Union Internationale des Sciences Biologiques
Organisation Internationale de Lutte Biologique
contre les animaux et les plantes nuisibles
SECTION REGIONALE OUEST PALEARCTIQUE

WORKING GROUP INTEGRATED CONTROL IN GLASSHOUSES

GROUPE DE TRAVAIL LUTTE INTEGREE EN CULTURES SOUS VERRE

DARMSTADT , 26 - 29.6.82

BULLETIN SROP
WPRS BULLETIN

1983/VI/3

International Union for Biological Sciences
International Organization for Biological
Control of noxious animals and plants
WEST PALAEARCTIC REGIONAL SECTION

CONTENTS

Page

Page

MODELLING

INTRODUCTION

Following the small specialized meeting in Naaldwijk in September 1982 which concentrated upon practical problems encountered in the control of leafminers, thrips and whiteflies, a full meeting of the Working Group was held in Darmstadt, 27-29th July, 1983.

42 delegates from 17 countries attended the meeting during which discussions emphasized the biological control of agromyzid leafminers, problems in the use of Encarsia under energy-saving low-temperature cultural regimes and progress in the development of full integrated programmes of pest control on different crops.

A significant aspect of the meeting was the attendance, for the first time, of workers from Japan and China as well as colleagues from Mediterranean countries, including Spain, Italy, Sicily and Crete.

Through the kindness of Prof. Klingauf delegates spent an interesting afternoon at the Biological Control Institute while the hard work and efficiency of his colleague, Dr S. Hassan, assured an enjoyable and profitable meeting punctuated with much appreciated social functions.

This meeting marked the beginning of a change in the emphasis of the Group's work which will become increasingly concerned with the adaptation of the biological control techniques now widely adopted in North Western Europe to other areas where protected crops are grown.

N.W. HUSSEY
Convenor

GREENHOUSE TOMATO PESTS AND THEIR CONTROL IN ISRAEL

M.J. Berlinger, R. Dahan & S. Cohen

Tomato is a thermophilic plant, growing in natural or artificial warm climates. In Israel it is grown year-round. In the warmer season (March-November) it is cultivated in open fields, and in winter it has been grown for the last ten years in greenhouses. Greenhouse tomatoes are sown, or planted, in September. The picking period generally lasts from January to May. The purpose is to ensure quantitative and qualitative yields suitable for export in winter (January-April) - mainly to Western Europe. The greenhouses are either of the Dutch glasshouse type, or of a type developed locally consisting of a windowless glass roof, and side walls made of plastic sheets which can be rolled up for ventilation purposes. The greenhouses are not artificially heated. Thus, indoor temperatures are high in the beginning of the season (September-November), low during the growth period (December-February) and again warm during the growth period (March-April). This temperature regime determines the activity of the pests. Severe damage is caused especially in the first period and control measures must be applied.

Tomatoes, almost wherever they grow, are attacked by the same range of pests. Thus, greenhouse tomatoes are usually attacked by the glasshouse whitefly (Trialeurodes vaporariorum), red spider mite (Tetranychus urticae), leaf miners (Liriomyza sativa and L. trifolii), thrips (Thrips tabaci), aphids and Lepidoptera larvae (Hussey et al., 1969; van Lenteren et al., 1980; Lindquist et al., 1980, etc.). In Israel, as in European glasshouses, these pests, or closely related species exist (Avidov & Harpaz, 1969; Berlinger et al., 1978): The tobacco whitefly (Bemisia tabaci) and the greenhouse whitefly (Trialeurodes vaporariorum), the carmine red spider mite (Tetranychus cinnabarinus), Liriomyza spp. Thrips tabaci, aphids, caterpillars like Spodoptera littoralis, Agrotis segetum, etc., and the tomato rust mite Vasates lycopersici.

Israel is a subtropical, rather warm country. Not only does the tomato grow in the open during the summer, but together with their host-plant, tomato pests also develop readily outdoors during the whole summer. During the warm period these pests are most abundant on various outdoor crops and weeds. In autumn, when summer crops are harvested and

weeds dry up, the pests appear in the greenhouse and attack newly emerged tomato plants (Berlinger et al., 1978; Gol'berg et al., 1979). This phenomenon of pest immigration was proved for B. tabaci by means of yellow sticky traps (Berlinger, 1980). It was found that adult whiteflies enter the greenhouses daily in autumn during this immigration phase.

In the beginning of the season (September-October) temperatures are still fairly high, particularly indoors. In October the average daily maximum was 35°C and the average daily minimum was 17.7°C. In order to maintain favourable environmental conditions the grower's habit is to open the greenhouses' openings as wide as possible for adequate ventilation. In the second growth period (December-February) pest activity is usually below the economic threshold. In the third growth period (March-May) pest activity increases, originating most probably from those insects which survived the winter indoors.

The most harmful tomato pest today is the tobacco whitefly (B. tabaci), the vector of Tomato Yellow Leaf Curl Virus (TYLCV). This is a notorious virus disease of tomatoes, transmitted solely by B. tabaci. Four hours of inoculation feeding are sufficient to inoculate a healthy plant. Incubation time is about four weeks. From the moment the symptoms appear, the growth of the plant ceases and no further fruit set occurs. The younger the plant is infected, the greater is the damage (Cohen, 1966).

In our experiments, a good correlation was found between B. tabaci population density outdoors and indoors and between the incidence of virus infected plants. TYLCV is an obligatory parasite of the living cell, therefore it cannot be controlled directly. The only way to control TYLCV is to control the vector's population or to prevent the physical contact between the whitefly and the host plant. In unsprayed control plots 90-100% of the plants became infected and in frequently sprayed greenhouses 10-30% were infected (Berlinger, et al., 1978).

The rather short period (four hours) of inoculation feeding gives the grower sufficient time to undertake some control measures:

1. Chemical control - was the first control measure that growers applied. This whitefly/TYLCV problem is so severe that the growers are forced to spray every other day and sometimes even daily(!) during the first three months of the growth season (September-November). Besides all known shortcomings, Cothnion (Gusathion) at the recommended

concentration (1.0%) suppressed the growth of the plants. Lower, and thus less damaging concentrations (0.75-0.5%) were not sufficiently effective. During our screening for new and more effective insecticides, two perithroides were revealed: Cymbush(Cypermethrin) containing 10% a.i. used at 0.3% and Smesh (Fenpropathirn) containing 10% a.i., also used at 0.3%. Details of the screening methods will be published elsewhere.

2. Yellow plastic mulch - in open field tomatoes this practice postponed the TYLCV infection for about one month, until the plants became large enough to partially cover the yellow mulch. This procedure did not prove to be effective indoors, at least in small (10 m^2) plastic houses. The number of TYLCV infected plants was only a little smaller than in a commercially sprayed control house.

3. Roof of greenhouse painted yellow - The idea was to attract whiteflies to the yellow (glass) roof which heats up during the day and so injure or kill the vectors, so that hey will not infect the plants with TYLCV. The experiment was carried out using six replicates. Each was represented by a small (10 m^2) glass-roofed plastic house. The number of whiteflies trapped was comparable with the control while the proportion of TYLCV infected plants was slightly reduced.

4. Pressurized glasshouses - obtained by using a fan to suck air from outside, via a pad, wetted with water. This air is passed by the same fan into the glasshouse. In several glasshouses the number of trapped whiteflies was significantly reduced and the incidence of TYLCV also reduced.

5. Covering plants with perforated plastic tunnels - this method can be used only in the first month before the plants reach the roof of the tunnel. Another shortcoming was that yield from the first flower truss, which was set beneath the plastic tunnel, was somewhat reduced. Altogether, from an entomological point of view, this method is one of the most efficient methods. A more detailed summary is in preparation for publication (Berlinger et al.).

6. Breeding for resistance - to the TYLCV and to the whiteflies, will be discussed in a later paper.

Concluding remarks

The main difficulty in pest control on greenhouse tomatoes in Israel today is the B. tabaci/TYLCV complex. Since the virus cannot be controlled directly the tomatoes must be sprayed frequently. At the same time all other pests are destroyed as well. Any different solution to the B. tabaci/TYLCV problem, e.g. breeding resistant cultivars, will result in the release of other pests and will permit the implementation of an IPM programme.

References

Avidov, Z. & Harpaz, I. (1969). Plant pests of Israel. Univ. Press, Jerusalem.

Berlinger, M.J. (1980). A yellow sticky trap for whiteflies, Trialeurodes vaporariorum and Bemisia tabaci (Aleurodidae). Ent. exp. & appl. 27, 98-102.

Berlinger, M.J., Gol'berg, Alla M. & Dahan, R. (1978). Integrated control of tomato pests under glass in the Negev area. Research Report No. 1, submitted to ARO, Bet-Dagan. Stencil, 22pp. (in Hebrew).

Berlinger, M.J., Gol'berg, Alla M. & Dahan, R. (1982). The usage of plastic tunnels to prevent the distribution of the Tomato Yellow Leaf Curl Virus. Submitted to Hassadeh (in Hebrew with English summary).

Cohen, S. (1966). Investigations on plant viruses transmitted by the tobacco whitefly (Bemisia tabaci Gennadius) in Israel. Pamphlet No. 110. The Volcani Inst. Agric. Res., Div. Sci. Publications, Rehovot 79 + VI pp. (in Hebrew with English summary).

Cohen, S. & Venezia Melamed-Madjar (1978). Prevention by soil mulching of the spread of tomato yellow leaf curl virus transmitted by Bemisia tabaci (Gennadius) (Hemiptera: Aleurodidae) in Israel. Bull. ent. Res. 68, 465-470.

Gol'berg, Alla M., Cohen, C., Dahan, R. & Berlinger, M.J. (1979). Integrated control of tomato pests under glass in the Negev area. Research Report No. 2, submitted to ARO, Bet Dagan. Stencil, 16 pp. (in Hebrew).

Hussey, N.W., Reed, W.H. & Hesling, J.J. (1969). "The pests of protected cultivation". Edward Arnold (Publisher) Ltd., London. 404 pp.

Lindquist, R.K., Wogamott, Mildred L. & Frost, Carol (1979). Integrated control of insects and mites on greenhouse crops. OARDC Res. Circ. 245, 18 pp.

Lenteren, J.C. van, Ramakers, P.M.J. & Woets, J. (1980). World situation of biological control in greenhouses, with special attention to factors limiting application. Unpublished manuscript 8 pp.

PRESENT STATE OF BIOLOGICAL CONTROL ON VEGETABLE CROPS UNDER PLASTIC IN CRETE, GREECE

E. Kozirakis

In Crete a few research workers have recently investigated biological control of whitefly and spider mite.

In Greece the application of this method is also in an early stage and (in the last two years) biological control is now applied on vegetables on about 170 stremata (160 st. cucumber, 10 st. tomato). 120 st. in North Greece, 40 st. in Peloponnesus, and 10 st. in different districts.

Results are poor because the farmers do not believe in this method for they have few experiences and many difficulties.

In Greece natural enemies are not commercially produced for vegetables and all are imported from the Netherlands (Koppert BV) by a main supplier "Mr Karantonis Skydra-Edessa" near Thesaloniki.

In Crete we grow vegetables in plastic houses on about 12850 st. (1285 hectares) of which 6600 st. are cucumber, 4685 tomato and the remaining 1565 st. are peppers, eggplants, beans, melons, etc.

Also 700 st. of flowers mainly carnations, roses, gerbera etc. are grown.

There are problems with spider mites, whitefly and leafminer throughout the island, mainly from April to November.

We have just started an experimental 4 year programme of biological control on vegetable crops under plastic.

The purpose of this programme is to get more experience in classical biological control under our special conditions and to persuade growers of the usefulness of the method.

Conditions under plastic are very difficult because of the great difference of temperatures (between 5-50°C) and the high humidity during winter.

This programme consists of the control of whitefly by Encarsia formosa and of spider mite by Phytoseiulus persimilis.

We started in May 1982 in two plastic houses in the Rethimnon area.

A. Crop: Cucumber

Date of planting: 25.4.82

Plastic house of 900 m^2

Last spray before introduction of parasite and predator on 15.5.82 by Lanate, Antracol and Bayleton

Date	Whitefly/ plant	No. of intro- duced *Encarsia*	Parasit- ism black scales	Grade attack *Tetranychus urticae*	No. of introduced *Phytoseiulus*	Parasit- ism
27.5.82	0.61	-		0.1	-	-
5.6.82	4.7	2000		0.4	2700	-
17.6.82	2.7	2000		1.0	3300	-
30.6.82	10.1	2000	1%		3000	Good
15.7.82	10.55	4000	2%		3000	Good

Date	Fluctuation	
	Temperature	Humidity
17.6.82	14-38°C	46-80%
30.6.82	18-41°C	48-80%
15.7.82	14-35°C	48-78%

Control of disease was by Daconil and Afugan. On 7.7.82 a soil application of systemic Vydate was made, to reduce the large number of whiteflies. On 17.6.82 and a week later two sprays of Ventex were made to control spider mite.

B. Crop: Tomato

Date of planting: 15.2.82

Plastic house of 1400 m^2

Last spray before introduction of parasite on 17.5.82 by Lanate and Antracol

Date	Whitefly/ plant	No. introduced Encarsia	Parasitism black scales	Range	
				Temperature	Humidity
28.5.82	0.65	-	-	-	-
5.6.82	2.90	2500	-	-	-
17.6.82	1.35	2500	Few	15-37°C	42-88%
30.6.82	12.9	2500	15%	18-40°C	40-85%
15.7.82	-	-	30%	15-38°C	38-84%

Control of diseases was achieved by Daconil and Afugan. On 30.6.82 a soil application of Vydate and a spray of Dimilin were made because of the high population of green aphids, Spodoptera littoralis and leafminer.

First observations on results are quite sufficient and we hope, against the difficulties, to spread that method in a great percentage of our island.

THE WHITEFLY PROBLEM IN CRETE-GREECE
THE FIRST EXPERIMENTS WITH ENCARSIA FORMOSA IN THE PLASTIC HOUSES OF THE ISLAND

S. Michelakis

Introduction

The importance of the vegetables within the economy of Crete is continuously increasing. The area covered by plastic houses increases rapidly every year. In the decade 1969-1979 the area of protected vegetables increased 160% for Greece while in Crete during the same period the increase was 596% - the largest increase was in the region of Lasithi (Ierapetra) 2624% and secondly in Chania 2002% (Table 1). Among the other parts of Greece, Crete has the majority of the plastic houses and the last available official statistical data of 1979 showed that 37% of the protected vegetables of Greece exist in Crete. These plastic houses are planted mainly with tomatoes and cucumbers and secondly with melons, peppers, eggplants, flowers etc.

The climatic conditions in Crete are favourable for protected vegetables and for this reason the unheated plastic houses are simple wooden or metalic structures with plastic PVC or polyethylene. The temperatures in the plastic houses never, or very rarely, fall below zero, in winter (Fig. 1).

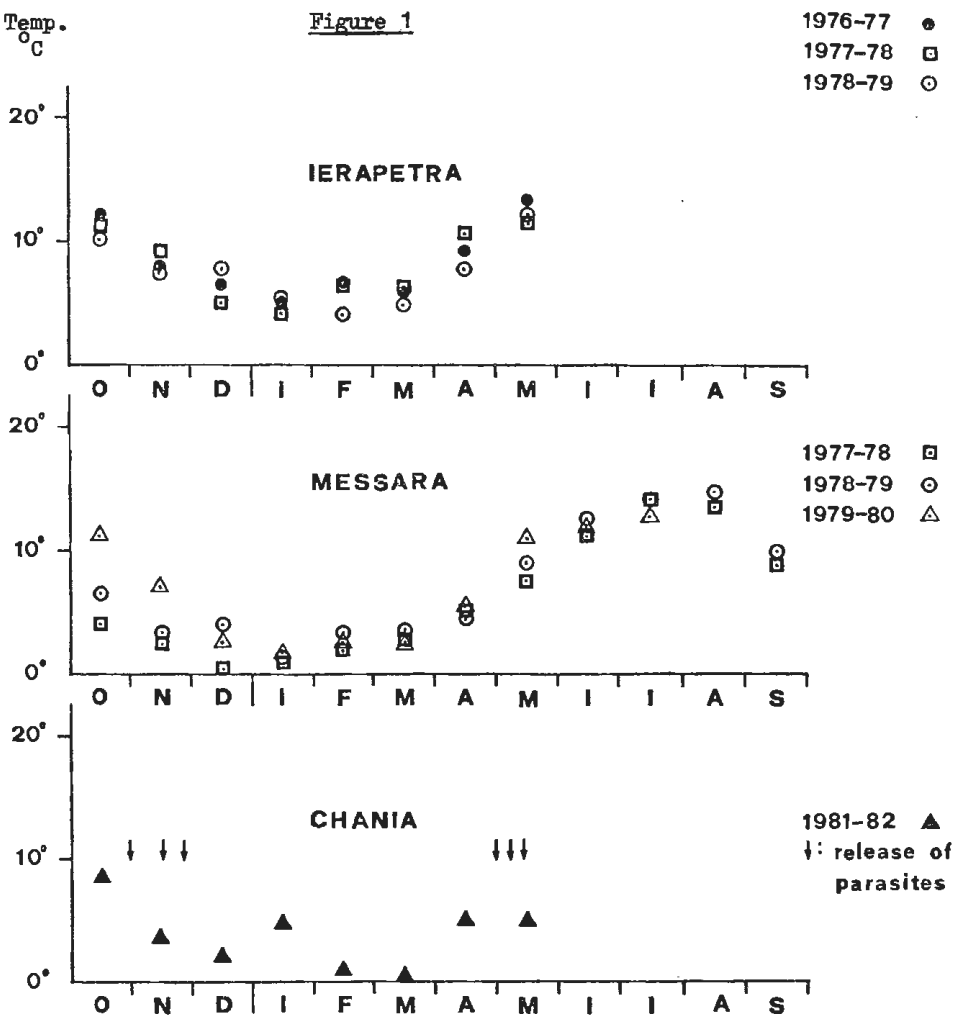
At first the farmers in Crete had no pest problems in their plastic houses except, rarely, Heliothis armigera Hub. and Spodoptera littoralis Boisb. In 1978, however, a new pest appeared for the first time in the region of Rethymnon. This insect had never been included previously in the lists of pests of the cultivated plants in Greece (Argyriou et al., 1976, Isaakides, 1941). This species was Trialeurodes vaporariorum Westw. of the family Aleyrodidae. Today this insect has increased and spread to other parts of Crete (Fig. 2). For its control the farmers mainly use Decis, Lannate and Actellic, with variable results between poor and satisfactory.

In March 1981 our Institute in Chania introduced, for the first time in Crete, about 3,000 black scales of Encarsia formosa Gahan from the GCRI in Littlehampton. These parasites were mainly used for laboratory and field experiments. A little later and during the same year a shipment arrived in the eastern part of Crete (Ierapetra) from

Table 1: The plastic houses of Crete* in stremmas (1 stremma = 0.1 ha)

District	1969	1979	% increase
Lasithi	265	7,219	2,624
Heraclio	1,332	3,719	179
Rethymno	63	364	478
Chania	49	1,030	2,002
Total of Crete	1,771	12,332	596
Total of Greece	12,672	32,918	160

* Greek Agricultural Statistic book


Temp. °C
Figure 1
1976-77
1977-78
1978-79
20°
10°
0°
IERAPETRA
O N D I F M A M I I A S
20°
10°
0°
MESSARA
1977-78
1978-79
1979-80
O N D I F M A M I I A S
20°
10°
0°
CHANIA
1981-82
: release of parasites
O N D I F M A M I I A S

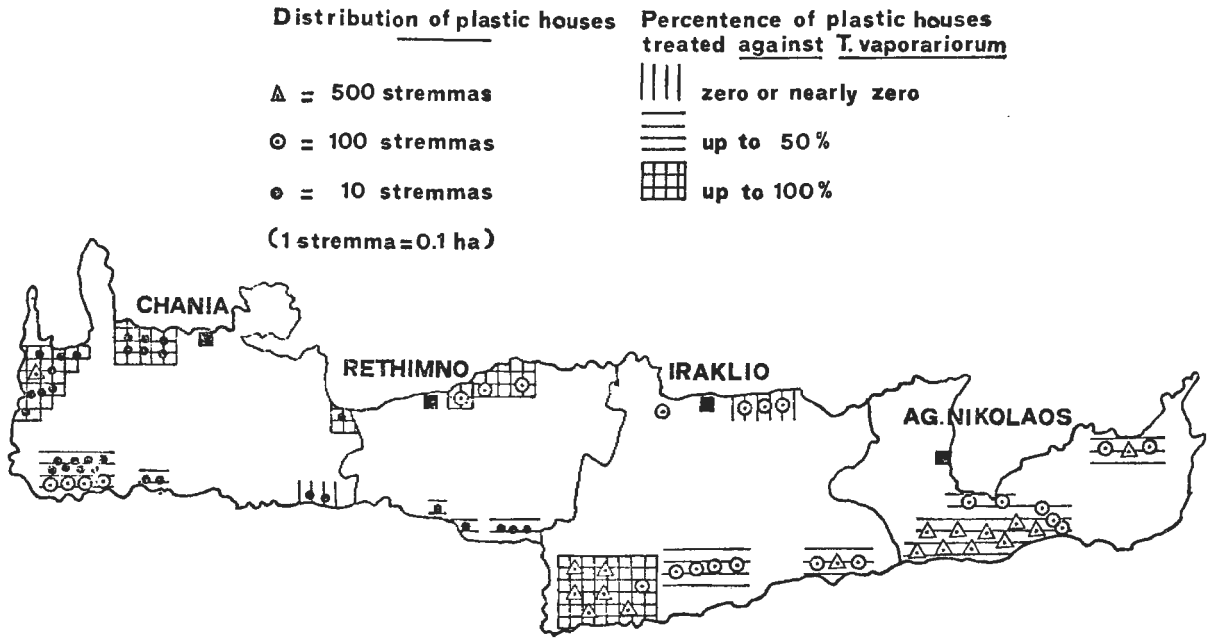

Distribution of plastic houses
Δ = 500 stremmas
⊙ = 100 stremmas
• = 10 stremmas
(1 stremma=0.1 ha)
Percentence of plastic houses treated against T. vaporariorum
zero or nearly zero
up to 50%
up to 100%
CHANIA
RETHIMNO
IRAKLIO
AG. NIKOLAOS

Figure 2

"Koppert" for 3000 m^2 of commercial plastic houses. This was repeated in 1982 on 1000 m^2 of plastic houses. The results of the introductions were very poor, mainly because of insufficient observations and late introductions.

Systematic studies on the application of biological control of T. vaporariorum by E. formosa were done for the first time in Crete with the experiments which started in the Institute of Sub-tropical Plants and Olive Trees in Chania, on five commercial plastic houses using parasites from the small stock in our insectary originally sent by "Koppert" in the autumn of 1981 and spring 1982.

The purpose of our experiments was the study of the possibility of the parasite becoming established in Crete and hence surviving the cold winter period. The development of the parasite population in relation to the pest was to be observed in the unheated plastic houses of Crete.

Materials and Methods

For the experiments five plastic houses were used and two in addition, as controls, where only insecticide treatments occurred near the others. Untreated controls could not be found among commercial plastic houses. Tomatoes were planted at the beginning of October 1981. In one house cucumbers were planted together with tomatoes and in another squashes. Three releases were made on 30 October, 16 November and 26 November and three during the spring 1982 on 30 April, 6 May and 14 May with the exception of two plastic houses in which the release of the 6 May did not occur. In all experimental houses the parasitism as well as whitefly populations were followed by weekly or fortnightly samplings. In three houses Mycotal was also used during the autumn. Where parasites were released insecticides were not used. The fungicides Euparen, Daconil, Antracol, Afugan and Rimidin were used by the farmers.

Especially for our experiments the following plastic houses were used:

a. Nerokourou where about 800 m^2 were planted with tomatoes. Five releases were made (three in autumn and two in spring) with a total of about 60,000 black scales. Near this house another, of about the same size, had received only chemical treatments.

b. Kamisiana. About 800 m^2 had been planted with tomatoes. Six releases were made (three in autumn and three in spring) with a total of about 67,500 black scales.

c. Drapanias. 2,000 m^2 were planted, mostly with tomatoes, except an area of about 50 m^2 covered with cucumbers which was renewed with a new cucumber crop in spring. About 83,500 parasites were released in five releases (three in autumn and two in spring).

d. Platanias. 1000 m^2 was planted with tomatoes. The parasites were released three times in spring using about 40,500 black scales. in another house which received only chemical treatments the white-fly population was followed for comparison.

e. Georgoupolis. About 1,200 m^2 was planted mainly with squashes and about 50 m^2 covered with beans. Three parasite releases of 43,500 scales were made during the autumn. The squashes remained in the house until March 1982.

Results and Discussion

Parasite releases started because, in early autumn, the plants usually get infested while they are still in the nursery, and because the temperatures during that period remain relatively high.

In each location, the following results were obtained:

a. Nerokourou

The whitefly population was high in the beginning with 23% of the upper leaves infested. From November to January the infestation on these leaves remained more or less constant (7-8%). In February the population declined to zero in March. From April the whitefly again increased (Table 2). Throughout the above mentioned period, except March, the number of adults per infested leaf was small, only 1.0 and 1.2. The decline in the population was due to the low temperature during February and March (1°-2°C) (Fig. 1).

It seems that the activity of the parasites released in autumn, was much restricted because of the low temperature combined with heavy deleafing of the plants during that period. The first parasitised scales following the autumn releases were observed on 19 January 1982, that is 81 days after the first release and 54 days after the last release in autumn. The parasitisation rate by that date was high (85.7%) but because of the severe deleafing we detected no more black scales until the new releases in spring.

The action of the parasites was then more promising. On 21 May, that is 21 days after the first parasite release, the parasitisation rate

Table 2: The presence of whitefly adults in plastic houses

Month	Nerokourou		Kamisiana	
	% infested upper leaves	Mean no. per infested leaf	% infested upper leaves	Mean no. per infested leaf
October	23.0	1.1	24.0	1.3
November	6.5	1.0	17.5	1.3
December	8.2	1.1	5.0	1.0
January	7.8	1.1	7.5	1.0
February	1.4	1.1	3.0	1.0
March	0.0	0.0	2.0	1.0
April	2.1	1.1	8.5	1.2
May	2.3	1.2	11.0	1.2
June	3.3	1.2	23.7	1.7

reached 63.6%. A reduction in the parasitable stages of whitefly followed and the parasitization rate increased again from 37.5% on 23 June to 72% on 29 June 1982. It is likely that the reduced increase of the whitefly population in spring, despite the favourable climatic conditions is due to the action of the parasites. This assumption is supported by the fact that the nearby plastic houses of equal size which had not received parasites, had the same level of infested upper leaves (3%) in June but after having received eight treatments with pesticides (namely with Lannate and Decis).

b. Kamisiana

The whitefly population was already high soon after the tomatoes were planted indicating that infestation had begun in the nursery. About 46% of the young upper leaves were infested with adults though this percentage dropped to 23% because of treatment with Lannate on 28 October. This treatment was also directed against the leaf miner Liriomyza bryoniae.

The whitefly population declined till March before increasing gradually from April onwards (Table 2). As it was said before, it seems that this was mainly linked with the curve of temperature (Fig. 1). Throughout the number of whitefly adults per infested upper leaf was between 1.0-1.3 individuals.

Towards June the population of L. bryoniae greatly increased although no specific action was taken against it.

Following parasite releases in autumn the first black scales were found on 17 December, i.e. 48 days after the first releases and 20 days after the last. In three samplings in January the parasitism rate fluctuated between 33.3% and 36.7%. From February to April parasitism ceased and parasite releases restarted at the end of April. This decline in parasitism is probably due to heavy deleafing of the plants but mainly because of the drop in temperature. The activity of the parasites sharply increased after the spring releases. On 25 May, i.e. 25 days after the first spring release the parasitism was 11.2% and it increased gradually to reach 75.5% at the end of June.

c. Drapanias

The pest remained in a very high level with 18% to 43% of the new upper leaves infested with 1 to 4 adults per infested leaf. No black scales were found after the autumn release.

It seems that the high population of the whitefly was mainly due to the small culture of cucumbers throughout the study period. Although they received chemical treatments every week the whitefly population remained almost constant with almost 100% infested leaves with more than 25 adults per leaf. The density of the pest population declined with distance from the cucumber culture. From the end of May onwards parasitism increased gradually but reached only 5% at the end of June.

d. Platanias

In this area the increase of the whitefly was very rapid, both in the plastic house where the releases were made as well as in the second plastic house which received chemical treatments almost weekly. Towards the end of June 95.4% of the upper leaves in the houses with parasites were infested while 77.8% were infested in the house with the pesticide treatments. The density of the adults varied from 1.2 individuals per infested leaf to 9.3 adults in June in the first house and from 0 to 4.6 adults per infested leaf in the second house (Table 3). The economical injury level of this insect is not known in our region and we are unable to estimate the difference in loss of revenue between the two houses. Nevertheless, the parasitisation rate was very small and towards the end of June had reached only 16%.

