INTEGRATED PEST MANAGEMENT AND MICROBIAL INSECTICIDES

D R DENT
International Institute of Biological Control, Ascot, Berks SL5 7TA, UK

ABSTRACT

Research into the development and use of entomopathogens as microbial insecticides is influenced by a range of factors including the current pest management paradigm of IPM. Interactions between entomopathogens and other control measures have been studied within the context of IPM which has allowed for poor performance standards of microbial insecticides. The implications of this are considered in relation to the relatively recent polarization of IPM into technological and ecological based approaches.

INTRODUCTION

The dynamics of scientific progress involves changes in the relevance, importance and impact of scientific disciplines over time. In the terminology of Thomas Kuhn (1970, 1977) science progresses through the scientific exploration of paradigms; when the limitations of one paradigm become overwhelmingly apparent and cannot be ignored then a new scientific orthodoxy supplants the prevailing one (Medawar, 1981). Within this framework science may progress in a stepwise manner (which need not be linear), addressing one key issue and then moving onto the next. The process is particularly clear in applied sciences where a definite end point can be identified. Within insect pathology such an end point might be the development of a microbial insecticide. The steps taken in developing a microbial insecticide might be: (i) strain isolation (ii) laboratory bioassay (iii) mass production (iv) storage (v) formulation (vi) application technology (vii) field evaluation and (viii) commercialisation (Dent, 1993; Baldwin, 1986). A number of these stages may have to be addressed in sequence while others can be dealt with in parallel, rarely however in the field of microbial insecticide development, are all stages carried out by one research group.

Progress may be limited by the constraints of a particular methodology. The state of development in a discipline is reflected in the balance of new and established methodologies (Walton and Dent, in press). A new, emerging discipline may be characterised by the establishment of new methods or analytical techniques (i.e. a "vertical progression" in capability), whereas an established discipline and especially one that is stagnating, is characterised by an overwhelming expansion in the use of established methods i.e. a "horizontal expansion", where established methods are used on a range of pest species, conditions and cropping systems, providing a general increase of our knowledge base.

Microbial insecticide research is usually funded piecemeal, largely by the public sector, and rarely involves multidisciplinary teams that develop a microbial insecticide from start to finish. The general knowledge base in microbial insecticides is built up in a haphazard way, through the uncoordinated efforts of many scientists all pursuing their own individual research objectives and interests. This contrasts markedly with the more focused factory-like screening and development process which characterises agrochemical R & D that produces new chemical insecticides.

All of the above factors influence the level of research output for a given subject; output which can be measured in terms of numbers and content of scientific publications. The content of the publications also will be influenced by the prevailing paradigm, which in the case of microbial insecticides, is" Integrated Pest Management" (IPM) (Perkins, 1982; Dent, 1995). IPM has had a significant impact on microbial insecticide research, influencing and guiding the choice and emphasis of topics addressed by scientists. However, IPM as a concept has also developed over time and it may now no longer reflect the approaches and aspirations of those who have conducted research into microbial pesticides as components of an IPM system, over the intervening period.

With all of these different levels and types of interaction, questions need to be asked about how well research has equiped microbial insecticides for their present day role in IPM and where should we be looking to improve their capability to meet future requirements.

TRENDS IN PUBLICATION

Trends in R & D associated with products are reflected in the trends in the number of scientific publications, funding levels or number of participating scientists in a particular subject area. There are essentially three phases in the R & D process. The first is the divergent phase which represents the growth in interest and research output following a new discovery, the second is the static phase where all feasible options for development are addressed, this is followed by a convergent phase where efforts are concentrated in key areas to complete development and maximise exploitation. If a chemical insecticide is replaced by a superior product then R & D on the original insecticide will tend to decline quite dramatically. The divergent and convergent phases of R & D are illustrated in Fig. 1; trends in the number of publications concerning permethrin (based on information from CABPESTCD Rom 1973-1988, 1988-1996). Fig. 2 shows the convergent phase of fenitrothion, a pesticide that was first developed in 1960 and has had a long successful use. The trends in publication of four entomopathogens are depicted in Figs 3-6 and are less easily defined in terms of the different phases. Trends for *Beauveria bassiana* (Fig. 5) and *Verticillium lecanii* (Fig. 6) indicate a slow divergent phase whereas those for *Bacillus thuringiensis* (Bt) (Fig. 3) and nuclear polyhedrosis viruses (NPV) (Fig. 4) are relatively static up until 1988 after which the numbers of publications increase. This increase is likely to be caused by an upsurge in papers dealing with different aspects of genetic manipulation. The contribution of such papers to the overall trends in publication for Bt and NPV is illustrated in Fig. 7.

