Biological Pest Control in Greenhouses: An Overview

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Abstract

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Biological pest control has been applied with commercial success for circa 20 years now in greenhouses. Although it is a relatively new pest control method in this cropping system, the growers did readily accept and rely on it. During the past 20 years 14 species of natural enemies have been introduced against 18 pest species. Natural enemies in use are insect parasites, arthropod predators and pathogens. Some 10 new species of natural enemies are in the process of being evaluated for future use. The greenhouse area on which biological control is applied has increased from 400 ha in 1970 to almost 14,000 in 1991. Most biological control occurs in vegetable crops. In ornamentals a zero-tolerance for pest organisms or their injury creates a great barrier for use of natural enemies. Biological pest control further made it possible that bumble bees and honey bees were used as pollinators for some important vegetable crops, particularly tomatoes. Biological pest control is an economically profitable endeavour, especially for growers of greenhouse crops. The rather fast evaluation and introduction of a number of natural enemies in situations where chemical control was either insufficient or impossible, has learned crop protection specialists that biological control, within IPM programmes, is a powerful option in pest control.

Introduction

The total world area covered by greenhouses is small (approximately 150,000 ha), yet developments in biological and integrated pest management (IPM[1]) in this cropping system have been significant. Greenhouses offer an excellent opportunity to grow high quality products in large quantities on a small surface area. In the Netherlands only 0.5 % of the area in use for agriculture is covered with greenhouses (9300 ha out of 2 million ha). On this small acreage 17 % of the total value of agricultural production is realized, i.e. 3.2 billion US $ in 1988 (12). Few specialists in biological control anticipated being able to employ natural enemies in greenhouses because growing vegetables in this protected situation is rather expensive and pest damage is not tolerated. For ornamentals the situation is even more serious, because presence of extremely low numbers of pest organisms prevents export, and therefore a zero-tolerance is literally in force.

Successful greenhouse production requires well-trained, intelligent growers who cannot afford to risk any damage from insects for ideological reasons, e.g. that integrated control may cause fewer negative side effects than chemical control. If chemical control works better they will certainly use it. In tomatoes, for example, pest control represents less than 2 % of the total overall cost of production, thus the cost of pest chemical control is not a limiting factor.

Yet despite the serious constraint that chemical control is so easy and inexpensive, the development and application of integrated control has been remarkably fast. The main reason for developing biological control methods was the occurrence of resistance against pesticides of several key pests in greenhouses. A close relationship among researchers, development and extension workers, and the growers has resulted in a rapid transfer and use of information on biological and integrated control. To date, most of the successes in greenhouse intergated control have first been accomplished inthe Netherlands and the United Kingdom, simply because 20 years ago these two countries together had more than 50 % of the greenhouse area.

Presently, biological control of the two key pests in greenhouses, whitefly *(Trialeurodes vaporariorum)* and spider mite *(Tetranychus urticae)* is applied in more than 20 countries out of in total 35 countries having a greenhouse industry. Recent surveys of work on biological control in greenhouses can be found in (7 and 16). Details of the developments in this field can best be traced in the Proceedings of the Working Group on Integrated Control in Glasshouses of the International Organization for Biological Control of Noxious Animals and Plants (Bulletins of the IOBC/WPRS from 1970 to 1991)

The Greenhouse Environment

Differences between the greenhouse and field environment may partly explain the success of biological pest control in greenhouses. Greenhouses are isolated units, particularly during the cold part of the season. At the start of a cropping period, usually during the winter, the greenhouse can be «cleansed» of pest organisms and subsequently kept pest free for quite a while. Later in the season, isolation prevents massive immigration of pest organisms. Furthermore, only a limited number of pest species occurs in greenhouses, partly

*IPM is defined as: A durable, environmentally and economically justifiable system in which damage caused by pests, diseases and weeds is prevented through the use of natural factors which limit the population growth of these organisms, if needed supplemented with appropriate control measures. In this article the term pest often includes diseases and weeds.

because of isolation, partly due to the fact that not all pests specific to a certain crop have been imported into countries with greenhouses. This makes biological pest control easier because the natural enemies of only a few pest species have to be introduced. Another point is that cultivars resistant to diseases (viruses and fungi) have been developed for the most important vegetable crops, and as a result relatively few diseases occur in greenhouses (16).

Culural measures and pest management programmes can be organized for each greenhouse unit. Interference with pest management in neighbouring greenhouses is very limited and so all measures can be applied per greenhouse. The frequently occurring problem of pesticide drift which negatively influences natural enemies in field crops does not exist here.