Table 3: The presence of whitefly adults in two plastic houses in Platanias

Counting date	Plastic house with E. formosa		Plastic house with insecticides	
	% infested	Mean no. per infested leaf	% infested	Mean no. per infested leaf
30.4.82	3.3	1.2	0	0
14.5.82	22.2	1.9	0	0
25.5.82	39.8	1.7	12.0	1.7
9.6.82	86.1	9.0	65.7	3.4
22.6.82	95.4	9.3	77.8	4.6

e. Georgoupolis

The adult whitefly population in this house with squashes, fluctuated at high levels, from October up to the end of the culture at the end of February. 44% to 89% of the upper leaves were infested and 2.5 to 14.3 adults per infested leaf. The high population in the beginning of the culture together with the heavy deleafing and perhaps the low temperature in winter are the main reasons of the failure of the parasite. It must be noticed that the few black scales found after the autumn releases in this house were observed on detached leaves outside the house on 28 January.

In brief, from this experimental work the following conclusions can be drawn:

The whitefly, which is a new pest in Crete is becoming of increasing importance and a severe problem for Cretan farmers. Chemical treatments have already proved insufficient to control whiteflies and an integrated method should be developed including the action of parasites. E. formosa is a useful tool in such a programme and the potential of this parasite must be investigated in our conditions. At the same time, efforts to find a strain or species more suitable for cooler conditions must continue and it will be of great help in our unheated plastic houses. Within an integrated control programme, the control of L. bryoniae must be considered in Crete. For the application of an integrated control programme the determination of the economic injury level is needed for the different plant cultures. More specifically with our

experiments we observed that the fluctuations of the whitefly population in Crete are influenced mainly by the temperatures. The action of the parasite in our unheated houses is more important from early spring onwards while other means including chemicals seem very important during autumn. Differences in the success of parasites in different plastic houses showed the importance both of early parasite introduction and deleafing, as pointed out previously by several authors (Stenseth, 1976; Gould, 1980; Foster, 1980).

References

Argyriou, L.Ch., Stauraki, E.G. & Mourikis, R.A. (1976). List of the recorded entomophagous insects in Greece. (In Greek). Benaki Phytopathological Institute, pp. 73.

Foster, G.N. (1980). Biological control of whitefly - initial pest density as the most important factor governing success. Bull. OILB/SROP 1980/3, 41-43.

Gould, H.J. (1980). The development of biological control of whitefly and red spider mite on tomatoes and cucumbers in England and Wales. Bull. OILB/SROP 1980/3, 53-57.

Isaakidis, K.A. (1941). The interesting insects of the Greek Agriculture and some observations on them. (In Greek). Practiak Academy of Athens I, 238-263.

Stenseth, C. (1976). Some aspects of the practical application of the parasite E. formosa for control of T. vaporariorum. Bull. OILB/SROP 1976/4, 104-114.

ADVANCES IN INTEGRATED CONTROL IN SICILY

A. Nucifora, V. Vacante & V. Firullo

Summary

The authors summarize the results of research and development on integrated pest management for greenhouse whitefly and leafminers and for the red spider mite in unheated houses in Sicily.

The crops involved are tomato, eggplant, vegetable marrow, sweet pepper and gerbera.

More effort is directed to the whitefly and leafminers, against which the trapping by sticky yellow dishes has proved effective.

Practical tests in vegetable and gerbera commercial greenhouses show that yellow sticky traps and quinomethionate treatments can inhibit the three phytophagous infestations.

In a tomato plastic house sticky yellow dishes protect the crop only from leafminer by intercepting adults flying between plants.

In a gerbera unheated glasshouse yellow sticky traps and quinomethionate gave a satisfactory control of severely infested plants during 5 months from January 1982.

Other tests demonstrated that yellow traps alone can effectively protect tomato crops from whitefly if they are exposed at the first sign of adult presence; on established whitefly populations sticky yellow traps and one or two treatments with quinomethionate are necessary to depress the whitefly infestation. In both cases naturally introduced populations of the chalcid wasp Encarsia formosa built up on the surviving whitefly progeny despite the presence of the traps or of these and two quinomethionate treatments. Both are therefore compatible in unheated commercial greenhouses with the use of this parasite.

Temoocid, the coating we used as sticking agent, continues to trap whitefly and leafminer adults efficiently for 15 days at most, after which it must be reapplied.

Introduction

Since 1979 trials have been carried out in Sicily to apply alternative techniques for the control of the main phytophagous insects and mites in unheated vegetable houses, to replace calendar chemical treatments.

First trials made on tomato crops during the spring 1979 using yellow sticky traps was successful against the glasshouse whitefly (Trialeurodes vaporariorum (Westw.)) and the tomato leafminer (Liriomyza bryoniae Kalt).

During 1980 the method was also applied on eggplant and gerbera, encouraging the natural development of the chalcid wasp Encarsia formosa Gahan from March onwards. Parasitization reached about 75% at the end of June.

Moreover, selective chemical control by quinomethionate was applied against adults, eggs and 1st and 2nd age larvae of glasshouse whitefly. This proved to be a good specific selective insecticide and acaricide, stopping the development of Oidium-disease.

Integrated pest control is nowadays applied in unheated houses in Sicily using yellow sticky traps, quinomethionate and E. formosa.

The first and second methods depress the whitefly infestations without disturbing the natural biocontrol of E. formosa and the natural balance between the spider mite (Tetranychus urticae Koch) and the predators Phytoseiulus persimilis A.H. and Therodiplosis persicae Kieffer.

Greenhouse whitefly (Trialeurodes vaporariorum (Westw.))

Experiments from 1979 showed that the chromo-attractive and chemical-selective methods can be applied alone or together as integrating techniques with control by E. formosa in programmes against the whitefly. Three kinds of intervention have been tried:

1. Intervention on newly established infestation. The chromo-attractive control system alone achieves good results if the yellow sticky traps are erected as soon as the first whiteflies are seen in the crops.

In Sicily this occurs in autumn or in late winter. Exposing the yellow traps and coating them periodically (every 10-15 days) with a sticky layer gives excellent results.

Thus, in a 1200 mq wide plastic tomato house 116 traps (usual yellow picnic dishes) coated with Temoocid, a sticky agent, were suspended on 29 March on wires among the rows in such a way that the tops of the dishes were level with the tops of the plants. They caught 1972 whitefly adults in April, 6505 in the first 25 days of March and 40842 from 26 May to 7 June, in only 11 days.

Our efforts to prevent whitefly infestation from becoming established were successful and the crop was clean on 10 June, except for the presence of Macrosiphum euphorbiae Thomas, against which a treatment with pirimicarb gave effective control.

In this crop, naturally-introduced populations of the parasite E. formosa built up on the surviving progeny of greenhouse whitefly.

2. Intervention on plants bearing well-established whitefly populations. This second method is recommended today, where the integrated pest management is applied to tomato and gerbera crops in unheated greenhouses in Sicily.

The traps are exposed in the crop very late compared with the previous technique. Before placing them the levels of whitefly must be assessed.

In this method the use of yellow sticky traps alone does not prevent infestations and therefore in order to improve control two or more chemical quinomethionate treatments must also be applied. In these crops the parasitic wasp (E. formosa) develops naturally, despite the presence of the yellow traps and the quinomethionate treatment, from the end of March (1981) or at the end of May (1982).

The first quinomethionate treatment is sprayed when the traps are exposed, about two months later the first whitefly adults appear in the greenhouse. Commercial product (Morestan) must be used at 0.050-0.070% and accurately sprayed, trying to wet the lower surfaces of leaves.

It is necessary to repeat the application after 10-15 days and so red mite infestations and the mildew infection is also controlled.

Every 15-20 days the sticky traps must be renewed.

In this way, the infestation can be depressed during the cropping stage without the use of pesticides and so the problem of toxic residues is avoided.

In a commercial plastic tomato house, where the first insecticide treatment and the yellow dishes were introduced on 15 May when an average

of 120 whitefly adults/plant were present and a second treatment with quinomethionate was carried out 17 days later. The average level of whitefly adults/plant remained very low until the middle of July, when the crop was removed.

No honeydew occurred and E. formosa migrating from the outside, developed naturally with parasitism reaching 60% in July. The yellow traps were placed at about 3 m intervals among alternate rows of plants, at 1/5 m^2. This system of control is more practical and economical than the first. It does not solve the problems of infestations of aphids and Noctuidae, which create serious problems in the late spring. The use of poisoned bran does not always provide control of noctuid larvae. Treatments with primicarb or ethiofencarb can control the aphid attacks.

3. Intervention with quinomethionate sprays alone. During 1982 we used quinomethionate against glasshouse whitefly, without using the yellow sticky traps. Three treatments at intervals of 10 days were as effective as the same treatments used together with the yellow traps in another house.

In a second case four treatments of quinomethionate were used in a plastic vegetable marrow house and the infestation was well controlled in the last two months of crop production. No sooty moulds, oidium or red spider mite occurred from the middle of April to the end of June.

In another neighbouring untreated greenhouse thousands of aphids/plant could be counted and the development of sooty moulds was severe.

The use of quinomethionate alone is able, at least for the present, to assure satisfactory results, without the use of traps. Traps become necessary when attacks of leafminers also occur, as quinomethionate has no effect on agromyzids.

The leafminers (Liriomyza bryoniae Kalt., L. trifolii (Burgess))

The chromo-attractive method in integrated pest control results in very effective control of leafminers. The strong attraction of adults to yellow led to their elimination before or soon after they became established on the crop.

On 30 March, 1 trap/10 m^2 in tomatoes, 538 leafminer adults had been caught in 40 days and 15 days later 5481. On 9 June another 2181 adults had been caught. At the end of May leafminers increased to 2/plant average, the highest level in the season.

In a second case a gerbera glasshouse 1600 mq wide was severely infested in December, so that the grower planned to destroy them; no control had been eachieved with DDVP or other insecticides. There was an average number of 10 mines in every leaf. On 28 December 1981 yellow sticky dishes were exposed at the rate of 1/13 m^2 and 20 days later they caught an average of 16,800 adults per trap. Three treatments were sprayed with pyrazophos (c.p. Afugan) against larvae on 29 December 1981, 12 January and 7 February.

In another equally infested glasshouse, 11 treatments with DDVP (c.p. Aminatrix) were sprayed without success from December 1981 to May 1982 and all leaves were infested on 30 May with an average of 10 mines/leaf. On the same date the trap-controlled crop presented only the old leaves affected with an average of 4 mines/leaf.

The chromo-attractive control method is able, therefore, to solve the leafminer problem.

Four species of parasites were collected and their activity increased during spring giving a good rate of parasitization despite the presence of yellow traps, but many were trapped from May onwards. It is, therefore, wise to remove the sticky traps during the summer from the gerbera crops, if there is leafminer, to let the parasite complete control.

Pyrazophos (= Afugan) was a great success against leafminer larvae but killed some entomophagouses.

Red spider mite (Tetranychus urticae Koch)

The use of Phytoseiulus persimilis and Therodiplosis persicae against red spider mite gave rather satisfactory results on sweet pepper. We have noticed that quinomethionate did not disturb the prey/predator ratio. The predators attacked the surviving phytophagous forms soon afterwards, completing the control. Quinomethionate, therefore, used in the commercial vegetable houses, appears to have a negative influence.

Conclusions

The following conclusions can be drawn:

a. It is possible today to accomplish integrated pest control on unheated vegetable plastic houses in the Mediterranean environment against the three chief phytophagouses (whitefly, leafminer and red spider mite) using the chromo-attractive technique and a chemical-selective treatment with quinomethionate.

b. These techniques allow parasite and predator action.

c. The yellow sticky traps and some treatments with pyrazophos (c.p. Afugan) can cure severe infestation of leafminers. This chemical showed a marked larvicidal action and can be useful for leafminer control.

d. In vegetable (tomato, eggplant, vegetable marrow) plastic houses, repeated treatments with quinomethionate alone can control high whitefly infestations, but do not affect leafminers. They control red spider mite infestations effectively.

References

Calabretta, C. (1982). Lotta con trattamenti insetticidi e trappole cromotropiche gialle contro Trialeurodes vaporariorum (Westw.) su pomodoro in coltura protetta primaverile-estiva. Atti Giornate Fitopatologiche 1982, Sanremo 15-19 marzo.

Calabretta C. & Licitra, G. (1982). Risultati di prove di lotta con trappole gialle invischiate, Chinometionato e alta temperatura su melanzana in coltura protetta contro Trialeurodes vaporariorum (Westw.) in Sicilia. Atti Giornate Fitopatologiche 1982, Sanremo 15-19 marzo.

Grill, D. (1979). La couleur contre certains insects de serre? Phytoma 305, 36.

Nucifora, A. & Vacante, V. (1980). Premiers résultats d'un projet de protection intégrée des cultures en serre au moyen de pièges chromotropiques jaunes. Colloque sur la protection intégrée des cultures 1980, Valence 18-19 Juin.

Nucifora, A. & Vacante, V. (1980). Attuali possibilità di lotta integrata e sue prospettive di sviluppo contro i fitofagi in coltura protetta. Bollettino delle sedute dell'Accademia Gioenia di Scienze Naturali in Catania, Vol. XIV (3), 129-138.

Nucifora, A. & Vacante, V. (1981). Lotta integrata su gerbera contro Trialeurodes vaporariorum (Westw.). Colture protette 3, 33-36.

Vacante, V. & Nucifora, A. (1980). Primi risultati e possibilità attuali di lotta in colture di pomodoro in serra mediante trappole cromotropiche gialle contro Trialeurodes vaporariorum (Westwood) e Liriomyza bryoniae (Kalt.). Tecnica Agricola 6, 335-345.

Vacante, V. (1982). Azione ovo-neanicida di Chinometionato e di Decametrina su Trialeurodes vaporariorum (Westwood) in colture protette di gerbera e pomodoro. Atti Giornate Fitopatologiche 1982, Sanremo 15-19 marzo.

Vacante, V. (1982). Effetto comparato di trappole cromotropiche e Chinometionato, a raffronto con insetticidi di sintesi, nella lotta contro Trialeurodes vaporariorum (Westw.). Atti Giornate Fitopatologiche 1982, Sanremo 15-19 marzo.

Webb, R.E. & Smith, F.F. (1979). Greenhouse whitefly control by integrated regimen based on adult trapping and nymphal parasitism. 4th Conf. Biol. Control Glasshouses, OILB/SROP, Helsinki, June 1979.

FACTORS PREVENTING THE DEVELOPMENT OF BIOLOGICAL CONTROL IN JAPANESE GREENHOUSES

Keiichi Nakazawa

Introduction

At the last meeting of this Working Group in Finland in 1979, Woets et al. made a progress report on the development of biological control in Dutch glasshouses. Van Lenteren et al. (1980) reviewed the world situation of biological control in greenhouses. Despite the remarkable achievement, they referred to many serious problems that limit the use of natural enemies. Although Japanese greenhouses cover an area of about 30,000 ha, biological control applies only to 3 ha. Why is it not applied extensively in Japan? The limiting factors are much the same as those reported from the Western countries, but we have other difficulties unique to Japan. The main aims of my paper are to analyse the obstacles in our way toward better pest control and to discuss some ways and means to overcome the difficulties.

Present situation of biological control

Phytoseiulus persimilis is the only biocontrol agent that is practically used at present. Since the mid-1960s, the spider mites have developed resistance to several acaricides one after another, and mite control is one of the most important problems in greenhouse horticulture today. In 1966 Dr Mori introduced P. persimilis into Japan from California, and organized a study group of the predacious mite (Mori & Shinkaji, 1977). From 1978 to 1979 production units of the predator were set up with governmental subsidy in 3 prefectural agricultural experiment stations. Their productivity, however, is very low and their annual distribution is 500,000 individuals at most. Most are used for controlling spider mites on greenhouse strawberry, but the area on which the predators are introduced is about 3 ha, accounting for only 0.4% of the total growing area (7,630 ha). About 40% of the growers who introduced the predators into their greenhouses in 1981 obtained satisfactory control. Failures are mainly attributable to (1) careless use of pesticides; (2) inadequate timing for introduction of predators or unbalanced ratio between prey and predator;

(3) unsuitable low temperatures for the predator during winter and early spring.

The greenhouse whitefly invaded Japan in the early 1970s when resurgence occurred in many other countries. The whitefly is now one of the most important pests in greenhouses all over the country. It has acquired a greater importance because of its role as a virus vector (Yamashita et al., 1979). In 1975 Encarsia formosa was introduced into Japan from England, and studies are now in progress to utilize the parasite (see contribution by E. Yano). The Ministry of Agriculture, Forestry and Fisheries plans to set up some production units of Encarsia. The plan may be realized within a few years if things go well. Oho et al. (1976) demonstrated that Aschersonia aleyrodis parasitic on Dialeurodes citri was a promising pathogen for the greenhouse whitefly Nakazawa (unpublished) found Verticillium sp. pathogenic to the greenhouse whitefly.

To utilize Aphidius gifuensis for control of Myzus persicae on greenhouse tomato, studies were conducted by entomologists of a prefectural experiment station in the early 1970s. However, the parasite has never been used practically. Another prefectural experiment station has attempted to use Coccinella septempunctata for control of Aphis gossypii on greenhouse strawberry and has obtained promising results. The mass rearing technique of the lady beetle remains to be developed.

Obstacles to progress

First, I outline the conditions of Japanese greenhouse horticulture which prevent the use of biological control. Of the total greenhouse area, the area of plastic houses accounts for 90% with poor equipment. For example, only 19% of the plastic houses have automatically controlled heating equipment. Japan has a preponderance of extremely small greenhouse holdings, with an average size of 0.13 ha. Of 179,000 greenhouse vegetable growers, 47,000 (26%) devote themselves to the job with an average holding of ca. 0.4 ha, while the rest are not professionals. The growers have complicated types of vegetable culture with relatively short growing periods. Major pests that occur in greenhouses are either the same species or the species occupying the same ecological niches, as those in Europe. Japanese growers, however, have

more pests to combat than those in Europe. High humidities in Japanese greenhouses tend to encourage various diseases. In summer the temperature sometimes rises far above the optimum level for the natural enemies' activities. On the other hand, progress in breeding has enabled the growers to grow their vegetables under relatively low temperatures in winter, and consequently, the conditions are adverse for biological control.

Japanese horticulture has depended on agricultural chemicals for many years. Growers who have smallholdings and manage intensive horticulture find chemical control easier to apply even if the cost of biological control is cheaper. Although pesticide-resistant pests such as spider mites, aphids, grey mould and powdery mildew have occurred widely, the Japanese chemical industry remains active, opportunely providing new compounds: e.g. several pyrethroids and buprofezin. There are very efficient networks to develop and support chemical control throughout Japan. On the contrary, the networks for biological control have not bee formed, and the absolute inferiority of manpower and investment in this field is a patent fact.

The prevailing chemical control of greenhouse pests also has problems. One of the most important is how we can reduce the amount of pesticides used. We have strict regulations for the safe use of pesticides, though growers do not always observe them and the system to check marketed products is still incomplete.

We now have a thrips problem that is more important than the whitefly and mite problems. Thrips palmi which is an inhabitant of the Torrid Zone, occurred in Japan in 1978. At present it ranges over 15 prefectures. The area infested by thrips in 1981 was estimated at 2,000 ha in greenhouses and 4,000 ha in the open field. The thrips attack most major crops except tomato. Even with frequent application of insecticides, resurgence occurs, because of pupation in the soil and high fecundity. We are, therefore, apprehensive that frequency of insecticide application will materially increase.

The outlook for better pest control

In spite of many pessimistic conditions, we are greatly encouraged at the remarkable development of biological control that entomologists of this Working Group of IOBC have achieved. Now, we must awaken to the

blind alley into which intensive chemical control is leading us, i.e. the problems of pesticide resistance, residual toxicity and other side effects. Increasing demands for clean products by vegetable consumers may encourage us to change the present policy of pest control.

Stagnation in the application of Phytoseiulus persimilis is due to the lack of an integrated strategy for the pest management in strawberry culture. In order to devise better pest control measures, more practical workers have to be involved in the new investigations.

Finally, considering the high humidity conditions in Japanese greenhouses, the use of microbial agents may be promising. We expect the plant protection industry to have special interest in the microbial insecticides.

References

Lenteren, J.C. van, Ramakers, P.M.J. & Woets, J. (1980). World situation of biological control in greenhouses, with special attention to factors limiting application. Med. Fac. Landbouww. Rijksuniv. Gent 45/3, 537-544.

Mori, H. & Shinkaji, N. (Eds.) (1977). "Biological control of Tetranychid mites by Phytoseiulus persimilis Athias-Henriot in Japa Japan"(in Japanese). Japan Plant Protect. Assoc., Tokyo, pp. 89.

Oho, N., Sato, T., Asano, K., Nonoshita, K. & Oshima, K. (1976). Pathogenicity of Aschersonia to Trialeurodes vaporariorum (in Japanese). Abst. 20th Ann. Meeting Jap. Soc. Appl. Ent. Zool. 29.

Woets, J., Ramakers, P.M.J. & Lenteren, J.C. van (1980). Progress report on development and application of integrated pest control in glasshouses in the Netherlands with an indication about limiting factors. Bull. SROP/WPRS 1980/3, 247-257.

Yamashita, S., Doi, Y., Yora, K. & Yoshino, M. (1979). Cucumber Yellows Virus: Its transmission by the greenhouse whitefly, Trialeurodes vaporariorum (Westwood), and the yellowing disease of cucumber and muskmelon caused by the virus. Ann. Phytopath. Soc. Japan 45, 484-496.

DEVELOPMENTS IN APPLICATION OF BIOLOGICAL CONTROL IN GREENHOUSE VEGETABLES IN THE NETHERLANDS SINCE 1979

W.J. Ravensberg, J.C. van Lenteren & J. Woets

Introduction

Until 1979 the application of biological control substantially increased in the three most important greenhouse vegetable crops (van Lenteren et al., 1980). Since the application in tomato more or less stabilised at well over 500 ha, while in cucumber it showed a 10% increase, up to 450 ha. In sweet pepper the area remained about 35 ha.

The causes of this levelling off are many-fold, some of these (changes in the greenhouse climate, integration with chemical compounds, control of secondary pests) will be discussed in this paper. For other factors which may play a role we refer to van Lenteren et al. (1980). Competitive to the application of biological control is the rise of the synthetic pyrethroids and 'fogging' machines.

The beneficials are no longer delivered on leaves but on an artificial substrate. This made introductions of predators together with spider mites in any required ratio possible and this was at first applied in 1982.

Present-day integration schemes (cf. Ramakers, in press[a]) are given, whereby the clearance of tetrachlorvinphos (1981) and of Bacillus thuringiensis (1982) is an improvement for our biological control systems.

Limiting factors for the application of biological control

There is a strong tendency to decrease energy costs by better insulation of the greenhouse and by decreasing the night temperature in the period from December till March. After March the temperature regime in the greenhouse is largely determined by radiation and outdoor temperature. In Table 1 the average temperatures during the winter period, which are mainly determined by heating, are given for tomato, cucumber and sweet pepper. About two hours before sunrise the heating system starts to increase the temperature to the minimum day level. Proportionally to radiation intensity growers increase the temperature a few degrees by heating and begin ventilation at about 2°C higher.

Table 1: Temperature regime in greenhouse vegetables in the Netherlands from December 1981-April 1982 (°C)

		Night	Day		Ventilation at
			Minimum	At bright conditions	
Tomato		15	18-19	22	24
	Dec-Jan	19-20	22	24	25
Cucumber	March	15-16	21	23	24
	January	17	22	24	26
Sweet pepper	March	17	21	23	26

Early in the season the small plants are incapable of building up an air humidity suitable for Phytoseiulus persimilis. In crops planted in alternative media, e.g. Nutrient Film Technique and rockwool, the relative humidity is even less than that in soil-planted crops.

Both the low temperatures and the low relative humidity are unfavourable for the development of the populations of the natural enemies.

Integration of the parasites and the predators with chemical applications against several other pests and diseases is a decisive factor for success. Usage of synthetic pyrethroids on the plants during propagation means that natural enemies can only be successfully introduced 4-6 weeks after the application (waiting-period). When the pyrethroids are applied this waiting-period is even 6-8 weeks. The waiting-periods for other frequently used pesticides are listed in Table 2. These date are established by experiences in the commercial holdings. The use of a 'fogging' machine can prolong these periods. Mixing of chemical compounds which are harmless for the beneficials when used separately, can cause mortality due to the extra amount of a wetting-agent in the mixture and is therefore not advised, as is dusting of pesticides.

Table 2: Waiting-period (weeks) for a successful introduction of Phytoseiulus persimilis and Encarsia formosa after the application of pesticides in cucumber and tomato crops

Pesticide active ingredient	Phytoseiulus	Encarsia
Benzimidazoles	2-3	-
Diazinon	-*	3
Dicofol	4	-+
Propoxur	1	2
Pyrqzophos	-	3
Synthetic pyrethroids	8-10**	6**
Sulfotep	-	6-8
Tetrachlorvinphos	-*	6-8
Trichlorphon	½	½++

* A small percentage of adults killed

\+ A large percentage of adults killed

** 4-6 weeks when plants are treated during propagation

\++ At ⅓ of the usual dosage

Progress in the method of delivering the beneficials

Formerly the beneficials were delivered on the leaves of their host plants. This method had several disadvantages: picking and distribution were very laborious and the risks of other pests and plant diseases could never be totally excluded.

Encarsia formosa used to be delivered as black pupae on cucumber leaves. But, since 1978 whiteflies and the parasites are reared on tobacoo plants and then the black parasitised pupae are mechanically removed from these leaves and glued on cards. In this way contamination with plant diseases or pests is almost impossible. Storage ca. 10°C) and transport of the black pupae is simple. The cards are easily distributed throughout the greenhouse in a short time by a grower.

Quality control showed that the emergence of the parasites from these cards is good (over 90%) and that the number of ovipositions on the first day is comparable with that of wasps emerging from leaves.

Until spring 1980 the producer of natural enemies, Koppert BV, supplied the predatory mites on bean leaves. Afterwards, the mites were packed in plastic bottles containing sawdust as a medium. But this

method of packing caused a high mortality in the bottles possibly because of poisonous vapours from the sawdust. The sawdust was later replaced by wheat bran. The bran was chosen for the following reasons: the material is very light, it provides many hiding-places for the mites, it is easily sprinkled and distributed in the greenhouse and remains in place on the hairy cucumber leaves. No other pests are introduced because the bran is cleaned by heating before mixing with the predators. Supplying Phytoseiulus persimilis in this way causes no mortality when storage and transport are done under cool conditions (7-10°C). In the Netherlands the time between preparing the bottles and the introduction of the predators in the greenhouse is only 1 to 3 days. During transport abroad problems can arise due to high temperate causing gas development and moulding in the bottle. Recently the method has been further improved by using a screw cap with gauze.

Biological control in cucumber

The two-spotted mite Tetranychus urticae is the most important pest and has been successfully controlled since the late 1960's with the predatory mite Phytoseiulus persimilis. After the rapid increase of the area on which Phytoseiulus persimilis was used in the 1970s (Koppert, 1978; Woets et al., 1980) this usage increased during the last three years only from 400 to 450 ha (Table 3). This is 65% of the total area of cucumber planted before May. If we consider only the long cultures (6-8 months), in which biological control is mainly applied, mostly because of economic reasons, this percentage is even higher.

The higher percentage (over 95) of successful applications is due to several factors, such as the number of predators introduced (8-9 predators per m^2), the intensive guidance and the increasing experience of growers working with integrated control.

By packing the predators in plastic bottles and mixing them with spider mites any required ratio is now possible. Introducing this mixture of pest and natural enemies should give a balanced control throughout the greenhouse and the need to wait for the first spider mites before introduction of the predator is no longer a necessity. Trials in 1982 on 5 ha in a ratio prey-predator of 5 gave good results.

Onion thrips (Thrips tabaci) is an increasing problem in sweet pepper and cucumber crops. In cucumber chemical control with diazinon or tetrachlorvinphos can be integrated with the use of P. persimilis because of OP-resistance of the Dutch strain (Schulten et al., 1976;

Table 3: Area (ha) of the three most important vegetable crops in the Netherlands over which biological control is applied. Total area in the main cropping period and the area of successful biological control of the greenhouse whitefly by Encarsia formosa in tomatoes and of the two-spotted spider mite by Phytoseiulus persimilis in cucumber and sweet pepper.

	Tomato *		Cucumber		Sweet pepper	
	Total	Encarsia	Total	Phytoseiulus	Total	Phytoseiulus
1972	2290	20	840	100	75	-
1976	2040	600	720	300	160	20
1979	2050	560	720	400	180	40
1980	2010	545	700	420	200	35
1981	2020	510	710	450	220	35

* Excluding non-heated houses

Hassan, 1979). When several applications are needed, growers often mix diazinon with frequently applied mildew chemicals to save labour. But this mixture can be especially harmful to P. persimilis. Moreover, spraying these organophosphorous compounds against Thrips makes the use of Encarsia formosa impossible.

Therefore, biological control of onion thrips was studied and a predatory mite, Amblyseius mckenziei seemed to be a promising candidate (Ramakers, 1978; 1980). Mass-rearing of this predator was developed and the first trials in commercial holdings gave good results (Ramakers, in press[b]).

In 1981 Koppert started the production of A. mckenziei and it was released on 20 ha of cucumbers. The predators were introduced at 10 per m^2 when thrips was first observed, when necessary a second introduction was made. On 16 ha thrips control was satisfying to the grower, although intensive sampling and guidance and 1-3 chemical applications were needed. In most cases only the lower parts of the plants were sprayed with diazinon or tetrachlorvinphos (low dose), leaving A. mckenziei unharmed.

