SESSION 1

SETTING THE SCENE

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MICROBIAL BIOPESTICIDES

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ABSTRACT

The market for microbial pesticides is a growing one but still only represents less than 1% of the total crop protection market and most of this is accounted for by Bt based products. While this may partly be due to the failure of governments to positively promote biopesticides, the actual performance of the products with their narrow target spectra, generally higher costs and sometimes unreliable performance are the main reasons for limited growth.

Another constraint to the development of successful commercial products has been the attitude within the agrochemical industry. Microbial products were too often perceived as marginal products that could be brought to the marketplace without extensive dedicated R & D, manufactured using spare capacity and without extensive consumer education about the mode of action of these products. In addition, much governmentally funded R & D of biopesticides has been poorly targeted and has contributed little to bringing effective new products onto the market.

However pesticide de-registration and use reduction programmes should increase the niche markets for microbials. New biotechnology should both improve the efficacy and reduce the relative costs of microbials. This should allow for a steady growth in the market for the next five years although competition may limit potential profits for producers.

INTRODUCTION

The markets for biopesticides are growing, although more slowly and from a smaller base than is commonly believed. Despite optimistic predictions, the value of biopesticides is still less than 1% of the total world market for agrochemical crop protection.

For many years, from the late 1960s until the late 1980s, the market was static with sales of around $20-25m, virtually all of which was certainly for products based on the bacterium, Bacillus thuringiensis (Bt). Between 1989 and 1992, the microbial insecticides market grew quite rapidly in percentage terms, to a minimum of $45m and possibly as much as $60m. The reasons for this included the introduction of additional products based on new strains of Bt which increased the number of target insects, better formulations that were more reliable, and increased market competition caused by the entry of a number of major companies. While the real market was picking up strongly, future prospects seemed to be growing more vigorously still, as new agri-based venture capital companies began registering their products and as many major firms made apparent progress with innovative new microbial insecticides.

In the past, biopesticide products had narrow target spectra, a number of them did not work very well and yet most were more expensive than chemical equivalents. The main reasons for growth is improved products and an increasing number of new registrations. Some of the high quality research efforts of recent years have resulted in improved products based on knowledge of how and why biopesticides work.

Biopesticides have an important role to play in the modern agricultural concepts of integrated pest management and sustainable agriculture. Many governments advocate reduced pesticide usage in crop production. One reason for this is a desire to preserve the environment, both for its intrinsic value and to protect an important tourist industry. For countries that export agricultural produce there are addition commercial reasons for wishing to reduce pesticide use. Surveys show that many consumers rank chemical pesticides among their most serious concerns about food safety. These consumers, via the food manufacturers and retailers, have already shown a strong preference for food produced using a minimum of chemicals.

The question is whether or not these factors combined, with technical improvements in biopesticides products, will lead to significant growth in the market for products for non chemical farming. To date, one of the reasons for slow growth is that government advocacy of biopesticides has often been limited to exhortations. Governments have not legislated against chemicals, nor provided significant public major funding for R&D into alternatives, nor have most governments really provided a fast track to registration of biopesticides. In fact, the UK, which once would put biopesticides ahead of chemicals in a queue for registration, will no longer do so. Another reason is that consumers, while genuinely anxious about chemicals, still require that food products be blemish-free and they remain reluctant to pay a premium for reduced-chemical food on the (perhaps reasonable) premise that it should cost less to produce. Only recently has one UK food retail chain begun experimenting with selling conventional and 'organic' food at identical prices.

However, the research and commercial communities cannot simply blame governments and consumers for the failure of biopesticides to obtain significant sales. World-wide, much of the research carried out with public funds is poorly thought out, badly done, or repeats work already completed. Many companies approach biologicals as though they were chemicals which leads to misleading results and, very commonly, disappointment. Companies also occasionally bring an excess of optimistic self-confidence to their investigations of biopesticides.

It has been thought since the mid-1960s that biopesticides can be developed in less time and for less cost than conventional agrochemicals. Registration, once a major unknown, has become more predictable in many major markets since the early 1980s. Money has gone into the formation of small companies to develop and sell biopesticides from venture capitalists. Large companies including agrochemical firms, pharmaceutical companies, companies with fermentation capacity, seed companies and many others have invested money and time pursuing the identification and development of biopesticides. Apparently, all this effort has produced fairly modest results. Yet most people believe the potential remains for biopesticides to make a contribution to reducing pesticide use.

