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Pest and disease control in glasshouses in North-west Europe

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The glasshouse environment differs both physically and biologically from crop production in the open, and its cost structure permits the use of more sophisticated products and techniques for pest and disease control. From the wide range of control methods that are available, including integrated programmes in which chemical and biological methods are combined, experience indicates those should be selected which limit the risk of developing resistant strains of insects or pathogens.

Introduction

In the past 25 years great changes have taken place in glasshouse production. During this period, relatively primitive growth of crops in glasshouses has developed into a sophisticated industry. The modern glasshouse holding has become highly specialized, mechanized and automated. These developments have greatly influenced the pest and disease pattern and consequently their control. Some formerly serious pests and diseases have disappeared, such as *Fusarium* wilt in cucumber, while other diseases that formerly occurred only rarely, have become established and require intensive control, such as powdery mildew (*Sphaerotheca fuliginea*) in cucurbits. The degree of specialization has a considerable influence on the population dynamics of the insects or pathogens; growing one crop virtually the whole year round for many years means that the host plant is available all the time, thus enabling the pathogen to build up high populations. At the same time, specialized firms have developed in several areas, e.g. soil disinfection contractors, firms producing potting composts, holdings for production of young plants, etc. and, although this specialization is essential in modern glasshouse production, it may involve risks in respect of pests and diseases. For example, holdings for the production of young plants may unwittingly distribute new diseases or pests or strains that have become resistant to pesticides over a large area. This has happened in the past with *Fusarium javanicum* in grafted cucumbers, and recently with a strain of *Alternaria chrysanthemi* resistant to benomyl in chrysanthemums.

In matters affecting pests and diseases, glasshouse production differs in several aspects—physical, biological and economic—from production in the open.

(a) *Physical.* In an enclosed environment, several climatic factors are eliminated, including wind and rain. This is generally advantageous because the disease risk will diminish. On the other hand, air humidity and temperature tend to fluctuate more than in the open, which may stimulate the build-up of higher populations of pests and disease organisms. The enclosed environment also offers extra possibilities in the use of techniques for applying pesticides, such as smokes and ultra-low volume applications.

(*b*) *Biological.* From the biological point of view a glasshouse can be regarded as an island. Emigration and immigration, of insects and mites in particular, will therefore be much less than in the open, and biological control offers better possibilities.

(c) *Economic.* The price of pesticides is of minor importance in relation to the total cost of a glasshouse product. Consequently, expensive chemicals or techniques do not constitute limiting factors in production. Soil disinfection, with steam or methyl bromide, will therefore almost always be profitable.

Ecological control

In an unheated glasshouse the possibility of climatic control is very small. Temperature and air humidity can be influenced only by opening or closing the ventilators. Under Northern European conditions the temperature is often too low and the air humidity too high. Condensation on the plants frequently occurs early in the morning, when the air temperature rises quickly whilst the plants stay cool. This is the ideal situation for many fungi to germinate, resulting, for example, in attacks of *Cladosporium fulvum* in tomatoes, *Pseudoperenospora cubensis* in cucumbers, and *Botrytis cinerea* in a number of crops. In such a situation, chemical control does not generally give satisfactory results. In a modern, well-equipped glasshouse, on the other hand, the climate can be controlled to a large extent. Although this climatic control is not aimed at disease control, it nevertheless greatly diminishes the risk of an attack by the above-mentioned fungi. If the environmental control equipment is used in the right way, the plant never becomes wet through condensation. A similar situation holds for watering. Overhead irrigation increases the chance of the plants remaining wet for too long and so being exposed to fungal attack; but, by using systems like trickle irrigation, risks like this are avoided. Ecological control of this type has not so far been used purposively in glasshouse production, but research in this field might well offer good possibilities for practical application.

