PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

The Current Status and Future Potential of Chemical Approaches to Crop Protection [and Discussion]

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Phil. Trans. R. Soc. Lond. B 1981 **295**, 5-16
doi: 10.1098/rstb.1981.0121

Phil. Trans. R. Soc. Lond. B **295**, 5–16 (1981) [5]
Printed in Great Britain

The current status and future potential of chemical approaches to crop protection

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Pesticide research has provided compounds of progressively increased activity, and recently discovered insecticides, fungicides and herbicides are outstandingly potent. Consideration of the practical use of such chemical agents suggests that greater attention should now be given to methods of application and to the physico-chemical properties that determine redistribution and biological availability following release. Effective economical control agents are not yet available for several categories of damaging organism including viruses, bacteria and certain soil-borne pests and diseases. Analysis of the reasons why these categories have proved so refractory suggests that alternative chemical approaches, such as treatments that modify the host plant, and additional properties such as mobility in plants should be investigated. Such analysis also emphasizes the need to consider chemical approaches together with other methods of control in relation to the life histories and population dynamics of the species concerned. Detailed consideration of this principle can not only yield information about the optimum deployment of chemical agents to ensure their continuing efficacy but also suggest the types of action that would be most appropriate. The potential for further improvements in the materials available and methods of use is substantial, but how far this potential is realized will depend as much on policy and economic considerations as scientific factors.

Introduction

Chemical approaches to crop protection were initially simple in concept. Pests and diseases were seen to be consuming crops intended for man or his livestock, weeds competing with these crops and inhibiting cultural operations. In considering ways to combat the offending organisms, poisoning must have come readily to mind and offered obvious logistic advantages. However, toxicants sufficiently active to allow exploitation of the concept were not quickly forthcoming. For centuries, while there was no doubt awareness of the need to safeguard the operator, the consumer and other non-target organisms, the principal concern was to find chemical agents more effective against the pest. During the last 40 years this search has been outstandingly successful and the situation has been transformed. Figure 1 shows that the potency of all the major classes of agent, insecticides, fungicides and herbicides, has increased progressively by several orders of magnitude since the beginning of this century.

This trend of increasing activity reflects attack on increasingly specific and sensitive sites within the organisms concerned, from the general enzyme inhibition characteristic of the inorganic pesticides, through disruption of commonly occurring processes as with uncouplers of oxidative phosphorylation such as the dinitrophenol compounds, to inhibition of specific enzymic or physiological processes as with pyrethroid insecticides or bipyridyl herbicides. The most recent discoveries represent remarkable levels of activity; nevertheless both biochemical considerations and circumstantial arguments (Graham-Bryce 1975*a*) suggest that the limits of activity have not yet been reached so that more potent compounds can be expected to emerge, either by high-throughput screening or from fundamental biochemical and physiological studies. In the light of experience gained through the widespread use of modern highly effective pesticides it is appropriate to question whether the emphasis on intrinsic activity in the quest for new products remains valid and to consider how to take full advantage of recent advances in potency. Existing techniques for using conventional control agents are based largely on previous standards of activity, which correspond to application rates of about 1 kg ha^{-1}. It is important to ensure that the evolution of methods for using pesticides keeps pace with the improvements in activity and to examine how molecular properties other than activity should be related to these techniques.

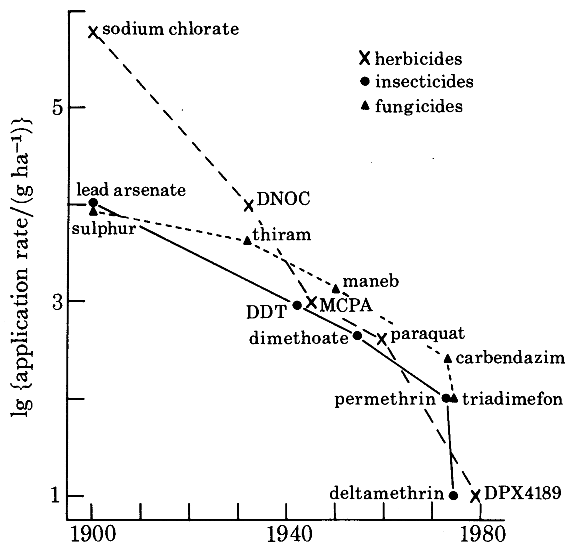

Figure 1. Application rates for representative crop protection chemicals plotted against the date of the introduction to illustrate the progressive increase in activity since the beginning of this century. Rates indicated are representative values from the range employed in commercial practice for each compound.