THE MARKET FOR MICROBIALS

At present the market for biopesticides is around $75m per annum accounted for principally by products based upon Bt but also including nematodes and other products. Within the past five years, the market has grown and its future potential has also grown substantially due to the introduction of new and better products, including many based on Bacillus thuringiensis (Bt) and to the entry of new companies into the biopesticides business. However, intense competition for the main (Bt) markets has resulted in lower prices; as a consequence the volume of sales has increased, but total market value has remained fairly static. In addition, seasonal variations in pest infestations in the small number of principal Bt markets (forestry, cotton, brassica crops) cause unpredictable changes in annual volumes. These factors can mislead those making future market projections, which include many predictions for sales well in excess of $300m by the year 2000, with some estimates ranging as high as $750m. We estimate that the growth rate will be around 10% per year for at least the next three years and will result in a market of $120-$130m by 2000.

Factors which have positively affecting the growth of the market for microbial insecticides include:

1 Improvements in product potency, formulation and delivery;

2 Lower prices making products competitive with chemicals;

3 Increasing political stability in countries in Asia, the Middle East, Central and Eastern Europe making these countries better potential markets;

4 Increasing exports of fresh produce to North America and Western Europe. Microbial insecticides can help growers meet quality standards and residue requirements;

5 Insect resistance to chemicals may require the use of microbial insecticides;

6 Re-registration requirements for chemicals may cause the withdrawal more chemicals, creating additional market opportunities.

Factors negatively affecting the growth of the market include:

1 Higher prices for microbial insecticides compared with chemicals;

2 Lower cost-effectiveness of microbial insecticides;

3 Insect resistance to Bt;

4 Genetically-engineered plants with Bt genes may profoundly affect markets both for Bt and chemical products especially in cotton and maize;

5 New and better chemicals may inhibit the growth of microbial insecticides.

During the 1960s and 1970s, the market for biopesticides was exclusively for a single product based on a strain of Bt used to control lepidopterous insects. Two companies, Abbott and

Sandoz, dominated the tiny (<$20m) market for Bt. However, because the product seemed easy and cheap to make and was thought to generate a good profit margin, a large number of companies (estimated at over 12 per year for around 20 years) considered making and selling Bt. "New" strains of Bt that were claimed by their discoverers to be more potent than existing commercial strains were continually offered by researchers and small companies. Several of these strains were shown to be more potent than those in commercial use when potency was measured in laboratory bioassays. However, a potency improvement of around 10-fold was generally thought to be required in order to see an appreciable difference in field efficacy. One major international company which was unfamiliar with this, announced its new product with public claims of 5-fold improvements in laboratory potency only to be embarrassed by subsequent failures in use. The rights to these new strains were usually available for a single large payment. Many companies (estimated at around 3 per year for 20 years) tried to make and sell Bt. All except one failed and most regret the attempt.

By the early 1980s, several strains of Bt had been discovered with activity against other insect groups, particularly Diptera (mosquitoes and blackfly) and Coleoptera (including Colorado potato beetle). The principle was established that Bt was not just a control agent for caterpillars, but could be used against many pests. Novo Nordisk, a company known for expertise in fermentation, joined Abbott and Sandoz as a principal Bt producer. Although Novo had not previously marketed crop protection products, it has persisted using a combination of acquisition, opening new markets (mainly in Central Europe), product innovation and competitive pricing. However in 1995 Novo abandoned biopesticides and sold its business to Abbot.

THE DEVELOPMENT OF MICROBIAL PRODUCTS

Twenty years ago, the development of biopesticides was considered unpromising by virtually all the major agrochemical companies. Despite the many observations that micro-organisms could control pests, commercial exploitation of that ability was modest. Micro-organisms were thought too narrow in spectrum, too expensive in manufacture, too fastidious in formulation and too erratic in performance while being simultaneously too common to patent. Agrochemical companies that understood the necessity of synthesizing and screening thousands of different chemicals every year, targeting the most promising candidates, and developing formulations tailored to each chemical, pest, crop and environment, did not extend that procedure to micro-organisms. The fact that most micro-organisms failed most of the time was taken as evidence that all micro-organisms would fail all the time. The industry remained uninterested in the meagre efficacy and market niches offered by biopesticides. Proponents of biopesticides were challenged to show that micro-organisms were as good as chemicals, without spending even a fraction of the resources normally spent on developing chemicals.

The real difficulty for those advocating research and development of biopesticides is the expectations, or pre-conceptions, that others have of these products. The first expectation is the product-for-product premise according to which a biopesticide replaces a chemical in form, function, application etc. This is very unlikely to happen. Chemicals are used and sold to carry out their functions because of their inherent characteristics. In selling chemicals, the chemical industry makes a virtue of necessity by teaching farmers to want the products it has to sell. For example, farmers supposedly require that insecticides have a rapid 'knock-down' action because that is what most chemicals do.