On the other hand, pest conrtol in greenhouses in complicated by the virtually year round culture of a crop and the continous heating. These conditions provide excellent opportunities for pest survival and development once it has invaded the greenhouse. Some field pests have adapted to the greenhouse climate by no longer reacting to diapause-inducing factors (6). But these complications do not create specific problems for biological control. On the contrary, they might even make it more attractive because low numberes of natural enemies may survive and be present for most of the time, making reintroduction unnecessary. The greenhouse climate is managed within certain ranges which makes prediction of population development of pest and natural enemy easier and more reliable than for field situation.

Histroy of Biological Control in Greenhouses

Biological control of pests in greenhouses started around 1930. Speyer (24) developed a method for whitefly control with the parasite *Encarsia formosa,* which was successfuly applied in several European countries and elsewhere until 1945. After the Second World War use of *E. formosa* was discontinued because the newly introduced insecticides provided convenient and efficient control on most greenhouse crops. A few years later, however, the first signs of resistance to pesticides were observed in spider mites *(T. urticae)*. Research by Bravenboer(1) revealed that a predator of spider mites, *Phytoseiulus persimilis,* was able to efficiently reduce the numbers of spider mites. It took several years before the predatory mite was used on a large scale. An important stimulus for its use came, unexpectedly, from the pesticide industry: a selective fungicide (Milcurb) became available and integration of the predator and Milcurb for control of spider mite and mildew, respectively, became popular.

Successful application of the predatory mite increased the interest for whitefly parasites because, at the start of the seventies, enormous outbreaks of whitefly populations took place. The knowledge of the availability of an efficient parasite paved the way for the development of a control programme and, after some trials, mass-rearing and introduction methods were developed for *E. formosa.* Since this revival, biological pest control in greenhouses has become firmly established.

Small scale application of biological control in greenhouses started in 1968 with the use of the predatory mite *P. persimilis. Encarsia formosa* is used again since 1970. Later, other natural enemies were selected, tested and introduced in programmes for commercial integrated pest control (table 1). The column «in use since» in table 1 refers to use on a commercial scale in West Europe. At the moment various natural enemies are being tested for use in the greenhouse (table 2). The number of companies that produce natural enemies for use in greenhouses has increased from 1 in 1968 to 30 presently.

The proceedings of the latest IOBC/WPRS meeting on integrated pest control in greenhouses in 1990 (8) show that use of almost all natural enemies is increasing. The growth in use of *E. formosa* and *P. persimilis,* and the fast increase in the employment of leafminer parasites, *Bacillus thuringiensis* and *Amblyseius* spp. prove that developments in greenhouse biological control have certainly not come to an end. Table 3 provides data on the developments in world use of biological pest control in greenhouses since 1970.

Table 1. Commercially produced natural enemies for control of greenhouse pests (after van Lenteren & Woets 1988 and Ravensberg 1991)

Natural enemy	Target pest	In use since
Phytoseiulus persimilis	*Tetranychus urticae*	1968
Encarsia formosa	*Trialeurodes vaporariorum*	1970(1926)
	Bemisia tabaci	1988
Opius pallipes	*Liriomyza bryoniae*	1980-1983*
Amblyseius barkeri	*Thrips tabaci*	1981-1990*
	Frankliniella occidentalis	1986-1990*
Dacnusa sibirica	*Liriomyza bryoniae*	1981
	Liriomyza trifolii	1981
Diglyphus isaea	*Liriomyza bryoniae*	1984
	Liriomyza trifolii	1984
	Liriomyza huidobrensis	1990
Bacillus thuringiensis	Lepidoptera	1983
Heterorhabditis spp.	*Otiorrhynchus sulcatus*	1984
Steinernema spp.	Sciaridae	1984
Amblyseius cucumeris	*Thrips tabaci*	1985
	Frankliniella occidentalis	1986
Chrysoperla carnea	aphids	1987
Aphidoletes aphidimyza	aphids	1989
Aphidius matricariae	*Myzus persicae*	1990
Oirus spp.	*Frankliniella occidentalis*	1991

* use terminated, other natural enemy available.

Biological Control Today

Most of the natural enemies mentioned above are employed in integrated pest management programmes, with difference in use of insecticides and natural enemies per crop and per country. The activities of the IOBC/WPRS Working

Table 2. Natural enemies in testing phase (after van Lenteren Woets 1988, and Ravensberg 1991)

Natural enemy	Target pest
Pathogens,predators,parasites	thrips spp.
parasites	*Aphis gossypii*
pathogens,predators,parasites	aphid spp.
parasites	leafminer spp.
Aschersonia aleyrodis & *Verticillium lecanii*	whitefly spp
nuclear polyhhydr.virus	*Spodoptera exigua*
nematodes	soil pests
Metarhizium anosipliae	*Otiorrhynchus sulcatus*
Bacillus thuringiensis var. *israelensis*	Sciaridae

Table 3. World use of biological control in greenhouses since 1970.