Pesticide application

With existing methods of pesticide application, the proportion of the applied dose that reaches the pest, pathogen or weed can be extremely small, commonly considerably less than 1 % (Graham-Bryce 1977). Low levels of utilization may be dictated by the nature of the control problem, for example by a low incidence of damaging organisms at an early stage of an infestation when treatment is required. Nevertheless there is usually substantial scope for improving the efficiency of utilization and thereby both increasing efficacy and decreasing unproductive release into the environment. Analysis of some of the causes of low efficiency suggests that the problem is likely to increase with decreasing rates of application.

Fate of pesticides after release

The amount of pesticide delivered to the target organism depends on the initial distribution achieved by the application system and by subsequent redistribution and biological availability, which in turn are determined by interaction between partition and transport processes in the environment, the physico-chemical properties of the pesticide and the formulation employed. In considering these factors, it should be recognized that deposits resulting from current rates of application are extremely sparse. A rate of 1 kg ha^{-1} is equivalent to a concentration of only 1 μg g^{-1} if incorporated uniformly into the top 10 cm of soil or a layer only 0.1 μm thick if spread evenly over a flat surface. Applied to the rough surface of soil or the leaf area of a crop the deposit thickness would be less than one-tenth of this, and figure 1 shows that rates of application of modern highly active compounds may be two orders of magnitude smaller.

In the field the chemical is exposed at such low coverage to severe chemical, microbial and physical weathering processes, which may be illustrated by considering evaporation. Table 1 shows the potential loss to the atmosphere from an inert surface under English summer conditions for some representative pesticides, calculated from measurements of water evaporation using the principle that relative rates of evaporation for different chemicals are proportional to the products of vapour pressure and the square root of the relative molecular mass.

TABLE 1. POTENTIAL EVAPORATION FROM 1 ha INERT SURFACE

	vapour pressure at 20 °C mmHg†	M_r	predicted annual loss/kg
DPX 4189	4.6×10^{-7}	357	1.20
binapacryl	4.7×10^{-7}	322	1.16
DDT	1.9×10^{-7}	355	0.49
deltamethrin	1.5×10^{-8}	505	0.05
simazine	6.1×10^{-9}	202	0.01
triadimefon	7.5×10^{-10}	294	0.002

† 1 mmHg ≈ 133 Pa.

The evaporative potential can clearly exceed the rate of application, especially for the highly active chemicals applied at small dosages. While in practice this will be counteracted by factors such as sorption by plant surfaces, incorporation in soil and formulation, this example emphasizes that as rates of application decrease there is a corresponding increase in the significance of certain redistribution processes, either for delivery to the target or exposure of unintended recipients. This argues for giving greater attention to the physico-chemical properties that determine response to such processes. The general case for devoting more consideration to these properties is already strong. Candidate pesticides are almost always selected for field evaluation on the basis of their activity to test species when applied under closely standardized conditions in the laboratory or glasshouse. Compounds that are most active in such screening tests may well differ from those that would perform most effectively in the field because of physico-chemical factors influencing transport in the environment and biological availability, which are usually not evaluated. For example, Briggs (1977) showed that, for a group of substituted urea herbicides, molecular electronic and partition properties influence mobility and availability to plant roots in the opposite direction to their effects on intrinsic activity. Compounds most effective in the field therefore represent a balance between these opposing tendencies.

More generally, there is now sufficient understanding of transfer processes and factors determining biological availability to specify with reasonable confidence the physico-chemical properties appropriate for many control requirements and enough knowledge of molecular features influencing these properties for informed consideration of structural possibilities, at least in relation to a parent compound (Hartley & Graham-Bryce 1980). With decreasing rates of application there seems to be a good case for devoting more attention to these properties.

Application techniques and formulation

The influence of application method and formulation on efficiency of use also merits further appraisal in relation to the increase in potency achieved in recent years. This can be exemplified by considering the application of sprays to control insect pests by direct interception.