Resistant varieties and rootstocks

Considerable progress has been made, with some vegetable crops grown under glass, in the breeding of varieties resistant to fungi. Diseases formerly causing considerable loss, such as cucumber scab (*Cladosporium cucumerinum*) and *Corynespora melonis* in cucumbers, have been eliminated. Although resistant varieties have already been grown for about 20 years, new strains of these pathogens have not yet arisen. The situation is different with other vegetable crops. Although resistance to *Cladosporium fulvum* in tomatoes, and to *Bremia lactucae* in lettuce, has been introduced into many varieties, new strains of these pathogens appear repeatedly, forcing plant breeders to seek out new genes for resistance. Varieties resistant to soil-borne diseases have been introduced only recently, and tomato varieties resistant to *Fusarium* wilt are now grown on a large scale. Several plant-breeding firms are currently working on resistance to other organisms such as spider mites (*Tetranychus urticae*), white fly (*Trialeurodes vaporariorum*), tomato mosaic virus, etc. It is to be expected that, in the near future, varieties resistant to those organisms will be introduced.

A special aspect of resistance is the use of resistant rootstocks. For both cucumber and tomato, rootstocks are available which are resistant to soil-borne diseases. *Cucurbita ficifolia* has already been used for many years as a *Fusarium*-resistant rootstock for cucumbers. An F_1 hybrid of *Lycopersicum esculentum* × *Lycopersicum hirsutum* is used as a rootstock for tomatoes, which is resistant both to corky root (*Pyrenochaeta lycopersici*) and to root-knot nematodes (*Meloidogyne* spp.). Resistance to the vascular *Verticillium* and *Fusarium* diseases can also be achieved in tomato rootstocks, but this has no practical value as the grafted plants usually retain both root systems. Grafted plants are, in general, not grown in early production but are used to a fairly large extent for late or second crops. Specialized holdings for plant propagation employ grafting on a large scale.

Chemical control

Although alternative control measures are available, chemical control still predominates in glasshouse production. Policy on the use of pesticides for glasshouse crops should differ from that for cultivation in the open, taking into account the following points.

(a) *Environment.* As the total area of glasshouses is negligible in comparison with the area on which agriculture is practised, environmental pollution by chemicals used in glasshouses is of negligible significance. In consequence, pesticides which are potentially harmful to the environment can be used in glasshouses without risks.

(b) *Residues.* As the same crop may be grown for many years in the same place, there is little diversification in pesticide use, and the same chemicals may be used frequently. If these are readily broken down, there will be no problem, but, if they are somewhat more persistent, difficulties may arise, in that the residue levels in the soil may slowly build up, which may eventually give rise to residue problems in the crop. Another aspect of increasing residues in the soil concerns the pathogens. As is well known, systemic fungicides like benomyl and thiophanate-methyl are converted into benzimidazole carbamic acid methyl ester (BCM), which proves to be rather persistent in the soil. Although such chemicals possess a broad spectrum of action, they are inactive towards certain groups of fungi, e.g. the Phycomycetes. The permanent presence of BCM in the soil might give rise to a permanent shift in the composition of the soil flora, favouring fungi such as *Pythium, Phytophthora* etc. In consequence, these pathogens might present an increasing problem. Great care should therefore be taken in the use of these fungicides on the various glasshouse crops.

(c) *Prolonged harvesting.* Most vegetable crops grown under glass are harvested at intervals of 3–7 days over a long period. As pesticides usually have to be applied during harvest, the time lapse between application and harvest cannot be longer than three days. This means that only those chemicals can be used that have a high residue-tolerance or a short life. The spectrum of pesticides to be used in vegetables under glass is, therefore, relatively small. Thus, of the many organophosphorus compounds available, only a few are suitable for glasshouse vegetables, e.g. mevinphos, dichlorvos and malathion. Moreover, most glasshouse-grown vegetables are eaten fresh, with a higher risk that the residues on the crop are consumed. The situation is quite different for ornamentals grown under glass, where residue problems practically do not exist. A far greater variety of pesticides is available for these crops, and these are indeed used.