Several questions still have to be answered before we have a reliable control system. Trials are going on to determine the number of predators required, how many introductions are needed and at what intervals, about

what kind of influence is exerted by the different culture methods of cucumber on the introduction method and the population development of A. mckenziei, and about integration with pesticides.

Whiteflies are generally controlled with hydrocyanic gas because chemical control of thrips makes the use of E. formosa impossible. Treatment with one of the suitable chemicals (diazinon, tetrachlorvinphos) delays successful introduction of the parasite for 4-6 weeks (depending on ventilation). Moreover, cucumber is a very good host plant for whitefly (van Boxtel, 1978; van de Meerendonk & van Lenteren, 1978) and E. formosa is hampered during searching by the hairy surface of the leaves (Woets & van Lenteren, 1976; Hulspas-Jordaan & van Lenteren, 1978).

However, as long as thrips is not present or it is controlled biologically, application of E. formosa becomes possible. Five introductions of 2 parasites per m^2 every week can give good control till May-June. This was successful on several hectares over the last three years (Table 4). In the future E. formosa might be used on a larger area together with A. mckenziei.

Another way of controlling whitefly is by means of the entomopathogenic fungus Verticillium lecanii, which is now being studied in growers' greenhouses. This fungus needs a high relative humidity to encourage an epizootic and this might be the limiting factor, especially in rockwool crops and in dry periods. One application in the winter of 1982 gave good control together with E. formosa till June 1982 on $2\frac{1}{2}$ ha of cucumber on soil.

The fungus Aschersonia aleyrodis, which is less dependent on a high relative humidity, might also be used in the future (Ramakers & Samson, in press), but this species is not yet commercially available.

Aphids are usually controlled by pirimicarb; caterpillars of Lacanobia oleracea and of Chrysodeixis chalcites by diazinon or Bacillus thuringiensis.

Powdery mildew, the most serious fungal disease, can be controlled by a number of fungicides such as triforine, imazalil, ditalimphos and pyrazophos (partly controlling thrips, but killing E. formosa). Control of other fungal diseases has no side-effects on the beneficials, with one exception: chlorothalonil is harmful to A. mckenziei.

The present-day integration scheme for growers and an experimental one are given in Table 5.

Table 4: The area (ha) and percentage of successful biological control of leafminer by Dacnusa sibirica and Opius pallipes (D/O) and of spider mite by Phytoseiulus persimilis in tomatoes and whitefly by Encarsia formosa in cucumber as three minor applications of biological control in the Netherlands

	Tomato				Cucumber	
	D/O	% success	Phytoseiulus	% success	Encarsia	% success
1979	-	-	14	86	10	70
1980	28	65	14	92	11	73
1981	33	70	12	90	16	75

Biological control in tomato

Whitefly has been successfully controlled by the parasite E. formosa since 1971 (Koppert, 1978 Woets et al., 1980). The area controlled in this way (550 ha (Table 3)) has not increased since 1975: 25% of the total area planted from December-May. Considering only the long cultures for the same reason as mentioned at cucumber, this percentage is even higher. The percentage of successful applications is very high (over 95) because of a good introduction method and intensive guidance.

A limiting factor in the success of E. formosa can be the low temperatures during the introduction period. The minimum temperature at which E. formosa is able to produce and lay eggs is 12°C, but migration only occurs at temperatures of 17°C or higher (see van Lenteren, these proceedings). This temperature is hardly achieved on dark days. In some cases this causes problems in the winter period. When needed, spot treatments are possible with hydrocyanic gas ($\frac{1}{2}$ dose) when the evening is completely still. In due course we might be able to use the microbial insecticides V. lecanii and A. aleyrodis or perhaps Safer's Insecticidal Soap (Downey & Elliot, pers. comm.). This insecticide, based on a high concentration of fatty acids, kills whitefly larvae and adults by direct contact. E. formosa adults are also killed but there are no residual effects to harm newly emerged wasps.

Application of pesticides needs careful attention when E. formosa is used. Waiting-periods are given in Table 2.

Table 5: Integrated schemes for cucumber, tomato and sweet pepper as applied in commercial greenhouses and in experiments in 1982

Pest	Applied	Experimental
Cucumber		
Spider mite	Phytoseiulus persimilis	P. persimilis
Powdery mildew	Triforine, imazalil, ditalimphos	Resistant varieties
Whitefly	Hydrocyanic gas, E. formosa	Encarsia formosa, Verticillium lecanii, Aschersonia aleyrodis,
Aphids	Pirimicarb	Aphidius matricariae, Aphidoletes aphidimyza V. lecanii
Thrips	Diazinon, tetrachlorvinphos, A. mckenziei*	Amblyseius mckenziei, Thripstick
Mycophaerella	Triforine, imazalil	Idem
Caterpillars	Bacillus thuringiensis	Idem
Tomato		
Whitefly	E. formosa, hydrocyanic gas	E. formosa, V. lecanii, A. aleyrodis
Spider mite	Fenbutatinoxide, P. persimilis	P. persimilis
Aphids	Pirimicarb	V. lecanii, A. matricariae A. matricariae, A. aphidimyza
Tomato leafminer	Trichlorphon, Dacnusa sibirica, O. pallipes	D. sibirica, O. pallipes, Oxamyl (against L. trifolii)
Caterpillars	B. thuringiensis	Idem
Botrytis	Vinclozolin, iprodione	Idem

* On a limited area (see text)

/Continued ...

Table 5 (Cont.)

Pest	Applied	Experimental
Sweet pepper		
Spider mite	P. persimilis, fenbutatinoxide	P. persimilis
Aphids	Pirimicarb	A. matricariae, A. aphidimyza, V. lecanii
Thrips	Diazinon, tetrachloryinphos	A. mckenziei, A. cucumeris
Tarsonemid mites	Dicofol, fenbutatinoxide	Sulphur dust
Caterpillars	Diazinon, tetrachlorvinphos, B. thuringiensis	B. thuringiensis
Botrytis	Vinclozolin	Idem
Rhizoctonia	Iprodione	

The crop protection scheme which is now used is given in Table 5, together with an experimental one that is applied in the trials of bio-control research workers.

An increasing problem in tomatoes is the occurrence of leafminers. The tomato leafminer, Liriomyza bryoniae has been more important as a pest since 1976. Chemical control makes the use of E. formosa impossible.

In some greenhouses parasites seemed to control leafminers spontaneously. When L. bryoniae first occurs in June, the best control is obtained without applications of insecticides. Then natural control occurs through one of three parasites: Opius pallipes, Dacnusa sibirica (both Braconidae) and Diglyphus isaea (Eulophidiae) (Hendrikse et al., 1980; Woets & van de Linden, in press). These Braconidae species were investigated as agents for biological control (Hendrikse et al., 1980) and considered to be promising candidates.

The Koppert Company started producing D. sibirica and O. pallipes in 1979 and introduced these parasites on 28 ha in 1980 and on 33 ha in 1981 (Table 3). Introductions were made at 2-7 parasites per m^2 depending on the number of leafminers and the percentage parasitism. A chemical application could be integrated (trichlorphon: 1/3 of the usual dose) beside the use of the parasites and was necessary in most cases.

With intensive guiding and sampling leafminer control was satisfactory in 65-70% of the cases, but a reliable method has yet to be developed.

In 1980 L. trifolii, the serpentine leafminer, appeared in fruit-bearing vegetables under glass while it had already been found in ornamentals since 1975. Chemical control of this species is hard to achieve. Only frequent applications (with, e.g. synthetic pyrethroids) will achieve control, which means that other biological control methods cannot be used in the same crop. Unfortunately, our native parasite O. pallipes cannot reproduce on this leafminer because of encapsulation of the eggs by the host. D. sibirica will parasitise L. trifolii but its efficiency seems to be low compared to that on L. bryoniae. Moreover, rearing these parasites and their hosts is difficult, laborious and expensive and until new methods of controlling this pest are available so the occurrence of L. trifolii is a threat to biological control.

Spider mites are not a serious pest in tomatoes and are therefore generally controlled with a few applications of fenbutatinoxide, leaving E. formosa unharmed. P. persimilis is used only on a small area (Table 4). Introductions of the predatory mite before May seem to give poor results.

Aphids are controlled by pirimicarb or perhaps in future by V. lecanii under humid conditions (Hall & Burges, 1979). Parasitization of aphids by Aphidius matricariae and predation by Aphidoletes aphidimyza can be of value in controlling them in spring and summer.

Caterpillars can be controlled by diazinon or B. thuringiensis.

Fungal diseases are of minor importance in tomato crops. This situation is mainly due to the many resistance factors bred into the common tomato cultivars. Application of the common fungicides against Botrytis cinerea does not harm our beneficials.

Biological control in sweet pepper

The area on which spider mites are controlled by P. persimilis has stabilised around 35 ha since 1977 (Table 3) because of the large number of pests occurring in sweet pepper. Many pesticide applications are needed and growers therefore usually apply fenbutatinoxide against spider mites, often in mixed solutions. Further residual effects on the predator last longer on this plant because of its slower growth compared to that of cucumber and tomato.

Aphids are the main pest, predominantly Myzus persicae, which are controlled by pirimicarb or partly spontaneously by Aphidius matricariae and Aphidoletes aphidimyza.

Thrips damage is not tolerated mainly because of cosmetic fruit damage and therefore thrips control is frequently sought with diazinon or tetrachlorvinphos. Biological control of thrips by the predatory mites Amblyseius cucumeris and A. mckenziei is being studied by Ramakers (in press[b]).

Pests like caterpillars and Capsid bugs are controlled by diazinon, tetrachlorvinphos of B. thuringiensis respectively. Tarsonemid mites by fenbutatinoxide or dicofol. Whiteflies are usually no problem although the yellow cultivar seems to be more sensitive.

A total biological control system in sweet pepper seems to be possible although it will be a complicated and expensive one (Table 5).

References

Boxtel, van W., Woets, J. & Lenteren, J.C. van (1978). Determination of host plant quality of eggplant (Solanum melongena L.), cucumber Cucumis sativus L.), tomato (Lycopersicum esculentum L.) and paprika (Capsicum annuum L.) for the greenhouse whitefly (Trialeurodes vaporariorum (Westwood)) (Homoptera: Aleyrodidae). Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 409-420.

Hall, R.A. & Burges, H.D. (1979). Control of aphids in glasshouses with the fungus Verticillium lecanii. Ann. appl. Biol. 93, 235-246.

Hassan, S.A. (1980). Integrated control on glasshouse vegetable crops. Proc. Int. Symp. OILB/SROP, Vienna, 484-486.

Hendrikse, A., Zucchi, R., Lenterent, J.C. van & Woets, J. (1980). Dacnusa sibirica Telenga and Opius pallipes Wesmael (Hym., Braconidae) in the control of the tomato leafminer Liriomyza bryoniae Kalt. Bull. OILB/SROP III/3, 83-89.

Hulspas-Jordaen, P.M. & Lenteren, J.C. van (1978). The relationship between host plant leaf structure and parasitization efficiency of the parasitic wasp Encarsia formosa Gahan (Hym., Aphelinidae). Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 431-440.

Koppert, P.C. (1978). Ten years of biological control in glasshouses in the Netherlands. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 373-378.

Meerendonk, van de S. & Lenteren, van J.C. (1978). Determination on mortality of greenhouse whitefly, Trialeurodes vaporariorum (Westwood) (Homoptera: Aleyrodidae) eggs, larvae and pupae on four host plant species: eggplant (Solanum melongena L.), cucumber (Cucumis sativus L.), tomato (Lycopersicum esculentum L.) and paprika (Capsicum annuum L.). Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 421-429.

Ramakers, P.M.J. (1978). Possibilities for biological control of Thrips tabaci Lind. (Thysanoptera: Thripidae) in glasshouses. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 463-469.

Ramakers, P.M.J. (1980). Biological control of Thrips tabaci (Thysanoptera: Thripidae) with Amblyseius spp. (Acari: Phytoseiidae). Bull. OILB/SROP III/3, 203-208.

Ramakers, P.M.N. (In press[a]). Biological control in Dutch glasshouses; practical application and progress in research. Proc. Symp. Int. Crop Protection, Valence.

Ramakers, P.M.J. (In press[b]). Start of commercial production and introduction of Amblyseius mckenziei (Acarina: Phytoseiidae) for the control of Thrips tabaci (Thysanoptera: Thripidae) in glasshouses. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent.

Ramakers, P.M.J. & Samson, R.A. (In press). Aschersonia aleyrodis, a fungal pathogen of whitefly. II. Application as a biological insecticide in greenhouses.

Schulten, G.G.M., Klashorst, G. van de & Russell, V.M. (1976). Resistance of Phytoseiulus persimilis A.-H. to some insecticides. Z. Ang. Ent. 80, 337-341.

Woets, J. (1978). Development of an introduction scheme for Encarsia formosa Gahan (Hym.: Aphelinidae) in greenhouse tomatoes to control the greenhouse whitefly, Trialeurodes vaporariorum (Westwood) (Homoptera: Aleurodidae). Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 379-386.

Woets, J. & Lenteren, J.C. van (1976). Studies on the parasite-host relationship between Encarsia formosa (Hym.: Aphelinidae) and Trialeurodes vaporariorum (Homoptera: Aleyrodidae). VI. The influence of the host plant on the greenhouse whitefly and its parasite E. formosa. Bull. OILB/SROP 1976/4, 151-164.

Woets, J. & Linden, A. van der (In press). On the occurrence of Opius pallipes Wesmael and Dacnusa sibirica Telenga (Braconidae) in cases of natural control of the tomato leafminer Liriomyza bryoniae Kalt. (Agromyzidae) in some large greenhouses in the Netherlands. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent.

Woets, J., Ramakers, P.M.J. & Lenteren, J.C. van (1980). Progress report on development and application of integrated pest control in glasshouses in the Netherlands with an indication about limiting factors. Bull. OILB/SROP III/3, 247-257.

CONSTRAINTS ON THE USE OF ENCARSIA FORMOSA IN TOMATOES IN JAPAN, WITH SPECIAL REFERENCE TO THE EFFECT OF TEMPERATURE ON ITS EFFICIENCY

Eizi Yano

Introduction

The greenhouse whitefly is now one of the most important greenhouse pests in Japan. There are only a few effective insecticides. So, if we depend only on insecticides to control whiteflies, resistant strains may appear. Use of Encarsia formosa is one of the solutions avoiding such a problem (Yano, 1981). This paper deals with results of experiments on the effects of greenhouse temperature on the efficiency of E. formosa, which is considered the most important constraint on its use in Japan.

Differences in temperature conditions in greenhouses between Europe and Japan and its significance in control effects of E. formosa

There are clear differences in the temperature conditions in tomato greenhouses between European countries and in Japan. For example, in the Netherlands, tomatoes are grown from late winter (6-8 months) (Vet et al., 1980). In England night temperatures are controlled at 16°C (Hussey, pers. comm. 1977). In contrast, the cultivation of tomatoes in Japan may be divided into three types: (1) from September to June; (2) from December to June; (3) from July to January. Types (1) and (2) are more popular than Type (3), so that tomatoes are mainly grown in winter. In this condition, night temperatures are controlled at 5-11°C with day temperature at 27°C. The mean daily temperatures lie in a range from 9 to 13°C.

Some studies on the effects of temperature on the efficiency of E. formosa suggested a decrease in the efficiency at 18°C compared with 24°C or above (Milliron, 1940; Burnett, 1949). If this is true, E. formosa could be used only in the type (3) cultivation in Japan. In connection with this problem, some control experiments of whiteflies by E. formosa in tomatoes have been performed under different temperature conditions in Japan.

Control experiments of whiteflies by E. formosa under different temperature conditions

Control experiments of whiteflies by E. formosa in tomatoes of type (1) cultivation (planted in October or November) were performed in plastic greenhouses in 1980-81 and 1981-82. Newly emerged whitefly adults were released (4 adults/plant) just after planting, then after the first discovery of mature whitefly larvae (3rd and 4th instar), parasitized black scales were introduced three times (8 black scales/plant/introduction) at 2-3 week intervals. Night temperatures were controlled at 11°C (treatment A), 8°C (treatment B) and 5°C (treatment C). The results are shown in Figure 1. Population changes of mature larvae (open circles) and black scales (closed circles) are expressed in logarithmic scale.

In all these treatments, the density of mature larvae did not exceed 300 individuals/plant throughout the cropping period so few sooty moulds occurred. In treatment A, both mature larvae and black scales gradually increased, while in treatments B and C, population changes showed convex curves. For treatments A and C, control plots were arranged where only whitefly adults were released. In both of the control plots, the development of sooty moulds on leaves or fruit was observed in the late cropping periods.

Control experiments in type (3) cultivation have not yet been performed. Instead, a control experiment was carried out using a glasshouse operated at 30°C during the day and 20°C during the night. This temperature corresponds to the average conditions in type (3) cultivation. The introduction method for whiteflies and E. formosa was the same as that in the experiments for type (1) cultivation. The results are shown in Figure 2. Density of mature larvae did not exceed the level of 300/plant and no sooty moulds occurred. Population changes of both species showed fluctuating patterns.

In conclusion, the use of E. formosa in tomatoes is promising for all the various types of cultivation in Japan.

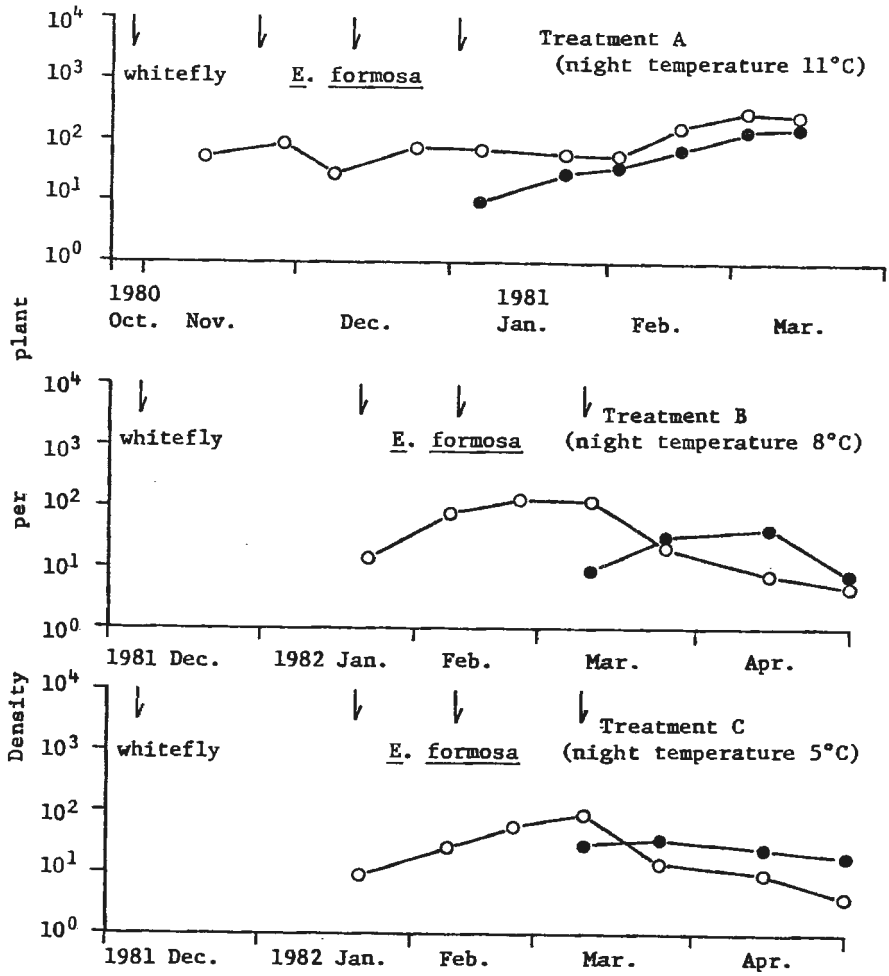


Figure 1: Population changes of mature larvae of whitefly (open circles) and black scales (closed circles) under different night temperature conditions in type (1) cultivation programme. Arrows indicate introduction of whiteflies or E. formosa.

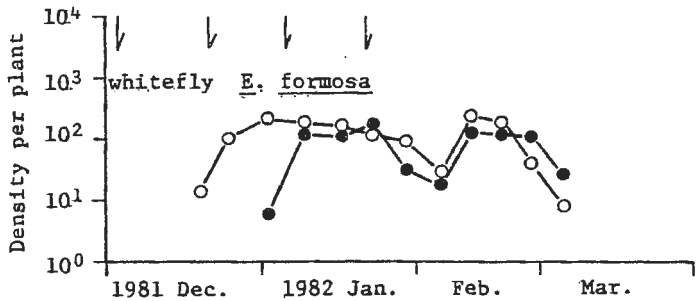


Figure 2: Population changes of mature larvae and black scales under the temperature condition of 30°C during the day and 20°C during the night

Other constraints on the use of E. formosa

There are further problems in the use of E. formosa. Tomato growers sometimes apply insecticides to control aphids to prevent them transmitting virus diseases. In Europe, the selective aphicide pirimicarb is recommended for control of aphids on tomatoes. But Aphis gossypii in Japan, one of the species attacking tomatoes, seems to be resistant to pirimicarb. In addition, in some areas of Japan, a kind of leafminer sometimes outbreaks in tomato greenhouses. So, integration of use of E. formosa with insecticides to control such minor pests is necessary in some cases.

References

Burnett, T. (1949). The effect of temperature on an insect host-parasite population. Ecology 30, 113-134.

Milliron, H.E. (1940). A study of some factors affecting the efficiency of Encarsia formosa Gahan, an aphelinid parasite of the greenhouse whitefly, Trialeurodes vaporariorum. Tech. Bull. Michigan Agric. Exp. Stn. 173, 1-23.

Vet, L.E.M., Lenteren, J.C. van & Woets, J. (1980). The parasite-host relationship between Encarsia formosa (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Homoptera: Aleyrodidae). IX. A review of the biological control of the greenhouse whitefly with suggestions for future research. Z. ang. Ent. 90, 26-51.

Yano, E. (1981). Greenhouse whitefly Trialeurodes vaporariorum (Westw.) (Hom., Aleyrodidae) in Japan and possibilities for its control by Encarsia formosa Gahan (Hym., Aphelinidae). Z. ang. Ent. 92, 364-370.

INFLUENCE OF LOW TEMPERATURE REGIMES ON THE CAPABILITY OF ENCARSIA FORMOSA AND OTHER PARASITES IN CONTROLLING THE GREENHOUSE WHITEFLY, TRIALEURODES VAPORARIORUM

J.C. van Lenteren & P.M. Hulspas-Jordaan

Summary

Literature data indicated that after the lowering of rearing temperatures in greenhouses, which is anticipated, biological control of the greenhouse whitefly with the parasite Encarsia formosa will be difficult or impossible.

In this paper we (1) review this literature, (2) summarize our work on collecting and comparing whitefly parasites, (3) describe research done to determine developmental and reproduction characteristics of whitefly and some of its parasites at the prospective low temperatures, and (4) give data about the migration capacity of E. formosa at low temperatures. The results of our research show that biological control with E. formosa at the new temperature regimes may very well be possible without drastically changing the present day system which is used on a large scale.

Introduction

Since the last meeting of the Working Group on Integrated Control in Glasshouses (Vantaa, Finland, 1979), research by our group has mainly been concentrated on testing the control capability of whitefly parasites at low greenhouse temperatures. For information on other aspects of our work we refer to Eggenkamp-Rotteveel Mansveld et al. (1980, 1982a & b; population dynamics of T. vaporariorum and E. formosa), Hendrikse (1980; biological control of leafminers), van Lenteren (1980; evaluation of parasites), van Lenteren et al. (1980a & b; review of biological control in greenhouses), van der Kamp & van Lenteren (1981; phloem localization by the whitefly), de Ponti & van Lenteren (1980; resistance and glabrousness in cucumber), van Vianen & van Lenteren (1982; improvement of E. formosa).

The use of the parasitic wasp Encarsia formosa Gahan to control one of the major glasshouse pests, the greenhouse whitefly Trialeurodes vaporariorum (Westwood) has proved to be an effective method of pest control and is applied in many countries (Eggenkamp-Rotteveel Mansveld,

1982a). Because of high energy consumption in glasshouses, research is under way to develop tomato varieties (one of the important glasshouse crops in the Netherlands) that produce well at lower glasshouse temperatures than used until now (Woets et al., 1980). Breeding is done on varieties that produce a good crop at a temperature regime of 18°C by day and 7°C at night, and introduction of these varieties is expected in 1984.

Literature data on control capacities of natural enemies of the greenhouse whitefly

We have collected the literature data on developmental characteristics and reproduction capacities of Encarsia formosa and Trialeurodes vaporariorum at low temperatures. If the necessary data were available (i.e. developmental period, longevity and fecundity) we calculated the intrinsic rate of increase (= r) using Lewontin's (1965) age specific fecundity equation based on the Volterra equation for exponential growth. (The advantages and disadvantages of the different ways of calculating the intrinsic rate of increase for comparison of (hosts and) parasites will be discussed in a future paper in our whitefly-Encarsia series.) The values for r, with their sources, are given in Table 1.

At temperatures below 20°C the values for the intrinsic rate of increase for E. formosa are lower than those for T. vaporariorum; above 20°C the situation is the reverse. Because of the slower rate of increase of E. formosa at temperatures below 20°C we expected problems to occur with our present biological control programme in the near future.

One other source of doubt about the control capacity of E. formosa at low temperatures was the information given by Madueke (1979): according to her the wasps do not fly and show hardly any activity when temperatures are lower than 21°C.

Therefore, we collected information from the literature on other natural enemies of whitefly (Vet et al., 1980). Detailed biological studies had only been conducted on some species and the data did not indicate one of these species to be able to control whitefly at low temperatures. We concluded that a serious attempt was necessary to collect and study other natural enemies of whitefly and other strains of E. formosa. Our research group has since then concentrated on collecting other parasites than E. formosa as well as E. formosa strains and on comparing their control capabilities. Ramakers (pers. comm.) started to

Table 1: Intrinsic rate of increase (r) of T. vaporariorum and E. formosa at different temperatures and the pre-1979 data used for calculation (authors indicated by initials)

Temperature (°C)	Developmental period (days)		Longevity (days)		Fecundity (no. of ♀ eggs)		r
Trialeurodes vaporariorum							
12	63.9**	e	36	b	20.35	b	0.040
15	50.6	e	50.5	b	46.8	b	0.060
18	30.1	b	42.5	b	159.8	b	0.127
18	42	k	42.5	b	159.8	b	0.096
21	27.7	b	28.5	b	104.75	b	0.132
21	22.3	h	31.3	h	65.75	h	0.139
21	48.4	c	58.7	c	124.85	c	0.077
21	47.8	c	29.1	c	46.05	c	0.068
22.5	28.3	sa	21.9	sa	48	sa	0.112
22.5	28.3	sa	49.3	sa	98.5	sa	0.116
24	24.6	b	17.2	b	61.95	b	0.138
24	19.8	h	36.3	h	105.25	h	0.167
24	24.7	m	36.3	h	105.25	h	0.140
24	24.7	m	17.2	b	61.95	b	0.138
27	21.3	b	8.3	b	14.75	b	0.111
27	18.2	h	22.5	h	121.5	h	0.201
30	26.5	e	5.4	b	9.55	b	0.079

/Continued ...

Table 1: (Continued)

Temperature (°C)	Developmental period (days)		Longevity (days)		Fecundity (no. of ♀ eggs)		r
Encarsia formosa							
15	56.4	e	31	b	15.6	b	0.042
15	52	e	31	b	15.6	b	0.044
18	29.5	b	27	b	28.2	b	0.090
18	34	s	27	b	28.2	b	0.080
21	22.9	b	21.5	b	28.8	b	0.115
21	30	s	21.5	b	28.8	b	0.092
21	26*	s	21.5	b	28.8	b	0.104
24	15	b	15.7	b	32.7	b	0.178
24	20	s	15.7	b	32.7	b	0.141
24	17*	s	15.7	b	32.7	b	0.161
27	11.9	b	8.1	b	30.5	b	0.234
27	15	s	8.1	b	30.5	b	0.193
30	10	b	3.9	b	9.9	b	0.198
30	16.4	e	3.9	b	9.9	b	0.127
30	14.3	3	3.9	b	9.9	b	0.144

* Temperature given is mean of day and night temperatures

** Interpolated

a = Arakawa, 1982

b = Burnett, 1949

c = Curry & Pimentel, 1971

ch = Christochowitz *et al.*, 1981 and Christochowitz & van der Fluit, 1981

e = Eijsackers, 1969

h = Hussey & Gurney, 1957

k = Kraaijenbrink, 1972

ka = Kajita, 1979

l = van der Laan *et al.*, 1982

m = van de Merendonk & van Lenteren, 1978

ma = Madueke, 1979

s = Stenseth, 1976

sa = van Sas *et al.*, 1978

v = Vet & van Lenteren, 1981

study the potentialities of entomopathogenic fungi in controlling whitefly and Kajita (1978, 1981 and pers. comm.) studied several predators and parasites in Japan. Ekbom (1979) also reported on the use of entomopathogenic fungi in whitefly control.