Fig. 1. Trends in numbers of publications: Permethrin

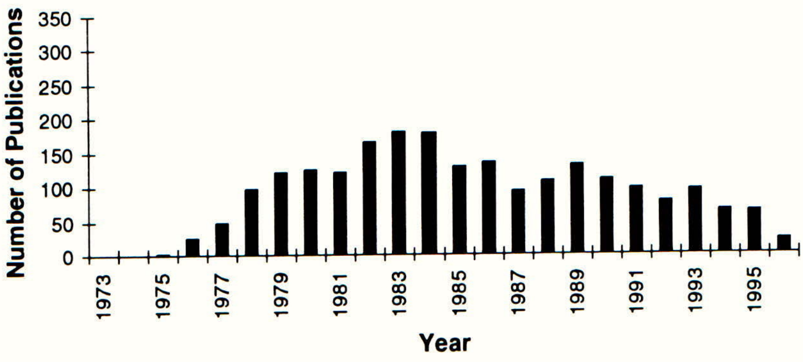


Fig.2. Trends in numbers of publications: Fenitrothion

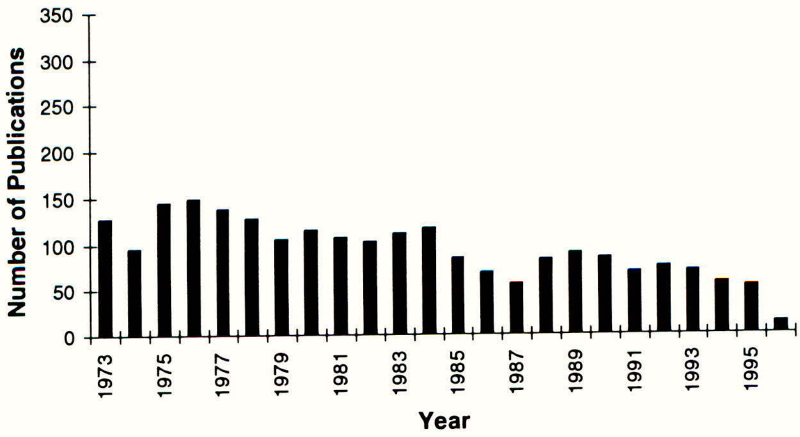


Fig.3 . Trends in numbers of publications: *Bacillus thuringiensis*

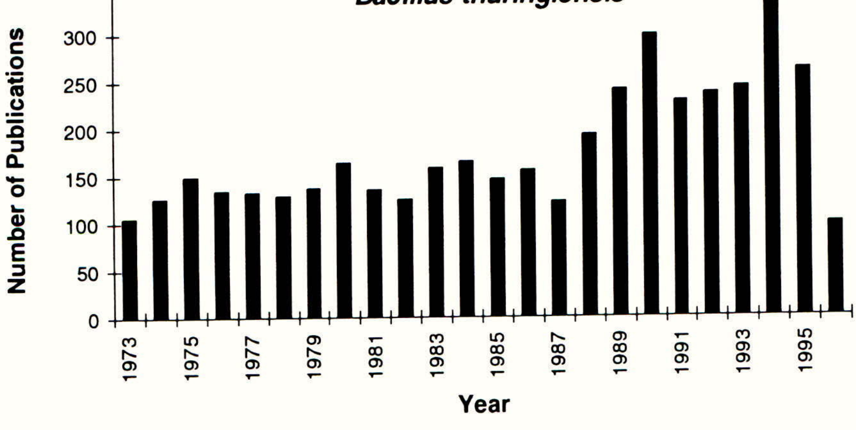