Biopesticides fail, the industry says, because they do not provide such rapid knock-down. Yet, where the action of the chemical is slower, as for most herbicides, fungicides and fertilisers, speed is somehow not expected by the farmer. What the farmers want is what they have been taught to want, that is, what the industry can provide. It is impossible for a biopesticide to fill niches that have been defined for chemicals. Objectives. must be redefined.

The second expectation is that biopesticides need only be collected from nature, bulked up and re-applied to work effectively. Yet, when a new chemical entity is discovered, has any company ever 'bulked it up' and used it immediately (registration questions aside)? Of course not. Chemicals may have thousands of derivatives made before the most effective are discovered; the products need formulation and years of field development before they are ready. Why should this not be so for biopesticides? Why should biopesticides not require at least a reasonable fraction of the effort and resources required to develop effective chemicals?

The third, sometimes dangerous, expectation is that production of biopesticides is trivial, an 'appropriate' technology. Nothing could be farther from the truth. Production can be difficult and is crucial to producing a consistent and effective product. Yet, agricultural wastes have frequently been proposed as suitable substrates for inexpensive, locally produced biopesticides. Few would expect to make effective chemicals from waste or by using 'village-level' techniques; why should biopesticides be different?

THE LIMITATIONS OF BIOPESTICIDES

A key deficiency of biopesticides is their generally poor and erratic performance in practice. Laboratory tests can be an inaccurate guide to how well a biopesticide would work in the field. Workers on biopesticides are frequently frustrated by the fact that biopesticides can work very well, controlling pest infestations completely oversubstantial periods of time, but that this performance is neither reliable nor predictable.

Another deficiency is lack of patentability. While strong "composition of matter" patents can be obtained for new chemicals; for biopesticides relatively weak process or use patents are the best that can be obtained. Another problem with biopesticides is equally fundamental. The roots of the agrochemical industry is in chemicals, not biologicals. Many employees are chemists who have conceptual difficulties working with biopesticides. They still call biopesticides "compounds" and expect them to behave as such, which they do not.

As with many fields about which a company knows little, microbial insecticides seem a superficially attractive market to enter. From a distance and in the absence of most of the key facts and any experience, companies make three fundamental mistakes in their approach to microbial insecticides.

1 The first is that companies believe, often without checking, the assertions and assumptions about microbial insecticides that commonly appear in print. There are two main themes: microbial insecticides are easy, quick and cheap to make; and microbial insecticides are in enormous demand. Both the press and many learned reviews suggest that the public is crying out for pesticide-free food, that regulators are endlessly attacking, removing and tightening controls on chemicals. Companies think

that they will make a biopesticide, any biopesticide, and regulators will co-operate with them in registration and the public will insist that farmers use it.

2 Companies tend to overestimate their own capabilities. They believe that they, unlike 163 of their predecessors, will read the papers of the 3,500 researchers world-wide who publish on biopesticides (see CPL's Worldwide Directory of Research and Researchers) and select the winners, probably on the basis of market-driven need. Or they may believe that they will carry out yet another screen for activity and select an isolate that is more active than all those hitherto known to science, develop an efficient production process, register and sell this 'better mousetrap'.

3 Companies under budget in time and resources. Microbial insecticides are done on the cheap. This fact is usually hidden behind various items of corporate strategy jargon but microbial insecticides are virtually always done at the margin, with 'spare' resources.

When industry analyzes the biopesticides market it finds a business in which the main market (Bt) is taken by producers with spare, written off, capacity. Other prospective markets open to biopesticides are generally all thought to be small niche markets. Registration, although acknowledged to be somewhat simpler and less expensive than for chemicals, might become more difficult in the future. Most companies have either had poor experiences with biopesticides or are familiar with those of other companies. These experiences are often accepted as valid predictors of future results. Finally, companies can point to the lack of interest by their competitors to support their own inaction.

THE RATIONALE FOR BIOPESTICIDES

Despite all this, the major agrochemical companies have recently taken a greater interest in biopesticides. This may be due to the pressures on the industry over the past few years. Most markets for conventional pesticides have been growing much more slowly than in the past; some are shrinking. Competition in the main agrochemical markets of the US and Western Europe is becoming more difficult as re-registration and use-reduction programmes depress sales. Although Central Europe and Asia offer new opportunities, it can be questioned whether the industry as a whole will ever return to the profitability of the past.