Year	Pest	Natural enemy	Area under control (ha)	Total area under control (ha)
1970	spider mite	*P.persimilis*	295	
	Whitefly	*E.formosa*	115	410(1970)
1980	spider mite	*P. persimilis*	3340	
	whitefly	*E. formosa*	1180	
	leafminers	*D. sibirica*	40	
	aphids	*A.aphidimyza*	10	4570(1980)
1990	spider mite	*P. persimilis*	7000	
	whitefly	*E. formosa*	4200	
	thrips	*Amblyseius* spp.	1200	
	leafminers	*D. iseae*	1000	
	aphids	*A. aphidimyza*	350	
	soil pests	nemathodes	50	13,800(1990)

Group on the effects of pesticides on natural enemies, «Pesticides and Beneficial Arthropods», are helpful for selecting those pesticides which interfere as little as possible with natural enemy activity (5). Even if selective insecticides are not available, there are still some alternatives: (1) apply chemicals at a time when natural enemies are not seriously harmed (separation of application in time, or selective timing); and (2) spray only the most seriously infested zones on individual plants or groups of plants (seperation of application in space, or selective spraying). Careful guidance by producers of natural enemies and advisory service personnel on the integrated use of pesticides is essential.

The assistance of another working group of the IOBC/WPRS, «Breeding for Resistance to Insects and Mites», may result in important improvements to biological control in the future. For those crops where the population development of the phytophagous insects is so fast that the parasite or predator cannot keep up with the pest, plant breeders search for partially resistant varieties so that population development of the pest is reduced. The first results of this sort have been obtained with partial resistance in tomato and cucumber against whitefly and spider mite respectively (20). An unexpected development from plant breeding research was to change morphological features of the host plant in order to facilitate the searching for hosts by natural enemies. In cucumber, the number of hairs per unit of leaf area has been reduced through a breeding programme, leading to improved parasitization of whitefly by *E. formosa* (15).

Sill another opportunity to broaden the application of biological control lies in the use of insecticide-resistant natural enemy strains. In greenhouse IPM an organophosphorus compound resistant strain of *P. persimilis* is used. In addition, climate management to improve the performance of natural enemies and/or to decrease development of pests and diseases may become a part of greenhouse IPM programmes.

Until a few years ago IPM was mainly limited to control of insects. During the past decade several initiatives have led to research in non-chemical control of nematodes and fungi. During the latest meeting of the Mediterranean branch of the IOBC/WPRS working group «Integrated control in Protected Crops» aspects of this work were reported, like: the effect of soil solarization on nematodes and fungi, the role suppressive soils may play in reduction of fungi and the potential use of antagonistic leaf fungi (9).

One specific example of an IPM programme is given below. Chemicals used in IPM programmes vary among countries, depending on availability and registration. Therefore, names of chemicals are not given; they can be found in the previously mentioned IOBC proceedings.

IPM in Tomato

The success of biological control in tomato crops is related to the rather simple pest and disease spectrum of this crop. Soil sterilization by steaming shortly before planting is used to eliminate soilborne diseases such as tomato mosaic virus (TMV), *Fusarium, Verticillium* and pests such as *Lacanobia oleracea, Liriomyza bryoniae* and *L. trifolii.* Furthermore, many tomato cultivars in West Europe are resistant to TMV, *Cladosporium* and *Fusarium.* Cultivars lacking TMV resistance are inoculated as young plants with a mild strain of the TMV virus to make them less susceptible. This procedure can be regarded as a form of biological control. Some cultivars are also tolerant to *Verticillium* and root-knot nematodes. Therefore only foliage pests and *Botrytis cinerea* require direct control measures.

The few pest organisms that «overwinter» in greenhouses and survive soil sterilization are the greenhouse red spider mite *(T. urticae)* and the tomato looper *(Chrysodeixis chalcites)*. Transferring young plants free of the other pest organisms into the greenhouse is important to prevent early pest development. Since five years the bulk of greenhouse tomatoes is grown on rockwool systems which makes soil sterilization redundant. As a result more organisms «overwinter» like *L. bryoniae* and its natural enemies, and *L. oleracea. Liriomyza trifolii* is not able to survive during the winter in greenhouses in temperature zones. Table 4 illustrates the tomate IPM programme.