Fig. 4. Trends in numbers of publications: NPV

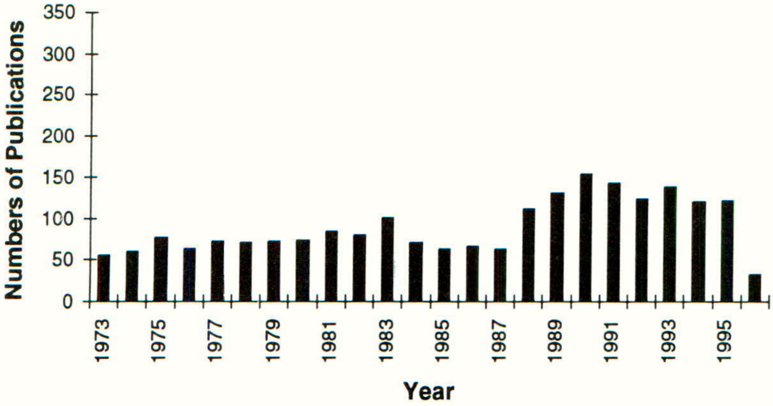


Fig. 5. Trends in numbers of publications: *Beauveria bassiana*

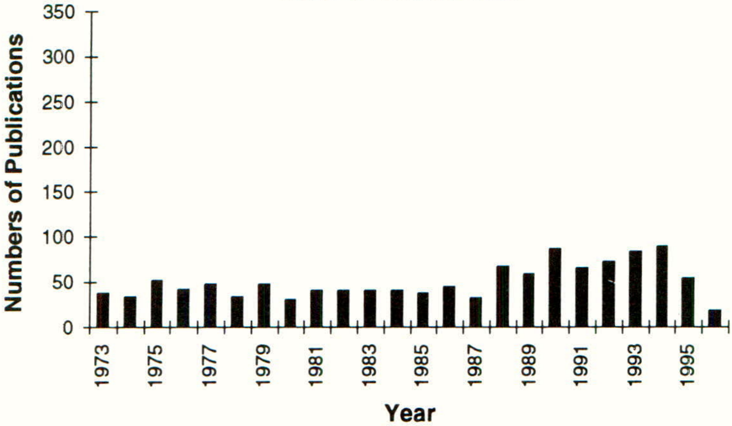


Fig. 6. Trends in numbers of publications: *Verticillium lecanii*

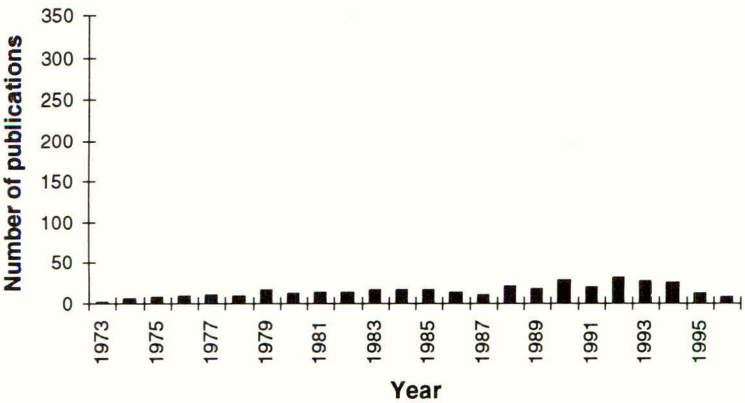
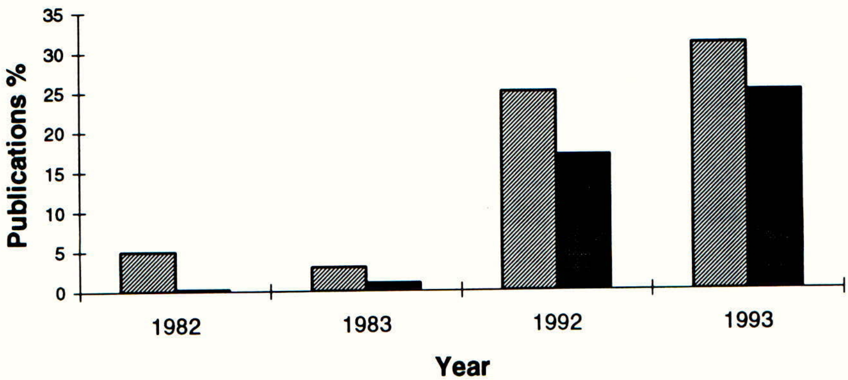