The agrochemical industry's interest in biopesticides is therefore strategic and tactical, but it is not especially commercial. Companies want to ensure that they do not miss a key opportunity (should one ever arise) and staying involved in biopesticides, even in small way, gives them ongoing information on technological developments. For bigger companies, joint ventures, R&D programmes and even a few products for sale are a relatively inexpensive form of technical and market intelligence. In addition, companies want to be seen to be doing something positive towards what are perceived as safer methods of crop protection and involvement in biopesticides can have significant public-relations value. In particular, participation in the low to medium technology end of the biopesticides business, such as insects, nematodes and other products not requiring registration, is relatively low-risk. Although profits may be small, any losses are likely to be similarly constrained.

For these reasons, virtually all the major companies have biopesticide products in

development, manufacture or marketing. However, the industry remains unconvinced of the commercial future of biopesticides. No major company anticipates that the sales volume of any biopesticide will approach that for chemicals. Despite lower development and registration costs than chemicals, individual biopesticides are unlikely ever to obtain the broad and varied markets achieved by chemicals. Overall, biopesticides will remain niche products, best suited to higher-value uses and requiring a correspondingly higher marketing input.

The advent in the early 1980s of venture capitalists and entrepreneurs enthused about agricultural biotechnology led to the formation of a number of new companies planning to succeed with products overlooked by the agrochemical majors. It was thought that innovative technology would overcome the perceived limitations of biopesticides. The spectrum of pests controlled by each product would be broadened, control would be more rapid and more persistent and the costs of production and marketing would decline as more products obtained larger markets. A high percentage of the companies formed during this era still exist, but almost none in their original form or with their original purpose. Developing, making, registering and selling biopesticides turned out to be, at best, a difficult business with lower margins and smaller prospects than hoped for at first. All the new, venture capital financed companies, have adapted to the fact that biopesticides based on micro-organisms requiring registration could not form the basis of a sound business. They now sell a variety of other products that do not require registration such as those based on insects and nematodes.

THE WAY FORWARD

It is likely that a continual decline will occur in the use of chemical pesticides in the main developed markets of the US and EU due to developments that include:

1 Re-registration procedures in the US and EU which will reduce the number of chemicals available or will restrict their permitted uses;

2 Pesticide use-reduction programmes in the US and other developed countries which will result in fewer products on the market and smaller volumes of them being sold;

3 Genetically engineered plants more resistant to insects and disease;

4 While new chemical discovery and development has become more difficult and expensive new chemicals are being introduced that are more specific and potent than their predecessors.

This may provide a increasing number of niche markets for which biopesticides may be appropriate. Market factors in favour of biopesticides include consumer preferences for pesticide-free produce and a growth in the market for organic or reduced-pesticide products; the development of more sustainable agricultural systems using integrated pest management programmes; the stabilization and harmonization of regulations governing registration of biopesticides containing either naturally occurring or engineered organisms; and the presence of many more major companies in the biopesticide business.

We anticipate that biotechnology will continue to improve the quality of the scientific work being done on biopesticides. As a consequence, more strains of Bt and other micro-organisms

will be developed with a greater range and quality of activities as crop protection and crop production products. Most of these new products will be used in higher-value niche markets since before biopesticides can be used in field crops, they will have to cost less than at present. However, competition may make some biopesticides into commodities, as has already happened for Bt in forestry and cotton. This will be good news for consumers but less beneficial for producers or venture capital investors.

BIOPESTICIDES AT THE CROSSROADS: IPM PRODUCTS OR CHEMICAL CLONES?

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ABSTRACT

Biopesticides are pest management products which have:

- unique and desirable pest control properties as living organisms;
- promising scope for production at a range of scales from local to multinational;
- a novel role as true IPM products which act synergistically with natural control.

Biopesticides are presently being developed following traditional, chemical pesticide models for design, production and use which will not realise their full potential. The future of biopesticides as valuable IPM components requires re-examination of their commercial potential in a range of contexts, including the multinational pest control industry, incentives which emphasis the demand rather than the supply end of biopesticide development, and awareness raising and training at the local level.

INTRODUCTION

In the past few decades, biological pesticides have been the subject of considerable research and product development. Interest in biopesticides has grown in response to widespread concern about the impact of broad-spectrum chemical pesticides on environment and health and the appearance of chemical pesticide resistance. Biopesticides are now seen as components of integrated pest management (IPM) systems, where they constitute one of a range of pest control methods which farmers can use to achieve cost effective, environmentally sound and sustainable pest management.