Collection and comparison of whitefly parasites

A search for other parasites than E. formosa was performed in the native area of T. vaporariorum (Southwestern USA), and in Europe. A report on the collection, culturing and testing of parasites from California, USA is given by Vet (1980) and Vet & van Lenteren (1981). Vet & van Lenteren (1981) also describe a laboratory method to assess the parasitization efficiency of new whitefly parasites under laboratory conditions. Eight primary whitefly parasites and one obligate hyperparasite of E. formosa (and perhaps of other Encarsia species) were collected. Four species could successfully be cultured and of these four species the fecundity, parasitization rate, developmental period and longevity were determine at 17 ± 1°C. The results are summarized in Table 2.

Table 2: Fecundity and rate of parasitization over a 20-day period, developmental period and longevity of several whitefly parasites at 17°C (with standard deviations)

Species	Fecundity (no. of eggs over 20 days)	Parasitization rate (no. of hosts par./♀/day; over 20 days)	Developmental period (days)	Longevity (days)
E. formosa	165.6 ± 32.86	8.3	31.6 ± 1.80	44
E. pergandiella	124.9 ± 7.59	6.2	25.9 ± 2.01	38.6
E. sp. near meritoria	85.4 ± 24.78	4.3	30.4 ± 2.12	37.1
Eretmocerus sp.	149.9 ± 61.87	7.5	47.8 ± 2.68	30.1

Encarsia sp. near meritoria produced significantly less parasitized pupae during the entire 20-day test period than the other three species ($P < 0.005$), and must therefore be considered less promising. Comparison of the developmental periods of the different species shows why

Eretmocerus sp. is also considered a less promising species for control of T. vaporariorum at low temperatures. The developmental period of Eretmocerus sp. is almost twice as long as that of E. pergandiella and more than two weeks longer than those of the other two Encarsia species. Adult longevity of Eretmocerus sp. was low compared to the three Encarsia species.

The Californian E. formosa strain and E. pergandiella showed the most promising results with regard to their reproductive potential at 17°C. E. formosa produced a significantly larger total number of parasitized pupae than E. pergandiella ($P < 0.005$). This difference is accounted for by the decreasing oviposition rate of E. pergandiella, especially in the second half of the test period. All E. formosa females were still ovipositing at the end of the test period, and it is not known how many days they would have continued to do so, but data of Arakawa (1982) show that they may live for about 37 days at 25°C and lay 442 eggs on average. In the case of E. formosa, the fairly constant oviposition rate, about 8 parasitized pupae per female per day found in the present experiment, does suggest that these females, known to possess on average 8 ovarioles (van Vianen & van Lenteren, 1982) were capable of depositing only one egg out of each ovariole each day at this temperature.

After this research E. formosa (Californian strain) and E. pergandiella were shipped to the Netherlands to conduct other experiments. Besides the American material, we obtained E. tricolor which was collected in Spain and which was said to be active at low temperatures (Bordas, pers. comm.).

Temperature threshold for oviposition

After shipment we have first measured the threshold temperature for oviposition to see whether the parasite species differ in this respect (van Lenteren & van der Schaal, 1981). Madueke (1979) by extrapolation found the lowest temperature at which E. formosa will lay eggs to be 15°C. In our test we determine the threshold temperature for oviposition of two E. formosa strains (the one produced by the Koppert Company (the Netherlands) and the one from California), E. pergandeilla and

E. tricolor*. All parasite strains and species were able to show their complete host-searching and oviposition behavioural repertoire at temperatures between 11.4 and 12.0°C (for details see van Lenteren & van der Schaal, 1981). For E. formosa, this is about 3°C lower than Madueke (1979) found by extrapolation. We have recently found (Kajita & van Lenteren, 1982, Kajita in prep.) that the threshold temperature for egg maturation lays between 10 and 15°C in E. formosa.

The differences in threshold temperatures for oviposition are very small and on basis of these results we cannot conclude one species to be a more promising candidate for control at low glasshouse temperatures than others.

Potentialities of Encarsia pergandiella

Vet's (1980) conclusion that E. pergandiella might be a promising candidate for control at low temperatures was based on the relatively short developmental time of this parasite compared with that of E. formosa.

E. pergandiella is, however, an arrhenotokous species and has the habit of hyperparasitizing hosts parasitized by individuals of her own or other whitefly parasites, for the production of males. The reduction in intrinsic rate of increase caused by this would be less dramatic if E. pergandiella would preferably use hosts parasitized by females of other whitefly parasites. Study of the intra- and interspecific host-selection behaviour showed that E. pergandiella has no preference for hosts parasitized by either E. formosa or by individuals of her own species (Buijs et al., 1981). This means that even if E. pergandiella were introduced together with another parasite the effective reproduction capacity is strongly reduced because of the hyperparasitic male production. We therefore consider E. pergandiella a less promising candidate and the research was continued without this species.

---

* Concerning other E. formosa strains, we could until now (July, 1982) not obtain strains which did definitely not originate from the English strain collected in the 19820s (Speyer, 1927). The only exception is the Californian strain. Most, if not all, of the commercial producers of E. formosa started their production with this English strain.

Determination of developmental and reproduction characteristics of whitefly and two of its parasites at a temperature regime of 18°C by day (14 hrs) and 7°C at night (10 hrs)

Because of the limited data on fecundity, longevity, developmental period and oviposition frequency of T. vaporariorum and E. formosa at low temperatures, our next research concerned collection of such data.

Christochowitz et al. (1981) determined the developmental period and the oviposition frequency during 17 days of T. vaporariorum at a day 18°C, night 7°C regime (Table 3). The developmental period fits well between data determined before 1979. The oviposition frequency is higher than found by Burnett (1949) at this temperature.

For E. formosa Christochowitz et al. (1981) found a developmental period of 40 days at an average temperature of 12.2°C, which is considerably shorter than values found at 15°C by Eijsackers (1969). Also the fecundity and oviposition frequency data deviate in a positive way from data determined by Burnett (1949). This did not surprise us as Burnett (1949) offered a number of hosts to the parasites that was certainly too small to accurately measure the fecundity. The longevity found by Christochowitz et al. (1981) is, however, somewhat shorter than found by Burnett (1949). The oviposition frequency for the Californian and Koppert strain of E. formosa did not differ (Table 3) so we decided, after having found several other similarities between these strains, to continue further research with only the Koppert strain of E. formosa. The oviposition frequency of E. tricolor was much lower than that of the E. formosa strains and this species was also excluded from further studies.

Due to technical problems, Christochowitz et al. (1981) could not obtain complete data for the fecundity of whitefly and E. formosa. The rather positive indications about the control capability of E. formosa at low temperatures gave us spirit to make another trial at the same temperature regime (for details see van der Laan et al., 1982). The fecundity of T. vaporariorum was found to be about 125 eggs per female, that of E. formosa about 70 eggs per female. The oviposition frequency for T. vaporariorum was higher in this test which can be explained as follows: Christochowitz et al. (1981) determined the oviposition frequency during the first 17 days after emergence, whereas van der Laan et al. (1982) measured it during the total life-span. Van der Laan et al.'s (1982) data show an increase in oviposition frequency especially after these first 17 days and it remains high for a considerable period.

Table 3: Developmental period, fecundity, longevity and oviposition frequency of T. vaporariorum (on tomato) and E. formosa at a day 18°C, night 7°C regime. The average temperature over the 24-hour period was 11.5°C, except for the experiment on the developmental period of E.formosa in which it was 12.2°C

Species	Author	Developmental period (days)	Fecundity (no. of eggs)	Longevity (days)	Oviposition frequency (no. of eggs/♀/day)
T. vaporariorum	Christochowitz et al., 1981	60			2.1
	van der Laan et al., 1982		124.5	41.9	3.1
E. formosa Koppert	Christochowitz et al., 1981	40	>100	32.6	3.5
	van der Laan et al., 1982		70.8	24.7	3.2
	Christochowitz et al., 1981				2.4
E. formosa California	Christochowitz et al., 1981				2.5
E. tricolor	Christochowitz et al., 1981				0.8

The oviposition frequencies of E. formosa as determined by both groups of workers do not differ much (Table 3); no increase in oviposition frequency during time was measured for E. formosa. Christochowitz et al. (1981) found a larger longevity for E. formosa than van der Laan et al. (1982), but the females used by Christochwitz et al. (1981) were not allowed to oviposit after the first 17 days. It has previously been established (Vet & van Lenteren, 1981) that E. formosa males that are not allowed to oviposit during (a part of) their adult life usually live longer than wasps that are allowed to oviposit continuously.

We also collected other data that were published after 1979 and with all of these new data we calculated the values for intrinsic rate of increase once more (Table 4): the values for E. formosa at the low temperatures are higher than those for T. vaporariorum.

Table 4: Intrinsic rate of increase (r) of T. vaporariorum and E. formosa at different temperatures and the post-1979 data used for calculation (authors indicated by initials, for explanation see Table 1)

Temperature (°C)	Developmental period (days)		Longevity (days)		Fecundity (no. of ♀ eggs)		r
Trialeurodes vaporariorum							
12	60*	ch	41.9*	l	62.25*	l	0.057
Encarsia formosa							
12	39.5*	ch	32.6*	ch	99*	ch	0.095
12	39.5*	ch	24.7*	l	70.8*	l	0.091
15	56.4	e	47.7	ka	75.8	ka	0.062
15	52	e	47.7	ka	75.8	ka	0.087
17	31.6	v	44	v	165.6	v	0.122
18	40.1	ma	17.8	ma	69	ma	0.093
18	40.1	ma	23	ch	223	ch	0.116
18	29.5	b	23	ch	223	ch	0.152
18	34	s	23	ch	223	ch	0.134
22.5	21	ma	14.6	ma	160.2	ma	0.201
25	15.9	a	36.8	a	442.2	a	0.268
25	15	a	36.8	a	442.2	a	0.281
25	15.9	a	12.5	ka	45.5	ka	0.194
25	15	a	12.5	ka	45.5	ka	0.203
25	15.9	a	19	ka	59.5	ka	0.194
25	15	a	19	ka	59.5	ka	0.203
27	14.3	ma	11.4	ma	91.1	ma	0.255
30	10	b	6	ka	23	ka	0.258
30	16.4	e	6	ka	23	ka	0.169
30	14.3	e	6	ka	23	ka	0.190

* Temperature given is mean of day and night temperatures

In Figure 1 we have plotted r values from before and after 1979. In Figure 1b the pre-1979 values for E. formosa have been deleted as all data on fecundity came from Burnett and were determined with too little hosts offered.

In conclusion, we may say that as far as the intrinsic rate of increase concerns, no problems seem to exist: the r values for E. formosa are at all temperatures higher than those for T. vaporariorum.

Migration at low temperatures

The methodology of the performed fecundity tests excluded measuring the parasite's searching capacity which certainly is an important factor for successful whitefly control (Eggenkamp-Rotteveel Mansveld 1982a & b). Migration capacity is of great importance in the process of searching. According to Madueke (1979) E. formosa does not fly and shows hardly any activity when temperatures are lower than 21°C.

This would mean that in spite of the rather positive data about the power of increase of E. formosa, biological control of T. vaporariorum at a temperature regime of D 18/N 7°C would practically be impossible because parasites would then be unable to migrate from places with a low host density to places with a high one. A preliminary experiment by Christochowitz et al. (1981) showed that freshly emerged females which had developed at about 13°C, were able to migrate at 17°C within 30 minutes after the vial containing these females was opened. More extensive work in greenhouses by Van der Laan et al. (1982) revealed that some migration occurred already at temperatures as low as 13°C, and that migration was very common at temperatures of 17-18°C. Contrary to Madueke's (1979) and Ledieu's (1976) results we frequently saw E. formosa landing on uninfested plants although always more parasites were counted on infested plants. Whether these higher numbers were the result of more landings on infested plants or of an arrestment response after landing could not be determined.

Final conclusions and future research

At the low temperature regime of D 18/N 7°C:

1. Whiteflies live longer than E. formosa.

2. The oviposition frequency of both species is about the same.

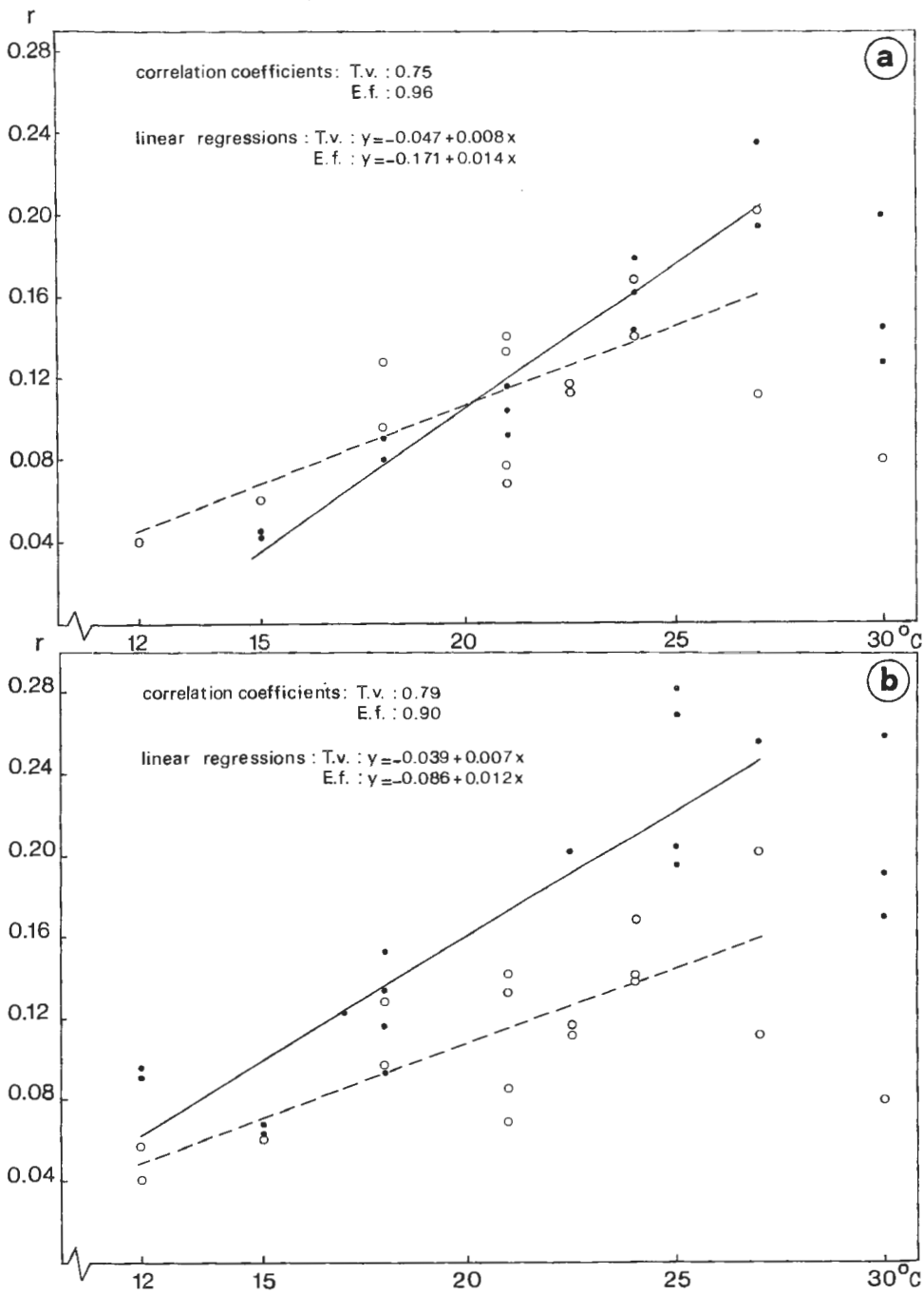


Figure 1: Pre-1979 (a) and post-1979 (b) values for intrinsic rate of increase of T. vaporariorum (o - -) and E. formosa (• - -) at different temperatures. The data for 30°C are not used for calculation of the linear regression.

3. The fecundity of whitefly is larger than that of E. formosa, but half of the eggs of the whitefly develop into males whereas E. formosa produces mainly females: the total number of females produced per female is about the same in both species. The offspring is, however, produced over periods of different lengths.

4. The developmental period of E. formosa is shorter than that of T. vaporariorum (40 and 60 days, respectively).

5. Migration of E. formosa is certainly possible.

To estimate the effect of these findings, two ways will be followed. Firstly, simulation models are in development through which we hope, among others, to be able to trace and estimate effects of changes in rearing temperatures. Secondly, we hope to do experiments on the greenhouse level. We will wait to test new parasite species or E. formosa strains till these simulations and experiments have been done.

Acknowledgements

The following persons have substantially contributed to this paper: J. Woets, A.v.d. Linden, G. Beurs, K. Bakker, L.E.M. Vet, J.M.J. Herzberg, Koppert Co., R.J. van der Kamp.

The research was partly supported by a grant of the Netherlands Organization for the Advancement of Pure Research (BION-ZWO).

References

Arakawa, R. (1982). Reproductive capacity and amount of host-feeding of Encarsia formosa Gahan (Hymenoptera, Aphelinidae). Z. ang. Ent. 93, 175-182.

Burnett, T. (1949). The effect of temperature on an insect host-parasite population. Ecology 30, 113-134.

Buijs, M.J., Pirovano, I. & van Lenteren, J.C. (1981). Encarsia pergandiella a possible biological control agent for the greenhouse whitefly, Trialeurodes vaporariorum: a study on intra- and interspecific host selection. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 46/2, 465-476.

Christochowitz, E.E. & van der Fluit, N. (1981). Onderzoek naar ovipositiesnelheid, ontwikkelings- en levensduur van Trialeurodes vaporariorum (Homoptera: Aleyrodidae), Encarsia formosa (2 stammen) en E. tricolor (Hymenoptera: Aphelinidae) bij lage temperaturen. Unpubl. thesis, Univ. of Leiden.

Christochowitz, E.E., van der Fluit, N. & van Lenteren, J.C. (1981). Rate of development and oviposition frequency of Trialeurodes vaporariorum, Encarsia formosa (two strains) and E. tricolor at low glasshouse temperatures. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 46/2, 477-485.

Curry, J.P. & Pimentel, D. (1971). Life cycle of the greenhouse whitefly, Trialeurodes vaporariorum, and population trends of the whitefly and its parasite, Encarsia formosa, on two tomato varieties. Ann. Ent. Soc. Amer. 64, 1188-1190.

Eggenkamp-Rotteveel Mansveld, M.H., Ellenbroek, F.J.M. & van Lenteren, J.C. (1980). The greenhouse whitefly, Trialeurodes vaporariorum (Westwood) and its parasite Encarsia formosa Gahan: population dynamics and sampling problems. Proc. Int. Symp. on Crop Protection Med. Fac. Landbouww. Rijksuniv. Gent 45/3, 545-553.

Eggenkamp-Rotteveel Mansveld, M.H., van Lenteren, J.C., Ellenbroek, F.J.M. & Woets, J. (1982a). The parasite-host relationship between Encarsia formosa (Hym., Aphelinidae) and Trialeurodes vaporariorum (Hym., Aleyrodidae). XII. Population dynamics of parasite and host in a large, commercial glasshouse and test of the parasite-introduction method used in the Netherlands (first part). Z. ang. Ent. 93, 113-130.

Eggenkamp-Rotteveel Mansveld, M.H., van Lenteren, J.C., Ellenbroek, F.J.M. & Woets, J. (1982b). The parasite-host relationship between Encarsia formosa (Hym., Aphelinidae) and Trialeurodes vaporariorum (Hym., Aleyrodidae). XII. Population dynamics of parasite and host in a large, commercial glasshouse and test of the parasite-introduction method used in the Netherlands (second part). Z. ang. Ent. 93, 258-279.

Ekbom, B.S. (1979). Investigations on the potential of a parasitic fungus (Verticillium lecanii) for biological control of the greenhouse whitefly (Trialeurodes vaporariorum). Swedish J. agr. Res. 9, 129-138.

Eijsackers, H.J.P. (1969). Ontwikkeling en verspreiding van Trialeurodes vaporariorum (Westwood) en zijn parasiet Encarsia formosa Gahan. Unpubl. thesis, Univ. of Leiden.

Hendrikse, A. (1980). A method for mass rearing two braconid parasites (Dacnusa sibirica and Opius pallipes) of the tomato leafminer (Liriomyza bryoniae). Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 45/3, 563-571.

Hussey, N.W. & Gurney, B. (1957). Greenhouse whitefly (Trialeurodes vaporariorum Westwood). Ann. Rep. Glasshouse Crops Res. Stn. 134-137.

Kajita, H. (1978). The feeding behaviour of Cyrtopeltis tenuis Reuter on the greenhouse whitefly, Trialeurodes vaporariorum (Westwood). Rostria 29, 235-238.

Kajita, H. (1979). Effects of temperature and humidity on fecundity and longevity of Encarsia formosa Gahan, an introduced parasite of the greenhouse whitefly, Trialeurodes vaporariorum (Westwood). Proc. Assoc. Pl. Prot. Kyushu 25, 112-113 (in Japanese).

Kajita, H. (1981). Native parasites of the greenhouse whitefly, Trialeurodes vaporariorum (Westwood) in Japan and results of first use as biological control agents. Z. ang. Ent. 92, 457-464.

Kajita, H. & van Lenteren, J.C. (1982). The parasite-host relationship between Encarsia formosa (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Homoptera: Aleyrodidae). XIII. Effect of low temperatures on egg maturation of E. formosa. Z. ang. Ent. 93, 430-439.

Kamp, R.J. van der & van Lenteren, J.C. (1981). The parasite-host relationship between Encarsia formosa Gahan (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Westwood) (Homoptera: Aleyrodidae). XI. Do mechanical barriers of the host plant prevent successful penetration of the phloem by whitefly larvae and adults? Z. ang. Ent. 92, 149-159.

Kraaijenbrink, E. (1972). Biologische bestrijding van spint en witte vlieg. Unpubl. thesis, Wageningen.

Laan, E.M. van der, Burggraaf-van Nierop, Y.D. & van Lenteren, J.C. (1982). Oviposition frequency, fecundity and life-span of Encarsia formosa (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum Homoptera: Aleyrodidae) and migration capacity of E. formosa at low greenhouse temperatures. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 47 (in press).

Ledieu, M.S. (1976). Dispersal of the parasite Encarsia formosa as influenced by its host, Trialeurodes vaporariorum. Bull. OILB/SROP 1976/4, 121-124.

Lenteren, J.C. van (1980). Evaluation of control capabilities of natural enemies: does art have to become science? Neth. J. Zool. 30, 369-381.

Lenteren, J.C. van, Ramakers, P.M.J. & Woets, J. (1980). Integrated control of vegetable pests in greenhouses. In: "Integrated control of insect pests in the Netherlands", eds. P. Gruys & A.K. Minks, 109-118. Pudoc, Wageningen.

Lenteren, J.C. van, Ramakers, P.M.J. & Woets, J. (1980). World situation of biological control in greenhouses, with special attention to factors limiting application. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 45/3, 537-544.

Lenteren, J.C. van & van der Schaal, A.W.J. (1981). Temperature thresholds for oviposition of Encarsia formosa, E. tricolor and E. pergandiella in larvae of Trialeurodes vaporariorum. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent. 46/2, 457-464.

Lewontin, R.C. (1965). Selection for colonizing ability. In: "The genetics of colonizing species", eds. H.G. Baker & G.L. Stebbins, London, Academic Press Inc.

Madueke, E.D.N.N. (1979). Biological control of Trialeurodes vaporariorum. Ph.D. thesis, Cambridge.

Merendonk, S. van de & Lenteren, J.C. va (1978). Determination of mortality of greenhouse whitefly, Trialeurodes vaporariorum (Westwood) (Homoptera: Aleyrodidae) eggs, larvae and pupae on four host-plant species: eggplant (Solanum melognena L.), cucumber (Cucumis sativus L.), tomato (Lycopersicum esculentum L.) and paprika (Capsicum annuum L.). Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 421-429.

Ponti, O.M.B. de & Lenteren, J.C. van (1980). Resistance and glabrousness: different approaches to develop biological control of two cucumber pests, Tetranychus urticae and Trialeurodes vaporariorum. Proc. Eucarpia meeting on breeding of cucumbers and melons, 28-32.

Sas, J. van, Woets, J. & Lenteren, J.C. van (1978). Determination of host-plant quality of gherkin (Cucumis sativus L.), melon (Cucumis melo L.) and gerbera (Gerbera jamesonii Hook) for the greenhouse whitefly Trialeurodes vaporariorum (Westwood) (Homoptera: Aleyrodid Aleyrodidae). Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 43/2, 409-420.

Speyer, E.R. (1927). An important parasite of the greenhouse whitefly (Trialeruodes vaporariorum, Westwood). Bull. ent. Res. 17, 301-308.

Stenseth, C. (1976). Some aspects of the practical application of the parasite Encarsia formosa for control of Trialeurodes vaporariorum. Bull. OILB/SROP 1976/4, 104-114.

Vet, L.E.M.(1980). Laboratory studies on three Encarsia spp. and one Eretmocerus sp. (Hymenoptera: Aphelinidae), parasites of the greenhouse whitefly (Trialeurodes vaporariorum (Westwood)) to assess their efficiency as biological control agents under low temperature conditions. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 45/3, 555-561.

Vet, L.E.M., Lenteren, J.C. van & Woets, J. (1980). The parasite-host relationship between Encarsia formosa (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Homoptera: Aleyrodidae). IX. A review of the biological control of the greenhouse whitefly with suggestion suggestions for future research. Z. ang. Ent. 90, 26-51.

Vet, L.E.M. & Lenteren, J.C. van (1981). The parasite-host relationship between Encarsia formosa Gahan (Hymenoptera: Aphelinidae) and Trialeurodes vaporariorum (Westwood) (Homoptera: Aleyrodidae). X. A comparison of three Encarsia spp. and one Eretmocerus sp. to estimate their potentialities in controlling whitefly on tomatoes in greenhouses with a low temperature regime. Z. ang. Ent. 91, 327-348.

Vianen, A. van & Lenteren, J.C. van (1982). Increasing the number of ovarioles of Encarsia formosa - a possibility to improve the parasite for biological control of the greenhouse whitefly, Trialeurodes vaporariorum. Proc. Int. Symp. on Crop Protection, Med. Fac. Landbouww. Rijksuniv. Gent 47 (in press).

Woets, J., Ramakers, P.M.J. & Lenteren, J.C. van (1980). Progress report on development and application of integrated pest control in glasshouses in the Netherlands with an indication about limiting factors. Bull. OILB/SROP 1980, III/3, 247-257.

PRELIMINARY ANALYSIS LIFE TABLE FOR GREENHOUSE WHITEFLY (TRIALEURODES VAPORARIORUM WESTWOOD)

Li Tzu-Yin & Li zhau-Hwa

Our experiments proceeded in two greenhouses in Beijing, kept warm in winter. The greenhouses faced south, 12 bays, each about 12 meter square, grew mainly cucumber. One bay of the eastern house, enclosed with plastic film, was used as a control without spraying insecticides. After singling the cucumber seedlings, the density in each bay was 80 plants. During the investigation, the area was sprayed with a mixture of fungicides (400 X) and Rogor (1000 X) every two weeks.

The cucumber grew in pots, in a nylon cage, into which female and male whiteflies were introduced. They laid eggs for two days and when the eggs changed from green to black, the cages were removed.

Development was observed daily with a stereomicroscope until emergence.

Results

Causes of death in different stages

1. Egg stage: None died though a few were sterile.
2. 1st-3rd nymph: Mortality was highest in these stages of the life history (Table 1).
3. Pseudo-pupa: Mortality of this stage was lower than the nymphs (Table 2).
4. Adult: The emergence rate of the whiteflies on the first and second cucumber crops (1979-1981) was higher where no pesticide was used and was higher in the first crop than the second (Table 3).
   i. Sex Ratio: A random sample in Bei-Jing (Table 4).
   ii. Oviposition: Fecundity of the female depends on temperature, humidity, nourishment and rearing either in groups or singly. Our experiments were carried out in the greenhouses. On first crop females each laid 39 eggs; on the second 54.

Table 1: Mortality of nymphs

Treatment	Number of nymphs	Number dead	Mortality (%)	
Without pesticide	76	20	26.3	36.8
		8	10.52	
Treated with pesticide	283	113	39.92	43.1
		26	9.18	
Treated with pesticide	31	27	87.09	87.09
		0	0	

Table 2: The mortality of the pseudo-pupa

Treatment	Number of nymphs	Number dead	Mortality (%)	
Without pesticide	59	11	18.6	26
		3	5.08	
		1	1.6	
Treated with pesticide	137	29		21.16
Treated with pesticide	4	0		0

Table 3: Emergence of whiteflies on the first and second crops of cucumber in the year 1979-1981

Different crops	Treatment	No. of eggs	Numbers emerged	Emergence rate
First crop (in winter of 1979 and 1980)	Control	39	26	66.66
	Treated with pesticide	185	77	41.62
Second crop (in spring of 1980 and 1981)	Control	37	18	48.64
	Treated with pesticide	129	35	27.13

Table 4: The sex ratio of whiteflies

Collecting time	Collecting site	No. of females	No. of males	Sex ratio
9.3.80	Si-Ji-Quing People's Commune, Bei-jing	371	136	63.35
14.3.81	"	1216	143	88.24
3.4.80	"	384	177	53.91
4.4.80	"	46	9	80.44
17.3.81	Dong-Sheng People's Commune, Bei-jing	147	75	66.21
6.4.81	"	314	210	59.92
Total		2478	750	68.67

iii. The life span of the adult: The female averages 41 days, and the male 28 days.