TABLE 2. RELATION BETWEEN TOXICANT CONTENT AND DROP SIZE

(Application rate 20 g ha^{-1} in 10 l carrier.)

drop diameter / μm	number of drops in 10 l	amount per drop / ng
50	1.5×10^{11}	0.13
100	1.9×10^{10}	1.04
300	7.1×10^{8}	28

activity of deltamethrin (from Elliott *et al.* 1978)

	l.d.$_{50}$/ng per insect
Anopheles stephensi	0.04
Phaedon cochleariae	0.19
Plutella xylostella	1.13

Both theoretical arguments and practical experience indicate that the efficiency of spraying (assessed in terms of, on the one hand, wastage from overdosing with drops that are too large and, on the other, underdosing or drift from drops that are too small) increases with increasing frequency of interception and consequently with decrease in drop size or content (Graham-Bryce 1977). The broad objective should be to distribute the lethal dose among many drops and adjust spraying procedures to achieve a corresponding number of impacts. Table 2 explores the application of these principles to highly active modern insecticides, represented by deltamethrin (Graham-Bryce 1981).

For the application rate illustrated (20 g ha^{-1} in 10 l of carrier, conditions reasonably representative of commercial practice) the toxicant content of even the smallest drops is greater than or comparable with the median lethal doses (taken from Elliott *et al.* 1978) except for *Plutella xylostella*. To achieve the objectives identified above would require either a substantial increase in volume rate, thereby sacrificing the logistic and economic advantages of low volumes, or a decrease in the drop size, which would increase the risks of drift if conventional application methods were employed.

The implied conclusion, that the potency of the active ingredient precludes its efficient application, rests on the volume rate chosen for illustration and would apply to any toxicant if rates of application were strictly related to intrinsic activity. In practice this does not appear to be so. Table 3 shows that for three representative insecticides included in figure 1, the increase in intrinsic activity has not given a corresponding decrease in application rate, presumably because of the dampening effect of the weathering and delivery factors discussed above.

The freedom of manoeuvre in seeking more efficient application may thus be increasingly constrained as activity increases. Recent major advances in application techniques are therefore especially timely. In particular the development of electrostatic spraying systems (Arnold 1979; Coffee 1979) opens up the prospect of improving deposition on the intended target and matching drop specifications more closely to the biological requirements without attendant problems of wastage or of drift where the requirement is for small drops.

Table 3. Application rates and intrinsic activities of insecticides

compound	application rate† (g ha^{-1})	relative application rate‡	relative lethal dosage§ *Phaedon cochleariae*	*Anopheles stephensi*	*Choristoneura occidentalis*	*Musca domestica*
DDT	1000	50	3700	1550	993	158
dimethoate	500	25	550	564	3000	42
deltamethrin	20	1	1	1	1	1

† Representative of the range of application rates used in commercial practice.
‡ Rates relative to that of deltamethrin = 1.
§ From Elliott *et al.* (1978). Values are for median lethal doses by topical application relative to deltamethrin = 1. Absolute values for deltamethrin in nanograms per insect are: *P. cochleariae*, 0.19; *A. stephensi*, 0.04; *C. occidentalis*, 0.74; *M. domestica*, 0.26.

Control of damaging organisms

In the light of the undoubted improvements in the armoury of chemical crop protection agents, it is of interest to consider progress made in the practical control of pests, diseases and weeds. There are, of course, numerous demonstrations of clear economic benefits from pesticide treatments, particularly where these are coupled with monitoring of infestation levels and a system of threshold values (see, for example, the review by Gough (1977)). Nevertheless, many estimates indicate that substantial scope for reducing losses remains; the formidable and frequently quoted survey by Cramer (1967) indicated that approximately one-third of the total value of the world's crops is lost to pests, pathogens and weeds, with a further 15% lost by attack on harvested produce, despite the extensive use of modern control methods.

It must also be acknowledged that many losses remain unrecognized, a point well illustrated by work on replant disease of apples. This soil condition inhibits growth in apple orchards replanted without a break crop. It can be alleviated by, for example, fumigating the soil with chloropicrin, or drenching with formalin. Recent studies (Sewell & White 1981) have shown that poor growth is not restricted to replanted soils, but may be a widespread phenomenon that is not usually detected and may well apply to other crops.