A number of papers in this conference will compare the performance and potential of biopesticides relative to chemicals as future crop protection products. In this paper, I would like to step back and examine the broader issue of biological control in pest management systems and ask whether we are developing and using biopesticides in a manner which will make the most of this potential. At the heart of my argument is a simple observation. Biopesticides, being living organisms, have properties which make their design, production and use potentially very different from that of chemical pesticides. However, present and planned development, production and delivery of biopesticides usually follows a chemical pesticide "model". I will suggest that realising the full potential of biopesticides requires that we move beyond this narrow focus.

BIOPESTICIDES AND THE GLOBAL MARKET PLACE

It is popular to begin an evaluation of biopesticides with an analysis of the "global market place" in which they compete as products. Thus, we might acknowledge that biopesticides currently command a very small but growing percentage of a $25b world pesticide market. In making such a start, however, we run the risk of equating the future of biopesticides with their role in replacing chemical pesticides, thereby ignoring some broader trends which will affect both kinds of products. For today's IPM or integrated crop management (ICM) practitioner, products constitute only a part of the crop protection strategy, and indeed a part to be made as small as possible. To understand where biopesticides may go in future, it is important to understand where IPM is going.

Unfortunately, this is not an easy task, as IPM today is developing on a number of tracks (Waage 1996a,b). IPM as a concept has its origin in a technological agricultural tradition (Perkins 1982), as a means of reducing over-reliance on chemical pesticides through the imposition of economic thresholds for spraying, and replacing broad spectrum chemicals insecticides with alternative technologies, including selective chemicals, biopesticides, pheromones, etc. In this way, undesirable pesticide side-effects, including resistance, environmental and health problems and pest resurgence could be minimised. IPM was heralded as the "new technology of pest control" (Huffaker 1979) and the agrochemical industry gradually embraced the challenge of product stewardship and pesticide resistance management, while investing in new IPM products, including biopesticides. This concept of "technological IPM" (Waage 1996a) finds clear expression today in the effort of industry to provide complete IPM packages to farmers through the purchase of seed companies and the engineering of crops so as to make them dependent on other products (e.g. herbicide resistant crops).

Parallel to this development of a technological IPM tradition, fallout from the Green Revolution in Asia has created a different perspective on IPM. Here, extensive use of broad-spectrum insecticides on high-yielding rice varieties led in the 1980s to widespread and devastating pest outbreaks. IPM developed as a reaction to inappropriate, technological intervention, and emphasis was placed on training farmers to be pest management experts and to rely more on their own observations and local pest control solutions. Empowered IPM farmers increased their reliance on natural biological control, host plant resistance and other self-renewing processes and greatly reduced their use of pesticides (Gallagher 1992). This more "ecological IPM" has since been taken up on other crops where excessive use of pesticides is creating problems, including cotton, vegetables and tree crops.

Both a technological and an ecological approach to IPM address the need to reduce the use of broad spectrum pesticides, but they take different perspectives which lead in turn to differences in how alternative methods like biopesticides are developed and used. A technological perspective would have biopesticides as products which replace chemical pesticides for widespread use and incorporation into pre-designed IPM packages. An ecological perspective would see biopesticides more as a way of augmenting natural control, by mass producing some natural enemies, often local species, and using them to protect the action of other natural enemies.

Elements of both technological and ecological IPM will certainly characterise the future environment for biopesticide development and use. Biopesticides will find niches as

replacement for chemical pesticides with global markets, but we must anticipate as well a growing demand for local biocontrol products tailored to particular production systems, and for a move away from packaged interventions towards more farmer-driven pest management and a greater emphasis on self-renewing pest control methods.

Are we designing biopesticides to meet these opportunities? In the next three sections I will ask this question of biopesticide design, production and utilisation. I will make some terminological assumptions. By "biopesticides" I mean any mass produced and marketed natural enemies, including predators, parasitoids, nematodes and microbial agents. By multinational pest control industry, I mean those agrochemical and biotechnology companies producing chemical and biological products for international markets. Finally, I issue the usual apology that much of what I have to say, like much of IPM and biopesticide development today, is directed at insect pest problems, and extrapolation to other pest groups, while possible, is beyond the scope of this essay.

DESIGNER BIOPESTICIDES: IS IT JUST THE LABEL THAT COUNTS?

Put aside for a moment your preconceptions on what a biopesticide is or should be, and consider taking a natural enemy of an insect pest, say a virus or a predator, and using it commercially to control populations of that pest. What properties of that natural enemy would you want to build into your product?