Life Tables

Table 5: The life table of whiteflies (without pesticide, potted cucumber)

12.12.80–26.2.81

Development stage (x)	No. of living insects (Lx)	Mortality factor (dxf)	Numbers dead (dx)	Mortality rate (100 qx)	Survivor rate (Sx)
Egg stage	39		0	0	1.0000
1st Instar	39	Shrunk	1	2.57	
		Lost	2	5.12	
			3	7.69	0.9231
2nd Instar	36	Shrunk	1	2.77	
		Mechanical damage	1	2.77	
			2	5.55	0.9445
3rd Instar	34	Shrunk	3	8.82	
Pseudo-pupa	31	Shrunk	5	16.13	0.8387
Adult	26 (♀14; ♂12)				
Generation			13	33.33	0.6667

The eggs in next Generation: 14 x 39 = 546

Population increase index: 546/39 = 14

Average temperature: 13.23°C

Average humidity: 83.67%

Table 6: The life table of whiteflies (without pesticide, potted cucumber)

8.3.80–13.4.80

Development stage (x)	No. of living insects (Lx)	Mortality factor (dxf)	Numbers dead (dx)	Mortality rate (100 qx)	Survivor rate (Sx)
Egg stage	37		0	0	1.0000
1st Instar	37	Shrunk	1	2.7	
		Lost	1	2.7	
			2	5.4	0.9460
2nd Instar	35	Shrunk	2	5.71	
		Lost	1	2.85	
			3	8.56	0.9144
3rd Instar	32	Shrunk	3	9.37	
		Lost	1	3.12	
			4	12.49	0.8571
Pseudo-pupa	28	Shrunk	6	21.42	
		Lost	1	3.57	
		Send up one buble	3	10.71	
			10	35.78	0.6430
Adult	18 (♀12; ♂6)				
Generation			19	51.36	0.4864

The eggs of next Generation: 12 x 39 = 468

Population increase index: 468/37 = 12.7

Average temperature: 17.81°C

Average humidity: 83.67%

Table 7: The life table of whiteflies (pesticide, potted cucumber)

Development stage (x)	No. of living insects (Lx)	Mortality factor (dxf)	Numbers dead (dx)	Mortality rate (100 qx)	Survivor rate (Sx)
Egg stage	90		0	0	1.0000
1st Instar	90	Shrunk	1	1.11	
		Lost	4	4.44	
			5	5.55	0.9445
2nd Instar	85	Shrunk	12	14.11	
		Lost	2	2.34	
			14	16.45	0.8352
3rd Instar	71	Shrunk	12	16.9	
		Lost	1	1.4	
			13	18.36	0.8170
Pseudo-pupa	58	Shrunk	11	18.96	0.8104
Adult	47 (♀30; ♂17)				
Generation			43	47.78	0.5222

The eggs of next Generation: 30 x 39 = 1170

Population increase index: 1170/90 = 13

Average temperature: 15.5°C

Average humidity: 71.1%

Table 8: The life table of whiteflies (pesticide, potted cucumber)

8.3.80–15.4.80

Development stage (x)	No. of living insects (Lx)	Mortality factor (dxf)	Numbers dead (dx)	Mortality rate (100 qx)	Survivor rate (Sx)
Egg stage	98		0	0	1.0000
1st Instar	98	Shrunk	5	5.1	
		Lost	1	1.02	
			6	6.12	0.9380
2nd Instar	92	Shrunk	23	25.0	
		Lost	6	6.52	
			29	31.52	0.6848
3rd Instar	63	Shrunk	12	19.04	
		Lost	3	4.76	
			15	23.8	0.7620
Pseudo-pupa	48	Shrunk	17	35.41	0.6459
Adult	31 (♀18; ♂ 11)				
Generation			67	68.37	0.3163

The eggs of next Generation: 18 x 39 = 702

Population increase index: 702/98 = 7.2

Average temperature: 23.48°C

Average humidity: 74.06%

Table 9: The life table of whiteflies (pesticide applied to soil)

12.12.80-26.1.81

Development stage (x)	No. of living insects (Lx)	Mortality factor (dxf)	Numbers dead (dx)	Mortality rate (100 qx)	Survivor rate (Sx)
Egg stage	95		0	0	1.0000
1st Instar	95		0	0	1.0000
2nd Instar	95	Shrunk	12	12.63	
		Lost	7	7.36	
		Mouldy	5	2.26	
			24	22.25	0.7475
3rd Instar	71	Shrunk	36	50.7	
		Lost	3	4.22	
		Mouldy	1	1.4	
			40	56.32	0.4368
Pseudo-pupa	31	Shrunk	1	3.22	0.9678
Adult	30 (♀21: ♂9)				
Generation			64	67.36	0.3264

The eggs of next Generation: 21 x 39 = 819

Population increase index: 819/95 = 8.62

Average temperature: 13.72°C

Average humidity: 87.02%

Table 10: The life table of whiteflies (without pesticide, potted cucumber)

1.2.81–19.3.81

Development stage (x)	No. of living insects (Lx)	Mortality factor (dxf)	Numbers dead (dx)	Mortality rate (100 qx)	Survivor rate (Sx)
Egg stage	31		0	0	1.0000
1st Instar	31	Shrunk	3	9.67	0.9033
2nd Instar	28	Shrunk	21	75	
		Mouldy	1	3.5	
			22	78.5	0.2150
3rd Instar	6	Shrunk	2	33.3	0.7297
Pseudo-pupa	4		0	0	1.0000
Adult	4 (♀2; ♂2)				
Generation			27	87.09	0.1291

The eggs of next Generation: 2 x 39 = 78

Population increase index: 78/31 = 2.5

Average temperature: 16.1°C

Average humidity: 80.8%

The above six life tables can be plotted according to the k-value ($k = \log N - \log S$) of each generation.

The mortality of the egg stage is zero, death mainly occurring in the 2nd-3rd instar and pseudo-pupa. From the K curve we can see that the k-value in winter (1st, 2nd and 5th generation) is lower than in the spring (3rd, 4th and 6th generation). Using k-value against K gave the following regression coefficients.

$k_0 = 0$
$k_1 = 0.2563$
$k_2 = 0.9431$
$k_3 = 0.4659$
$k_4 = 0.4659$

Plotting the survivor rate of each instar (Table 5-10) (Fig. 1) survival for each generation was 66.67%, 48.64%, 52.22%, 31.63%, 32.64% and 12.71% respectively. Even though the survival of the last generation was 12.71%, because of their high fecundity, the rate of increase in the next generation was still 2.59 times higher than the first generation.

If we compare in the average death rate with the control in the 6 life tables (Fig. 2) we see that the mortality of the 1st and 2nd instars in the control bay was higher while the mortality of the 3rd instar was highest with insecticidal control. In the pseudo-pupa both were similar. This was an abnormal phenomena because the plants were more heavily infected with powdery mildew in the control than in the insecticidal house.

Discussion

From the analysis of the above six life tables the mortality of the egg even when treated by insecticide was zero, this related to the kinds of insecticide used and the effectiveness of spray cover. This problem merits attention, because this greenhouse was a typical one in our municipality (Bei-jing).

Death occurred mainly in the 1st and 2nd instar stage and a few in the pseudo-pupa stage. The death of insect was due to shrinkage of the nymph and pseudo-pupa, caused by withering of the cucumber leaves caused either by powdery mildew disease (Sphaerotheca fuligenea (Schl.) (Poll) or aphid injury; to natural death even without infection with

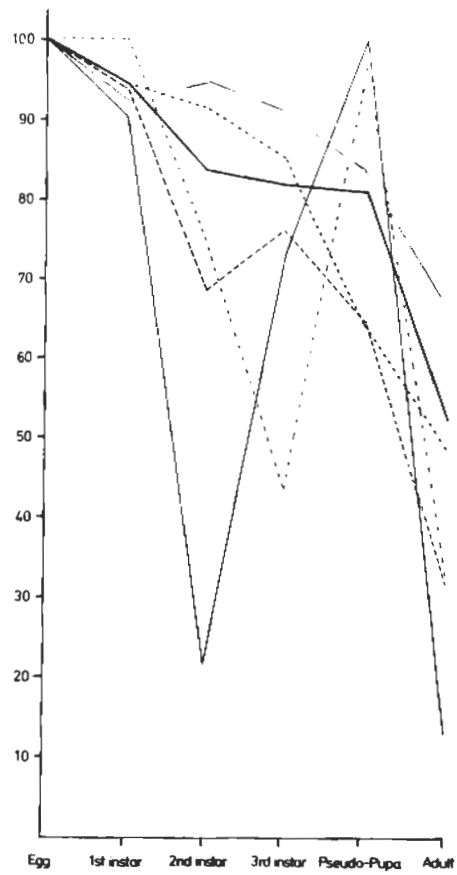


Figure 1: The survivor curves of six generations of whitefly (from Tables 5-10)

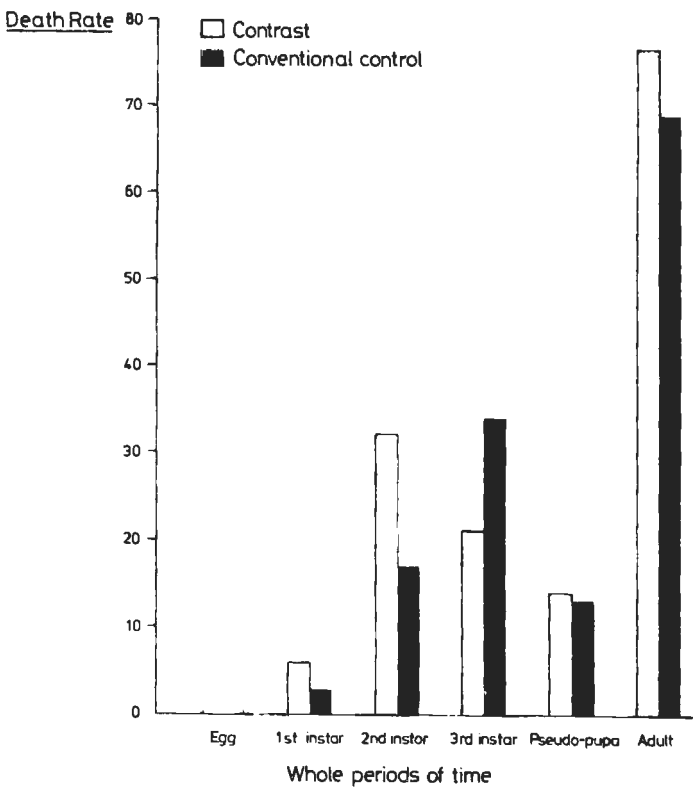


Figure 2: Comparison of mortality in control and conventional pesticide treatments

powdery mildew disease; to death by insecticide.

Because of insecticide spraying in successive years the fauna of this closed habitat was simple. No predators except a few spiders were found. No parasitism was observed.

References

Harcourt, D.G. (1969). The development and use of life tables in the study of natural insect. Ann. Rev. Ent. 14, 175-196.

Hiroshi Kajita (1979). Survival rate of the greenhouse whitefly Trialeurodes vaporariorum (Westwood) in the field and its domestic natural enemies. Sci. Bull. Fac. Agr., Kyushu Univ.

Raymond, P. & Sylvia, L.P. (1921). Experimental studies on the duration of life. The American Naturalist LV, Nov.-Dec. (641), 481-509.

Richards, O.W. (1961). The theoretical and practical study of natural insect populations. Ann. Rev. Ent. 6, 147-162.

Southwood, T.R.E. & Reader, P.M.(1976). Population census data and key factor analysis for the viburnum whitefly, Aleurotrachelus jelinekii (Frauenf.) on three bushes. J. Anim. Ecol. 45, 313-325.

Varley, G.C. & Gradwell, G.R. (1960). Key factors in population studies. J. Anim. Ecol. 29, 339-401.

Varley, G.C. & Gradwell, G.R. (1970). Recent advance in insect population dynamics. Ann. Rev. Ent. 15, 1-24.

COLD-HARDINESS IN EGGS OF GREENHOUSE WHITEFLY (TRIALEURODES VAPORARIORUM)

C. Stenseth

The greenhouse whitefly (Trialeurodes vaporariorum) has no special stage adapted for hibernation. Survival is dependent on suitable host plants all throughout the year. It is known that the larval stages are less cold-resistant than adults and eggs (Lloyd, 1922).

This paper describes laboratory experiments set up to test the cold-hardiness of the eggs.

Materials and Methods

A stock colony of greenhouse whitefly was kept on dwarf beans (Phaseolus vulgaris), 'Saxona'. Adult whiteflies from the stock colony were transferred to strawberry plants (Fragaria x cultorum), 'Senga Sengana', for oviposition for 24 hours. The eggs were then acclimatized at 1° to 3°C for 24 hours before they were subjected to the temperatures +6°, 0°, -3° and -6°C. After different exposure times at these temperatures, the strawberry leaflets were taken out for observation of egg hatching at 21°-23°C. For egg hatching the leaflets were placed on cotton wool floating in a waterbath, and the larvae counted daily.

In the region of lethal exposure time (LT) 3 replicates of 100 to 300 eggs were used for each exposure time. The percentages of dead eggs were plotted on a probit scale against the exposure time for the different temperatures.

Results

The percentages of dead eggs after different temperature-exposure times are shown in Figure 1.

Storage at -6°C resulted in a LT_{99} of 3.5 days and all eggs were dead after 6 days at this temperature. At -3°C and 0°C the LT_{99} were 12 and 14 days respectively, but these differences were not significant. At -3°C and 0°C all eggs were dead after 16 days.

The maximum exposure time at +6°C was 20 days which gave an average of 40% dead eggs.

Discussion

As eggs and adults of greenhouse whitefly are more cold-resistant than the larval stages (Lloyd, 1922) the egg stage will give the threshold for survival of the species at low temperatures. The eggs are very sensitive at -6°C. Only six days at this temperature eradicated them, but the survival time at 0°C is also rather limited.

The hatching pattern after exposure at +6°C indicates a prolonged survival at this temperature, and the mortality curve seems to be of sigmoid type in spite of the probit scale.

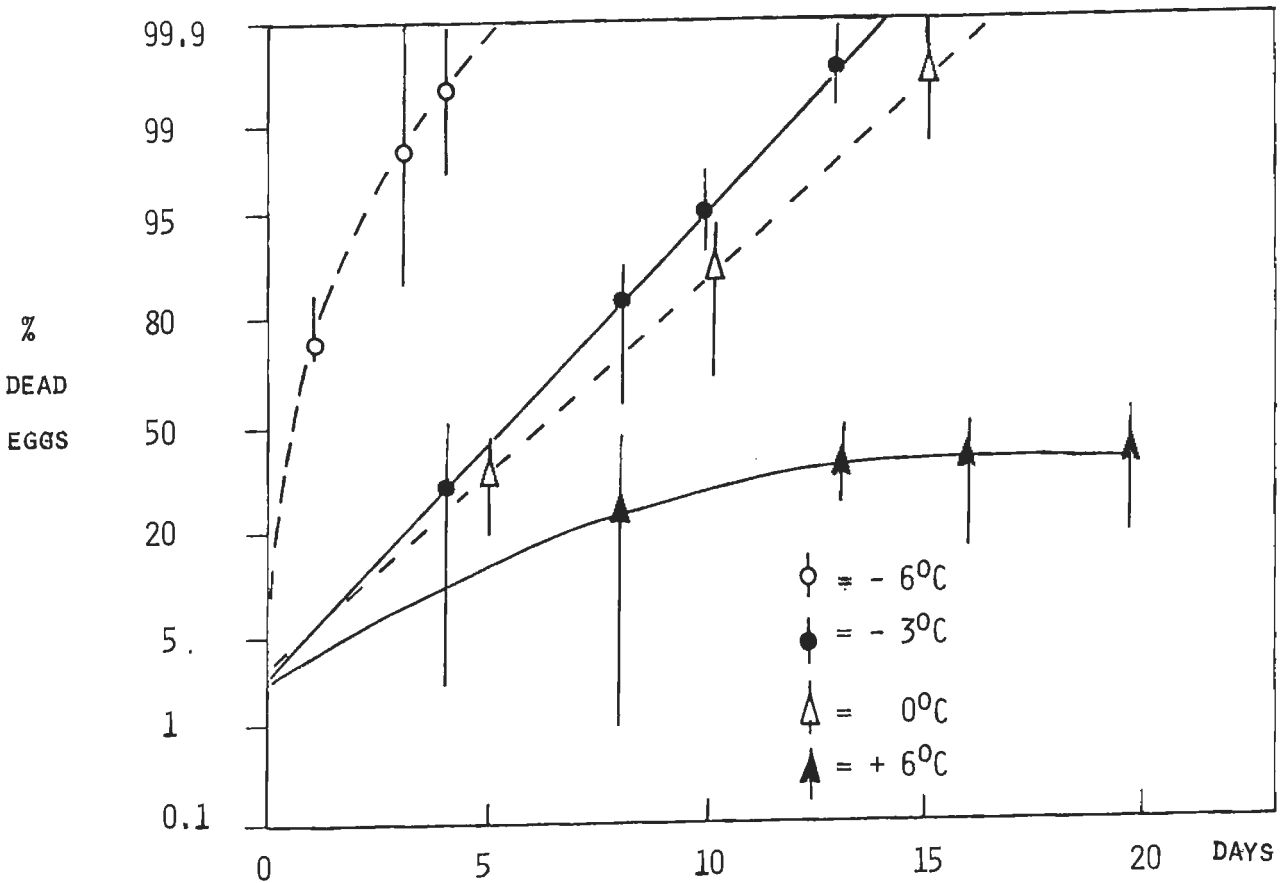


Figure 1: Percent dead eggs of Trialeurodes vaporariorum exposed to low temperatures in different time. Vertical bars represent the range.

SEXUAL PHEROMONE IN THE GREENHOUSE WHITEFLY TRIALEURODES VAPORARIORUM WESTW.

Tzu Yin Li & Ulrich Maschwitz

Introduction

The whitefly T. vaporariorum is found in vegetable gardens and greenhouses all over the world. Though a serious pest, its biology is not yet fully understood. Little is known about the signals releasing and co-ordinating sexual behaviour (Las, Allan, 1979), which may be important keys for control of these insects. In analysing the sexual behaviour of T. vaporariorum, we investigated whether the whiteflies possess sexual pheromones.

Materials and Methods

The whiteflies were cultivated on tobacco, string bean and tomato. For the tests the insects were anaesthetized with CO_2 and according to their sex put with forceps into chambers. After an hour records began.

According to the experimental requirements we used several types of cages. They were constructed out of hard transparent plastics, the compartments of which were separated by single or double white nylon nets. In these cages, the animals could be observed under the binocular.

The following types of cages were used:

1. Single chamber cage (Fig. C): For observing the direct contact of whiteflies with each other or extracts.

2. Three chamber cage (Fig. A): Fig. A shows the three chamber cage mostly used for our tests. In the central chamber we put different numbers of males, mostly ten, in the side chambers female, male, or different extracts were placed or left empty for control. In the experiments we counted every 20 seconds over 20 minutes the number of males on each side of the central chamber respectively. We checked their resting time on the nets. To avoid side effects we turned the chambers several times during the experiment. Similar to this type of cage we tried a larger central chamber which had two smaller side chambers also separated by net (Fig. D), the results were the same as in the normal three chamber system.

3. Five chamber cage (Fig. B). To increase the pheromone gradient we used five chambers arranged in the same way as the three chambers. Animal and extracts were placed respectively in the central chamber and in chambers one and five.

Pheromone extraction

For pheromone extraction we used propanol -(2), n-pentan and dichlormethan. Extracts were left in the empty glass bottles in which 100-400 females had been kept for more than one hour or washed females or crushed females. For thin layer cromatography silicagel with n-Hexan was used as solvent. For statistical analysis we used the chiquadrat-test.

Results

To eluciate whether pheromones play a role in the sexual behaviour of the whitefly, we first observed thoroughly the search of the sexual partner, their courtship behaviour and copulation. We recognized that males normally actively search for the females by running over the underside of the leaves, when he encounters a female he circles and contacts the female with his fore legs and antennae, sometimes he tries to lift her wings to reveal the end of her abdomen with his fore legs or flapping his wings, or dives his head beneath her wings.

To find a test reaction for a pheromone we checked whether males are attracted by females without having direct mechanical contact. Ten males were placed in the central chamber of the three chamber cage, which was separated from the side chambers by double layer of the nylon net. At one side ten females were placed, at the other ten males. The males in the central chamber moved or rested on the side chamber nets and were counted. The experiments were conducted at day light and under dark red light to exclude every possibility of optical orientation.

Table 1 shows that the males are attracted by the female. If we placed ten males one side of the central chamber, "0" female on the other side, no attraction could be observed.

As an attractant, the females have an arresting effect on males. The males were resting longer at the female side than at control side of that of the males (Table 2).

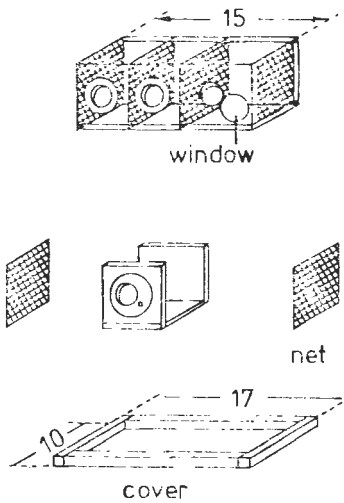


Figure A: Three chamber cage (measurements in mm)

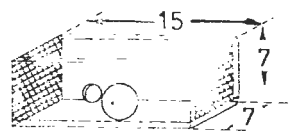


Figure C: One chamber cage

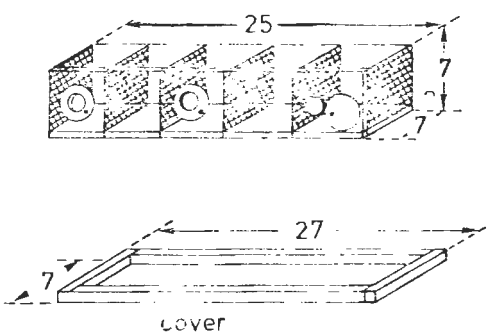


Figure B: Five chamber cage

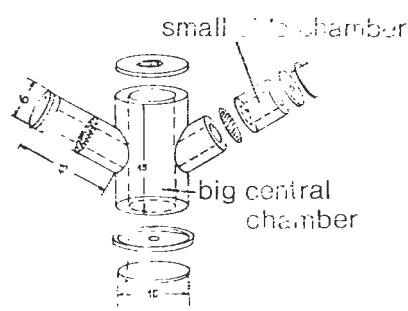


Figure D: Two arm cage

Table 1

Experiment	No. of times	Light	Position of males & females in the cage			No. of males on both sides of the central chamber		Chi quadrate test
			♀	♂	♂	♀ side	♂ side	
1	20	Day light	0	10	10	1930	1918	$x^2 = 28.694 < x^2_{0.01}$ 36.19 Not significant
2	31	Day light	10	10	10	2813	1978	$x^2 = 369.35 > x^2_{0.01}$ 50.89 Significant, twice reversed
3	12	Dark red light	10	10	10	753	539	$x^2 = 60.87 > x^2_{0.01}$ 24.72 Significant, once reversed

Table 2

Experiment	Position & no. of ♀ & ♂ in the cage			Counting time (min.)	Number of males resting more than 1 min. on each side of the central chamber	
	♀	♂	♂		♀ side	♂ side
1	10	10	10	80	18	1
2	10	10	10	30	8	3
3	10	10	10	90	20	1
4	10	10	10	60	14	2
5	10	10	10	90	19	9
6	10	10	10	60	8	2

This means that the females of T. vaporariorum, therefore, possess a chemical which attracts and arrests males.

1. Number of females attracted to males in the three chamber bioassay:

Table 3 shows that 1 female in the side chamber does not significantly attract the males in the central chamber. However, 10 (Table 1), 20, 30 and 50 females do so. 100 females curiously were not so significant in the three chamber cage. In the five chamber cage the attractive effect of 100 females is, however, clearly significant.

Table 3

Experiment	No. of times	Position of males & females in the cage			No. of males on both sides of the central chamber		Chi quadrate test
		♀	♂	♂	♀ side	♂ side	
1	10	1	10	10	1454	1337	$x^2 = 19.8 > x^2_{0.01}$ 21.67 Not significant, twice reversed
2	10	20	10	10	1643	1239	$x^2 = 153.137 > x^2_{0.01}$ 21.67 Significant, twice reversed
3	10	30	10	10	1534	1380	$x^2 = 154 > x^2_{0.01}$ 21.67 Significant, once reversed
4	10	50	10	10	2543	1579	$x^2 = 403.436 > x^2_{0.01}$ 21.67 Significant
5	16	100	10	10	1429	1245	$x^2 = 40.5395 > x^2_{0.01}$ 30.58 Significant
6	28	100	10	10	3656	2385	$x^2 = 561.89 > x^2_{0.01}$ 46.96 Significant, four times reversed

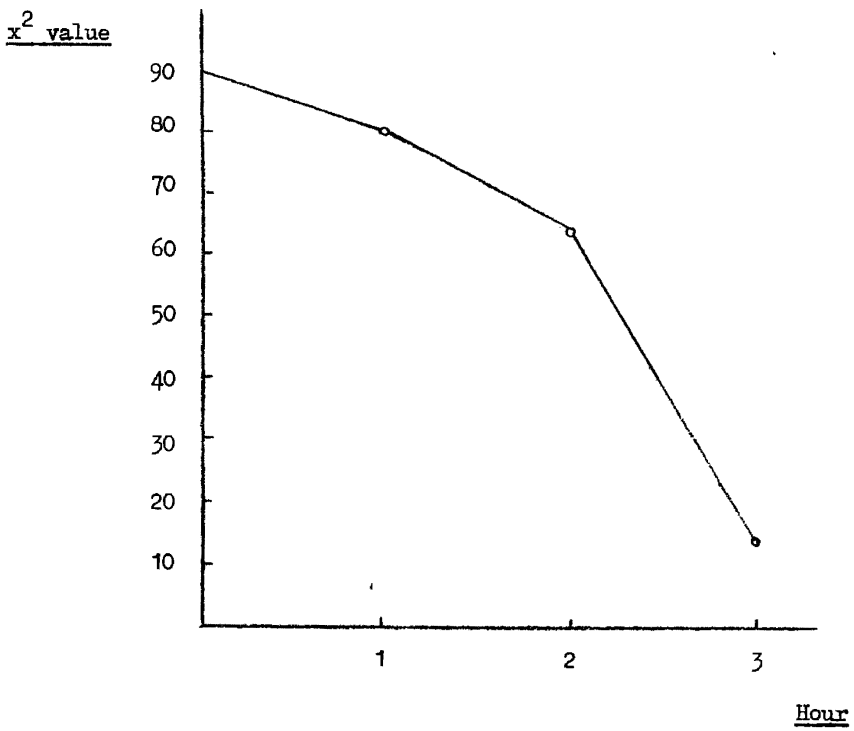


Figure E: The volatility of sex pheromone gradually decreases as time goes on

Apparently in the three chamber arrangement the pheromone is not large enough to be clearly recognized.

2. Persistence of the pheromone:

When we put 100 females in the five chamber cage and delivered them after one hour, the empty cage remained attractive. This attractiveness was still clearly significant after two hours. After three hours significant attraction could no longer be demonstrated.

Table 4

Experiment	No. of times	Position of males & females in the cage ♀	♂	♂	After delivery of females	No. of males on both sides of the central chamber ♀ side	♂ side	Chi quadrate test
1	10	100	10	10	1 hour after	1145	846	$x^2 = 82.539 > x^2_{0.01}$ 23.01 Significant
2	4	100	10	10	2 hours after	519	344	$x^2 = 65.47 > x^2_{0.01}$ 13.28 Significant
3	4	100	10	10	3 hours after	357	293	$x^2 = 13.43 > x^2_{0.01}$ 13.28 Significant

Means the adult had been delivered

3. Having found that the pheromone remained in the test chamber after removal of the females, we tested the solubility of this substance in two solvents of different polarity, n-pentan and propanol. 200-300 living females were put in a glass tube for 1 hour before washing the tube with 0.5 ml solvent. The solvent was evaporated on a small piece of filter paper which was tested in the 3 chamber cage. As Table 5 shows with the unpolar n-pentan and with the mixture of n-pentan and propanol the pheromone was extracted and transferred to the test cage. This was not possible with the polar solvent.

Table 5

Experiment	Chemicals	No. of females	Counting time (min.)	Counting interval (sec.)	Position & no. of males & females			No. of males on both sides of central chamber		Chi quadrate test
					E	♂	C	E-side	C-side	
1	½ propanol + ½ pentan	200	17	15	E	10	C	827	654	$x^2 = 53.54 > x^2_{0.01}$ 15.08 Significant, once reversed
2	½ propanol + ½ pentan	300	17	15	E	10	C	1371	892	$x^2 = 144.1 > x^2_{0.01}$ 21.67
3	Propanol	200	17	15	E	10	C	1351	1295	$x^2 = 15.4 > x^2_{0.01}$ 26.22 Not significant
4	Pentan	200	17	15	E	10	C	4895	3083	$x^2 = 873.1 > x^2_{0.01}$ 54.7 Significant

E = Extraction

C = Control

According to these experiments the pheromone is a nonpolar substance. This result could further be proved by thin layer chromatography. For this Hexan was used as solvent on a silica gel plate. From the upper part of the chromatogram we could again extract a pheromone activity with pentan, while the lower part did not show any attractive effect to males (Table 6).