Table 4. Commercially applied IPM programme for tomato crop.

Pest and diseases	Control method
Trialeurodes vaporaiorum	*Encarsia formosa*
Tetranychus urticae	*Phytoseiulus persimilis* and chemical control
Liriomyza bryoniae	*Dacnusa sibirica* and natural control
Liriomyza trifolii	*Diglyphus isaea* and natural control
Liriomyza huidobrenisis	*Diglyphus isaea*
aphids	chemical control and natural control
Lacanobia oleracea	*Bacillus thuringiensis*
Chrysodeixis chalcites	*Bacillus thuringiensis*
Botrytis cinerea	fungicides
fungi and viruses	resistant and plant material
soil nematodes	tolerant plant material

IPM in Other Crops

For a number of other important greenhouse vegetables (e.g. cucumber, eggplant,sweetpepper) reliable IPM programmes have been developed as well (16). There are, however, some problem inscets threatening continuation of IPM in some crops, e.g. cucumber. The most important species are aphids and thrips. *Aphis gossypii* occurs frequently in cucumber and cannot be controlled with the selective pesticide pirimicarb. Biological control of thrips with *Amblyseius* spp. was almost completely discontinued after several years of application, because of poor results, and new natrual enemies are being evaluated presently.

A recent invader to West Europe, the western flower thrips, *Frankliniella occidentalis*, has led to a critical situation for cucumber growers: both chemical and biological control of this pest are very unsatisfactorily. An intensive search for new natural enemies has been initiated, but it will take several years before this results in a commercial control programme. *Bemisia tabaci* is another recent invader in Europe,but seems to be creating limited problems only and can be kept at low densities by regular releases of *E. formosa* (8).

Although IPM programmes are available for a few flower crops (chrysanthemum, gerbera), they are applied on a very limited scale and usually for non-export flowers because of extremely low tolerance levels for pest infestation.

Selecting Natural Enemies

The selection of natural enemies for biological control programmes has been an empirical procedure until now, like the selection of new chemical pesticides. Most natural enemies have been found through trial-and-error. Many researchers have thought about ways of optimizing the preintroductory studies so as to increase the predictability of success before introductions are made. We should keep in mind, however, that the success ratio (1:100, i.e. 1 species out of 100 introduced natural enemies is a good control agent) and the economic evaluations are strongly in favour of biological control when compared with chemical control (1:10,000). Presently, we use a set of selection criteria to evaluate natural enemies (11,16). These selection criteria are particularly helpful in making a first selection between potentially promising and apparently useless natural enemies.

Why is Development of Biological Control Necessary?

The reasoning behind searching for pest control methods other than chemical control, consisted until recently mainly of the risks of chemicals for the environment and human heath (e.g. Metcalf 1980). With increasing pesticide resistance, incrasing costs of pesticides and the present difficulties in developing new effective pesticides (19,4), there are nowadays also strong signals from the field of agriculture itself that the time has come to change from opportunism in pest control - whereby problems are awaited, solutions in the field of chemical control are hoped for and danger signals are neglected - to biologically based pest control (11).

Factors Limiting Implementation of Biological Control

Most of factors limiting biological control in greenhouses are general and relate to all types of biological control. I will try to make clear why biological control is applied on only circa 14,000 of the 150,000 ha with greenhouses.

Firstly, ***there are situations where the application of biological is unneccessary or impossible*** due to a variety of reasons. For example, some crops are grown during too short a period to make biological control an economic investment, e.g. lettuce needs only 6 weeks from planting to harvest. Further, when a zero-tolerance exists, like in ornamental crops which are grown on about 50 % of the greenhouse area, biological control is difficult to apply, unless the production is not exported. In addition, climatological conditions may make biological control in some areas impossible, e.g. in the Mediterranean area it is frequently too hot and dry for *P. persimilis* to control spider mites,and frequently applied non-selective fungicides will harm the natural enemies. Finally, pests may occur which cannot (yet) be controlled by natural enemies or selective insecticides, therefore requiring the application of broad spectrum insecticides. If there is a large probability that such a pest will occur, the control of which will upset biological control,growers are not interested in applying biological control for other pests. In field crops this is the most important limiting factor. For the main vegetable crops in greenhouses it is less important. Considering these limitations it is estimated that presently about 30.000 ha of the total greenhouse area have potential for use of biological control.

With the development of new, more selective chemical control methods, a much larger area will be available.