Pesticide application

The enclosed environment of the glasshouse allows more techniques of pesticide application to be used than in the open. These additional possibilities, which include smokes, aerosols, fumigants and ultra-low volume applications, may be summarized in the term "space treatments". The obvious advantages of these space treatments are that the distribution of the chemical is even and very little labour is involved. A further advantage is that the amount of active ingredient used per square metre, or per plant, is much lower than with other techniques, so leaving smaller residues. A consequence of this, however, is that the pesticides have practically no residual effect on the organisms to be controlled. Frequent applications are therefore necessary in most cases to achieve satisfactory control. This is particularly true of fungi, and of insects and mites with a complicated life-cycle. For the control of aphids, on the other hand, a single application is sufficient to reduce the population to a low level.

Smokes containing lindane, parathion, diazinon, sulfotep, tetradifon and pirimicarb are available for the control of insects and mites, whilst the fungicides tecnazene and dicloran are also available as smokes. The aerosols in use mainly contain dichlorvos. Hydrocyanic acid can be used successfully against white fly, for example, if sufficient precautions are taken to prevent phytotoxicity. A recent development in space treatment is the application of pesticides through thermal fog generators (Swingfog, Puls Fog, etc.). Insecticides like dichlorvos, mevinphos, malathion, pyrethrum and propoxur have proved to be suitable for this technique whilst, with the fungicide pyrazophos, good control can be obtained of powdery mildew in cucurbits.

Dusts are used on a large scale in the glasshouse industry. In the early stages of plant development, preventive dusting against pests and diseases is common practice. For this purpose, most of the pesticides used are obtainable in this formulation. In lettuce-growing in particular, practically the whole control programme is based on dusts. As soon as an attack occurs, however, dusting usually gives unsatisfactory results and other techniques have to be used. One possibility is high-volume spraying, which is still used to a fairly large extent, especially in cases where the attack is beginning to become severe. High-volume spraying is still the most effective method of control, as in this way the plant is thoroughly wetted and the maximum residual effect is obtained. It is, however, a laborious operation and needs relatively expensive machinery. For this reason, high-volume spraying is often carried out by contractors. Furthermore, in some cases, the distribution of pesticides applied in this way may be inadequate; particularly in crops with dense foliage, coverage of all the leaves may not be obtained, so leaving many sources of re-infestation.

Biological and integrated control

To aid understanding of this aspect, the development of biological control will be briefly outlined. Biological control in glasshouses is not new, having already been practised on a small scale in both England and Holland in the late 1920s, when the parasite, *Encarsia formosa*, was successfully used against the white fly, *Trialeurodes vaporariorum.* Due to the spectacular development of the synthetic pesticides after the Second World War, the need for biological control became less urgent. However, due to the rapid build-up of resistance to insecticides, especially amongst the spider mites, there was renewed interest in biological control, and research was begun on the possibility of biological control of spider mites. As resistance problems were most severe in fruit-growing under glass (at that time, an important line in glasshouse production), efforts were concentrated in that field. The endemic predators, *Stethorus punctillum* and *Typhlodromus longipilus*, in combination with one or two applications of selective acaricides, proved capable of keeping populations of spider mites down to acceptable levels. Both predators, however, were ineffective on vegetables grown under glass. Prospects improved when the predatory mite, *Phytoseiulus persimilis*, was discovered. The latter predator proved capable of reducing any population of spider mites to very low levels within 4–6 weeks. This method came into use on a large scale when the systemic mildew fungicide, dimethirimol, was introduced. As mildew and spider mites were the prevalent problems in cucumber growing at that time, this combination seemed to be ideal. Dimethirimol was applied to the soil, the spider mites were controlled biologically, and application of other pesticides was usually unnecessary. This system worked, however, for only 1 to 2 years, because new problems arose. On the one hand, mildew became resistant to dimethirimol and, on the other hand, a sudden explosion of the white fly population took place. This stimulated research on biological control of the white fly by *Encarsia formosa*, thus resulting in a system in which both spider mites and white fly are controlled biologically. This has been proved to work particularly successfully in tomatoes, and at the present time several hundred hectares are treated in this way. Use of *Encarsia formosa* on cucumbers is limited, as results under practical conditions are still conflicting.