Natural enemies have, to varying degrees a capacity to find pests (or sit in wait in the right places for hosts to pick them up), to kill them and to reproduce on them. In ecological terms, they have a functional response (pests found and killed per unit time) and a numerical response (reproduction per unit pest and time). To combat a pest outbreak, I would suggest that the natural enemy product which a farmer would most want to use would have all of these properties. It would apply itself to the pest, it would kill the pest and it would give lasting, widespread control by its own reproduction and spread. The farmer would get effective control over large areas and over entire seasons with only a small initial input at a particular place and time.

Some natural enemy products on the market today exhibit these properties, such as predators and -parasitoids for the glasshouse system, where small, well-timed releases early in the season give season long control over the entire crop. Others, like some insect pathogens, do not appear to be as effective at finding pests or spreading between generations under a range of circumstances, although spectacular epizootics may occur in nature under certain conditions.

Development of biopesticides today by the multinational pest control industry exploits, by and large, the functional but not the numerical response of living natural enemies. Leading products like BT or entomophilic nematodes are not designed or expected to persist in the field once applied. This is not surprising, as they are not native to the crop environments where they are usually applied, and do not survive there. But even for organisms which have potential for persistence and the compounding benefits of numerical responses, such as viruses and fungi, commercial development favours a traditional chemical pesticide model - quick kill, low persistence, frequent application. Thus we see considerable research aimed at increasing speed of kill of biopesticides, the ecological consequence of which is to reduce

persistence and reproduction. Enhancing speed of kill by genetic engineering, e.g. by incorporating genes for toxins into insect viruses, creates an additional, environmental incentive for short persistence in the field. Finally, cynics might say that the potential of repeated sales is sufficient in its own right to discourage exploitation of the numerical response of biopesticides.

It is true that many natural enemies must be mass produced and regularly applied to give effective control of a pest. My argument is that we are, perhaps, not looking for opportunities to utilise these additional properties of host finding and reproduction, which are precisely those properties which make biopesticides superior to chemicals. The reason we are not doing this, I suggest, is that biopesticide development is locked into an inflexible and unimaginative chemical pesticide model. In this position, all of the shortcomings of biopesticides relative to chemicals emerge, and few of the benefits. Poor performance is a self-fulfilling prophecy. Is it surprising that living organisms do not make as good chemical pesticides as chemicals do?

PRODUCING BIOPESTICIDES: A MATTER OF SCALE

Producing, storing and distributing biopesticides is often presented as a problem. From the perspective of the multinational pest control industry, it frequently is. The production technology for biopesticides is different from that for chemical products, which means a substantial investment for chemically oriented companies. It is not surprising that an industry now actively prospecting amongst natural enemy faunas and floras around the world are more excited by the prospect of finding metabolites and toxins rather than living agents.

Once more, however, I would ask that we set aside preconceptions and take a broader perspective. While biopesticide technologies are a challenge for our present multinational pest control industry, they do have the virtue of being relatively simple and amenable to development on a much greater range of scales than synthetic chemical products. Fermentation technology is within the grasp of a wide range of commercial operations ranging from multinational companies to local micro-breweries.

And *in vivo* production of natural enemies is particularly accessible to those numerous small and large businesses around the world which have, for other reasons, regular access to cheap sources of pests and crops as potential production substrates. Farms, that is. Indeed, many of the successful biocontrol businesses today, including the European glasshouse industry and tropical sugarcane industries, were established by farmers who began by producing products for their own use, and eventually found it more lucrative to supply local farming communities than to grow crops themselves.

Because of its flexibility of scale, the biopesticide business can have the desirable properties of exploiting local biodiversity, creating employment and wealth in agricultural communities, and reducing the need for import of pest control products from distant centres of production. In the developing world, this is particularly desirable, as importing chemical pesticides uses up valuable foreign exchange, extension systems experience difficulties supporting training required for safe and effective use of chemicals (with dramatic consequences to health and the environment) and the entire economy will benefit from local businesses generating new wealth from agricultural production.

To counter this, there is of course the argument that globally marketed biopesticides which take advantage of established commercial extension systems of multinational companies will out-compete local, national or even regional producers, just as cheap chemical products from the same industries have generally suppressed development of local pest management business date. But are we that confident that biopesticides will realise economies of scale when marketed globally? What evidence do we have? The value of biopesticides in the portfolios of the multinational pest control industry is still being explored, as enterprises supported by venture capital go boom and bust and agrochemical companies cautiously buy up and experiment with small biocontrol companies. At the same time, who can say that alternative, local, national or regional production and marketing systems have been satisfactorily explored, particularly in developing countries?

Do not interpret the statements above as posing a competition between big and small, between the multinational pest control industry and local business or between North and South. It is simply a question of scale - what is the right scale for sustainable production and marketing? It is likely that the multinational pest control industry, with its enormous investment in R&D relative to the public sector, will generate much of tomorrow's biopesticide technology, and make money from it, but this does not mean that these companies will wish to hold these products in their own portfolios.