Secondly, ***factors may hamper use of natural enemies in crops where biological control seems feasible.*** These factors are related to the quantity and quality of natural enemies at arrival in the greenhouse, and the service that growers obtain from the producer of natural enemies and/or from advisory personnel. If a grower begins to use Biological control, the quality and intensity of the initial guidance determines the success of the programme. For beginning producers of natural enemies the problems can be manyfold (14) and production of a qualitatively good beneficial insect is often underrated. These drawbacks will not necessarily always cause failure, but amateurism in production and guidance has had more than once a negative influence on application of biological control. Governmental insitutions demanding certain standards of performance for insecticides should apply the same standards for natural enemies.

Thirdly, biological control may be impeded by ***a group of various factors.*** One of these is new chemical compounds that appear on the pesticide market before possible negative effects on natural enemies have been evaluated. Such pesticides may totally disrupt a well balanced IPM programme. This situation is expected to change in Europe, where some governments may soon require inclusion of data concerning the effects on natural enemies as part of applications for registration of new pesticides Another important factor is the accidental importation of new pest organisms. Many of the greenhouse pests in countries with a temperate climate have been introduced through the importation of infested plant material. In the Netherlands, for example, more than thirty out of fourty species of greenhouse pests are introduced ones, seven of these are among the 10 most important pests (17). Almost every year a new greenhouse pest invades Europe. New imports require initially extensive chemical control programmes until proper natural enemies have been found.

The above factors do limit the implementation of biological control and IPM currently. But new developments may stimulate increase of the use of IPM. Soil solarization is one of the positive developments, the application of antagonistic fungi, or the exploitation of suppressive soils may further enhance IPM in greenhouses.

Incorrect Criticism Hampering Introduction of Biological Control

In the following section I will discuss a number of often heard, but incorrect statements about and unfair criticism of biological control.

Biological control creates new pests. Use of biological control against one specific pest is said to lead to new pests due to a termination of spraying with broad spectrum pesticides. For the glasshouse situation this criticism is not correct. Research on biological control was started to control pests which were resistant to pesticides. During the first years (1965-1975) control of the key glasshouse pests, spider mite and greenhouse whitefly, did not result in the occurrence of new pests. The new pests which have occurred since 1975 were unintentional imports (e.g. *Spodoptera exigua, L. trifolii, L. huidobrensis, F. occidentalis, B. tabaci).* These newly imported pests have created serious problems in glasshouse both under biological and chemical control. They threatened the biological control of other pests because natural enemies for them could not always be identified quickly enough. Chemical control of these pests was also very difficult because the pests were already resistant against most pesticides before they were imported in Europe. Several of these pests are so hard to control chemically that biological control appears to be the only viable option!

Biological control is unreliable. The idea that biological control is less reliable than chemical control has emerged mainly as a result of a strong pressure to market natural enemies which were not fully tested for efficacy. This criticism also arose because some amateuristic producers of natural enemies did not check whether the agents they sold were effective for control of the target pest. In the Netherlands it has always been our philosophy only to market natural enemies which have proven to be effective under practical conditions and within the total pest and disease programme. Natural enemies for which such efficiency studies were performed, e.g. *P. persimilis, E. formosa,* and leafminer parasites, have shown to be as reliable or even better than chemical control agents. The present difficulties in controlling *F. occidentalis,* have resulted in a too early large scale usage of predatory mites which have not been tested sufficiently under practical condtions. As in chemical control, a period of ten years between the start of research and marketing of an agent is often needed for correct evaluation of a natural enemy. It is unrealistic to expect that researchers in biological control can solve pest control much faster than those working with chemical control. Biocontrol workers often have to deal with much more complex ecological variables than researchers in chemical control. Biological control workers should be careful - even if the pressure is very strong - not to release natural enemies too early due to the resultant negative advertisement for our profession.

Biological control research is expensive. All cost-benefit analyses show that biological control research is more cost effective than chemical control (cost-benefit ratio's of 30:1 for biological control and 5:1 for chemical control,(3,25)). The fact that despite this, biological control is not used on a larger scale is mainly due to the relatively cumbersome production and distribution of parasites and predators. The whole methodology of natural enemy production is very different from that of pesticides. It is often thought that finding a natural enemy is more expensive and takes more time than identifying a new chemical agent. The opposite is usually true: costs for developing a natural enemy are on average 2 milion US $ and those for developing a pesticide on average 50 million US $.

