or low density infestations and one funnel trap design is most effective in dusty areas or where sticky traps are unacceptable.

Food attractants

Bait bags containing carobs, wheat and groundnuts have been used to detect and monitor residual infestations of pests in empty stores, warehouses etc. One advantage for food attractants is that a wide range of insect species can be trapped by the same source: more than 50 species of beetles, moths, psocids and mites have been recorded from bait bags.

Laboratory studies have been carried out to discover which volatiles given off by the foods, especially carobs, are responsible for the attractancy of the bags. An aqueous distillate of carobs was produced and the effect of various dilutions of this material on *Oryzaephilus surinamensis*, the major grain pest in the UK, was tested using an insect activity detector. *O. surinamensis* was attracted by water alone but showed a much greater attraction to carob distillate.

Carob distillate was then separated into 3 fractions: acidic, basic and neutral and of these, the attractancy of the acidic component was most similar to carob distillate. Of the five major components of the acidic fraction identified by gas chromatography and mass spectrometry, hexanoic acid mimicked the effect of carob distillate closely both in its immediate attractiveness and its long-lasting effect.

References

Cogan, P.M. (In Press) Use of pheromones to detect stored product moths in premises in the UK. *Mitteilungen Deutsche Gesellschaft fur allgemeine und angewandte Entomologie* (*II. Europaischer Entomologen Kongress, Kiel*)

Pinniger, D.B. (1975) An assessment of residual insecticide treatments for the control of the Saw-toothed grain beetle (*Oryzaephilus surinamensis*) in farm grain stores. *Proceedings of the 8th British Insecticide and fungicide conference* 365-372.

Stubbs, M.R.; Griffin, R. (In Press) The response of *Oryzaephilus surinamensis* (L) to water. *Bulletin of Entomological Research*.

MONITORING TECHNIQUES FOR PHYTOPHAGOUS MIRIDS IN QUEBEC APPLE ORCHARDS.

R.K. STEWART, G. BOIVIN

Macdonald College of McGill University, Montreal, Canada

Background and objectives

Phytophagous mirids are responsible for considerable damage to apples but there are conflicting reports on the economic importance of individual species. Current control techniques do not affect all of the species present to the same degree and the introduction of integrated pest management techniques could alter differentially the pest status of the several species. The development of suitable integrated controls depends on being able to monitor potential pests and predict the resulting damage levels. We therefore used monitoring techniques to establish the relation between the population densities and movements of the mirids and damage to apples.

Materials and Methods

Unsprayed orchards were monitored in the three seasons 1978-80. A beating tray was used to sample apple trees, a D-Vac® suction apparatus was used for ground vegetation and sticky traps, set at various heights were used to trap flying adults. These methods were chosen for their reputed efficiency, relative ease of use and known familiarity to field workers. The relation between numbers of mirids and damage to apples was determined by placing known numbers of insects in sleeve cages on trees and monitoring their development and resulting damage.

Results and conclusions

Five species of phythophagous mirids formed a species complex in the orchards. The first species to appear, Lygus lineolaris, was present as overwintered adults in low numbers only on apple trees early in the spring. It was only captured occasionally on the trees for the rest of the season although it built up considerably in numbers on the orchard vegetation between the trees. This was the only species present early enough to damage buds and flowers, but only 2% of these were damaged and the resulting fruit from them was included in the June drop. As they did not result in damaged apples at harvest, we regard them as a natural thinning agent. Lygocoris communis, Lygidea mendax and Camplyomma verbasci were present as nymphs and adults but most of the damage to apples was done by nymphs. This damage was caused before June drop and in addition to increasing fruit drop it resulted in damaged apples at harvest. It proved very difficult to assign damage to particular species, but most of the damage to harvested apples was due to either L. communis or L. mendax. Only preliminary results were obtained on the relation between population density and damage to apples. However decrease in damage observed between 1979 and 1980 was reflected by a proportional decrease in mirid numbers in these two seasons. This would suggest that economic thresholds could be developed.

C. verbasci caused no significant damage to apples. Although it was present in considerable numbers it is likely that fruit is too well formed by the time the nymphs are present to allow them to be mechanically damaged. Heterocordylus malinus was shown experimentally to be capable of damaging apples, but its numbers in the experimental orchards were too low to cause significant damage.

We concluded that beating was a suitable technique for monitoring nymphs and adults on trees and the D-Vac was satisfactory forground vegetation. Sticky traps set at a height of 0.5 m were satisfactory for a qualitative estimate of flying adults of L. lineolaris, H. malinus, L. communis and L. mendax but C. verbasci tends to fly higher than the other species and would require a trap between 2 and 3.5 m above ground.