Table 6

Position of the TLC aluminium sheets	Silica gel with extract in bottle where 400 adults were released			No. of males on both sides of central chamber		Chi quadrate test
	E	♂	C	E-side	C-side	
Lower part	E	10	C	426	451	$x^2 = -18.9753 < x^2_{0.05}$ 11.07 Not significant, reversed
Upper part	E	10	C	2020	1077	$x^2 = 602.01 > x^2_{0.01}$ 21.67 Significant

E = Extract

C = Control

We proceeded also to extract the pheromone from crushed females (Table 7).

4. Further pheromone effects:

Pheromone extracted from the glass tube with pentan was not only attractive for males, but also had an arrestant effect (Table 8).

Table 7

Method	No. of females	Total counting time (min)	Counting interval (sec)	Position of ♂ in cage			No. of ♂ on both sides of central chamber		Chi quadrate test
				Cru	♂	C	Cru side	C side	
Crush	100	17	15	Cru	10	C	823	650	$x^2 = 75.8 > x^2_{0.01}$ 18.47 Significant, twice reversed
Crush	150	17	15	Cru	10	C	455	319	$x^2 = 62.5 > x^2_{0.01}$ 11.35 Significant
Crush	200	17	15	Cru	10	C	612	519	$x^2 = 22.8 > x^2_{0.01}$ 15.09 Significant, twice reversed

Cru = crush

C = control

Table 8

Experiment	Cage arrangement			Total counting time (min)	No. of males resting on both sides of central chamber more than one minute	
	E	♂	C		E side	C side
1	E	10	C	74' 68"	14	4
2	E	10	C	70' 7"	14	4

E = extracted by pentan from the bottle where 200 were released

C = control

Males afforded direct contact with filter paper extract increased behavioural elements of the courtship behaviour such as wing flapping and antennae grooming (Table 9).

Table 9

Experiment	No. of males	Counting time (min.)	Sexual display	Frequency E	Frequency C
1	5	130	Wing flapping	139	95
2	5	60	Antennae grooming	21	11

E = extracted by pentan from the bottle where 200 were released
C = control

Discussion

Life habits of the Aleyrodidae are in several ways quite different from those of other Homoptera (Alexandrakis, 1980; Babayan & Oganesyan, 1979; Meyerdirk & Newell, 1979; Rice & Jones, 1977). Especially conspicuous is their strong flight ability during which they orientate themselves optically. Possibly their bright white colour is a signal which may play an important role in mating behaviour. This may explain why the reactions of the males to the female pheromone in our experimental cages were never dominant. The males flew around in their chamber apparently orientating optically before sitting or resting on the female chamber nets. Nevertheless the attractant and arrestant effects of the pheromone could be clearly demonstrated. The pheromone also plays an important role in species identification. We could not find any olfactional reaction between males in our experiments, whether males release odours, which are important for the behaviour of the females, we do not know.

Solubility and volatility properties of the pheromone suggest that it is an unpolar substance without very high molecular weight which is active in about 5-10 mm range (Eisenbach & Mittler, 1980).

Summary

A female pheromone was discovered in Trialeurodes vaporariorum Westw. It attracted males over a distance of 5 to 10 mm in experiment cages. Additionally, the pheromone released a resting behaviour in the males. Males were not attracted by other males. The pheromone could be extracted with unpolar solvent both from empty glass tubes which had been inhabited by females for some time or from crushed females. Thin layer chromatography of the isolated pheromone confirmed the unpolar properties.

Acknowledgements

We thank Dr Laurence A Mound and David Hollis at the British Museum (Natural History) in London for identifying our specimen of whitefly which was collected in Frankfurt/M. We are also grateful to Mr Walzer and Scherer for their helpful assistance in making our experimental cage, Mr Wagner and Spieler for supplying us with seedlings from the Botanical Garden of our department, Mr Grommet in drafting and Miss Nesselhauf in typing and other technical help.

References

Alexandrakis, V. (1980). Bio ecological data on Pollina-Pollini Homoptera Coccoidae Asterolecanidae on Olive trees in Crete, Greece. Ann. Soc. Entomol. Fr. 16 (1), 9-18.

Anderson, R.J. & Henrick, C.A. (1979). Synthesis of (E)-3,9-Dimethyl-6-isopropyl-5,8-Decadien-1-Yl Acetate. The sex pheromone of the yellow scale. J. Chem. Ecol. 5 (5), 773-779.

Anderson, R.J., Chinn, H.R., Gill, K. & Henrick, C.A. (1979). Synthesis of 7-methyl-3-methylene-7-octen-1-Yl Propanoate and (z)-3,7-Dimethyl-2,7-octadien-1-Yl Propanoate, components of the sex pheromone of the San Jose scale. J. Chem. Ecol. 5 (6), 919-928.

Anderson, R.J., Adams, K.G., Chinn, H.R. & Henrick, C.A. (1980). Synthesis of the optical isomers of 3-Methyl-6-isopropenyl-9-decen-1-yl Acetate, a component of the California red scale pheromone. J. Org. Chem. 45 (11), 2229-2236.

Askari, A. & Alishah, A. (1979). Courtship behaviour and evidence for a sex pheromone in Diaeretiella rapae (Hymenoptera: Braconidae), the cabbage aphid primary parasitoid. Ann. Ent. Soc. Amer. 72 (6), 749-750.

Assem, van den J. (1975). Temporal patterning of courtship behaviour in some parasitic Hymenoptera, with special reference to Melittobia acasta. J. Ent. (A), 50 (3), 137-146.

Babayan, G.A. & Oganesyan, S.B. (1979). New data on the bio ecology of the Armenian scale Lepidosaphes malicola Diaspididae in the Armenian-SSR USSR. Biol. ZH. Arm. 32 (3), 187-193.

Bierl-Leonhardt, B.A., Moreno, D.S., Schwarz, Mayer, Forster, H.S., Plimmer, J.R. & Devilbiss, E.D. (1980). Identification of the pheromone the comstock mealybug. Life Sci. 27, 399-402.

Cox, C.R. & Boeuf, B.J. (1977). Female incitation of male competition: A mechanism in sexual selection. The American Naturalist III (978), 317-335.

Eisenbach, J. & Mittler, T.E. (1980). An aphid circadian rhythm factors affecting the release of sex pheromone by oviparae of the greenbug Schizaphis graminum. J. Insect Physiol. 26 (8), 511-516.

Heath, R.R., McLaughlin, J.R., Tumlinson, J.H., Ashley, T.R. & Dolittle, R.E. (1979). Identification of the white peach scale sex pheromone. J. Chem. Ecol. 5 (6), 941-953.

Gieselmann, M.J., Moreno, D.S., Fargerlund, J., Tashiro, H. & Roelofs, W.L. (1978). Identification of the sex pheromone of the yellow scale. J. Chem. Ecol. 5 (1), 27-34.

Gieselmann, M.J., Rice, R.E., Jones, R.A. & Roelofs, W.L. (1979). Sex pheromone of the San Jose scale. J. Chem. Ecol. 5 (6), 891-902.

Heath, R.R., Doolittle, R.E., Sonnet, P.E. & Tumlinson, J.H. (1979). Sex pheromone of the white peach scale: highly stereoselective synthesis of the stereo isomers of pentagonol propionate. J. Org. Chem. 45 (14), 2910-2912.

Las, A. (1979). Male courtship persistence in the greenhouse whitefly, Trialeurodes vaporariorum Westwood (Homoptera: Aleyrodidae). Behaviour 72, Parts 1-2, 107-126.

Meyerdirk, D.E. & Newell, I.M. (1979). Seasonal development and flight activity of Pseudococcus comstocki in California USA. Ann. Entomol. Soc. Am. 72 (4), 492-494.

Negishi, T., Uchida, M., Tamaki, Y., Mori, K., Ishiwatari, T., Asano, S. & Nakagawa, K. (1980). Sex pheromone of the Comstock mealybug, Pseudococcus comstocki Kuwana: Isolation and identification. Appl. Ent. Zool. 15 (3), 328-333.

Rice, R.E. & Jones, R.A. (1977). Monitoring flight patterns of male San Jose scale, Homoptera Diaspididae. Can. Entomol. 109 (10), 1403-1404.

Roelofs, W., Gieselmann, M., Carde, A., Tashiro, D.C., Henrick, C.A. & Anderson, R.J. (1977). Identification of the California red scale sex pheromone. J. Chem. Ecol. 4 (2), 211-224.

Roelofs, W.L., Gieselmann, M.J., Carde, A.M., Tashiro, H., Moreno, D.S. Henrick, C.A. & Anderson, R.J. (1977). Sex pheromone of the California red scale, Aonidiella aurantii. Nature 267, 698-699.

Tashiro, H., Gieselmann, M.J. & Roelofs, W.L. (1979). Residual activity of a California red scale synthetic pheromone component. Environ. Entomol. 8 (5), 931-934.

DENSITY EFFECT ON FECUNDITY AND MORTALITY ON GREENHOUSE WHITEFLY POPULATIONS

Xu Ru-mei

Though the role of density in population regulation and its mechanism may vary in different species and a variety of opinions may be concerned, nevertheless, it is certainly one of the most important aspects in population ecology. For the understanding of population dynamics, it is necessary to know whether there is self-regulation in the populations concerned.

In observations on populations of greenhouse whiteflies, there were decreases under high population densities which were not due to spraying. It is worthwhile therefore, to measure the occurrence and intensity of density effect and to incorporate these effects into population models to improve population prediction for pest management (Xu et al., 1981; Zhu et al., 1981).

Density effect on fecundity

Different numbers of pairs of newly emerged adults were kept in clip-on cages and the total number of eggs laid during a five day interval recorded. There was a significant effect of density on fecundity (Fig. 1).

Density effect on mortality

Cohorts of whitefly eggs on bean leaves were observed until they matured to adults. Their position and density were replicated on transparent scale paper. Therefore, the correlation between mortality and population density can be determined. From Fig. 2 it can be seen (i) that the mortality from eggs to the beginning of the 3rd instar nymphs is density-dependent, (ii) that from the beginning of the 3rd instar to emergence of adults is strongly density-dependent ($P < 0.01$) and that (iii) the generation mortality, as a combination of both, is density-dependent but of a lesser intensity ($P < 0.05$). As mortality is affected not only by the population density but also by the spatial distribution of the scales, it is more reasonable to use mean crowding (M^*) as the independent variable. Methods from various authors for detecting density effect were tested and compared, and the results are qualitatively similar (Xu, in prep.).

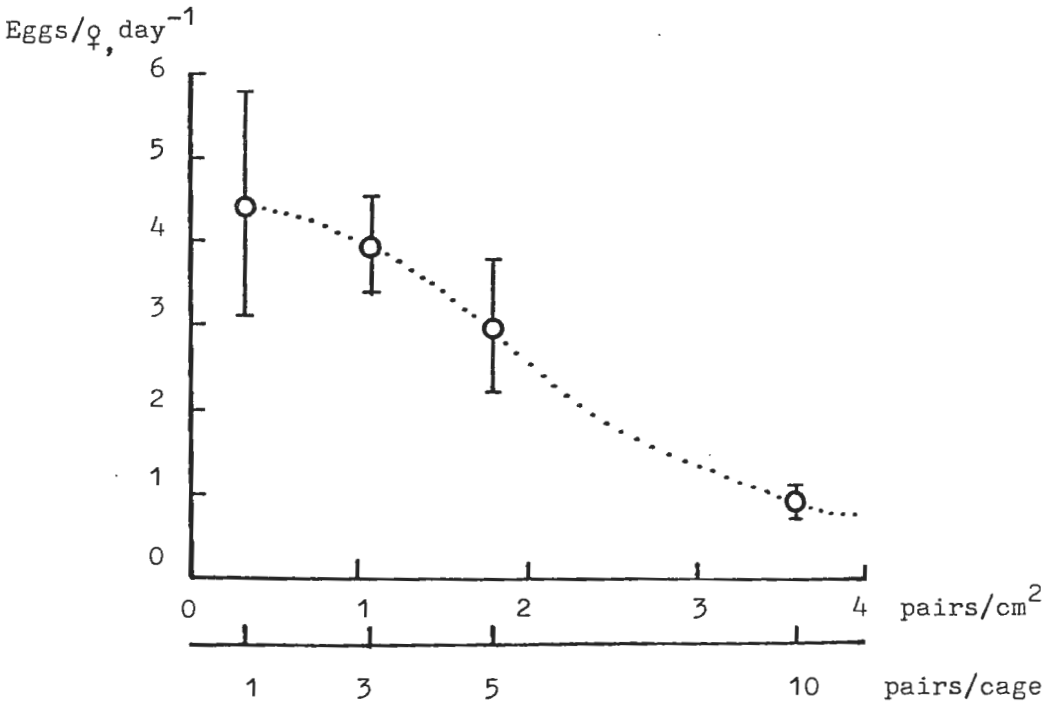


Figure 1

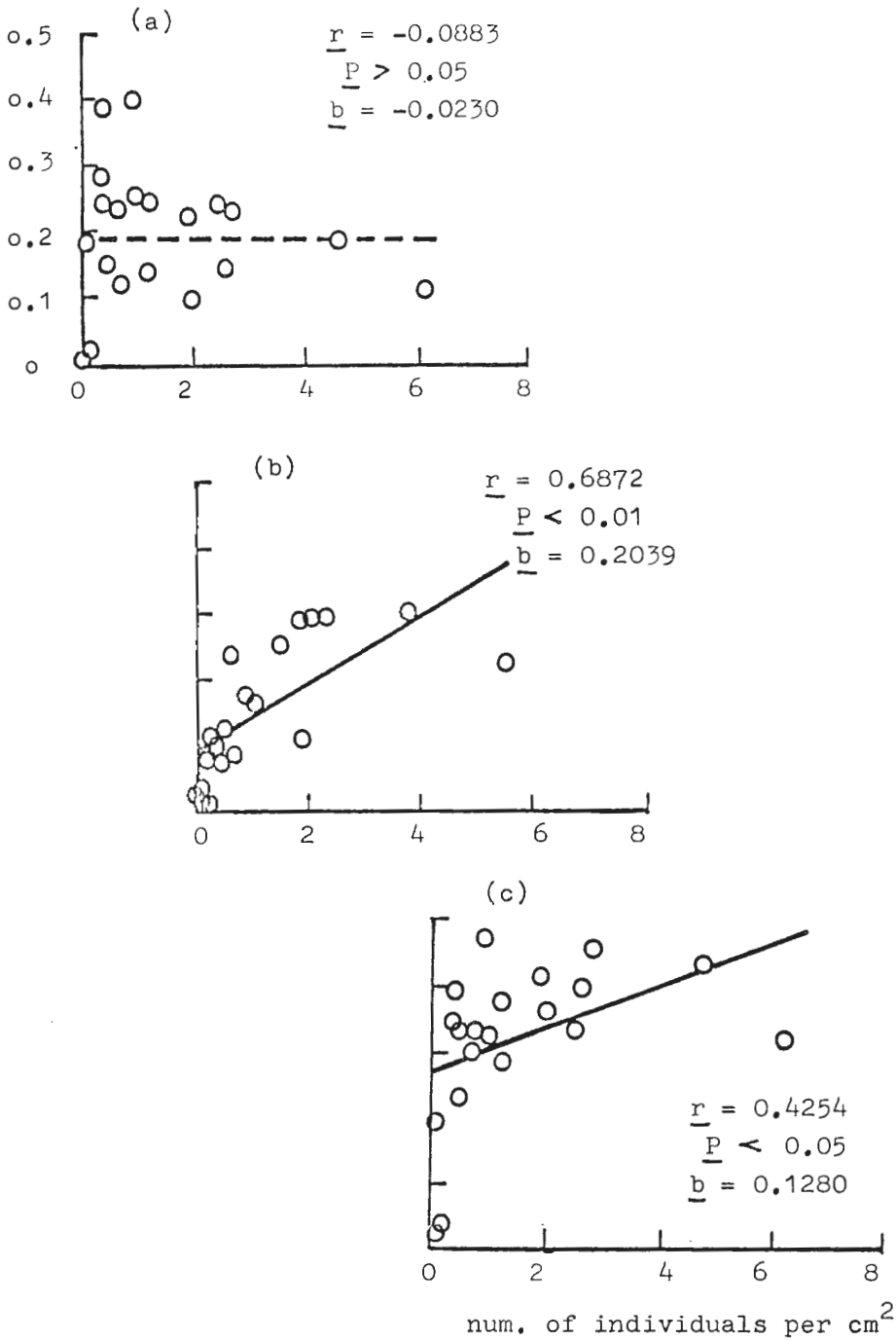

MORTALITY
(a)
r = -0.0883
P > 0.05
b = -0.0230
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
(b)
r = 0.6872
P < 0.01
b = 0.2039
0
2
4
6
8
(c)
r = 0.4254
P < 0.05
b = 0.1280
0
2
4
6
8
num. of individuals per cm2

Figure 2

The density of eggs in this experiment ranged from 0.08 to 6.2 eggs per cm^2 as normally in nature. But, as under some conditions the density of eggs may be higher, complementary experiments were made. Artificial infestations of whiteflies were made to obtain much higher densities of eggs in the range 1.79 to 26.42 eggs per cm^2, where density dependent mortality is detected. Both experiments are combined in Fig. 3.

As older whitefly nymphs are sedentary, the fate of almost all individuals could be traced. Therefore, the mortality in quadrats with different numbers of whiteflies could be calculated and the density dependency of the mortality from 3rd instar nymphs to adult emergence could be detected (Table 1). It is evident that the mortality increases with density. This result is consistent with that shown in Fig. 2b.

Table 1: Detection of density dependent mortality in the late nymphal stages of greenhouse whiteflies

Density (no./quadrat)	1	2	3	4-5
N (no. of quadrats)	292	122	48	22
No. of individuals	292	244	144	94
No. of deaths	63	85	60	42
Mortality rate (%)	21.6	34.8	41.7	44.7

Test of inter-dependency of deaths

The mechanism of self-regulation in animal populations has not been extensively approached and that in whitefly populations is unknown. But, from present knowledge, especially from aphids and other fluid or blood sucking arthropods, some possible mechanisms are worth considering.

The increase in mortality of mosquito larvae may be induced by toxic chemicals secreted by crowded larvae (Ikeshoji et al., 1977), injection of salivary substances by aphid nymphs into the host leaf or tactile stimulation of the adults (Kidd, 1977), or other varieties of ecomones (Ikeshoji, 1977). The density dependent mortality of ticks may be caused by the increase of host cattle resistance after exposure to the parasite (Sutherst et al., 1979). The presence of dead material significantly depressed larval survival in Drosophila (Polivanov et al., 1980). There

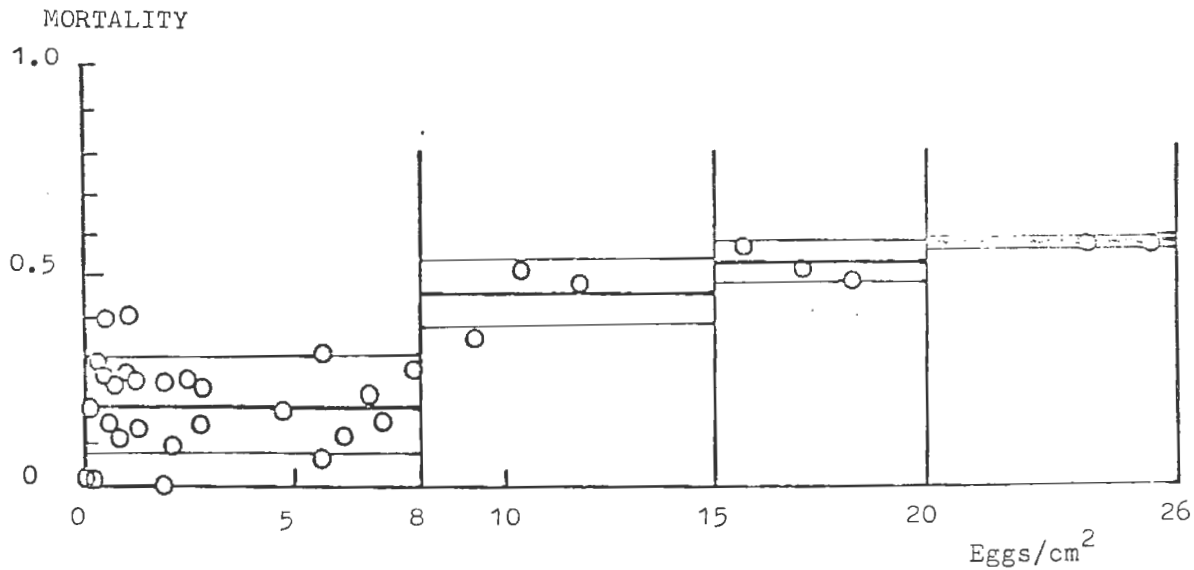


Figure 3

may of course, be other processes involved but, as a first step, it may be useful merely to test whether density dependent mortality is induced by chemicals originated from living (secreted materials) or from dead scales (dead materials).

If the mechanism is concerned with dead scales, then, not only will the mortality be higher in quadrats where living scales had been more crowded, but also the death of a scale in a certain quadrat will increase the probability of other scales (living in the same quadrat) dying. The inter-dependency of deaths can be used to test this.

The probability distribution of quadrats with n scales should follow the binomial distribution $(p + q)^n$, if there is no interdependency of deaths (p: mortality rate; q: survivor rate). As an example, if the total number of quadrats is N and $n = 2$, the distribution of quadrats should be $N(p + q)^2$. That is, the number of quadrats in which both scales are dead should be $N(p)^2$, the number of quadrats with one scale living and one dead should be $N(2pq)$, while the number of quadrats in which both scales are alive should be $N(q)^2$. This is tested by chi-square tests (Table 2).

Table 2: Chi-square tests for inter-dependency of deaths in the late nymphal stages of greenhouse whiteflies

Quadrats with 2 nymphs		
	Observed	Expected
Both dead	15	14.8
One living	55	55.4
Both living	52	51.8

$x^2 = 0.0064$

$P > 0.05$

Quadrats with 3 nymphs		
	Observed	Expected
3 living	11	9.5
2 living	21	20.4
1 living	9	14.6
All dead	7	3.5

$x^2 = 5.9023$

$P > 0.05$

In this case, only those deaths which occurred during the later nymphal stages were tested for inter-dependency. Quadrats with two and three nymphs were tested, because quadrats with more nymphs are too scarce to make significance tests.

There was no significant inter-dependency of deaths. This

information may assist in considering the direction for further approaches to the mechanism of density-dependent mortality.

The role of density-dependent mortality and fecundity on the development of greenhouse populations of whiteflies will be discussed in another paper.

Acknowledgements

Sincere thanks to Dr B Ferebee and Dr W Ehm for discussions on detection of inter-dependency of deaths, and to Dr N W Hussey for correcting the paper.

References

Ikeshoji, T. (1977). Self-limiting ecomones in the populations of insects and some aquatic animals. J. Pesticide Sci. 2, 77-89.

Ikeshoji, T., Ichimoto, I., Ono, T., Naoshima, Y. & Ueda, H. (1977). Overcrowding factors of mosquito larvae. X. Structure-bioactivity relationship and bacterial activation of the alkyl-branched hydrocarbons. Appl. Ent. Zool. 12 (3), 265-273.

Kidd, N.A.C. (1977). The influence of population density on the flight behaviour of the lime aphid, Eucallipterus tiliae. Ent. exp. & appl. 22, 251-261.

Polivanov, S., Peck, P. & Dorman-Kendig, K.A. (1980). The effects of male genotype on some aspects of population dynamics in lozenge-Muller-5 system of Drosophila melanogaster. J. Hered. 71 (4), 235-240.

Sutherst, R.W., Utech, K.B.W., Kerr, J.D. & Wharton, R.H. (1979). Density dependent mortality of the tick, Boophilus microplus, on cattle - further observations. J. Appl. Ecol. 16, 397-403.

Xu Rumei, Liu Laifu, Zhu Quoren & Shen Jiaji (1981). Application of a dimension-changeable matrix model on the simulation of the population dynamics of greenhouse whiteflies. Acta Ecologica Sinica 1 (2), 147-158 (in Chinese).

Zhu Quoren, Chang Tzili & Kang Zunjian (1981). Approaches on the dynamics and integrated control of greenhouse whiteflies in greenhouses at the suburb of Beijing. Beijing Agric. Tech. 1981 (2), 12-18 (in Chinese).

INTRODUCTION OF PARASITES FOR CONTROL OF LIRIOMYZA LEAFMINERS ON GREENHOUSE TOMATO

R.K. Lindquist & M.L. Casey

Introduction

Leafminers, Liriomyza spp., have caused serious problems for many greenhouse chrysanthemum and tomato producers in Ohio for the past several years, due mainly to the failure of most pesticides to provide adequate control. Since 1979, we have been working toward developing a practical program for managing leafminers on greenhouse crops by investigating a number of possible alternative methods, including pesticides, parasites, and resistant plants.

Fogg (1981) conducted experiments in our greenhouse with a leafminer identified in 1980 as L. sativae (by the USDA Systematic Entomology Laboratory). However, subsequent identifications from the same insect colony (obtained from both greenhouse tomato and chrysanthemum) have been as L. trifolii (N. Scopes, GCRI, pers. comm.; Paul Seymour, ADAS, pers. comm.). The specimens that Fogg submitted apparently were lost in shipment and are no longer available. Therefore, L. trifolii will be the species name used in this paper, but some of the 1979 and 1980 work may have been with L. sativae. Reported here are summaries of our work with parasites.

Methods, Results and Discussion

Three experiments with leafminer parasites on tomato will be discussed. The parasite species were Opius bruneipes Gahan (Braconidae) and Diglyphus pulchripes (Crawfd.) (Eulophidae). Methods used in these experiments were based on past experience and designed to evaluate introduction and sampling under different conditions likely to be encountered in commercial growing conditions during different seasons of the year. Experiment 1 was conducted during August-November, 1980 in a greenhouse containing 800 tomato plants at The Ohio State University. The plants were already infested with leafminers when transplanted, and contained 5-10 active mines/plant when parasites were introduced. O. bruneipes adults were introduced 20, 35, and 45 days after transplanting (total 0.2 parasites/plant). D. pulchripes also were introduced on

"trap" plants 20 and 29 days after transplanting. A total of 20 tomato plants, each containing larvae apparently parasitized by D. pulchripes also were placed in the greenhouse. These introduction procedures were based on experience in previous years where we noted invasion of parasites from outside the greenhouse which eventually controlled the leafminers. We felt that introduction of low numbers of parasites early in the crop, followed by subsequent invasion from outdoors could provide control. Results (Table 1) were tabulated by recording the presence/absence of live leafminer larvae, dead/parasitized leafminer larvae, and parasite adults (no. and species) on 40 randomly-selected plants at intervals after parasite introduction.

Table 1: Introduction of parasites for leafminer control on greenhouse tomatoes. Columbus, Ohio, 1980

% plants with	27 Aug	5 Sept	25 Sept	22 Oct
Live leafminer larvae	100	97	49.5	5
Dead/parasitized larvae	0	47	100	100
Parasite adults (Opius or Diglyphus)	0	0	47.5	100

The percentage plants containing dead/parasitized larvae increased dramatically, as did the parasite adults observed. On 25 September, 22% of parasites observed was D. pulchripes (N = 18), and this increased to 93% (N = 86) on 22 October. This predominance of D. pulchripes has been observed in subsequent experiments at Wooster during this time of year on both tomato and chrysanthemum.

In a previous study, using leafminers identified as L. sativae, Fogg (1981) introduced O. bruneipes at 2/plant 7 and 35 days after introducing L. sativae adults at 2/plant. The average percentage parasitism (as measured by collecting pupae) during the experiment was only 5%. We conducted an experiment similar to Fogg's during the winter/spring of 1981. Seventy-eight plants were transplanted into a 6.1 x 6.1 m greenhouse compartment on 12 January. No leafminers were present, so L. trifolii adults were released 14, 17 and 23 days after transplanting

(total: 4.5/plant). Five introductions of O. bruneipes were made, 2, 8, 9, 11 and 13 wks after transplanting (total: 2.5/plant). Twenty-four trays were placed below plants (4/row x 6 rows) to catch larvae prior to pupation. This constituted approximately 5% of the area where larvae were likely to fall. Pupae were collected weekly and held in containers in an environmental chamber at 25.5°C until emergence. This percentage parasitism (Figure 1) was based on the total number of pupae collected, and reached nearly 52% during the last collection. A rather consistent percentage of pupae did not produce either a parasite or leafminer (x = 28%, range: 18-35%). Average number of leafmines/plant (Figure 2) indicated 2 distinct generations between February and May, which was somewhat reflected in the pupal counts. Injury ratings also increased, but the relationship between leaf injury and tomato yields was not measured. The percentage parasitism by O. bruneipes in this experiment was considerably higher than that obtained by Fogg (1981) (5%), and McClanahan (1980) (2%), using another Opius species, but did not approach the 96% parasitism obtained by Zucchi & van Lenteren (1978), using Dacnusa sibericia at a ratio of 1.5/tomato plant to control L. bryoniae. Fogg also stated that O. bruneipes did not become established until there were ca. 40 active leafmines/plant. Our data indicated establishment of parasites at lower levels. Overall, it seemed that O. bruneipes did not achieve and maintain control of leafminers during this experiment, despite a high introduction rate. No Diglyphus adults were observed during this study.