Fig. 7. Percentage of publications dealing with genetic manipulation ▨ NPV ■ Bt



In 1992 and 1993 the proportion of papers dealing with genetic manipulation was 25% and 31% respectively for NPVs and 17% and 25% for Bt. This would suggest that the trends in publication for both NPV and Bt (in the absence of genetic manipulation) over this period, remained fairly static. All of these figures have to be considered against a general background of increasing numbers of publications throughout the late 1980s and 1990s but even so, it is evident that the trends for the entomopathogens are not as easily identified and explained as those of chemical insecticides.

INTERACTIONS, COMBINATIONS AND MIXTURES

The advent of IPM produced a niche for the development of microbial pesticides, away from the direct competition with chemical insecticides. This is because IPM allowed for the use of a number of techniques, which although not effective on their own, when used in combination with others provided adequate levels of control (Dent, 1993). The IPM philosophy set the standard and provided the context for microbial insecticide development among public sector scientists. In contrast to this approach, microbial insecticide performance relative to chemicals remained a clear requirement for successful exploitation in the commercial sector. Public sector scientists have largely been responsible for a programme of research over a twenty five year period that has looked at a range of interactions between entomopathogens and other control measures and factors relating to their "use" in IPM. However, such work has tended to be undertaken by many independent researchers involved in many different pest/crop systems but all too often without any clear idea of who would implement or how any IPM system that included microbial pesticides would be implemented.

The interactions that have been studied are numerous (Fig. 8). In terms of the list of control options that are often cited as belonging to the IPM armoury; chemical insecticides, host plant resistance, natural enemies and cultural control (Dent, 1991;

Figure 8. An interaction matrix for five entomopathogens.

	Nuclear polyhedrosis virus	Bacillus thuringiensis	Beauveria bassiana	Verticillium lecanii	Metarhizium flavoviride
Nuclear Polyhedrosis Virus		●	●		
Bacillus thuringiensis	●		●		
Beauveria bassiana	●	●			
Verticillium lecanii					
Metarhizium anisopliae		●			
Paecilomyces spp.			●		
Other Natural Enemies					
Entomopathogenic fungi					
viruses	●				
bacteria					
protozoa			●		
nematodes		●	●		
Predators		●	●		
Parasitoids	●	●			
Chemical Pesticides					
Insecticides	●	●	●	●	●
Fungicides	●		●	●	
Herbicides			●		
IGRs	●	●	●		
Natural Products					
Oils			●		
Neem	●		●		
Plant Metabolites		●			
Host Plant Effects					
Species	●	●	●		
Cultivar	●	●			
Surface factors	●				
Plant extracts			●		
Cultural control			●		
Soil					
Soil type			●	●	
Soil condition			●		
Fertilizer			●		
Irrigation	●		●		
Environmental conditions		●		●	●
Temperature					
Humidity				●	●
Irradiation	●	●	●		●
Rainfall		●	●		
Formulation	●	●	●	●	●
Adjuvants	●	●			
Application Technology	●	●	●	●	●
Economics		●			
IPM	●	●	●	●	
Resistance	●	●			