A significant proportion of the recognized losses must be due to failure to adopt existing technology, particularly in developing countries. Other losses arise from inadequacies in the deployment of chemical agents, some of which are discussed above: inefficient application, insufficient knowledge of population dynamics of damaging organisms with consequent inability to forecast infestations, and dependence of performance on weather. There are still, however, important groups of damaging organism for which no economically effective chemical treatments are available. Some are listed in table 4, together with certain general requirements or shortcomings that can apply to chemical agents currently available within each main category. Among these general requirements, the need to maintain effectiveness by circumventing the development of resistance in the treated population is probably the most important.

Requirements for controlling refractory organisms

The notable success in finding control agents for most groups of damaging organism prompts the question as to why those listed in table 4 have proved so intractable. Three possible causes can be suggested, which may interact to varying degrees.

First, they may represent relatively small markets commercially and therefore not justify the extensive efforts that have gone into the search for agents to control organisms causing major economic losses. The importance of this factor should not be underestimated: with research and development costs now approaching £10M per marketable product, potential sales must be very substantial and usually on a global scale to justify the necessary investment (Braunholtz, this symposium). Even damaging agents that cause severe losses locally or occur widely but on minor crops may fail to reach the critical economic importance and the threshold is likely to rise further as economic pressures on the agrochemical industry increase.

TABLE 4. CROP PROTECTION CHEMICALS: SOME REMAINING PROBLEMS AND OPPORTUNITIES

category	*organisms for which control agents are required*	*general considerations*
pests	soil-borne insect pests nematodes	susceptibility to resistance mammalian toxicity hazard to beneficial insects mobility in plants
diseases	viruses and related organisms bacteria soil-borne pathogens	susceptibility to resistance mobility in plants persistence of control
weeds	volunteer crops perennial weeds in growing crops	carry-over effects emergence of resistance

The second possible reason is that the organisms concerned are intrinsically less vulnerable to chemical attack. Certain characteristics of refractory organisms could be said to lend support to such an hypothesis. For example, viral and bacterial pathogens, and to a lesser extent possibly nematodes, lack some of the sensitive processes that have proved particularly susceptible to chemical attack in other groups, such as the neurophysiological processes in arthropods or the photosynthetic apparatus in higher plants. However, there seems to be a wide range of remaining biochemical and physiological processes that should be amenable to disruption, so that other factors must operate.

Selectivity is an obvious possibility. Thus the very intimate dependence of viruses and mycoplasmas on the cellular functions of the host makes it difficult to find chemical agents which can inhibit them without disrupting the plant. More complex considerations may also apply. In bacterial diseases various inorganic and organic materials are known to be active against plant pathogens (see review by Egli & Sturm 1980), and the outstanding success of antibiotics in the treatment of human infections demonstrates that as a class these organisms are by no means inviolate against chemical attack, although it should be recalled that the majority of plant pathogenic bacteria are Gram-negative in contrast to those pathogenic against humans. Factors such as instability and cost have mitigated against the use of antibiotics in crop protection, but some including blasticidin, validamycin, the polyoxins and notably streptomycin are sufficiently effective against bacterial diseases of plants in the field to be used as practical control agents. Widespread use of streptomycin against fireblight (*Erwinia amylovora*) in the western U.S.A. has led to the emergence of resistance (Coyier & Covey 1975), and there has been reluctance to use such antibiotics for controlling plant diseases because of the additional concern that resistance might develop in related human pathogens or be passed on to them by plasmid transfer.

Table 5. Distribution between phases in soil

compound	$P_{\text{air}}^{\text{water}}$†	K_d‡	percentage in phase: air	water	solid
dimethoate	2.5×10^{8}	0.3	1.6×10^{-7}	40	60
EDB	43	0.5	0.7	28.4	70.9
DPX 4189	6.6×10^{6}	0.5	4.3×10^{-6}	28.6	71.4
simazine	7.4×10^{7}	1.9	1.3×10^{-7}	9.5	90.5
dichlobenil	3.5×10^{3}	4.2	0.0013	4.6	95.4
linuron	3.8×10^{5}	18	2.9×10^{-6}	1.1	98.9
lindane	2.0×10^{4}	25	4.1×10^{-5}	0.8	99.2
ethirimol	8.9×10^{6}	33	6.7×10^{-8}	0.6	99.4

† Partition coefficient between water and air calculated from aqueous solubility and vapour pressure.
‡ Coefficient of adsorption on soil solids corresponding to the quotient of amount adsorbed per unit mass of soil and amount per unit volume in the equilibrium solution.