Application of commerical biological control is expensive for the grower. An important incentive for the use of biological control in glasshouses has been that the costs of natural enemies have been lower than that of chemical pest control. Ramakers (21) estimated costs (agent and labour) for chemical and biological pest control in 1980. At that time chemical control of whitefly was twice as expensive as biological control with the parasite *E. formosa.* Currently, chemical control of *T. urticae* is almost twice as expensive as biological control with predatory mites (13). A comparison for costs of biological control and chemical control of other pests in given by (12,13). Wardlow (26) states that biological control of pests in tomato and cucumber is one fifth to one third that of chemical control in the U.K. Ramakers (22) concludes that even the biological control programmes where quite a number of different natural enemies are used (e.g. cucumber), are not more expensive than chemical control programmes. Ramakers gives the following figures for the costs of biological control in the Netherlands: 0.25 US /m^2/year for tomato (4 natural enemies), 0.55 US /m^2/year for sweet pepper (6 natural enemies) and 0.75 US /m^2/year for cucumber (9 natural enemies). The trade in beneficial arthropods amounts to 20 million US in the Netherlands in 1990.

Biological control is now so common in the main crops (tomato, cucumber and sweet pepper) that it is sometimes hard to make an estimate for pure chemical control costs.

Pratical use of biological control develops very slowly This criticism has already been disputed above. The developments in use of natural enemies over the period 1970-1988 are given in table 3. The total area now under biological control amounts to 14,000 hectares, and represents circa 45 % of the present potential area for biological control. The method is applied mainly in vegetables, although recently many activities have been additionaly directed in developing biological control for ornamental crops. Table 1 and 3 show that after the initial phase when only *P. persimilis* and *E. formosa* were used, the natural enemy market has considerably diversified. Today, biological control of whitefly and spider mite is applied in more than 20 countries out of the total 35 countries that have glasshouses.

Vital Considerations Before Starting with Biological Control

Good research alone does not guarantee application of non-chemical control methods. Based on my experience of the past 20 years, I have formulated some points to consider before starting research in biological pest control; they might help to prevent ivory tower work and frustration.

Acceptance of biological control and integrated pest management as the official control strategy of the country should be the first goal of biological control workers. The most important stimulus for an increase in use of biological control is the acceptance by governments of IPM as the main control strategy. If governmental bodies do not support implementation of IPM, activities of researchers should first and only be directed at a change of the policy at high levels. A change in policy should not only be expressed on paper, but has to be materialized in research, education and extension.

Without long-term planning of research and application, biological control programmes are doomed to fail.

It is an essential prerequisite that all participants -including extension workers and farmers - in an IPM project are receptive for new developments and are willing to implement them. A goal-oriented, long-term planning of crop protection is necessary to base IPM development work on. With a good planning, existing alternative methods can be used to realize a gradual improvement of crop protection. The applicability of new methods should be tested within the economic constraints of the farmer, to demonstrate and verify that these methods will not impair financial returns and will probably be beneficial, in the long-term, to society as a whole.

Introduction of biological control demands a good advisory service. At the introduction of the first biological control agent in a crop, special attention should be paid to extension: the growers have to rediscover the way biological control works and learn to rely on it. For extension workers the problem is that proper guidance of biological control demands considerable entomological knowledge and understanding. The phase of the initial implementation of biological control is often neglected. Experience in the Netherlands has shown that the amount of application of IPM is strongly related to the activity and attitude of extension personnel. If governmental extension services are weak, biological control will have no chance, unless the producer of natural enemies has well trained extension personnel and is willing to invest in guidance. For glasshouse growers a period of one or two years suffices to obtain additional knowledge of, and insight in biological control.

Acceptance of biological control as a serious control technology necessitates good public relations and education. Although researchers often do not like to invest time in writing articles that are not for scientific publications, it is essential to do so. Publications in the public press, radio and television programmes are usually more helpful in gaining acceptance for biological control than pure scientific articles. The teachnig of crop protection should drastically change at all levels (from vocational schools to university). Presently essentially purely technical information is taught on how to spray and with what chemicals. This should partly be replaced with information on other forms of pest control, especially biological control.

In the Netherlands such changes have occurred already and discussions with young growers have undergone a positive change over the past decade: it is no longer a matter of trying to convince them to use biological control, it is more a matter of being able to appropriately satisfy them with natural enemies for new pests. Integration of natural enemies and (selective) chemical control is a normal procedure nowadays.