Dent, 1995), there are examples of entomopathogens having been evaluated within each category. The combined effects of entomopathogens and host/crop plants have been assessed at the level of plant species (More & Chundurwar, 1991), the crop cultivar (Cowgill & Bhagwat, 1996) and host surface factors (Rabindra *et al.*, 1994). Biological control using macro-organisms has been considered in terms of the combined effects of NPVs and *Trichogramma* (Balasubramanian *et al.*, 1989), Bt and *Trichogramma* (eg Mertz *et al.*, 1995) as well as more generally on the impact of entomopathogens on predator and parasitoid effectiveness (Giroux *et al.*, 1994; Murray *et al.,* 1995). In addition, entomopathogens have also been studied from the perspective of the detrimental effects they can have on natural enemies (eg James & Lighthart, 1994) and transmission of active principles, (Young & Yearian 1989; 1990). The interaction of cultural control and agronomic factors with microbial insecticides has been mainly concerned with variation in tillage (eg Storey *et al.,* 1989) and fertiliser regimes (Pianoski *et al.,* 1990).

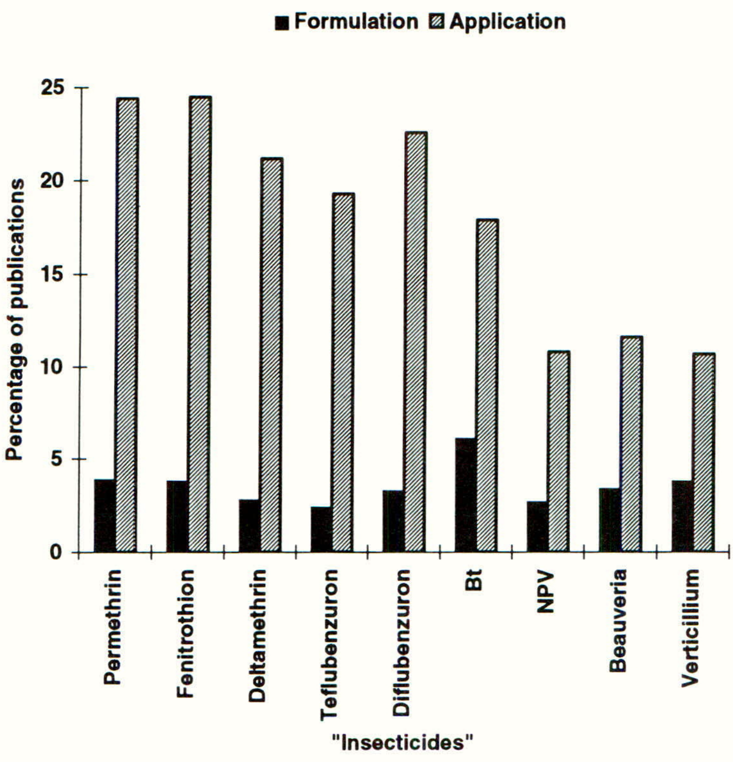
Entomopathogen compatibility with fungicides (Majchrowicz and Poprawski 1993) and herbicides (Poprawski & Majchrowicz, 1995) has been studied. Chemical and microbial insecticides have been considered in terms of their relative performance (Hassan & Graham-Smith, 1995), application in sequence (Karel & Schoonhoven, 1986) and as mixtures (Mohammed *et al.,* 1983a,b). The comparison and use of microbial insecticides with insect growth regulators has also proved popular (eg Saleh & Wright, 1989).

A series of studies that have considered the compatibility and viability of combinations of entomopathogens; NPV and Bt (Payne *et al.*, 1996), NPV and microsporidia (Novotny, 1988) NPV and Cytoplasmic polyhedrosis virus (CPV) (Lobinger, 1991), Bt and nematodes (Bauer & Nordin, 1989), Bt and *Metarhizium anisopliae* (Wernicke & Funke, 1995) and Bt and Bb (Lewis & Bing, 1991), to name just a few. Despite this profusion of work there seem to be very few general principles that can be drawn from these interactions. For instance, with chemical/Bt mixtures, variation in responses occur within and between chemical groups in their interactions with Bt (Dent, 1993). The effects seem to vary with the specific insecticide, concentration, method of treatment and duration of exposure (Mohammed *et al.,* 1983a, b). In addition, although the microbial insecticide research and development has been conducted under the all encompassing umbrella of IPM, the development of IPM systems around this research does not seem to have occurred.