The third experiment, during the winter/spring of 1982, involved 460 plants and used a similar O. bruneipes introduction rate. Because plants were transplanted into an area that had been subjected to heavy L. trifolii pressure during the previous crop (also tomatoes), and many L. trifolii adults were observed on the newly-set plants, a pyrazophos application (100 ppm) was made in an attempt to lower the number of L. trifolii larvae prior to parasite introductions. Ten O. bruneipes introductions were made from 21 December-2 February (total: 2.8/plant). Eighteen yellow sticky traps, 6 at soil level, 6 at 0.3 m high and 6 at crop height trapped/wk was reduced from approximately 500 in December to 0 in March (Fig. 3). Only a very few O. bruneipes adults were trapped during this study, but many were observed and during April, a few D. pulchripes were trapped, indicating establishment of this species

without it being purposely introduced. Two distinct population peaks of L. trifolii occurred, but the second was much smaller than the first. In contrast to the 1981 experiment, damage ratings did not increase, indicating successful suppression of leafminers. The pyrazophos application probably aided in lowering the number of surviving L. trifolii larvae initially, but it is difficult to believe that a single application could make a great overall difference in the results. Perhaps O. bruneipes performed better in a larger greenhouse, or the additional introduction dates were more successful. The establishment of D. pulchripes may also have been the difference between the two experiments, as our previous trial with the two species resulted in successful control.

Additional work is needed, on the best parasite species/leafminer species combinations, introduction methods, numbers, etc., but these experiments illustrated that certain leafminers can be suppressed on tomatoes by one or more parasite species. In Ohio, our best chances for success will be during the late summer-autumn period, when introduced parasites will probably be supplemented by invasion of additional numbers (and species) from outdoors. These additional species, such as D. pulchripes, may be very important in leafminer control, since in these experiments (and others not reported here), best control has been obtained when D. pulchripes was either introduced or invaded the greenhouse naturally.

References

Fogg, C.J. (1981). Studies on the natural control of Liriomyza sativae. M.S. Thesis, The Ohio State University, 59 pp.

McClanahan, Robert J. (1980). Biological control of Liriomyza sativae on greenhouse tomatoes. Bull. SROP/WPRS, 1980 III/3, 135-139.

Zucchi, R. & Lenteren, J.C. van (1978). Biological characteristics of Opius pallipes (Hymenoptera: Braconidae), parasite of the tomato leafminer Liriomyza bryoniae Kalt. Med. Fac. Landbouww. Rijksuniv. Gent 43 (2), 455-462.

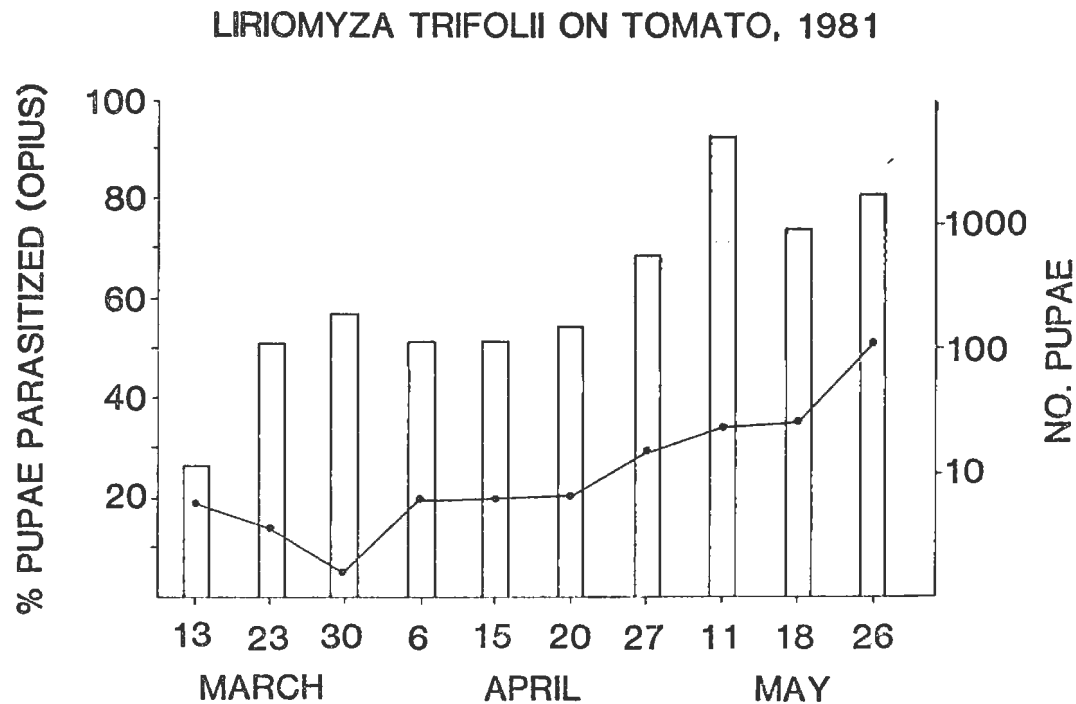


Figure 1: Introduction of O. bruneipes for leafminer control on greenhouse tomato. Solid line indicates percentage parasitism based on total pupal catch for each week; bars indicate total number of pupae trapped.

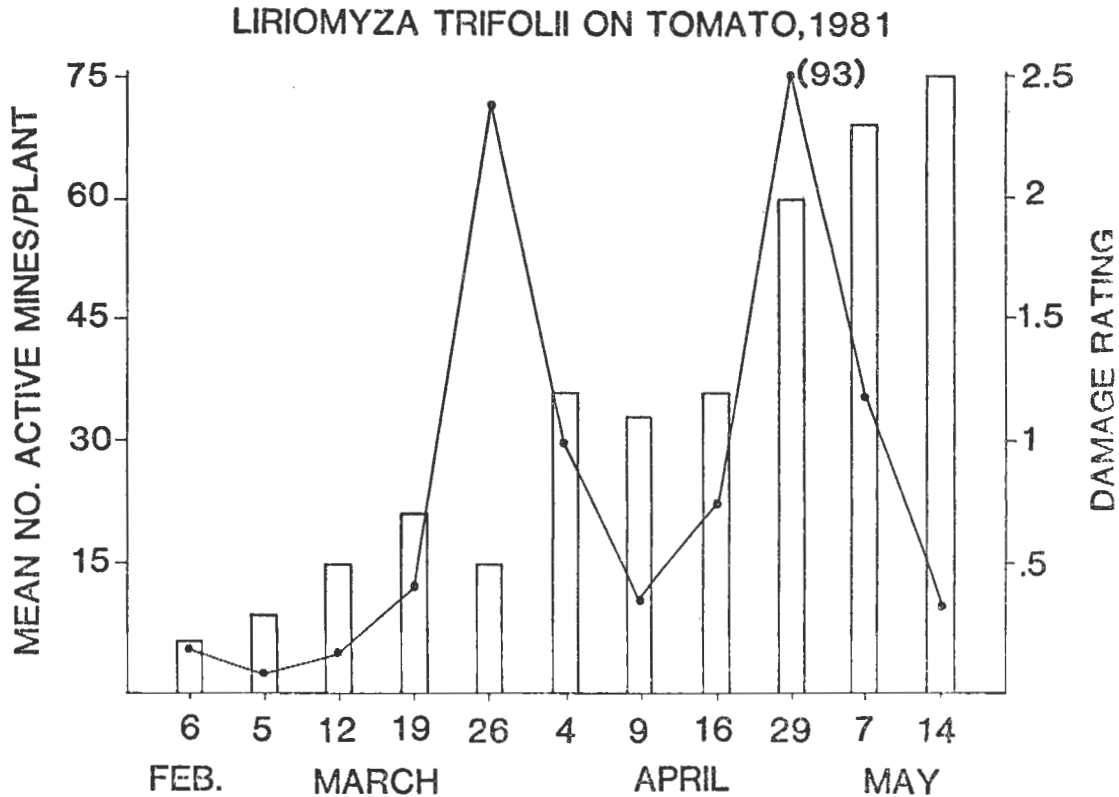


Figure 2: Mean number of active leafmines/tomato plant after introduction of L. trifolii and O. bruneipes; solid line indicates mean number of leafmines, and bars indicate injury rating at each sampling date.

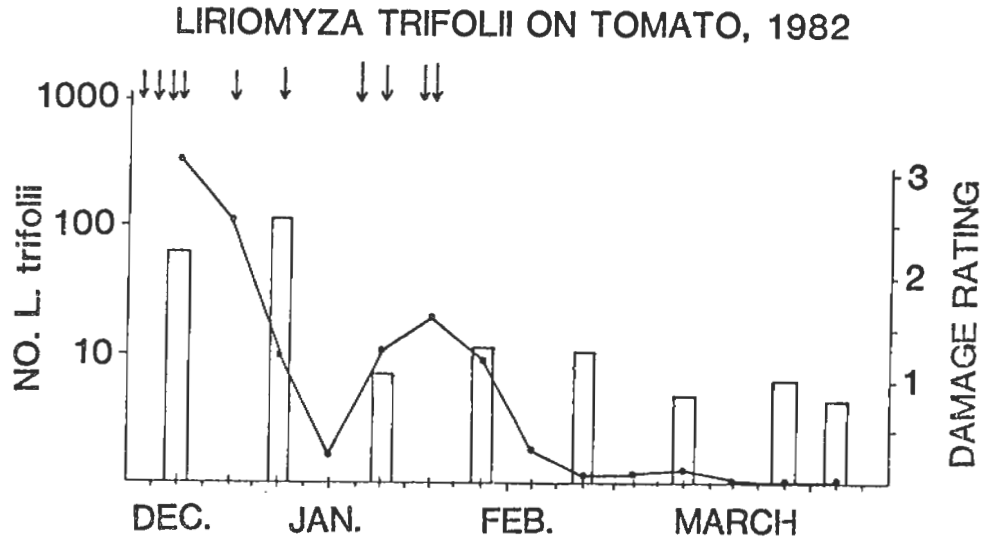


Figure 3: Introduction of O. bruneipes for leafminer control in greenhouse tomato. Solid line indicates mean number of leafminer adults/sticky trap, and bars indicate injury rating at each sampling date. Arrows indicate parasite releases.

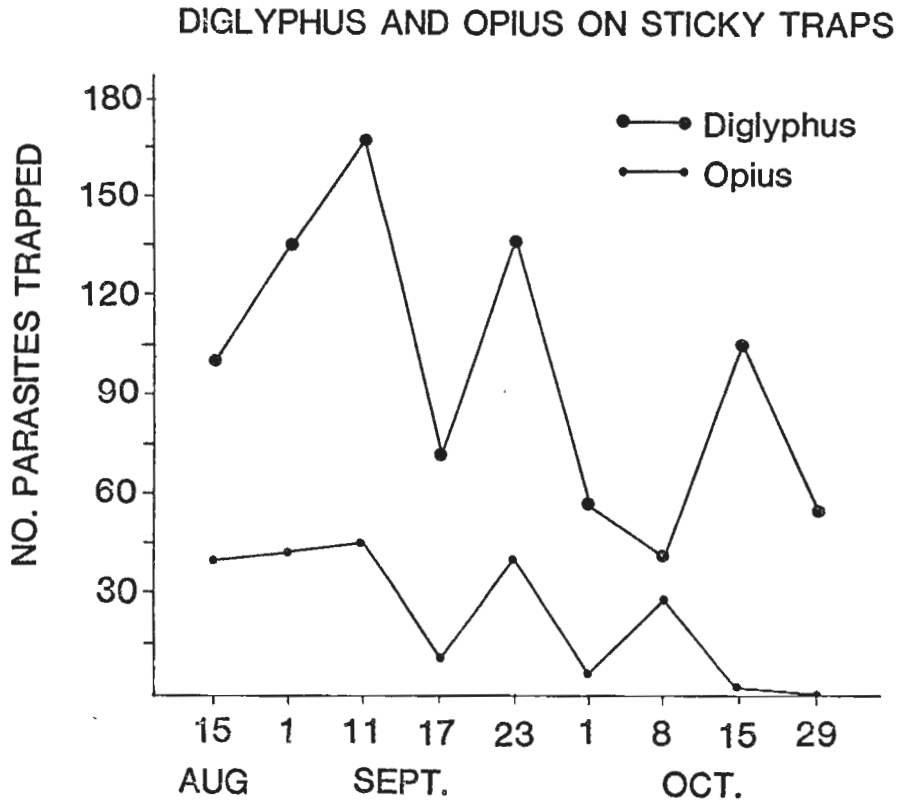


Figure 4: Number of D. pulchripes and O. bruneipes caught on yellow sticky traps after drench application of methoprene (4.4 kg a.i./ha) on 14 August 1981

CONTROL OF LIRIOMYZA TRIFOLII ON GREENHOUSE CHRYSANTHEMUMS

R.J. McClanahan

The leafminer,(Liriomyza trifolii (Burgess), has been a serious pest of greenhouse chrysanthemums in Canada since early 1980. Evidently it was introduced on chrysanthemum cuttings imported from Florida. It was initially thought to be L. sativae Blanchard, a very similar species which had been a problem on greenhouse tomatoes and cucumber in the mid 1970s. Taxonomic studies with assistance from Barbro Nedstam and Sidney Poe in the fall of 1981 clarified the situation. The colony of leafminers at the Harrow Research Station that I had been working with since 1974 was L. sativae, validating the use of this name in earlier research papers (McClanahan 1977, 1980). However, specimens collected from commercial greenhouses in 1980 and 1981 were all identified as L. trifolii.

There were a number of native leafminer parasites which utlized L. sativae as a host, and they would also likely attack L. trifolii. Despite considerable effort over several years, I was unable to develop a mass rearing procedure for 4 of the most promising parasite species. The colonies did persist for 6 to 10 generations, but numbers remained low.

The research was then directed to the control of leafminers on chrysanthemums, initially by chemical means. The synthetic pyrethroid materials were very effective against adult leafminers and permethrin was registered for use on greenhouse crops for control of whiteflies and leafminers. Growers also had the systemic insecticide aldicarb as a means of controlling larvae. In spite of aldicarb and twice-weekly sprays of permethrin, the leafminer populations built up in 1980 to the point where substantial portions of the crop were unmarketable because of severe leaf damage. Laboratory tests showed that cypermethrin and fenvalerate were not much more toxic than permethrin, since all three had LD_{95} values in the range of 6 to 10 ppm. These toxicological studies were conducted with L. sativae. Current studies with L. trifolii confirm opinions that the latter species is generally more tolerant to insecticides.

An alternative control method was investigated beginning in 1981. It was known that leafminer adults were attracted to yellow, and yellow sticky traps were being used to monitor the vegetable leafminer in celery in Florida (Musgrave et al., 1975). No reference could be found concerning leafminer control by using many traps, but I considered it should be

possible within a greenhouse. Yellow plastic Stiky Strips(R) are sold[1], and they are advertised to control leafminer flies as well as many other insects.

Preliminary tests with 4 shades of yellow on 10 cm x 20 cm pieces of pressed hardboard showed that a fluorescent yellow was most attractive to leafminer adults. However, that colour did not remain stable under greenhouse conditions, and a bright yellow enamel was chosen for future use. Yellow paints with slight tints of green or orange were less attractive.

In a 0.3 ha greenhouse consisting of 2 large sections (K. Oleson), 458 traps were hung over the beds of chrysanthemums so that each trap served about 5 m^2 of crop area. At first all traps were checked, but after October 7 only 1 out of 20 was counted regularly every week.

In June 1981 two other chrysanthemum growers hung similar yellow sticky traps over all their plantings. I agreed to monitor 20 of these in 2 separated small houses at E. Nickels, and 17 traps in a 0.3 ha area of connected houses at Derkach Farms. Most of these plantings were sprayed twice a week with permethrin, and each bed of chrysanthemums usually received 2 applications of aldicarb. Aldicarb was omitted at Oleson's from February until July 1982.

The results of the trap monitoring are presented in Figures 1 to 4. At Oleson's the plants showed little damage until September 1981, whereas they had suffered severe damage the previous year with the same spray schedule. All cut flowers were marketed in 1981, even in October and November. No leafminers were trapped in the east block (5 houses) at Oleson's from March 5 to May 27, 1982. It was only on July 8 that more than 3 flies were trapped in a week in this area. The west block (6 houses) had light but scattered numbers in the same period. Unfortunately the manager could not be persuaded to keep the door between the two blocks closed.

Nickels' house 1 showed high numbers in June, July and August 1981, but it looks more promising this year. In this greenhouse eradication seemed evident over a 13 week period with the exception of a single specimen March 25. It could have entered from the headerhouse, although the doors were usually closed at this time of the year. The cyclical nature of the population at Nickels is due to the isolated nature of each house. Steaming, for example, was done for the whole house over a

---

[1] Olson Products Inc., Medina, Ohio 44256

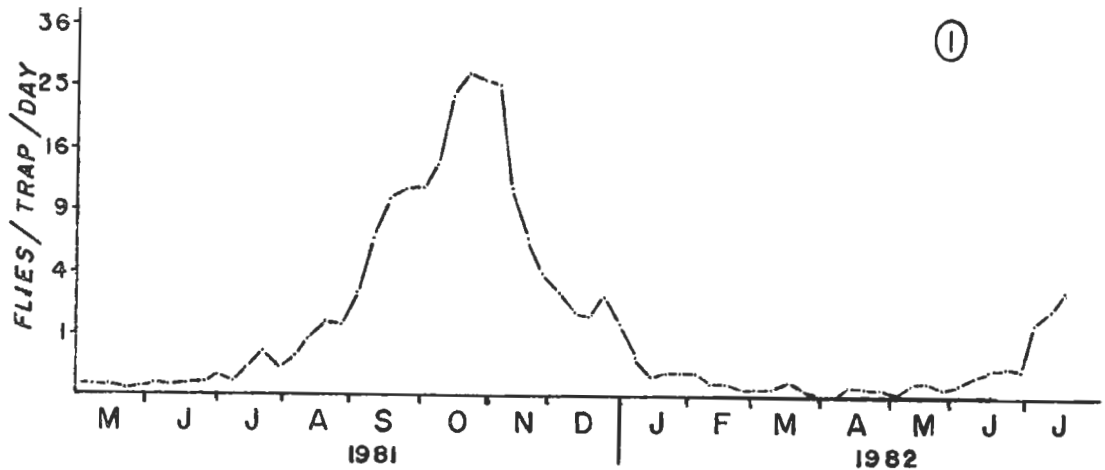


Figure 1: Oleson's greenhouses, Kingsville: Liriomyza trifolii trapped on yellow sticky traps over chrysanthemums. The points plotted were $\sqrt{x}$, but the scale indicates actual numbers.

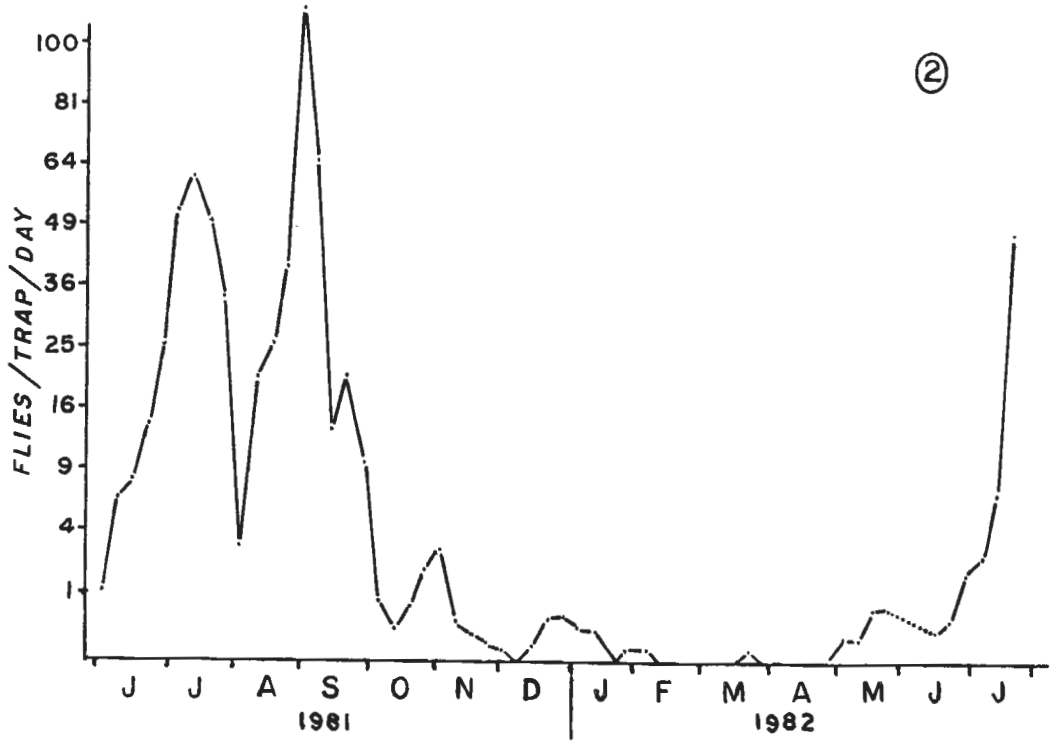


Figure 2: E. Nickels (House 1), Leamington, Ontario: Liriomyza trifolii trapped on yellow sticky traps over chrysanthemums. The points plotted were $\sqrt{x}$, but the scale indicates actual numbers.

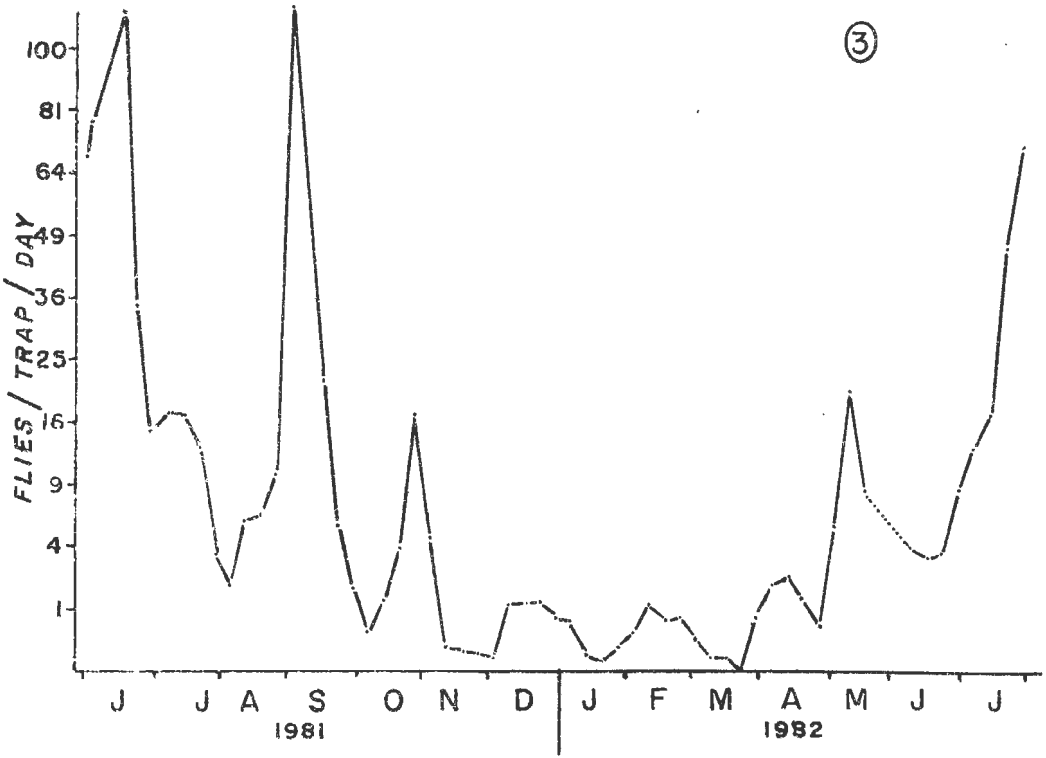


Figure 3: E. Nickels (House 10), Leamington, Ontario: Leafminers on monitor traps in greenhouse areas protected with many sticky traps

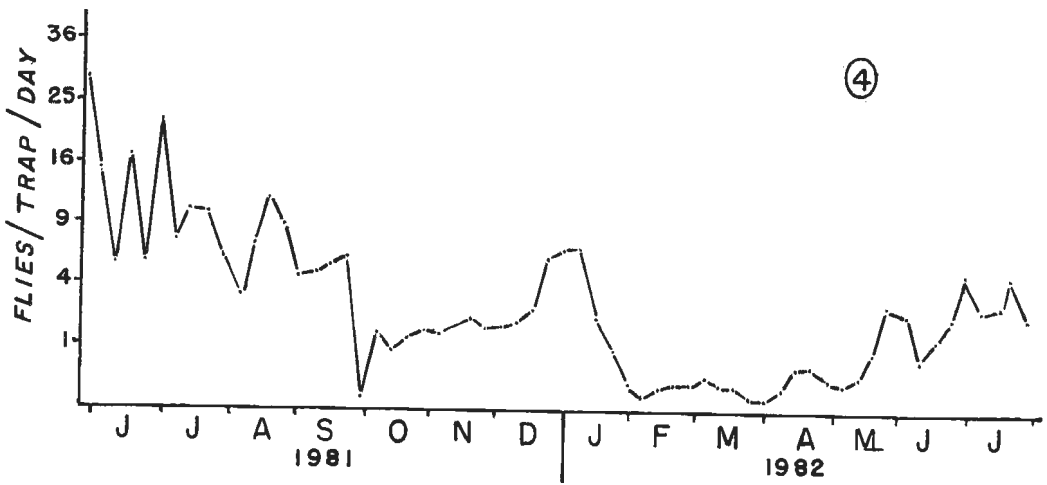


Figure 4: Derkach Farms, Ruthven, Ontario: Leafminers on monitor traps in greenhouse areas protected with many sticky traps

short period. Leafminer pupae could survive in the aisles between the beds since they were not steamed.

In house 10 the population seemed to be generally higher through the whole observation period. Possibly this was because the adjacent area of the headerhouse was used to trim and bunch the flowers. In the summer the doors to the greenhouses were left open for ventilation. The high peaks of leafminers at Nickels' caused definite damage but the flowers were still marketable. If the high numbers had been sustained, losses would have been severe.

The graph of leafminers at Derkach Farms showed more random changes. In the monitored area transplanting was carried out systematically from one bed to the next, and the complete planting could take 4 or 5 weeks. At Derkach's cuttings were obtained from a US source in Florida, possibly introducing more leafminers as eggs. They also had beds which served as stock plants for cuttings. Leafminer numbers were always higher over these beds, despite the routine sprays and aldicarb applications.

To remain effective the traps must be washed in a petroleum solvent and recoated with Tack Trap when they become coated with insects or dust. They must hang just above the foliage, not down in it. There are more flies near the edge of the trap, so larger traps would be less efficient. Traps probably could be placed as close as every 3 m along the beds.

How many leafminers can be caught by sticky traps? Our highest count for a week was 1438 on a trap at Nickels in August 1981, and many traps had over 900. During a 4-week period it was estimated that the 75 traps in house 1 at Nickels removed 89,000 leafminers from circulation.

In conclusion, sticky traps provide a highly visible means of leafminer control while, at the same time, providing a means of measuring the relative level of the population. Trapping will detect leafminer numbers at levels far below those that can be found by visual examination. This control method is compatible with other chemical, biological or cultural means of control and does not leave any residue. Other insects are caught as well, including whiteflies, winged aphids, thrips and fungus gnats. I think yellow sticky traps can work with other control measures to eliminate leafminers from the greenhouse.

References

McClanahan, R.J. (1977). Biological control of the leafminer Liriomyza sativae in greenhouse crops. USDA ARS-NE-85, 45-48.

McClanahan, R.J. (1980). Biological control of Liriomyza sativae on greenhouse tomatoes. Bull. SROP/WRPS III/3, 135-140.

Musgrave, C.A., Poe, S.L. & Weems Jr., H.V. (1975). The vegetable leafminer, Liriomyza sativae Blanchard (Diptera: Agromyzidae) in Florida. Fla. Dept. Agric. & Consumer Services, Ent. Circ. 162, 4 pp.

CONTROL OF LIRIOMYZA BRYONIAE KALT. BY DACNUSA SIBIRICA TEL.

Barbro Nedstam

Summary

Parasitization increased when Dacnusa sibirica, a parasite of the tomatoe leafminer Liriomyza bryoniae was given a food supply of honey or honeydew in two experiments in glasshouse chambers. Access to a source of nectar (melon plants) had no significant effect, although the percentage of parasitism was higher than in the control. All three treatments led to significantly lower levels of leafminer infestation.

Introduction

In Sweden the leafminer Liriomyza bryoniae is a pest of tomato, cucumber and melon. Chemical control disturbs the use of Encarsia formosa Gahan against whiteflies in the glasshouses, so there is a need of a biological control method for the leafminer. Research reports from the Netherlands have shown promising results from the use of Dacnusa sibirica and Opius pallipes Wesm. as biological control agents against the tomato leafminer (Hendrikse et al., 1980). These species are - among other parasites - also present in Swedish glasshouses (Nedstam, 1981). Rearing of D. sibirica was started in 1979 to supply parasites for introduction trials in cucumber and tomato. Parasites are introduced as pupae (two or three introductions at weekly intervals giving a total of 1 pupae per m^2) starting as soon as the first signs of an attack are observed. The results in commercial glasshouses have been quite varied, ranging from total success to complete failure. A general trend has been that D. sibirica establishes more readily in cucumber than in tomato (Nedstam, 1980). There could be many reasons for this - the tomato plant might be a better host for the leafminer than cucumber, or different climatical conditions might have some influence. In the artificial environment of a tomato house there is no natural source of food for the adult parasites (apart from the opportunity of host feeding on leafminer larvae). The experiments reported here were carried out in order to study the effects on population development when an extra food supply was available to the wasps.