The system of mass rearing and distribution of the natural enemies differs from country to country, depending on local conditions. In some countries (e.g. England, Holland) this is done by specialized firms and growers who deal only with mass rearing. Distribution is done on a personal basis and often growers are advised as to further handling, the use of pesticides against pests and diseases, etc. The price the grower has to pay is calculated at a set rate per unit area, so that in effect it is a control system that is being sold. In other countries (e.g. Scandinavia) the mass rearing is done by firms selling pesticides, etc.; the predators are then usually sent by air, with written recommendations, and in this case the price is calculated on the number of predators supplied.

The prospects of biological control in vegetable-growing under glass look good. As has already been stated, a glasshouse is an island from a biological point of view, and past experience indicates that biological control offers good possibilities on islands. Moreover, the number of different pests in glasshouses is restricted, so insecticides against pests other than spider mites and white fly are generally unnecessary. Aphids, which occur in most crops, can easily be controlled by means of selective aphicides such as pirimicarb, whilst most fungicides used in glasshouse crops are harmless to the predators. Omitting insecticides completely from the control scheme, however, may give rise to new insect problems. Pests such as thrips and the leaf miner, *Liriomyza solani*, which are normally kept under control when insecticides are applied, tend to increase under these different conditions. A formerly virtually unknown pest of glasshouse tomatoes, *Vasates lycopersici*, was found recently on some holdings where biological control had been carried out for some years. Research efforts will therefore have to be increased in order to find answers to these problems, whether biologically or through development of selective chemicals.

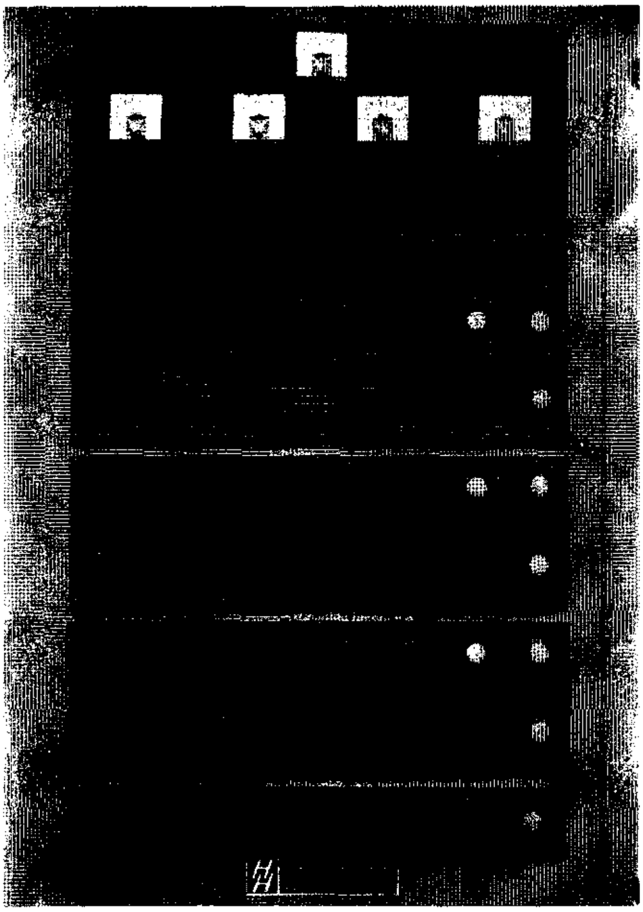

Figure 1 Control panel typifying the sophistication of the modern glasshouse industry.

The prospects for biological control in ornamentals grown under glass look less promising. In most cases, not only the flowers but also the leaves of the plants are sold. As, with biological control, a certain proportion of the pest population remains, some damage is inevitable, and this results in a much lower price for the flowers concerned.