IPM : A CHANGING ENVIRONMENT

IPM is the prevailing paradigm in pest management and as such it dominates scientists attitudes, perceptions and approaches to their research. For microbial pesticides this has meant, at least on the part of public sector science, an acceptance of lower performance standards compared to chemical insecticides. This was based on an understanding that deficiencies in efficacy could be "made up" for in the context of an IPM system. Combinations of control measures would be used in IPM to provide overall levels of control similar to those obtained with chemical control. The problem has been however, that although research with entomopathogens was undertaken on this basis, "no one" took responsibility for the integration of measures or of delivering IPM to the farmers. Farmers were left to somehow sort it all out for themselves. Over the last 10 years however, this shortfall has been addressed in both the private and the public sector. The result has been a polarisation of IPM into technological and ecological based approaches (see Waage this volume). The technological approach, advocated by the agrochemical industry involves selling farmers an "integrated solution package" of multiple, complementary products and information (decision making aids) (Shimoda, 1997). The integrated solution package can include chemical insecticides, transgenic plants and microbial insecticides. This environment will allow for the use of more selective microbial agents. However, increasing competition will place greater emphasis on the need for higher performance standards from microbial insecticides, making them more comparable with those of chemicals. Genetic manipulation will undoubtedly contribute in the longer term to improving performance standards of

Fig. 9. Percentage of publications dealing with formulation and application



microbial insecticides but in the short term advances can be made in terms of formulation and application technology. Formulation appears to be dealt with in microbials research at a level comparable with that of chemical insecticides (Fig. 9). However, most of the formulation technology used in microbial insecticide development is based on that for chemical active ingredients, which requires significant adaptation to meet the needs of biological agents (Rhodes, 1993). Greater emphasis needs to be placed on developing formulations specific to the needs of the entomopathogen "active ingredient", for greater success in the field with biological agents (Powell & Rhodes, 1994). Success in the field is also highly dependent on an understanding and use of appropriate application technology, yet for microbials the amount of research carried out on application seems to be well below that for chemical insecticides (Fig. 9). Experience shows that attention to the detail of application technology can markedly improve microbial insecticide performance (Bateman in press). Without attention to both formulation and application, microbial insecticides will not, in the short term, meet the performance standards required of the technological based IPM approach.

The ecological approach is embodied in the farmer field schools that have been promoting IPM in developing countries from the late 1980s (Escalada & Heong, 1993). In the field schools farmers are taught an ecosystem approach to pest management, how to observe plants and insects, and to manage the crop on the basis of their observations, experience and the weather. Research on the interactions of microbial insecticides with other pest control measures can, in this context, be used as a basis on which to encourage farmers to experiment with combinations of measures. However, to a large extent, the results of all this research will have little direct value unless it applies to the specific system in which the farmers work, which will rarely be the case. In situations where the use of an insecticide, (chemical or microbial) on a regular basis may be too costly, or where the use of chemicals will disrupt natural biocontrol, the additional option of inoculating crops with entomopathogens and encouraging epizootics may be desirable. However, this is not an area of research that has received very much attention (since 1973 only 19 papers have been published that include NPV with the terms secondary cycling, horizontal transmission or cross infection). In general, it would seem that there has been a great deal of research conducted on microbial insecticides which may have little practical relevance to IPM in its present form, either in terms of the technological or the more ecological based approaches. Different areas of research may require greater emphasis in order to advance the use of microbial insecticides in IPM in the future.

CONCLUSIONS

The static trend in numbers of publications dealing with Bt and NPV since 1973 (prior to the increasing interest in genetic manipulation from 1988), may reflect a stagnation of research through an increasing "horizontal expansion" relative to a vertical progression within these subject areas. This may have been compounded by the extensive effort directed towards research on the interactions between these entomopathogens with other control measures within the context of IPM The polarisation of IPM into the technological and ecological approaches has meant that the vast amount of research that dealt with these interactions may not now be relevant. If microbial insecticides are to meet the needs of the technology based IPM approach then higher performance standards are required. These will necessitate a greater emphasis on formulation and application technology for biological "active ingredients," than has occurred in the past. In terms of the ecological approach, research on the different interactions may be of value in guiding farmer experimentation but it is unlikely to have direct relevance in the majority of cases. More research aimed at secondary cycling will probably be valued in the context of the ecological approach to IPM.