Consideration of this second possible reason does not suggest that chemical methods should be abandoned, but rather that a different direction might prove more rewarding. A most promising alternative approach is modification of the host to prevent entry of the pathogen, to suppress symptoms or to encourage recognition processes in the plant and promote naturally occurring defence mechanisms. There are now established examples demonstrating the practicality of all these possibilities, including the suppression of mosaic virus symptoms in lettuce after application of the fungicide carbendazim (Tomlinson *et al.* 1976), the use of the growth regulator daminozide against common scab (*Streptomyces scabies*) of potato (McIntosh 1975) and the discovery of experimental cyclopropane carboxylic acid compounds that encourage natural defence mechanisms in rice (Langcake, this symposium).

The third possible explanation for lack of successful chemical treatments is that the behaviour and life histories of the organisms concerned make them relatively inaccessible to applied chemicals. Such an explanation would apply particularly to soil-inhabiting species, which are prominent among those listed in table 4. Even when compounds intrinsically toxic to these organisms are available, there is a severe problem in delivering an effective dose to what are usually minute targets, widely distributed within a medium through which movement is retarded by the tortuous nature of the pore system and by adsorption on particle surfaces and in which the applied dose is progressively diminished by a wide range of microbial and chemical degradative processes. Table 5, calculated from solubilities, vapour pressures and adsorption coefficients (Hartley & Graham-Bryce 1980), emphasizes that even when adsorption is only moderate, the amount immobilized and biologically unavailable by adsorption on the solid phase greatly exceeds that freely available in the mobile phases.

These figures put into perspective the outstanding potency of the herbicide DPX 4189 (figure 1), which is active via the soil at rates as low as 10 g ha^{-1} (Palm *et al.* 1980). They also underline the need to give consideration to optimizing physical properties, discussed above. It is because of the problems of achieving effective delivery of toxicant from soil treatments, that systemic insecticides, fungicides and nematicides translocated downwards in plants would be particularly welcome for controlling this refractory group of soil-borne organisms, and the discovery of active compounds with such a property must remain a major goal of agrochemical research.

The problems of inaccessibility must also be related to the population dynamics of the organism and in many cases the need for very high levels of control. Studies on the control of the dagger nematode (*Xiphinema diversicaudatum*), the vector of arabis mosaic virus in hops, by McNamara *et al.* (1973) provide a good example. This work indicated that even 99.9% mortality would leave 120 nematodes per root system, assuming an initial population of only 5 per litre. In the case of virus transmission such a residual population could be quite sufficient to cause significant damage.

Objectives of control

This last example embodies an important general principle, namely the need to keep in mind the true objective of the treatment. The purpose of crop protection treatments is to prevent damage to crops, not to kill damaging organisms. The distinction is well exemplified by considering disease vectors, such as the nematodes discussed above or aphids carrying viruses. There are formidable problems in designing experiments to evaluate pesticide treatments against such vectors: with small replicated plots there is often a serious risk of interference as sprayed areas influence the behaviour of untreated controls and vice versa. Immigration from outside the treated area may also occur. Multiple infection becomes increasingly important as the level of infection increases, and differences between treatments tend to be underestimated (Gregory 1948).

Nevertheless there are some striking demonstrations that control of the vector does not necessarily prevent virus spread. Work by Thresh (1968) on the control of reversion virus and its gall mite vector (*Phytoptus ribis*) may be cited. Blackcurrant bushes exposed to infestation from neighbouring sources were sprayed with endrin or lime–sulphur, or left unsprayed. The pesticide treatments significantly decreased both mite infestation and virus infection, but whereas endrin controlled mites much more effectively than did lime–sulphur, it gave poorer control of virus. Figure 2 shows representative results from plots for which infested and unsprayed bushes acted as virus sources. Thresh suggested that the results could be explained by the different types of action of the two pesticides. Lime–sulphur acts primarily as a contact poison, decreasing the number of mites reaching sites susceptible to infection with virus. Endrin, in contrast, kills relatively slowly and while it may eradicate mites after they have invaded the bushes, this allows time for virus transmission. Assessment of mite eradication in screening tests might therefore give a misleading impression of practical potential. More generally this example illustrates the need to judge the success of chemical treatments in relation to the true objective and not on the basis of some prominent but possibly invalid criterion.