BIOPESTICIDES: THE METHADONE OF IPM?

The prospects for using biopesticides in modern IPM systems is exciting, but IPM also has some tricks up its sleeve which may reshape our perceptions of biopesticide markets. Firstly, the experience of IPM in crops such as rice, vegetables, cotton, tree fruit and plantations suggests that many of our most serious pests are aggravated or actually induced by broad-spectrum pesticides, because these products eliminate local natural enemies. Not surprisingly, it is against these same resurgent pests that much development of alternatives like biopesticides is directed, because they represent large markets for which existing products are experiencing pest resistance, banning or regulatory restriction.

Directing biopesticide development at pesticide-induced pests is not a forever proposition. Biopesticides and similar selective products will, it is hoped, help local natural enemy populations to recover, and in so doing they will reduce the pest problem and the need for further intervention, leading to more sustainable, low-input and cost-effective crop protection. So is it appropriate to view biopesticides as long-term, frequent use products in such systems, as we viewed their chemical predecessors? Or are they really products for environmental remediation, the "methadone of IPM", which gets farming systems off the hard drugs of broad-spectrum pesticides and have a longer term value in checking intermittent local outbreaks on a at-need basis?

One might imagine that local biopesticide suppliers could be well placed to service the small but regular markets that such a biopesticidal, IPM-product would enjoy. However, a multinational pest control industry with high overheads to cover might want to see new biopesticide products realise the duration and level of use of the chemical products which they replace. The small market niches of biopesticides must be sufficient disincentives to their development without the *additional* possibility of having a product which is less needed the more it is used.

It is not surprising, therefore, that we seem biopesticides like BT being marketed today in the same way as traditional chemical products, for prophylactic and regular use, without acknowledgement of their synergy with natural control.

The environmental safety of biopesticides is a strong marketing message, but it is only half-used by the multinational pest control industry. The logical second half of the message is that the environment which is protected provides additional pest control in the form of conserved, local natural enemies. But it is not the industry alone, but the entire pesticide regulatory process which has not adapted itself to the new opportunities which biopesticides provide. In their emphasis on high efficacy standards typical of fast-acting, potent chemical products, registration procedures make little allowance for new products whose effect is a combination of direct kill and the conservation of natural enemies. How can government regulators and industry count as part of a product's efficacy the impact of natural enemies whose action it conserves, when that action may be locally variable? But how can regulators and industry *not* count such impact if they are committed to products which are truly IPM compatible, true *IPM products*?

While it may be hard for biopesticide producers to view or market biopesticides as true IPM products, the decision to pursue a traditional chemical product approach may prove even less remunerative in the medium term. In Asia, for instance, effective IPM of diamondback moth in tropical highlands has now come to depend on use of BT which protects important, introduced natural enemies. However, the sustainability of this system requires that BT use be on an augmentative, at-need basis. The alternate use of BT on a calendar basis, e.g. as a direct replacement for the chemical strategy which induced outbreaks of this pest, is leading to resistance and the loss of this crucial product to IPM. Beyond the cabbage fields of tropical Asia, it is now widely suggested that the incorporation of BT genes into crops is a similarly wrong-footed strategy which will encourage resistance and render worthless a valuable IPM product.

To conclude this section, I suggest that most biopesticides are not being developed or promoted today as true IPM products. Rather, the specifications for most biopesticides remain those for the chemicals which preceded them - they must be highly effective, single technology pest-killing agents. Used as such their cost effectiveness to the farmer is wasted, their value to IPM reduced and their sustainability compromised. Finally by targeting their development at outbreak pests associated with chemically-abused crop systems, many other opportunities for biopesticides as key components of IPM against other pests are missed.

A WAY FORWARD

Putting all of these observations together, I am drawn to the conclusion that the potential for biopesticides has been largely unrealised because of the context in which they are presently being developed. Governments and society have turned to the multinational pest control industry for innovation and investment in biopesticide development. This industry has been understandably cautious in developing products for narrow niche markets, and has been conservative in following a traditional chemical pesticide model which offers the best short-term return given the production and marketing systems with which these industries are familiar. At the same time, these industries have been investing in new generation selective chemical products which may prove more appealing than biologicals, and in genetic

modification which holds the promise of greater control of crop protection markets through ownership of the seed itself.