References

Boivin, G. (1980) Bionomie de cinq espèces de mirides phytophages (Hemiptera: Miridae) dans une pommeraie du sud-ouest du Québec. Ph.D. Thesis McGill University. 269 pp.

Boivin, G.; Stewart, R.K.; Mailloux, G.; Rivard, I.; Paradis, R.O. (1979) Observations sur la punaise de la pomme, Lygocoris commununis (Knight)(Hémiptères: Miridae). Phytoprotection 60: 119-124.

Braimah, S.A.; Kelton, L.A.; Stewart, R.K. (1982) The predaceous and phytophagous plant bugs (Heteroptera: Miridae) found on apple trees in Québec. Naturaliste canadien 109(2): 153-180.

1B—R26

BIOMETEOROLOGICAL FORECASTING SCHEME FOR APPLE MILDEW

D.J. BUTT, M.J. JEGER and A.A.J. SWAIT

East Malling Research Station, Maidstone, Kent ME19 6BJ, England

Background and objectives

Infection by powdery mildew conidia is not dependent upon surface wetness. Although abiotic factors influence the disease cycles of these pathogens a major determinant of the level of daily infection is the amount of inoculum. A simple disease assessment technique already used in the supervised control of apple mildew incorporates the key role of inoculum by restricting the assessment to leaves bearing sporulating colonies (Butt & Barlow 1979): an objective is to develop a forecasting scheme from this technique.

Materials and methods

Daily leaf infections were monitored by exposing potted plants (MM.106 rootstock) for 24-hour periods in an unsprayed orchard, and incubating under glass. A spore trap (Hirst) and meteorological instruments were operated. In another study natural leaf infections were recorded, leaf by leaf, on vegetative extension shoots of several cultivars. Leaf positions were numbered relative to the youngest unrolled leaf (leaf 0), with rolled leaves +1, +2 etc. successively younger and leaves -1, -2 etc. successively older. Sporulation was assessed by leaf washing. Colonies were stained with Trypan Blue.

Results and conclusions

Most leaf infections occur on young, rolled leaves above the +1 position and first appear as visible colonies on leaves -1 to -3. Assuming a new leaf is produced every 3 days at position +4, then each leaf is susceptible for 9 days. With respect to any forecast day (FD), the susceptible period of the current +2 leaf covers, therefore, the period FD to FD -(minus)8. During this time colonies on older leaves produce conidia: a measure of the amount of inoculum is given by disease intensity in the infectious region, at leaf positions -1 to -5. Disease assessments, adapted to allow for incubating colonies, would be repeated every 6 days. Inoculum production is affected by weather; high humidity at night and high temperature favour sporulation, whilst heavy rain is damaging and its effect persists for several days. Daily values of these weather factors can be used in conjunction with the intensity of infectious disease to estimate, at 3-day intervals, the exposure to inoculum of each developing leaf during its susceptible period. Infection is favoured by high humidity at night, dew, low wind speed and high temperature - unless the daytime humidity falls to *c.* 40% RH. Daily values of these factors can be used to calculate, at 3-day intervals, infection risks in the period FD to FD -8.

Assuming a latency of 6 days, latent periods for leaves +1, 0 and -1 extend from FD -5 to -10, FD -8 to -13 and FD -11 to -16 respectively. On these same leaves conidiophore production and sporulation extend from FD to days -4, -7 and -10 respectively. This temporal structure provides a basis for including in the scheme the weather in the latent and post-latent phases of incubation, when effects on colony survival and growth are better understood.

The integrated dynamics of shoot and pathogen development provide the basis for a biometeorological disease forecasting scheme that could improve short-range decisions on chemical control. A feature of the forecast is the use of disease and weather data to measure the inoculum originating from one important source (Butt 1978). In early summer, however, conidia are also produced by primary mildew from diseased buds; this other source of inoculum should be included in the scheme.

References

Butt, D.J. (1978) Epidemiology of powdery mildews. In: The Powdery Mildews D.M. Spencer (Ed.), London: Academic Press, pp. 51-81.

Butt, D.J.; Barlow, G.P. (1979) The management of apple powdery mildew: a disease assessment method for growers. Proceedings 1979 British Crop Protection Conference - Pests and Diseases 1, 77-86.

MONITORING HOST, WEATHER AND INOCULUM IN THE CONTROL OF PRIMARY APPLE SCAB

M.J. JEGER, D.J. BUTT and A.A.J. SWAIT

East Malling Research Station, Maidstone, Kent ME19 6BJ, U.K.