The problems of controlling viruses by attacking the vector are well recognized. In some instances, for example on soybean in the U.S.A., virus spread can be by itinerant insects that never settle, feed or breed on the crop, they merely land, probe and fly off, offering no prospect of control by residual insecticides. Again, this should not be regarded as a cause for abandoning

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chemical control, but rather as a stimulus to consider other approaches. In this case, one possibility is to seek chemicals which are repellent or which prevent probing. Mineral oils have shown promise for this purpose (Loebenstein & Raccah 1980) and recently Sawicki *et al.* (1981) made the interesting observation that the potent pyrethroid insecticide deltamethrin can decrease virus transmission by disturbing aphid behaviour.

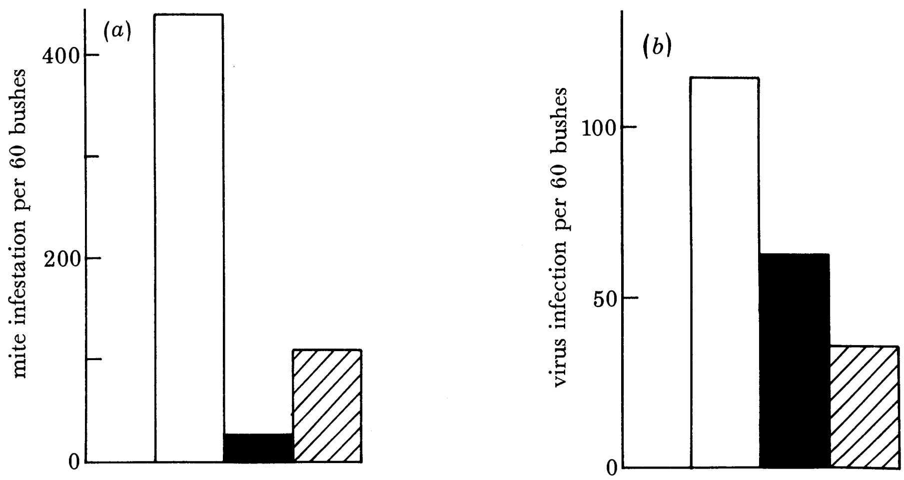

FIGURE 2. Mite infestation (*a*) (total of infested buds, shoots and bushes per 60 bushes) and reversion virus infection (*b*) (total of virus infected shoots and bushes) on blackcurrant bushes receiving different insecticide treatments (selected results from Thresh (1968)). □, Unsprayed; ▨, lime–sulphur; ■, endrin.

These cases represent just one example of the now well established approach of turning to behaviour-modifying chemicals to improve the effectiveness of conventional pesticides (as in pheromone monitoring traps used to improve timing of pesticide application) or for direct control when traditional lethal action proves unsatisfactory. Baker (this symposium) discusses the current status of these approaches.

Epidemiological and ecological considerations

The discussion of vector control in the preceding section also exemplifies the much wider principle of considering any control agent in relation to the life history and population dynamics of the treated organism. Experience gained from the extensive adoption of modern synthetic pesticides has emphasized the importance of this principle. The risks of resistance, of persistent residues and of damage to natural enemies and other unintended recipients are now widely appreciated. They may be regarded as problems of success, deriving from the provision of a range of potent and effective products that have been eagerly exploited; they should not be overemphasized but their recognition has helped to promote the general realization that noxious organisms should be regarded not as individuals but as members of populations. The complementary principle is that chemical control is just one of the types of check that can be imposed on the development of a damaging population. This epidemiological or ecological approach is the essence of integrated pest, disease or weed management, however defined. Further discussion of integrated approaches lies outside the scope of this paper; recent summaries are provided in this symposium by Geissbühler and by Fryer (1981). However, some implications relating to requirements for future agrochemicals will be considered briefly.