The role of the consumer should be exploited to the benefit of biological control. The consumer is generally very receptive to information on and use of pest control not involving chemical pesticides. He is even willing to pay more for non-sprayed produce. Problems with residues on food, accidents with pesticides at production sites and environmental pollution have resulted in a strong awareness of side-effects involved in the use of chemical pesticides. Those working in the field of IPM should now positively interfere with the present attitude of the consumer which is that any reduction in chemical treatments is considered an improvement. A serious problem is that the consumer has no direct influence on the production and sale of pesticide free crops. It is the middle man who determines crop quality. Their standards are by no means influenced by the consumer, and their selection criteria result in an overuse of pesticides. It would be to the benefit of farmers and the general public if the last group could have more influence on pesticide-poor or-free production, e.g. by introducing a protected salesmark for food produced under IPM.

Information on biological and integrated control should be provided in the same books and pamphlets of the state advisory service which contain information on chemical control. The first Dutch guide for pest control (The Crop Protection Guide issued by the Advisory Service and Plant Protection Service (both from the Ministry of Agriculture) published in 1968 provided no information on biological control. In the 1981 volume (eight's edition) the first information on biological control was included, more than ten years after the use of *P. persimilis.* The 1989 volume, consisting of 589 pages, has 7 pages with information on biological control, including lists of which pesticides can safely be used in combination with specific natural enemies. (This is all in sharp contrast with the contents of the first book written by a Dutch author-Ritzema Bos - on pest control «Pest and Benefical Organisms» in 1891: of the 876 pages only 3 had inforamtion on chemical control).

Reliable production of good quality natural enemies should be guaranteed. The past 30 years have been characterized by the appearance and disappearance of natural enemy producers. Only a few producers active in the 1970's are still in the market. The market has somewhat stablized and besides many small, rather amateuristic producers, less than 5 large facilities are available providing qualitatively reliable material. The number of beneficials produced at these large production sites is often more than 5-10 million per agent per week (16). The rise and fall of so many producers resulted in a negative marketability for biological control.

The background of producers is rather diverse. Rearing of natural enemies can be a full-time or part-time activity of glasshouse growers. They can be reared by companies related to the glasshouse industry like seed companies and producers of fertilizers. In some cases production was started by a research group with governmental support and later continued as a private endeavour. The natural enemy producers mainly rear predators and parasites, only a few deal with microbial agents like nematodes, entomopathogenic fungi, bacteria or viruses. The chemical industries are interested primarily in production of microbials and it is expected that all activities in this area will soon be exclusively the domain of the pesticide industry.

The large natural enemy producers can now be considered as professionals, with research facilities, application of quality control, an international distribution network, P-R activities and an advisory service. They are well respected for their work and their market will certainly increase with the increasing demand for unsprayed food and the growing pesticide resistance problem.

Quarantine and inspection services should be improved to prevent unintentional imports of pest insects. During the past decade numerous pest insects have been imported into Europe (see elsewhere in this paper for examples). The initial chemical control programmes developed to eradicate these pests usually failed, but the spray frequencies advised were so high that each time a new pest was imported, the biological control of other pests was put at risk. The creation of a database with information on potential invaders and methods to control these organisms might help to prevent panic reactions aimed at eradiction.

Adaptation of export requirements to make biological control possible. Current export requirements are often unrealistic. They result in overuse of pesticides, with the additional risks of a fast development of resistance, high residue levels and health risks. More realistic requirements should be designed. The first priority should be to change the criterion that products should be without signs of damage, to that of products having no living pest insects.

Specific Advantages of Biological Control in Greenhouses

After having heard all these obstactes for biological control one might start to wonder why there are still growers using this method.

There are, of course, the general advantages of biological control such as reduced exposure of producer and applier to toxic pesticides, the lack of residues on the marketed product and the extremely low risk of environmental pollution. These are, however, not of particular concern for the grower. More impotant is that specific reasons exist that make growers working in greenhouses to prefer biological control:

(a) with biological control there are no phytotoxic effects on young plants, and premature abortion of flowers and fruit does not occur.

(b) Release of natural enemies takes less time and is more pleasant than applying chemicals in humid and warm greenhouses.

(c) Release of natural enemies usually occurs shortly after the planting period when the grower has plenty of time to check for successful development of natural enemies, thereafter the system is reliable for months with only occasional checks; chemical control requires continuous attention.

(d) Chemical control of some of the key pests is difficult or impossible because of pesticide resistance.

(e) With biological control there is no safety period between application and harvesting fruit; with chemical control one has to wait several days before harvesting is allowed again.

(f) Biological control is cheaper than chemical control.

Biological Control in Greenhouses: A Success?