Background and objectives

Apple scab (caused by Venturia inaequalis) overwinters on fallen leaves as pseudothecia, producing ascospores in spring which infect developing foliage. Certain combinations of leaf wetness duration and mean temperature - the Mills criteria - have been found useful in warning of infection risks, but the coincidence of three factors, i.e. inoculum, susceptible foliage and favourable weather, is necessary for infection to occur. Three basic strategies for controlling primary infections may be identified, corresponding to the monitoring of host, weather and inoculum: protectant sprays commence at a host phenological stage and continue at regular intervals, curative sprays are applied when infection criteria are satisfied, sprays (either protectant or curative) are applied flexibly according to the amount of inoculum. From these, more complex strategies can be developed (MacHardy & Jeger 1983). The implications of each strategy for control of primary apple scab in the United Kingdom have been examined.

Materials and methods

Historical records of each factor were available at East Malling for at least the last 20 years. Bud developmental stages differ in timing between cultivars as well as years (Jeger 1981, Jeger et al. 1982) and were examined for Cox's Orange Pippin only. Mills periods have been monitored continuously using a Hirst wetness recorder and the frequency distribution with time of year was obtained. Fallen leaves have been routinely sampled for the presence of mature pseudothecia, i.e. containing dischargeable ascospores, and the date of first observance for each year was obtained. Finally, for those years in which outbreaks occurred, the first observance of primary scab was noted.

Results and conclusions

The first production of dischargeable ascospores and the presence of susceptible foliage were not well-synchronised but overlapped: the inoculum could first be present as early as mid-January but occasionally not until the beginning of May. The most frequent time was in mid-February, just prior to the earliest record of bud-burst. The range of dates for bud-burst was much narrower than for the first production of inoculum and the most frequent time was 4-5 weeks later than that for discharge. There was a narrow peak in the time foliar scab was first seen; this occurred in the first two weeks of May, some 5-6 weeks after bud-burst. The Mills period data were expressed as the proportion of years in which an infection period was completed within the next 5, 10 or 15 days as the season progressed. In late April and early May these proportions were 0.55, 0.73 and 0.77 respectively. The main conclusions to be drawn are that susceptible foliage and ascospore inoculum coincide in most years and that protectant strategies are soundly based - provided that scab was present during the previous year and leaf litter remains on the orchard floor. Also, the high frequency of Mills periods during April makes the dependence on a purely curative strategy of dubious value especially as many protectant fungicides also have curative properties. On the other hand, if the monitored or forecast amount of ascospore inoculum is low (Jeger et al. 1982, Jeger & Butt 1983, MacHardy & Jeger 1983) then more flexibility in spray programmes is possible provided early control has been obtained.

References

Jeger, M.J. (1981) Disease measurement in a study of apple scab epidemics. Annals of Applied Biology 99, 43-51.

Jeger, M.J.; Butt, D.J. (1983) Overwintering of Venturia inaequalis the causal agent of apple scab, in relation to weather. Annals of Applied Biology (in press).

Jeger, M.J.; Swait, A.A.J.; Butt, D.J. (1982) Overwintering of Venturia inaequalis, the causal agent of apple scab, on different cultivars. Annals of Applied Biology 100, 91-98.

MacHardy, W.E.; Jeger, M.J. (1983) Integrating control measures for use in the management of primary apple scab. Protection Ecology 5, 103-125.

1B—R28

ECOLOGICAL BASIS FOR FORECASTING THE NEED TO CONTROL THE SUGARCANE BORER

F. OSCAR TERAN

Centro de Tecnologia Copersucar, Piracicaba, SP, Brazil

Background and objectives

The sugarcane borer, Diatraea saccharalis is the most important sugarcane insect pest of Neotropical America. Therefore efforts are needed to control it. Trying to organize the present knowledge in terms of IPM philosophy, this study attempts to identify some ecological factors that govern high infestations in cane fields in the State of São Paulo, Brazil. Unbalanced borer populations cause much damage and losses to cane.

Materials and Methods

"Final" infestation surveys (damage caused to cane determined at harvest) were carried out in the commercial cane fields of the sugar factories from 1977-1981. Population surveys of the borer and its larval parasites were also carried out during 1981 in cane fields of 3 sugar factories.

In looking for the causes of differential infestations the following tests were run: (a) on the reproductive capacity of adults reared from different cane fields in order to determine their fecundity and fertility, (b) on natural control of borer eggs, by exposing them to parasites and predators in different canefields; (c) on survival and life span of borers, following their fate after artificial "inoculation" of isolated cane stools.