REFERENCES:

Balasubramanian, S; Arora, R S; Pawar, A D (1989) Biological control of *Heliothis amigera* using *Trichogramma pretiosium* and nuclear polyhedrosis virus in Sriganganagar district of Rajasthan. *Plant Protection Bulletin* **41**, 3 - 4

Baldwin, B (1986) Commercialisation of microbally produced pesticides. In: *World Biotech Report* 1986 Vol. 1. *Proceedings of Biotech 1986 Europe*, London, May 1986. pp.39 - 49.

Bauer, L S; Nordin, G L (1989) Response of spruce budworm infected with *Nosema fumiferanae* to *Bacillus thuringiensis. Environmental Entomology* **18,** 816 - 21.

Cowgill, S E; Bhagwat, V R (1996) Comparison of the efficacy of chemical control and *Helicoverpa* NPV for the management of *Helicoverpa amigera* on resistant and susceptible chickpea. *Crop Protection* **15**, 241 - 6.

Dent, D (1991) Insect Pest Management. CABI. Wallingford

Dent, D (1993) *Bacillus thuringiensis* as an insecticide. In: Exploitation of Microorganisms. D Gareth Jones (ed). Chapman & Hall. London. pp. 19 - 44.

Dent, D (1995) Integrated Pest Management. Chapman & Hall, London.

Escalada, M M; Heong, K L (1993) communication and implementation of change in crop protection. In: *Crop Protection and Sustainable Agriculture*. John Wiley. Chichester, pp. 191 - 202.

Giroux, S; Coderre, D ; Vincent, C; Cote, J C (1994) Effects of *Bacillus thuringiensis* var. san diego on predation effectiveness, development and mortality of *Coleomegilla maculata lengi* larvae. *Entomophaga* **39**, 61 - 69.

Hassan, E; Graham-Smith, S (1995) Toxicity of endosulfan, esfenvalerate and *Bacillus thuringiensis* on adult *Microplitis demolitor* and *Trichogrammatoidea bactrae. Zeitschrift fur pflanzerkrankheiten und pflanzenschutz* **102**, 422 - 8.

James, R R; Lighthart, B (1994) Susceptibility of the convergent lady beetle to four entomogenous fungi. *Environmental Entomology* **23**, 190 - 2.

Karel, A K; Schoanhaven, A V (1986) Use of chemical and microbial insecticides against pests of common beans. *Journal of Economic Entomology* **79**, 1693-6

Kuhn, T S (1970) The Structure of Scientific Revolutions, University of Chicago Press, Chicago.

Kuhn, T S (1977) The essential tension: tradition and innovation in scientific research. In *Essential Tension*, T S Kuhn (ed.). The University of Chicago Press, Chicago pp. 225 - 39.

Lewis, L C; Bing, L A (1991) *Bacillus thuringiensis* and *Beauveria bassiana* for European com borer control: program for immediate and season-long suppression. *Canadian Entomologist* **123**, 387 - 93.

Lobinger, G (1991) On the synergism of a cytoplasmic polyhedrosis virus isolated from *Dasychira pudibunda* in mixed infections with different nuclear polyhedrosis viruses. *Journal of Applied Entomology* **112**, 335 - 40.

Majchrowicz, I; Poprawski, T J (1993) Effects in vitro of nine fungicides on growths of entomopathogenic fungi. *Biocontrol Science and Technology* **3**, 321 - 36.

Medawar, P B (1981) Advice to a young scientist, Pan Books, London.

Mertz, B P; Fleischer, S J; Calvin, D D; Ridgway, R L (1995) Field assessment of *Trichogramma brassicae* and *Bacillus thuringiensis* or pesticidal soap for control of insect pests. *Biological Control* **5**, 432 - 41.

Mohammed, A I; Young, S Y; Yearian, W C (1983a) Effects of microbial agent-chemical mixtures on *Heliothis virescens*. *Environmental Entomology* **12**, 478 - 81.