Due to earlier mentioned resistance problems we were forced to look for other pest control methods than chemical control. Intensive cooperation between researchers, extension workers, producers of natural enemies and growers has led to considerable success both in research and application of biological control. This cooperative effort has led in the past 20 years to introduction of 14 natural enemies against 18 pests (table 1). In some countries integrated pest management is practiced on a large part of the main vegetables crops in greenhouses (up to 90 % of the total area for certain crops, (16). In the Netherlands, for example, growers have learned to rely on biological control and now ask for new natural enemies before we can provide them with the necessary information. This enthusiasm might, however, create a new problem: a too early release of a natural enemy can result in a bad control effect and thus in negative advertisement for biological control! To date, we can safely conclude that biological control in greenhouses has been very successful.

A number of conditions have to be met before the technical implementation of biological control will become a success, however. Biological control agents should be as cheap, as easily available, as reliable, as constant in quality, and as well guided as chemical control. They should fit well in the total crop protection programme and not be seen as an endeavour separate from other crop protection measures.

Conclusions: The Future of Biological Control in Greenhouses

Several current trends will stimulate the application of Biological control in greenhouses. Fewer new insecticides are becoming available because of skyrocketing costs for development and registration (18). The few new insecticides that are being developed are not likely to be targeted for greenhouse use because the greenhouse area is small and represents a poor opportunity for chemical companies to recover developmental costs.

Second, the sudden use of bumble bees and honey bees for pollination on a large greenhouse acreage, strongly reduces chemical control and intensifies demands for biological control. Ramakers (22) illustrates that during the first period of biological control in greenhouses the area under biological control increased fast, and that presently, besides a further increase in area, the trade volume per surface unit is strongly increasing. Over the past 5 years an 8-fold increase in turnover/ha was measured in the Netherlands.

Third, pests continue to develop resistance to insecticides, a particularly prevalent problem in greenhouses where intensive management and repeated insecticide applications exert strong selective pressure on insects (10,2). Therefore we expect a greater demand for non-conventional pest control methods.

We should not see biological control as a control method that will completely replace chemical control. It is a powerful option and can be applied on a much larger area than is presently done. It should be used in combination with other pest control methods, among which chemical control, in IPM programmes. In this way mutual benefit will be harvested. For chemical control it may result in extended use of products because of slower development of resistance and a more positive perception of the role of the pesticide industry by laymen. In order to serve agriculture as well as the environment and human health, we should harvest the best from both methods to develop effective IPM methods. Designing such environmentally safer IPM programmes is a challenge for our profession.

الملخص

فان لنترن، ج. س. 1992. مراجعة في المكافحة الاحيائية للآفات داخل الدفيئات الزجاجية. مجلة وقاية النبات العربية 10 (1): 35 - 43

استخدمت المكافحة الاحيائية للآفات داخل الدفيئات وعلى نطاق تجاري ناجح منذ أكثر من عشرين عاماً. ورغم أن هذه الطريقة من المكافحة تعتبر حديثة نسبياً، إلا أن المزارعين تقبلوها وباتوا يعتمدون عليها. وقد تم خلال العقدين الماضيين ادخال 14 نوعاً من الأعداء الطبيعية لمكافحة 18 نوعاً من الأفات وتشمل الأعداء الطبيعية المستخدمة طفيليات حشرات ومفترسات من مفصليات الأرجل وممرضات. ويتم حالياً تقويم عشرة انوع جديدة من الأعداء الحيوية كي يتم استخدامها في المستقبل. وقد تزايدت مساحات الدفيئات الزجاجية التي تستخدم فيها المكافحة الاحيائية من 400 هكتار في عام 1970 إلى حوالي 14000 هكتاراً في عام 1991. ومعظم المساحات المعالجة تزرع محاصيل خضر. أما في نباتات الزينة، فإن الرغبة في الحصول على نباتات خالية تماماً من الآفات تضع حاجزاً كبيراً امام استخدام الأعداء الطبيعية. هذا وسمح ادخال هذه الطريقة باستعمال نحل العسل لتأبير بعض محاصيل الخضر الهامة وبخاصة البندورة/ الطماطم. والمكافحة الاحيائية للآفات عملية مربحة من الناحية الاقتصادية وبخاصة لمزارعي الدفيئات. وقد علّمت عمليتا التقويم والادخال السريعتين لعدد من الأعداء الطبيعية، وفي حالات كانت المكافحة الكيميائية فيها غير كافية أو مستحيلة، اخصائيي وقاية النبات أن المكافحة الاحيائية ضمن برامج المكافحة المتكاملة للآفات تعتبر خياراً قوياً في مكافحة الآفة.

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