Results and conclusions

The overall analysis of the results of this study shows:

(1) The age of the cane crop has a profound influence on infestation by borers. The main causes of decreased infestation are the lower reproductive capacity of borers in ratoon canes and the higher natural control of borer eggs in old cane fields.

(2) The age of the cane plant at harvesting, i.e. the period of vegetative growth, markedly influences borer infestations with higher infestations in prolonged vegetative periods. Accumulation of borer generations during these prolonged vegetative periods is probably the main cause of increased infestation.

(3) Despite frequent variation in susceptibility and resistance of cane varieties, there is a clear tendency for some varieties, e.g. CP51-22, NA56-79, IAC52-150, IAC51-205 and IAC58-480, always to show infestations above average, while others, e.g. CO740, IAC50-134, CB47-355 and IAC48-65, always show infestations below average. The causes of these differences are not clear.

(4) There is a clear influence of cane nutrition on borer infestation levels. Fertilized canes always suffer higher infestations which tend to increase with increased dosage of potash and nitrogen, while there is no clear influence of the interaction of these and other cane nutrients. It seems that the higher reproductive capacity of borers is responsible for these increases. Zinc appears to interfere with borer fertility, resulting in lower infestation of canes provided with this minor nutrient.

(5) "Vinasse" (liquid residue of alcohol distillation) applied to canefields (specially to ratoons) increases borer infestations, which are higher at higher doses. The effect is caused by a combination of irrigation and cane nutrition. Vinasse and fertilization of ratoon canes modify the normal tendency of less infestation in older ratoons.

Using the above information together with knowledge on the influence of climatic factors (especially frosts), a scheme of forecasting was developed. The scheme integrates data from 2 field activities: damage surveys (done during harvest in all cane fields) and population surveys (done in immature growing cane), and shows where and when to take the correct control action (release of larval parasites in this case). This forecasting is done dynamically by pin pointing, in advance, the "hot spots" in a map of cane fields.

FORECASTING SQUIRREL DAMAGE

R.E. KENWARD

Institute of Terrestrial Ecology, Monks Wood, Huntingdon, UK

Background and objectives

If the likelihood of crop damage can be forecast, it is often possible to reduce the expense of controlling pathogens and invertebrate pests. The main aim is to predict when pest density or pathogen-susceptibility is likely to be high, in which case damage is more or less inevitable, because the crop is normally an important resource for the attacking organism. However, when the grey squirrel damages young hardwoods, by stripping bark and eating the underlying sap, damage forecasting is complicated by the squirrel's lack of dependence on this resource. Although there is a tendency for this mid-summer damage to be greatest when squirrel numbers are high, there can be high squirrel densities without serious bark-stripping, and bark-stripping even when control measures have reduced squirrel density.

Materials and methods

To investigate the squirrel population parameters associated with damage, squirrels at 18 study sites were trapped, marked and released in spring, and then retrapped during the June-July damage period in 1980 and 1981. Summer weights and weight changes since spring were used as indices of food-shortage, which might be a reason for bark-stripping. Another hypothesis was that juveniles from spring litters might trigger bark-stripping during agonistic encounters with established squirrels, because squirrels in enclosures had been seen to gnaw aggressively at branches when a stranger was introduced. The total number of squirrels caught in each area during summer, and the number of juveniles, were divided by the number of traps to give density indices (the trap density was the same in each area).

Results and conclusions

Damage was most strongly correlated with the density of juvenile squirrels (Table). Although there was also a correlation between damage and total squirrel density, this appeared mainly to result from the correlation between juvenile density and total squirrel density: the partial correlation between damage and total squirrel density was a negative and non-significant -0.158. Damage was only weakly related to squirrel weight loss. Moreover, hunger is unlikely to be an important cause of bark-stripping because damage also occurs when captive and wild squirrels are fed artificially.

	Density index		Weights of yearling squirrels (non-breeders)	
	Spring young(2)	All squirrels(3)	Summer weight(4)	Weight change spring to summer(5)
Damage(1)	0.783***	0.580*	-0.461	-0.514*
(2)		0.824***	-0.381	-0.281
(3)			-0.361	-0.251
(4)				0.511*

* $P<0.05$ *** $P<0.001$

Although the results support the hypothesis that aggressive encounters with young squirrels are a cause of damage, agonistic gnawing is unlikely to account for whole trees being stripped of bark. Other trees nearby may have only one small flake of bark removed, indicating that damage is also determined by tree quality. Strong relationships were found between the sap depth and the area of bark freshly stripped from individual beech trees in one area ($r_{(20)}=0.648$, $P<0.001$) and sycamores in another ($r_{(25)}=0.780$, $P<0.001$).