Mohammed, A I; Young, S I; Yearian, W C (1983b) Susceptibility of *Heliothis virescens* larvae to microbial agent-chemical pesticide mixtures on cotton foliage. *Environmental Entomology* **12**, 1403 - 5.

More, M R; Chundurwar, R D (1991) Effectiveness of nuclear polyhedrosis virus against *Spodophera litura* larvae on different host plants. *Journal of Maharashtra Agricultural Universities* **16**, 364 - 66.

Murray, D A H; Monsour, C J; Teakle, R E; Rynne, K P; Bean J A (1995) Interactions between nuclear polyhedrosis virus and three larval parasitoids *of Helicoverpa amigera. Journal of the Australian Entomological Society* **34**, 319 - 22.

Novotny, J (1988) The use of nucleopolyhedrosis virus and microsporidia in the control of the gypsy moth, *Lymantria dispar. Folia Parasitologica* **35**, 199 - 208.

Payne, N J; Cunningham, J C; Curry, R D; Brown, K W; Mickle, R E (1996) Spray deposits in a mature oak canopy from aerial applications of nuclear polyhedrosis virus and *Bacillus thuringiensis* to control gypsy moth, *Lymantria dispar. Crop Protection* **15**, 425 - 431.

Perkins, J H (1982) Insects, experts and the insecticides crisis: the quest for new pest management strategies. Plenum. New York.

Pianoski, J; Bertucci, E; Capassi, M C; Cirelli, E A; Calafiori, M H; Teixeira, N T (1990) Efficiency of *Beauveria bassiana* for the control of *Diabrotica speciosa* on beans *Phaseolus vulgaris* with different fertilizer treatments. *Eccossitema* **15**, 24 - 35.

Poprawski, T ; Majchrowicz, I (1995) Effect of herbicides on *in vitro* vegetative growth and sporulation of entomopathogenic fungi. *Crop Protection* **14**, 81 - 7.

Powell, K A; Rhodes, D J (1994) Strategies for the progression of biological fungicides into field evaluation. In: *BCPC Monograph No. 59*: Comparing glasshouse and field pesticide performance II. 307 - 315.

Rabindra, R J; Muthuswami, M; Jayaraj, S (1994) Influence of hostplant surface environment on the virulence of nuclear polyhedrosis virus against *Helicoverpa armigera* larvae. *Journal of Applied Entomology* **118**, 453 - 60.

Rhodes, D J (1993) Formulation of biological control agents. In: *Exploitation of microorganisms* (ed) D Gareth Jones. Chapman & Hall, London. pp 411 - 39.

Saleh, M S; Wright, R E (1989) Effects of the IGR cryomazine and the pathogen *Bacillus thuringiesis* var. *isrealensis* on the mosquito *Aedes epacticus. Journal of Applied Entomology* **108**, 382 - 5.

Shimoda, S M (1997) Challenges of commercialising biopesticides in a more competitive marketplace. Annual Conference on Biopesticides and Transgenic Plants, Jan 27 1997, Washington DC.

Storey, G K; Gardiner, W A; Tollner, E W (1989) Penetration and persistence of commercially formulated *Beauveria bassiana* conidia in soil of two tillage systems. *Environmental Entomology* **18**, 835 - 839.

Wernicke, K; Funke, W (1995) Impact of Dipel and Bio1020 on arthropods with soil - living developmental stages. *Mitteilungender Deutschen Gesellschaft fur Allgemeine und Angewandte Entomologie* **10**, 207 - 10.

Young, S Y; Yearian, W C (1989) Transmission of nuclear polyhedrosis virus by the parasitoid *Microplitis ooceipes* to *Heliothis virescens* on soybean. *Environmental Entomology* **19**, 251 - 56.

Young, S Y; Yearian, W C (1990) Contamination of arthropod predators with *Heliothis* nuclear polyhedrosis virus after Elcar applications to the soybean for control of *Heliothis* spp. *Journal of Entomological Science* **25**, 486 - 92.