Soil disinfection

As crop rotation is practically impossible in glasshouse production, soil-borne diseases can build up high populations, which may cause large losses. Fungi, such as *Fusarium*, *Rhizoctonia*, *Verticillium*, *Sclerotinia*, etc., and nematodes, are liable to be found in all glasshouse areas. In some cases, fungistatic chemicals can prevent an

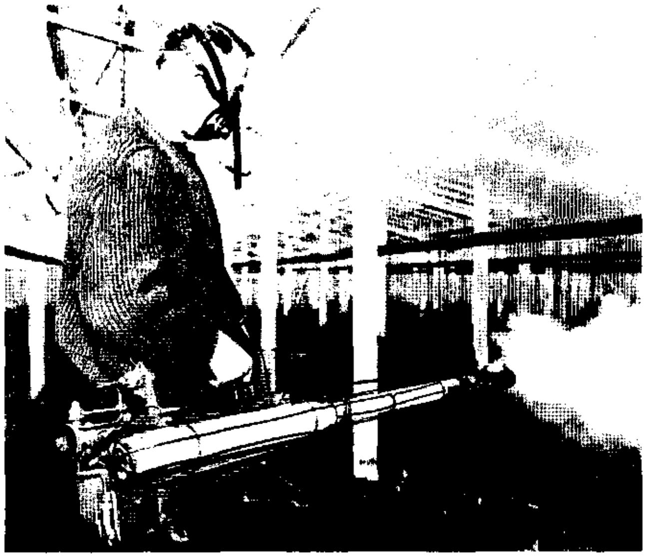

Figure 2 Space treatment gives extra possibilities for application of crop protection chemicals.

attack (quintozene against *Rhizoctonia*) but, in general, eradicants have to be used to avoid the risk of unacceptably heavy attacks.

Steam sterilization. In principle this is the most effective method of soil treatment. No pathogens can survive temperatures of 100°C and even virus diseases—such as tomato mosaic virus and cucumber virus 2—which may be left in the soil, are readily killed. Formerly, soil steaming was done by means of Hoddesdon pipes, which are dug into the soil. Due to the labour involved, this method is no longer used; most growers have changed to steaming under plastic sheets. This generally gives sufficient assurance that the next crop will not suffer economic loss due to soil-borne diseases. The disadvantage, however, is that only the top layer of the soil is thoroughly disinfected, with the result that diseases are able to survive in the deeper layers of the soil, particularly in crops grown for more than one year—e.g. carnations—fungi such as *Phialophora* and *Fusarium* may cause substantial loss during the growing period. This can be overcome by steaming through a system of drainage pipes, buried in the soil at a depth of 50 cm. This type of permanent system has now been installed on several holdings.

Steaming the soil at 100°C may also have an influence on both its physical and chemical properties. This mostly has no deleterious effect on the crop, except in respect of manganese, which is transferred into a form which can be taken up by the plant, resulting, in some circumstances, in manganese toxicity. Most crops do not suffer from this excess of manganese, but lettuce is very susceptible to it. Steaming through the drainage-pipe system offers the possibility of pasteurizing the soil at 70°C, at which temperature the manganese is not mobilized, and so manganese toxicity will not occur.

Chemical disinfection. Although chemicals are less effective in sterilizing the soil than steaming, chemical disinfection is employed on a large scale, mainly because of the lower cost. Such chemicals can be divided into two groups: general sterilants such as methyl bromide, chloropicrin, metham-sodium and dazomet, and specific nematocides such as EDB (ethylene dibromide), 'D-D' (a mixture of dichloropropene and dichloropropane) and dibromochloropropane. All the chemicals mentioned act as fumigants and are either injected into the soil by means of special equipment or used in the form of granules, which are distributed through the soil. If the soil is well prepared, the vapours penetrate evenly, so resulting in effective control. These vapours, however, are toxic to plants, and a certain interval has to elapse between application and the time of planting. This interval depends on the chemical used and on the soil temperature. Methyl bromide can be used all the year round—even in winter—as its boiling point is only 4°C; and, depending on soil temperature, the waiting interval varies from a few days to a fortnight. All the other chemicals require longer intervals between application and planting, varying from about ten days to six weeks; they are generally not used during the winter, as the waiting period then becomes too long.