In 1982, the amount of damage in the original study areas was found to correlate more strongly with sap thickness (volume per unit area), averaged for trees in each area at the time of stripping, than it had with any squirrel population parameter in the previous two seasons. It seems that damage may be triggered by squirrel population factors, but then become severe only if the trees are suitable; experiments are under way to test this possibility.

Future forecasting should therefore take account not only of factors likely to enhance successful squirrel breeding, such as winter nut and mast availability, but also of factors likely to enhance sap thickness in summer. With a better understanding of these factors we can forecast how to reduce squirrel damage in the long term, by planting woods which have little winter food for squirrels until the trees are too mature to be damaged, and perhaps also by developing tree strains which have low sap thickness or are unpalatable.

Reference

Kenward, R.E. (1982) Bark-stripping by grey squirrels - some recent research. Quarterly Journal of Forestry 48, 108-121.

1B—R30

DAMAGE BY CEREAL APHIDS AND ITS IMPLICATIONS FOR FORECASTING AND CONTROL

E. GRIFFITHS, J. HOLT, A. D. WATT, S. D. WRATTEN

Department of Biology, Building 44, The University, Southampton, SO9 5NH, U.K.

Introduction

The potential adverse effects of chemical control of crop pests are well documented. There is little evidence of these effects in association with cereal aphid control in Britain, hence the incentive for "insurance" spraying is strong. The models presented in this paper reveal that the advantages of cereal aphid spraying when guided by expected damage levels and costs outweigh such prophylaxis under most circumstances.

Damage assessment

In this analysis the maximum yield loss caused by an outbreak of Sitobion avenae was taken from published work to be 12.5%. Incorporating the influence of growth stage on damage levels, yield losses due to Metopolophium dirhodum at various sites in the U.K. and Europe during the 1979 outbreak were calculated to be between 3.5% and 9%.

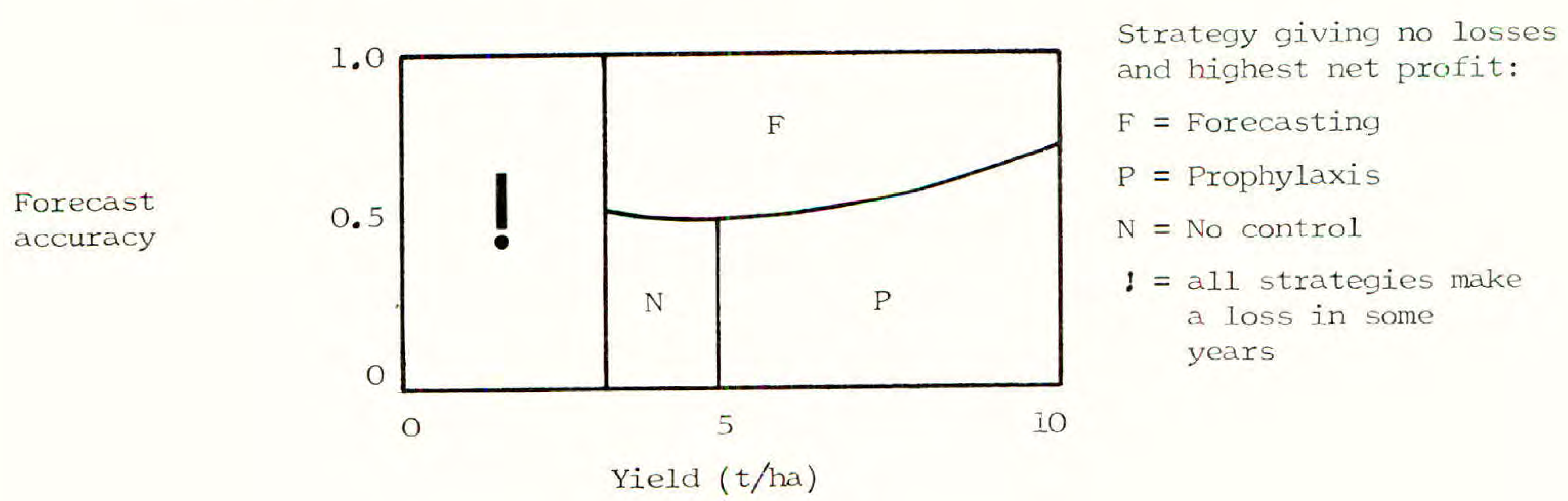
Control strategies for long-term maximum profit