First, the epidemiological attitude can lead to views not only about the optimum deployment and environmental properties of chemical agents, but also about the type of action that would be most effective. This may be illustrated by recent studies by M. Jeger (unpublished) on powdery mildew of apple. The starting point is the concept that the various possible population checks should be considered as equivalent in terms of control (see also Vanderplank

Table 6. Resistance of *Phorodon humuli* to organophosphate insecticides

	introduction	resistance reported	resistance factor
demeton-*S*-methyl	1954	1965	29
methidathion	1970	1975	4
omethoate	1972	1973	26
mephosfolan	1975	—	2

1963; Wolfe 1975; Fry 1980), specifically for this example fungicide treatment and host plant resistance. Rational strategies for using the two control measures to maintain disease levels below a predetermined threshold may be devised by considering the effects of each on the rate of disease development. Further insight may be achieved by considering the components of partial resistance in the host plant. Jeger has identified a series of components for apple mildew that may be related to the following experimentally observable characteristics: incubation period, numbers of leaves infected, area colonized and numbers of conidia per leaf. Different cultivars may thus be classified not only on the basis of their overall resistance to disease but also in terms of the different components underlying the overall effect. It will be clear how such analysis can indicate the optimum method of applying a chemical agent of given activity and persistence to complement the host resistance most effectively. Furthermore, by identifying the nature of the host resistance it can suggest the stage in the pathogen life cycle most vulnerable to chemical attack. In this case sporulation appeared to be particularly important for the developing infection suggesting that especial consideration should be given to antisporulant fungicides.

Secondly, preserving the useful life of chemical agents by circumventing resistance in the treated population is an important component of integrated management strategies. In this connection it should be pointed out that although resistance is probably the most important and intractable problem affecting chemical methods of crop protection, it does not appear to be inevitable even when selection pressure is maintained; or at least there are great differences between compounds in the speed at which it develops and the level that results. Insecticide treatments against the damson-hop aphid, *Phorodon humuli*, provide a good example (Muir & Cranham 1979). Resistance to organophosphate aphicides in this pest was first reported in 1965; the rate of development and level of resistance to members of this insecticide class introduced subsequently has varied (table 6) from cases where high levels have occurred almost immediately (omethoate) to those where resistance is not significant after several years use (mephosfolan). Clearly an understanding of the molecular properties that give rise to such differences would be of the greatest value in planning integrated management strategies.

Thirdly, it is readily apparent that in seeking to employ chemical approaches more discerningly, selectivity between the noxious organism and unintended recipients is a key property. Selectivity results from differences in three types of process operating singly or interacting: penetration to the site of action, metabolic attack during passage to this site, and interaction with the target site. In some cases the basis of selectivity in a particular compound can be deduced in terms of these mechanisms. In principle it should be possible to go a long way towards devising selective compounds within established pesticide classes by more deliberate study of the underlying processes within different organisms (Graham-Bryce 1975*b*). This would be a formidable undertaking, but it will probably be a question of cost in relation to possible returns rather than technical feasibility that determines whether such studies are made.

Such arguments apply to many suggestions for improving crop protection practices. The potential for further technical advance is still very substantial. How far this potential will be realized in practice will depend as much on policy and economic considerations as on scientific factors.

I thank many colleagues for stimulating discussions and permission to quote published and unpublished results, in particular Dr E. Billing, Dr J. E. Cranham, Dr M. Jeger, Dr R. M. Sawicki and Dr M. Thresh.

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Discussion

J. H. Stevenson (*Rothamsted Experimental Station, Harpenden, U.K.*). Dr Graham-Bryce has discussed the possibilities of using physico-chemical properties of compounds to assess and even forecast their performance as pesticides in the field. He has also drawn attention to the high costs of providing data on pesticides for government registration authorities.

To what extent can physico-chemical data be used to simplify the provision of registration data and so reduce these costs? For example, would it be possible to forecast dosage rates in different soil types or life expectancy for residues?

I. J. Graham-Bryce. There is no doubt that the broad patterns of behaviour in the environment can now be predicted for candidate pesticides from a knowledge of vapour pressure, solubility and polarity by applying established theoretical relationships and by comparing these properties with those of reference compounds of known behaviour. Forecasting stability is rather more difficult on the basis of current knowledge, but reasonable estimates can be made by careful consideration of molecular structure, again in relation to compounds whose stability has been well characterized in the field. In principle it should therefore be possible in suitable cases to reduce the amount of experimental information on environmental behaviour required for registration substantially, relying on a reduced number of tests to validate the predictions. In view of the importance attached to these issues, however, it could be difficult to persuade registration authorities to accept such an approach, although this would unquestionably reduce costs. Furthermore, the potential for exploiting such knowledge in the design of compounds with appropriate environmental properties should not be overlooked.