For differing reasons, the soil is covered with plastic sheets either before or after chemical treatment. When using methyl bromide, it is necessary to do this before the application, because of the chemical's volatility. In the case of chloropicrin, however, the plastic sheets are used after application, as the vapours are extremely phytotoxic and may easily damage neighbouring crops. With the other soil sterilants, a water seal is usually applied to delay evaporation; plastic sheets are only used when the soil temperature is high.

Methyl bromide and chloropicrin are about equal in their effect on soil-borne diseases and will effectively destroy heavy infestations; metham-sodium and dazomet can only be used successfully when the infestation is slight. As nematodes rarely occur alone in glasshouse crops, the use of 'D-D' and EDB is restricted to special cases. Dibromochloropropane granules are usually applied where cucumbers are grown, as an additional measure after steam sterilization.

Thanks to the herbicidal effect of both steaming and most of these chemicals, weeds are generally not a problem in glasshouse production. As the soil is disinfected practically every year in one way or another, herbicides therefore only need to be used incidentally.

An important side effect of soil sterilization is the phenomenon of growth stimulation. In terms of production this means that, apart from killing pathogens, there is a definite increase in growth after treatment. This stimulation of growth is greatest with steaming, methyl bromide and chloropicrin. With the other chemicals, this effect is less and generally of no practical importance.

Soil disinfection has become a very important tool in glasshouse production, and it is not to be expected that other measures will replace it in the near future. Neither does it look likely that other chemicals will become available to replace the sterilants now in use, as it seems to be difficult to find pesticides suitable for this purpose that have comparable qualities.

Resistance to pesticides

Pest and disease populations in glasshouses are more or less isolated, and selection for special properties is therefore likely to occur. Selection for resistance to pesticides is one possibility. Apart from the resistance of houseflies to insecticides, the first example of selection for insecticide-resistance was found in glasshouses. Shortly after the introduction of the organophosphorus compounds, resistance to these chemicals was found in the glasshouse spider mite (*Tetranychus urticae*). Research showed that genetic variability in these mites is very great and resistance to acaricides is therefore likely to occur readily. Resistance to almost all acaricides has indeed been found in practice and it looks as though there will be an unending race between the spider mites to become resistant and the pesticide industry to develop new acaricides. Although resistance to insecticides has also been observed in aphids and white fly, the situation there is less acute as most of the chemicals used against these insects still give sufficient control under practical conditions. Until recently, no resistance of fungi to fungicides had been observed under practical conditions. This situation has changed since the development of systemic fungicides and their introduction in practice. Mildew in cucumber provided the first example of resistance to the specific systemic fungicide, dimethirimol. Within two years of its introduction, the results were in many areas so disappointing that the latter chemical could no longer be used. The same thing happened with systemic fungicides of the BCM type (benomyl, thiophanate-methyl etc.); resistance of cucumber mildew was widespread within 1–2 years of their introduction and these chemicals are no longer used for that purpose.

A further example is the resistance of *Alternaria chrysanthemi* in chrysanthemums to BCM-type fungicides. The mother plants, from which the cuttings were taken, had been frequently treated with these chemicals, thus resulting in a build-up of resistant strains of the fungus. Through these cuttings, the resistant strains were distributed over a large area and consequently these fungicides can no longer be used in chrysanthemum growing. It can be learned from this experience that the problem is one that requires great care, and it therefore seems sensible to develop control schemes in which the risk of resistance can be minimized.

Conclusion

In several aspects, pest and disease control in glasshouses offers more possibilities than in the open. This is true of application techniques, the more expensive chemicals and methods, biological control, etc. More research will, however, be necessary if these possibilities are to be exploited fully.