Three strategies were compared: no control, insurance spraying each year and spraying only in some years based on an outbreak forecast. The value of insurance spraying depends upon aphid damage levels, the cost of control and the probability of an outbreak. The value of forecast-based spraying depends upon the accuracy of the forecast. An analyses with both aphid species showed that insurance spraying was more profitable than no control for yields greater than 3 t/ha. Forecast-based control is better than insurance spraying when forecasting accuracy is greater than about 60%. The degree to which control measures used against one aphid species also control the other aphid species depends on the temporal coincidence of the species; the above assumed a complete interaction of control measures. If no interaction occurs, insurance spraying is a better option than no control only when yields exceed 6 t/ha. An intermediate level of control interaction probably exists in practice. It may be possible to forecast with 100% accuracy when an S. avenae outbreak will not occur, but with lower accuracy when an outbreak will occur. Such asymmetry of forecast will prevent all damage but sprays are sometimes applied unnecessarily. In combination with even a very inaccurate symmetrical forecast of M. dirhodum outbreaks, an asymmetric forecast for S. avenae would ensure that insurance spraying against cereal aphids is never worthwhile even though M. dirhodum damage may occur in some years.

Short-term strategies

The above analysis could only apply to farms where a loss in some years is tolerated in return for an overall year-to-year profit. More usually a loss cannot be tolerated in any one year and careful costing is required to reveal the best strategies in this situation. Also, at their highest, spray costs are small relative to the gross profits and fixed costs of growing wheat, so the true cost of spraying can be masked. A more detailed analysis based on the above suggests that on a yearly net profit basis, prophylaxis is the best option only if the farmer applies cheap broad-spectrum insecticides himself and if any available forecast system is very inaccurate.

Example of graphical output from the "short-term strategy model"



MODELS FOR PREDICTING INSECT PEST DEVELOPMENT: COLORADO BEETLE

A.I. BREZHNEV, N.Yu. KONOVALOV, V.G. MALININA

Institute of Agrophysics, Leningrad, U.S.S.R.

Background and objectives

Integrated methods of plant protection have recently become widely used. The prediction of pest population development, including the dynamics of age structure, is extremely important for decisions about the choice of methods of plant protection and timing of treatments. As is well known, systems analysis and computer simulation approaches are very appropriate for research of complex field biocenoses (Konovalov and Malinina, 1979). This paper deals with these approaches to describe a model "plant - insect pest population - biotic interactions - environment - management" for the potato crop invaded by Colorado beetle, Leptinotarsa decemlineata.

Materials and Methods

Quantitative methods are proposed to describe the intrasystem processes in the five compartment mentioned in the name of the model. The compartments (or sub-models) include mathematical descriptions of air, water and heat conditions in soil and crop, of photosynthesis and respiration, of the ontogenesis of plants, of the detailed dynamics of pest population age structure (egg - larvae of different ages - pupa - imago), of the "insect pest - plant" and "predator - prey" interactions, and of the pesticide treatments.

The plant growth submodel incorporates the concept of limiting factors, the method of growth functions, and the layer-balance approach (Aleshin et al. 1981). To calculate the dynamics of number and age structure of insects, three mathematical methods are investigated: matrix models with uniform and non-uniform distributions of individuals into age gradations, and the differential-difference model with time lag. The data on ecology of Colorado beetle population and potato crop are also included in the submodels.

The different quantitative methods are analysed and their efficiency for applied simulation models is estimated. The programs are written in FORTRAN-IV and executed on mini-computer SM-4.

Results and conclusions

The layer-balance approach enables us to substitute the original system of productivity equations with continuously distributed parameters with the equivalent equations with discrete parameters; Computer time is thus decreased. The non-uniform matrix submodel of age structure is more closely correlated with the natural instars than uniform one. It simplifies considerably the identification of parameters, but nevertheless shows good agreement with the experimental data. The differential-difference equations written in the terms of natural instars, allow the exact solution and have an advantage if it is possible to choose a relative time, (for example, the sum of effective temperatures), eliminating the weather effects on the instar duration.

The suggested quantitative methods are designed for applied simulation models and for mini-computer implementation. The wide range of situations that are common in the different soil-climate areas of the European part of the U.S.S.R. have been numerically simulated using standard meteorological measurements. The yield damage caused by the Colorado beetle population has been calculated. The analysis of computer experiments proves the adequacy of the general model. This developed approach seems to be appropriate for searching the optimal plant protection strategy within the management problems of crop productivity.