Nonetheless there is a growing demand for biopesticides, associated with political and public concern about the use of broad spectrum products and with a growing commitment to IPM by governments and farmers. New national IPM programmes and the banning of chemicals in particular countries and crops are creating windows of opportunity for products which are simply not available. In the present scenario, this appears to be a lose-lose situation, with producers unable to fully benefit from demand, and consumers failing to have their needs met. How can we make this a win:win situation?

Present effort to encourage biopesticide development focuses on incentives to the development of products. Thus, governments create supply-side incentives by reducing the cost of registration, by fast-tracking the process relative to chemicals, or by allowing certain products to sit outside the registration process (e.g. macrobials and nematodes). Parallel to this is a massive but less obvious system of incentives associated with research grants to public institutes and universities to develop new biopesticide technologies for transfer to industry. Even development assistance agencies now support major programmes to create new biopesticide products, such as the mycopesticide for locust control developed by the LUBILOSA project (Jenkins & Thomas 1996 - see Thomas & Wood this volume).

The problem with this approach is that it assumes that there exist suitable markets for all these new biopesticides and appropriate production and delivery systems to reach those markets. At present, expectations have centred on the multinational pesticide industry. However, one need only look at the number of biopesticide products which sit inaccessible and undeveloped on the shelves of multinational pest control companies to see that this scale of industry has difficulty in making economically attractive products from biopesticides.

It is easy to conclude that a disproportionate amount of attention and incentives have been made on the supply side of biopesticides and too little on the demand and delivery side. There is an urgent need to understand better the economics and logistics of different scales of biopesticide production and use, from multinational to local. There are many models for biopesticides, ranging from the farmer who grinds up disease-infect caterpillars and sprays the slurry back on his or her crop, to the subsidised biocontrol industries of centralised economies like the former USSR and China, to the ommodity-specific systems which address glasshouses in temperate countries and sugar cane plantations in tropical ones. By comparison to the multinational pest control industry, much of our knowledge of the economics and potential of these systems is anecdotal, contributing perhaps to the view that these alternative systems are unsustainable. One must ask today, with biopesticide products and initiatives terminating all around, how sustainable is the present system? A careful economic analysis of biopesticide production systems at different scales and in different agricultural economies would go a long way in determining the most sustainable systems, and in refocusing incentive schemes to support these.

Beyond analysis and incentives to stimulate demand-driven supply systems, future support to biopesticide development will also need to address awareness-raising and farmer training. Farmers, extension specialists, researchers and government policy makers are poorly informed about biopesticides and their potential. Our experience with BT in Southeast Asia, for instance, is that many farmers simply do not understand that it is not a chemical product.

Application methods suitable for chemicals are used which are quite unsuitable for BT. In one IPM farming community, we were encouraged to see BT promoted as a "green label product" until we learned that the same label was applied to cypermethrin - "green" simply meant safe to humans.

The failure of adequate promotion and extension of biopesticides is universal, not just a problem of developing countries, and it has several causes. Biopesticides are frequently marginal or minor products of big companies, or major products of small companies. In neither case do the companies involved have the resources to mount an international sales and extension programme for the product. Government extensionists have rarely been trained in biopesticides. Where national expertise in biopesticides exists, largely in the university and government research community, the dialogue is largely academic and internal, or between researchers and companies. Communication between the research and extension sectors in biopesticides is very limited. Thus, while the human resources exist in almost every country to help farmers, extensionists and policy makers understand and benefit from biopesticides, they have not been effectively mobilised.

I have outlined three actions to enable the promise of biopesticides to be realised in future pest management systems: *analysis*, *incentives* and *training*. All require investment, and this should come logically from both the private and public sector. Only a joint effort would ensure that an effective commercial base is established, that public benefits of IPM are met and that sustainable biopesticides systems are realised.

Throughout this essay I have observed that the multinational pest control industry may not be the best home for all future biopesticide business. If this is true, why should this industry invest in a public/private sector initiative to realise the promise of biopesticides in crop protection? For three reasons. Firstly, it will probably be the home of some of that business and will be itself interested to know what is feasible. Secondly, whether or not it is a producer, this industry may be the owner of some of the intellectual property developed by future biopesticide businesses, on whatever scale they may operate. Thirdly, and most importantly, the industry has an interest in ensuring that components of future IPM systems which it wishes to deliver as corporate packages exist, are compatible with its own technologies and are available to farmers who know how to use them.

In conclusion, I suggest that biopesticides have a substantial future potential as IPM products, a potential which is not being realised today because of the environment in which they have developed. There is an opportunity now for a public/private sector initiative to examine and improve that environment, so as to ensure that biopesticides replace undesirable current products, generate income for the pest control industry and feature as sustainable elements of future IPM systems.

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