References

Aleshin, V.D.; Brezhnev, A.I.; Poluektov, R.A.; Hlopotenkov, E.D. (1981) The layer-balance dynamical models of water and heat exchange in soils. Doklady VASHNIL 12, 38-39. (in Russian).

Konovalov, N. Yu.; Malinina, V.G. (1979) The modelling of insect pest dynamics in agro-ecosystems. Doklady VASHNIL 5, 43-45. (in Russian).

Malinina, V.G. (1979) The simulation model of the "pest - plant - environment" agroecosystem. In: Theoretical Foundations and Quantitative Methods of Yield Programming, Leningrad, pp. 93-105. (in Russian).

1B—R32

ECONOMIC THRESHOLD FOR BOLLWORMS ON GOSSYPIUM ARBOREUM IN THE PUNJAB

N.S. BUTTER; H.S. SUKHIJA

Department of Plant Breeding, Punjab Agricultural University, Ludhiana (Punjab), India

Background and objectives

Pink bollworm, Pectinophora gossypilla, is a key pest of cotton. Spiny bollworm, Earias spp., has also become a regular pest in the changed agroecosystem; it appears early and damages terminal shoots. Its attack then shifts to reproductive organs which are shed and therefore lost. Simultaneously, pink bollworm activity starts from July. Gossypium arboreum cottons are more prone to spiny bollworm injury and there are no effective natural enemies of these bollworms. Therefore, studies were carried out at Ludhiana and Jalandhar Research Stations of Punjab Agricultural University for two years to determine the appropriate crop stage for timing pesticide sprays.

Materials and Methods

Three trials during 1981 and 1982 were conducted on cotton variety LD 230, in a randomized block design. The sowings were done on hills 60cm apart with 30cm between plants. The effects of sprays at five square (first flower buds)/flower initiation stages were compared with complete control where sprays were repeated at 10-day intervals until 2 weeks before boll burst. Cypermethrin (Ripcord 10 EC) at 50 g a.i. ha^{-1} was used with a hand sprayer at constant pressure of 13.75 kg/2.5 cm^2. Nearly one month before the boll-burst stage, ten plants were selected at random from each plot, preferably from the central rows. The seed cotton was picked from these plants and the bollworm damage was calculated on locule basis. The data of all the trials were statistically analysed.

Results and Discussion

The lowest bollworm incidence (1.5%) was recorded in a treatment where spray was initiated at the start of squaring. However, this was statistically similar to the treatment which received first spray at 50% squaring. The remaining treatments where spraying started either at the start of flowering, one week after the start of flowering, and two weeks after the start of flowering, were similar in terms of reduction in bollworm infestation and increase in yield. However, they were significantly better than the unsprayed control. The bollworm incidence of the unsprayed control was 13.0%. The highest yield (22.41 qtl ha^{-1}) was recorded where the crop was sprayed at 10% squaring, and this was similar to the treatment which received first spray at 50% squaring. The reduction in yield was noted in all treatments in which the first spray was delayed beyond 50% squaring. The results clearly show that chemical control against bollworms on G. arboreum should be started when 50% of plants are at square initiation stage. Sukhija and Reddy (1983) also reported that short cycle larvae of pink bollworm in the shed material was low where spray was initiated at the early squaring stage.

The authors are grateful to Dr T.H. Singh, Senior Cotton Breeder-cum-Head, Department of Plant Breeding, Punjab Agricultural University, Ludhiana (India) for providing research facilities and Dr H.S. Rataul, Professor of Entomology for critically reviewing this report.

References

Sukhija, H.S. and Reddy, J.G. (1983). Time of initiating insecticidal application for the control of Pectinophora gossypiella (Saunders). Journal of Research of Punjab Agricultural University 20, 47-56.

IMPROVEMENT OF A WHEAT PEST MANAGEMENT SYSTEM

D.W. ONSTAD, R. RABBINGE, W. ROSSING

Department of Theoretical Production Ecology, Wageningen, the Netherlands

Background and objectives

EPIPRE is a centralized computer-based warning system for pests and diseases in winter wheat in The Netherlands. Participating farmers are provided with field-specific recommendations on monitoring and spraying, based on cost-benefit analysis. Monitoring is carried out by the participants themselves with an efficient standard procedure. Population growth and development is predicted 1-2 weeks ahead using simplified versions of explanatory simulation models. A spraying recommendation is given when losses calculated as a function of expected yield, exceed costs of pesticide application (Rabbinge and Rijsdijk 1983).

Decision procedure

The EPIPRE decision criteria do improve pest management in wheat, but they do not necessarily provide the best (i.e. most economical) solution. Dynamic programming (D.P.) is a technique that can efficiently determine optimal control policies for complex management models of the wheat ecosystem (Shoemaker 1981). This method transforms the problem of making a series of N decisions during a growing season into the more easily solvable problem of making one decision in each of N stages which together represent the whole season. The algorithm is suited for optimization of deterministic and stochastic models containing up to six variables describing the state of the system and a large number of complex management decisions.

Results and discussion

From several D.P. models developed for yellow stripe rust and cereal aphids it became clear that this technique can be a powerful tool in optimizing control recommendations of EPIPRE. As a result of accurate timing of applications, the number of recommendations to treat with a pesticide was reduced. A deterministic model combining the effects of yellow stripe rust and aphids showed lower economic thresholds than when only aphids or yellow rust was present.

Future efforts will be directed towards incorporation of stochastic variables, e.g. crop development stage and sampling errors, in such a way that an estimation can be made of the risk associated with a recommendation.

References

Rabbinge, R.; Rijsdijk, F.H. (1983) EPIPRE: a disease and pest management system for winter wheat, taking account of micrometeorological factors EPPO Bulletin 13, 297-305.

Shoemaker, C.A. (1981) Applications of dynamic programming and other optimization methods in pest management IEEE Trans. Automatic Control 26, 1125-1132.

1B—R34

THE MATHEMATICAL PREDICTION OF THE MAIN PESTS OF FRUIT IN GEORGIAN SSR

G. ALEKSIDZE, A. MILNIKOV

The Georgian Institute of Plant Protection USSR Tbilise, 380062, Chavchavadze Av. 82

A system for storing and using information characterizing the relationships of plants and their pests is described. The system mainly depends on climatic data which are stored in an index-successive file for DOS of an EC computer. This file contains daily temperatures, rainfall, humidity, also phenological data on fruit tree development and information on pests.

In a series of programmes it has been possible to sum temperatures, rainfall and humidity and work out hydrothermic coefficients for given phenological periods. This information is used in programmes of multiple regression analysis which enable the significance of varying certain factors to be determined.

Regression models are examined in three ways: as linear models, nonintrinsically nonlinear models, and nonlinear estimation.

The system enables a satisfactory prediction to be made of fruit pests in different regions of Georgia.

PEST MANAGEMENT PERMITS PESTICIDE USE TO BE REDUCED

S. UMAROV, M. TAJIBAYEV

Institute of Zoology and Parasitology, Tajik Academy of Sciences, USSR.

The use of biological control and integrated control techniques have enabled pesticide use to be reduced and pest management is now widely used in the USSR.

In cotton integrated control is possible and is based on an understanding of the economic damage thresholds of pests. Integrated methods, by allowing less pesticide to be used are also less expensive.

In the first year of field experiments on certain state-farms only 25-30% of the cotton growing area required treatment with pesticide which was much less than on neighbouring farms.

Under the most favourable climatic conditions a further reduction in pesticide use might be expected.

Reduced pesticide use favours the build up of entomophagous insects which can control pest populations. Counts on cotton in July in the Yavan region showed that up to 1000 entomophagous insects could be found on 100 plants.

1B—R36

INSECT PHEROMONES IN INTEGRATED PEST MANAGEMENT

I. HRDÝ et al.

Institute of Organic Chemistry and Biochemistry 16610, Praha 6, Flemingovo n.2. Czechoslovakia.

Synthetic chemicals which modify insect behaviour, especially insect sex pheromones, can be useful in integrated pest management. Different ways in which pheromone-baited traps have been employed are described.

1. Pheromones can be used for detection and monitoring. Two new important pests have been found by their use in Czechoslovakia: Oriential fruit moth, Cydia molesta and the Alfa-Alfa moth, C. medicaginis.

2. Timing of control methods. Pheromone trap catches of the codling moth C. pomonella in combination with meteorological data have been used for forecasting flight peaks.

3. Pest surveying. Monitoring systems based on pheromone-baited traps have been developed for several economically important insect pests of field crops, orchards, vinyards, forests and stored products.

1B—R37

COMPARISON OF REGISTRATION METHODS FOR FORECASTING APPLE SCAB

J. CIMAMOWSKI,
Institute Pomology and Floriculture, 96-100, Skierniewue, Poland.