Methods

Six glasshouse chambers of 18 m^2 were planted with 22 tomato plants of the variety "Ida" on mineral wool mats. Every second plant was infested with L. bryoniae eggs and larvae, giving 500-600 larvae per chamber. Newly emerged males and females (10 pairs) were introduced into each chamber. Two experiments were carried out using complete randomization.

A. Comparing honey supply, nectar plants and control chambers

A small amount of honey was put on a yellow plastic board (25 x 25 cm^2) placed on the floor in two chambers). 4 melon plants were planted in the corners of two other chambers, and there were also two control chambers.

B. Comparing honey supply, honeydew from whiteflies and control chambers

Honey as in Experiment A. Whiteflies had been established in two chambers before the release of D. sibirica. Two control chambers. Also one chamber without parasites. The experiments ran for 3 months (April-June) after parasite introduction, allowing at least 3 generations to develop. Night temperature 18°C, day temperature 22-27°C. The percentage of parasitism was determined from weekly collections of pupae. Leaf mines were counted by the end of Experiment A. During Experiment B falling larvae were collected under funnels (r = 16.2 cm, 14 per chamber) and counted weekly.

Results

A.1: % parasitization in 2nd + 3rd generations

	Control	Nectar	Honey
	60	76	93
$P < 0.05$	LSR = 17		

A.2: Number of mines per 100 leaves (3rd generation)

	Control	Nectar	Honey
	1231	426	207
$P < 0.01$	LSR = 426		

B.1: % parasitization in 2nd + 3rd generations

Control	Honeydew	Honey
61	83	86

$P < 0.05$ LSR = 18

B.2: Number of pupae collected per 1.15 m^2 during the last three weeks of the experiment (pupating larvae mainly from 3rd generation)

Control	Honeydew	Honey	(No parasites)
2510	480	323	(14500)

$P < 0.05$ LSR = 1720

Conclusions

In these experiments the introduction of D. sibirica without "food aid" has been insufficient to restrain the fly population. Of the different food types the honey and whitefly honeydew had best effect, nectar plants were less satisfactory.

Discussion

The high numbers of leafminer larvae in the beginning of these experiments would generally not represent a "natural" situation in a commercial glasshouse, but were considered necessary in order to give enough sampling material. A practical application of the results would be to introduce these numbers of D. sibirica (1 per m^2) against L. bryoniae only when a whitefly population is present - which is not always the case in Sweden. Otherwise it seems necessary to supply the wasps with honey. Another solution might be to increase the number of introduced parasites. Nectar plants cannot easily be integrated in a tomato production programme. A few trials with introduction of D. sibirica together with honey on yellow boards (1 per 50 m^2) have been laid out in commercial glasshouse tomatoes. The control has mainly been good, but no definited conclusions can yet be drawn because of disturbing factors like other parasites, as Diglyphus spp., whiteflies and aphids producing honeydew.

To get a reliable method of biological control of the leafminer, it might be better to work with O. pallipes instead, as this appears to be a better candidate for a biological control agent in tomato (Woets, 1982). This species could also be useful in cucumber and melon.

References

Hendrikse, A., Zucchi, R., Lenteren, J.C. van & Woets, J. (1980). Dacnusa sibirica Telenga and Opius pallipes Wesmael (Hym. Braconidae) in the control of the tomato leafminer Liriomyza bryoniae Kalt. Bull. IOBC/WPRS 1980/III/3, 83-98

Nedstam, B. (1980). Biologisk bekämpning av minerarflugor med parasitsteklar i växthus. Nord. Plantevern Konf. 1980, 123-126.

Nedstam, B. (1981). Minerarflugor (Fam. Agromyzidae) i växthus. Växtskyddsnotiser 44 (6), 135-137.

Woets, J. (1982). On the occurrence of Opius pallipes Wesmael and Dacnusa sibirica Telenga (Braconidae) in cases of natural control of the tomato leafminer Liriomyza bryoniae Kalt. (Agromyzidae) in some large greenhouses in the Netherlands. Med. Fac. Landbouww. Rijksuniv. Gent (in press).

INSECT GROWTH REGULATORS FOR THE CONTROL OF LIRIOMYZA TRIFOLII AND COMPATIBILITY WITH A NATURAL ENEMY

M.P. Parrella

Insect growth regulators (IGRs) offer several advantages when compared to conventional, broad spectrum insecticides. These include specificity to the target insect, low mammalian toxicity and a mode of action which is distinct from broad spectrum insecticides. The latter aspect is important when controlling Liriomyza spp. where suspected resistance to conventional insecticides has a long history (Genung, 1957). Initial research with IGRs (Wright & Spates, 1972) demonstrated great promise for compatibility with insect parasites. However, subsequent work has both supported (Wilkinson & Ignoffo, 1973) and refuted this (Outram, 1974; Vinson, 1974; Granett, 1975; Riviere, 1975) with the final conclusion that different species parasitic on a particular host will react differently to the application of a specific IGR. Research with the potential of IGRs (Kinoprene and [ethyl N-methoxy-3,7,11-trimethyl-(2E,4E)-dodecadienoate]) for Liriomyza sp. control and for compatibility with the endoparasite, Opius dimidiatus (Ashmead) concluded that these IGRs were of greater potential harm to biological control agents than a benefit to leafminer control (Poe, 1974, 1978 .

Reported herein are efficacy data for selected IGRs and the potential for compatibility with the endoparasite, Chrysocharis parksi (Crawford).

Materials and Methods

Laboratory Efficacy

The following were selected for efficacy testing against larvae of L. trifolii: CGA 77622 5SC (N-cyclopropyl—1,3,5-triazine-2,4,6-triamine) - mode of action unknown but suspected to be hormonal; methoprene 5E - juvenile hormone analog; RO 13-5223 1E (Ethyl [2-(p-phenoxyphenoxy) ethyl-carbamate) - juvenile hormone analog.

Materials were applied with a 3.75 l pressurized sprayed at 60 psi to standardized chrysanthemum plants containing known numbers of 3rd-stage larvae of L. trifolii. Exact procedures for standardizing chrysanthemum plants, obtaining infestations of larvae of a known age and handling of plants after spraying have been reported (Parrella et al., 1982a, 1982b).

Compatibility with Chrysocharis parksi

Ten standardized chrysanthemum plants with known numbers of 3rd-stage larvae served as replicates in the following treatments:

1. Water control - no IGR or parasites.

2. Parasite control - exposed to ca. 150 C. parksi adults in a 0.1 m^3 rearing cage for 24 h.

3. IGR application (RO 13-5223 1E) applied as described previously.

4. Parasite exposure and IGR application - exposed to parasites as described in 2. and then sprayed with RO 13-5223 1E immediately after removal from the parasite cage.

All plants, after treatment, were handled as described in Parrella et al. (1982a, 1982b).

Results

In laboratory evaluations, all IGRs demonstrated good leafminer control capability (Table 1). However, striking differences were found comparing when the materials exerted their action. CGA 77622 5SC, at all rates, acted on larvae while still in the mines and significantly ($P < 0.05$) reduced larval emergence and pupation compared to the controls and other IGRs. Methoprene 5E and RO 13-5223 1E had no effect on larval emergence and pupation; however, both materials significantly ($P < 0.05$) reduced adult emergence; only the two highest rates of methoprene demonstrated this effect.

Preliminary data on phytotoxicity revealed that CGA 77622 5SC caused severe damage to chrysanthemums grown for cut flowers and numerous beeding plant species. Similar data was obtained for RO 13-5223 1E; however, limited applications on potted chrysanthemums could be made safely. Methoprene 5E was compatible with chrysanthemums grown for cut flowers and most bedding plants. However, the rates of methoprene 5E required to obtain at least 70% control, 907 and 1814 gm ai/378.5 l (Table 1), make the cost of this material uneconomical. One or two applications may be practical; however, as a foliar spray this IGR would have to be applied on a weekly basis.

The IGR, RO 13-5223 1E, demonstrated remarkable compatibility with C. parksi; greater than 20% parasitization occurred in treated and

Table 1: Efficacy of selected insect growth regulators against 3rd-stage larvae of Liriomyza trifolii

Treatment and rate[a]	Pre-treatment count[b] $\bar{x}$ no. larvae/plant[c]	Post-treatment count $\bar{x}$ no. pupae/plant[c]	Post-treatment count $\bar{x}$ no. adults/plant[c]
CGA 77622 5SC			
0.5	19.2 a	0.0 a	-
0.25	18.6 a	0.1 a	1.0 ab
0.10	28.5 a	2.7 a	0.5 a
0.05	27.2 a	3.5 a	0.9 a
Methoprene 5E			
4.0	21.2 a	17.6 bc	1.8 ab
2.0	23.6 a	21.0 bc	7.1 b
1.0	25.0 a	22.2 c	13.4 c
0.5	22.7 a	20.2 bc	14.7 cd
RO 13-5223 1E			
0.8	17.1 a	15.6 b	7.3 b
Control A	22.8 a	22.2 bc	20.3 d
Control B	23.6 a	21.6 bc	18.9 cd

[a] gm ai/378.5 l water

[b] Made 5 days after exposure to ovipositing flies; 10 plants per treatment and rate

[c] Means followed by the same letter are not significantly different ($P > 0.05$), Duncan's new multiple range test. No data transformation was necessary.

untreated larvae (Table 2). No significant ($P > 0.05$) difference was detected when parasite emergence was compared for treated and untreated plants. Although host feeding by C. parksi significantly reduced the number of L. trifolii pupae per plant (Table 2), the number of adult flies emerging per plant from the parasite control, IGR application and parasite plus the IGR application did not differ significantly ($P > 0.05$). However, these were significantly different ($P < 0.05$) from the control (no IGR or parasites).

Table 2: Effect of the insect growth regulator, RO 13-5223, on Liriomyza trifolii (L.t.) and its endoparasite, Chrysocharis parksi (C.p.)[a]

Treatment	Pre-treatment count $\bar{x}$ no. L.t. larvae/plant[b]	Post-treatment count $\bar{x}$ no. L.t. pupae/plant	$\bar{x}$ no. L.t. adults/plant	$\bar{x}$ no. C.p. adults/plant
Control	30.0 a	28.2 a	27.7 a	-
Parasite control	30.2 a	16.1 b	4.0 b	8.3 a
RO 13-5223 1E	31.7 a	31.5 a	5.6 b	-
Parasite + RO 13-5223[c] 1E	29.3 a	17.6 b	1.6 b	6.4 a

[a] Means followed by the same letter are not significantly different ($P > 0.05$), Duncan's new multiple range test. No data transformation necessary.

[b] Pre-treatment count made 5 days after exposure to ovipositing L. trifolii females. Ten plants per treatment.

[c] Plants exposed to parasites for 24 h; IGR applied immediately after removal from the parasite cage.

Discussion

Considerable research has been done on the use of selective insecticides which provide some control of Liriomyza spp. leafminers and allow parasite survival (Wene, 1955; Getzin, 1960; Schuster et al., 1979). However, most of these studies demonstrated that even the best, most selective insecticide had a negative effect on the parasite fauna. The study reported here has shown that RO 13-5223 1E has no effect on survival of C. parksi while still providing good control of L. trifolii. However, RO 13-5223 1E was applied early in the development of C. parksi which would minimize the effect of the IGR on the parasite (Vinson, 1974). Further research is needed to determine if a sublethal effect is present which would adversely affect the parasite. A sublethal effect has been found when adult female L. trifolii emerging from all RO 13-5223 1E and methoprene 5E treatments were monitored for fertility and longevity (Parrella, unpubl. data). These data increase the efficacy of both IGRs and may improve the potential for the use of methoprene (e.g. at lower rates) for control of L. trifolii. Preliminary data suggest that the phytotoxicity caused CGA 77622 5SC and RO 13-5223 1E is attributable to the carrier and not the active ingredient. Therefore, alternative

formulations of these materials may allow them to be used on a much broader range of host plants in an integrated approach with parasites.

References

Genung, W. (1957). Some possible cases of insect resistance to insecticides in Florida. Proc. Fla. State Hort. Soc. 70, 148-152.

Getzin, L.W. (1960). Selective insecticides for vegetable leafminer control and parasite survival. J. Econ. Entomol. 53, 872-875.

Granett, J., Weseloh, R.M. & Helgert, E. (1975). Activity of juvenile hormone analogues on hymenopterous parasitoids of the gypsy moth. Entomol. exp. et appl. 18, 377-383.

Outram, I. (1974). Influence of juvenile hormone on the development of some spruce budworm parasitoids. Environ. Ent. 3, 361-363.

Parrella, M.P., Robb, K.L., Christie, G. & Bethke, J. (1982b). Control of a serpentine leafminer, Liriomyza trifolii, using biological agents and insect growth regulators. Calif. Agric. (Nov.-Dec. issue) (in press).

Parrella, M.P., Robb, K.L. & Morishita, P. (1982a). Response of Liriomyza trifolii (Diptera: Agromyzidae) larvae to insecticides with notes about efficacy testing. J. Econ. Entomol. 72 (in press).

Poe, S.L. (1974). Liriomyza munda and parasite mortality from insect growth regulators. Fla. Entomol. 57, 415-417.

Poe, S.L. (1978). Juvenile hormone analogues: effects of ZR-777 on Liriomyza sativae and its endoparasite. Fla. Entomol. 61, 67-68.

Riviere, J.L. (1975). Effect of a juvenile hormone analogue on the development of a parasitic insect, Pales pavida (Dipt. Tacinidae). Entomophaga 20, 373-379.

Schuster, D.J., Musgrave, C.A. & Jones, J.P. (1979). Vegetable leafminer and parasite emergence from tomato foliage sprayed with oxamyl. J. Econ. Entomol. 72, 208-210.

Vinson, S.B. (1974). Effect of an insect growth regulator on two parasitoids developing from treated tobacco budworm larvae. J. Econ. Entomol. 67, 335-336.

Wene, G.P. (1955). Effect of some organic insecicides on the population levels of the serpentine leaf miner and its parasites. J. Econ. Entomol. 48, 596-597.

Wilkinson, J.D. & Ignoffo, C.M. (1973). Activity of a juvenile hormone analogue on a parasitoid, Apanteles rubecula, via its host, Pieris rapae. J. Econ. Entomol. 66, 643-645.

Wright, J.E. & Spates, G.E. (1972). A new approach in integrated control: insect juvenile hormone plus a hymenopteran parasite against the stable fly. Science 178, 1292-1294.

OBSERVATIONS ON OPIUS PALLIPES WESMAEL (HYM., BRACONIDAE) AS A POTENTIAL CANDIDATE FOR BIOLOGICAL CONTROL OF THE TOMATO LEAFMINER LIRIOMYZA BRYONIAE KALT. (DIPT., AGROMYZIDAE) IN DUTCH GREENHOUSE TOMATOES

J. Woets & A. van der Linden

Introduction

Liriomyza bryoniae Kaltenbach is known to oocur sporadically in the Dutch greenhouse district since several decades. In 1965 and 1966 some growers had severe damage by this miner. The leaves of the tomato plants became brown and the growers finished their spring tomato crop a few weeks before the initially planned date in summer (de Brouwer & van Offeren, 1966). More data about damage and biology are provided by Hussey et al. (1969 & 1975).

During the second half of the seventies L. bryoniae again achieved a pest status in Dutch greenhouse tomato crops, both in crops with chemical and biological control of the greenhouse whitefly as the key pest. In 1973 it was determined that many tomato growers who get an infestation by the leafminer spontaneously in June will have no problems with the pest if they do not apply insecticides. In most cases the pest numbers stay below one per plant (Woets & van der Linden, 1982). It is easy to collect three parasite species from such cases of "natural control": the two Braconid endoparasites Dacnusa sibirica Telenga, and Opius pallipes Wesmael and the Chalcid ectoparasite Diglyphus isaea Walker.

Since 1977 the biology of the two Braconids was investigated in the Department of Ecology, Leiden University, (Hendrikse et al., 1980). From simultaneous experiments in our experimental station during 1979 it was determined that Opius pallipes is most successful under glasshouse conditions.

To know more about the possibilities for using Opius pallipes in growers' greenhouses we made observations in potential cases of natural control in growers' greenhouses(1980) and we made an experiment on introduction numbers of Opius (1981). For global temperature data see Ravensberg et al. (these proceedings).

Cases of natural control in 1980

Some tomato growers do not sterilise the greenhouse soil directly before planting the tomatoes in December or January. They prefer a date before the planting of the autumn crop. So leafminer pupae can remain in the soil from an autumn crop of cucumber or lettuce which are host plants of the leafminer. So it is with endoparasites.

We made observations in 1980 and 1981 and we present here the data of the two cases of tomato crops in which Opius pallipes achieved a good control after remaining from the previous autumn cucumbers, which showed a few leaf mines.

The number of mines on tomatoes was counted in that part of the greenhouse with higher infestation levels, mostly in ten bays (1000-1500 plants). It was done at the end of every maggot generation. A sample (5) was taken for dissection. In June and July counts of the mines were on a few hundred plants.

Results

The counts of the number of mines and the parasitization per generation are presented in Table 1.

The growers got their young plants from the nursery clean of leafminers. So the infestation in January/February occurred from pupae that remained in the soil. The Opius emergence was also from remaining pupae, because entrance through the windows is possible only from May-June onwards. Dacnusa sibirica occurred in June, but Diglyphus was not found.

Both growers, van der Hoeven and Vermeer, were satisfied about the natural control level, but the majority of the growers do not like 10 or 20 mines/plant until now. It was a pity that van der Hoeven finished his crop in mid July as usual.

From these two cases it seems clear that Opius pallipes can control a tomato leafminer population after an early occurrence (van der Hoeven 17% on 17.3.80 and Vermeer 2.5% on 13.3.80).

Table 1: Observations on the spontaneous occurrence of the tomato leafminer Liriomyza bryoniae Kalt. and its parasites in a spring tomato crop in two growers' greenhouses, respectively 8,000 and 12,000 m^2, from January to August 1980

Grower	Van der Hoeven			Vermeer		
	Mines*	Op./n*	Dac./n*	Mines	Op./n	Dac./n
Date:						
16.1.	2.2	-	-			
24.1.				2	0/6	0/6
18.2.	19	0/53	0/53			
13.3.				7.5	1/39	0/39
17.3.	1	6/41	0/41			
16.4.	1	19/20	0/20	5.5	3/6	0/6
13.5.	1	-	-	45	12/39	0/39
10.6.	500	52/87	0/87	170	84/92	5/92
4.7.	2000	50/65	3/65	1000	21/31	6/31
24.7.				0	0	0

* Mines: number of mines per 100 plants

Op./n = Number of leafminer maggots parasitised by Opius pallipes in a sample of n full-grown maggots

Dac./n = Number of leafminer maggots parasitised by Dacnusa sibirica in a sample of n full-grown maggots

Experiment on introduction numbers in 1981

In two greenhouses of 70 m^2 area, 164 plants cv. Sonatine were planted in January 1981, after a steam sterilization of the soil. On 23.2.81 in each house, 50 leafminers were released (sex ratio 1:1), i.e. 0.3 miners per plant. After each generation the total numbers of mines were counted. Opius pallipes was introduced on 8.4.81 just at the start of the second maggot generation. In house 1 194 female and 421 male Opius (1.18 ♀ per plant), in house 2, 29 ♀♀ and 68 ♂♂ were released (0.18 ♀/plant).

The mines of the first generation were counted on all plants (164), in the second on 6 plants and from then onwards on 3 plants out of the 164.

The numbers of mines are presented in Table 2.

Table 2: Numbers of mines per plant during five generations of the tomato leafminer Liriomyza bryoniae Kalt., numbers of unparasitised maggots per plant and the multiplication factor of the number of mines and of the number of leafminer maggots in a spring tomato crop (1981)

Generation	Count date	Sample size (no. of plants)	Greenhouse 1				Greenhouse 2			
			No. of mines/plant	Multiplication factor of mines	No. of unparasitised maggots/plant	Multiplication factor of leafminer	No. of mines/plant	Multiplication factor of mines	No. of unparasitised maggots/plant	Multiplication factor of leafminer
0	23.2.		0.3 ♀♀				0.3 ♀♀			
				25 x		25 x		37 x		37 x
1	25.3.	164	7.4		7.4		11.1		11.1	
				68 x		68 x		45 x		45 x
2	27.4.	6	504 ± 79		131		504 ± 98		365	
				26 x		10.1 x		3.3 x		4.6 x
3	25.5.	3	1328 ± 407		53		1607 ± 231		221	
				0.25 x		6.2 x		0.38 x		2.9 x
4*	25.6.	3	328 ± 33		0		637 ± 17		3	
				0.12 x		?		0.04 x		8.0
5*	21.7.	3	39 ± 1		0.2		24 ± 3		0.4	

* 4th generation: out of 326 maggots there were 196 dead
637 536

5th generation: out of 39 maggots there were 34 dead
24 18

Table 3: Parasitisation percentages per sample during five generations of the tomato leafminer Liriomyza bryoniae Kalt. in spring 1981. Opius pallipes was introduced as adults on 8.4.81, just at the start of the second maggot generation.

Date	Generation	Size sample of maggots	Greenhouse 1			Greenhouse 2		
			O.p.+	D.s.+	D.i.+	O.p.+	D.s.+	D.i.+
14.4.	2	52	60	-	-	13	-	-
21.4.	2	50	78	-	-	30	-	-
28.4.	2	55	89	-	-	40	-	-
6.5.	3	22	73	14	-	73	-	-
15.5.	3	50	90	8	-	64	20	-
21.5.	3	50	88	12	-	76	18	-
29.5.	3	50	94	6	-	84	12	-
4.6.	4*	25	52 (100)	0	48	76 (88)	4 (12)	20
1.7.	5*	25	52 (80)	16 (20)	32	36 (68)	12 (32)	52
21.7.	5*	17	65 (71)	18 (24)	12	56	31	0

* Note: Between brackets the parasitisation percentages of Opius and Dacnusa are mentioned when Diglyphus isaea is not taken into account

+ O.p. = Opius pallipes
D.s. = Dacnusa sibirica
D.i. = Diglyphus isaea

The levels and percentages of parasitization are given in Table 3. These are based on dissection of a sample of full grown maggots of each generation (preferably 50 maggots collected through the whole greenhouse). Only the first and second generation of the miner were really separated and so it was possible to sample for parasitization weekly (Table 3).

Results

From Table 2 it can be seen that the multiplication of the number of mines varies strongly (columns 5 and 9) and so it is with the rate of increase of the pest itself: 2.9-68 times (columns 7 and 11). It seems

that multiplication in February-March is much higher (25-68X) than in May-June (2.9-8.0X). The infestation levels were the same (2nd generation: 504) and even the development of the numbers of mines to an acceptable level (30 and 24 per plant) was nearly identical despite different introductions of the parasite.

In Table 3 it can be seen that Dacnusa sibirica and Diglyphus isaea occurred spontaneously since May and June respectively. Opius was mainly responsible for the destruction of the pest population in July, respectively (80) and (68)% on July 1, when Diglyphus parasitization is neglected. But the high number of larvae killed by Diglyphus should not be overlooked (respectively 28 and 39% parasitized on July 1, and 132 and 196 dead larvae; in Figure 1).

In greenhouse 2 an introduction of Opius at 3% of the numbers of the previous (first) maggot generation resulted in a sufficient control as good as the 17% introduction in greenhouse 1.

Summary

An early occurrence/introduction of Opius pallipes at a rate of 3% of the maggots of the preceding generation of tomato leafminer can achieve a good level of control in spring crop tomatoes in Dutch greenhouses.

References

De Brouwer, W.M.Th.J. & Offeren, A.L. van (1966). De mineervlieg Liriomyza solani Her. bij tomaat. A.R. Glassh. Crops Res. & Exp. Station 1966, 151-153.

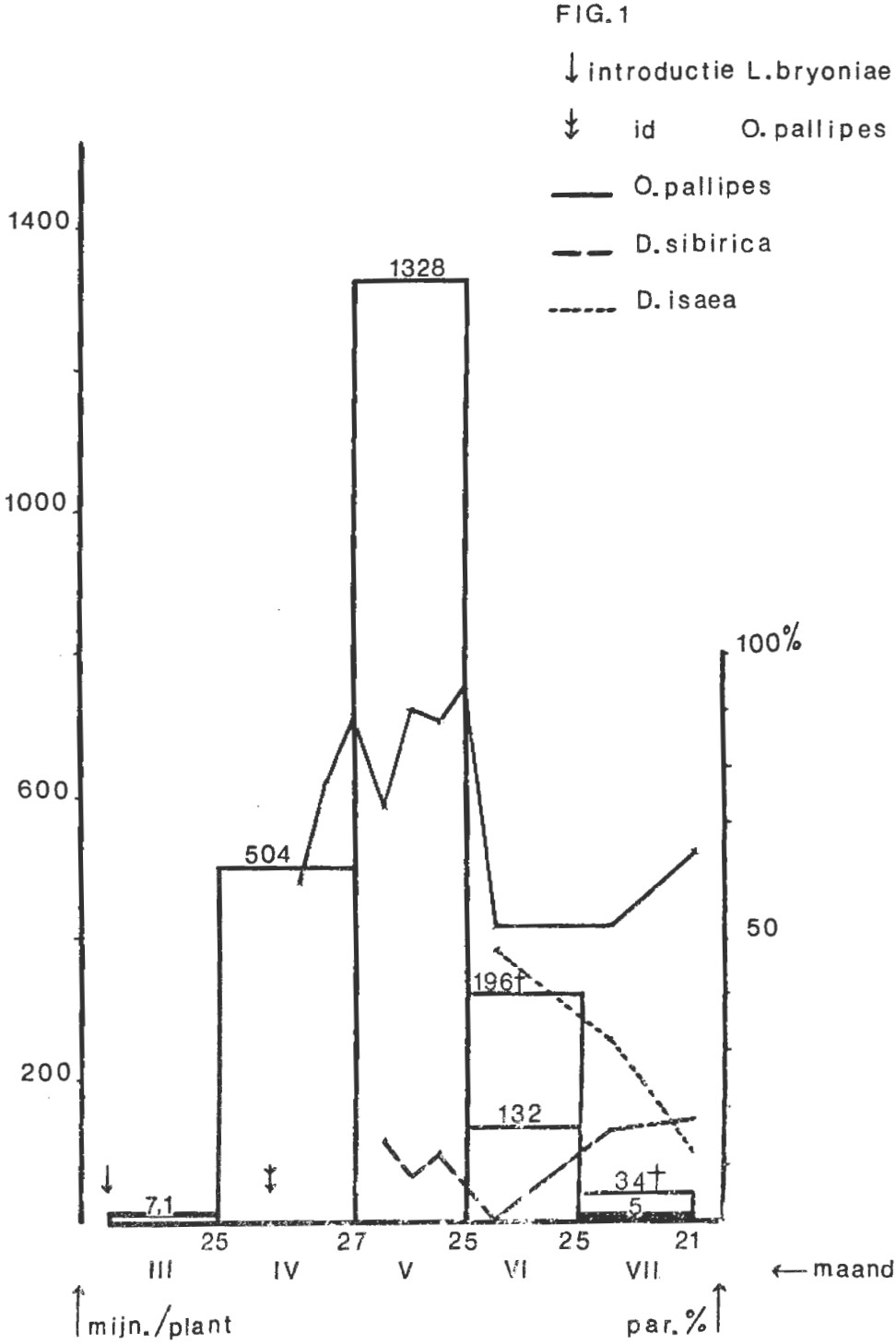
Hendrikse, A., Zucchi, R., Lenteren, J.C. van and Woets, J. (1980). Dacnusa sibirica Telenga and Opius pallipes Wesmael (Hym., Braconidae) in the control of the tomato leafminer Liriomyza bryoniae Kalt. Bull. IOBC/WPRS 1980/III/3, 83-98.

Hussey, N.W., Read, W.H. & Hesling, J.J. (1969). The pests of protected cultivation. London, Edward Arnold, 404 pp.

Hussey, N.W., Stacey, D.L. & Parr, W.J. (1975). Control of the tomato leafminer Liriomyza bryoniae within an integrated programme for pests and diseases of tomato. Proc. 8th British Insect and Fungic. Conf. (1975), 109-116.

Woets, J. & Linden, A. van der (1982). On the occurrence of *Opius pallipes* Wesmael and *Dacnusa sibirica* Telenga (Braconidae) in cases of natural control of the tomato leafminer *Liriomyza bryoniae* Kalt. (Agromyzidae) in some large greenhouses in the Netherlands. *Med. Fac. Landbouww. Rijskuniv. Gent* 47 (in press).

FIG. 1


↓ introductie L. bryoniae
↧ id O. pallipes
O. pallipes
D. sibirica
D. isaea
1400
1000
600
200
1328
504
196†
132
34†
5
7,1
100%
50
25
27
25
25
21
III
IV
V
VI
VII
← maand
mijn./plant
par.%

TEMPERATURE CONSTRAINTS IN THE CONTROL OF MEALYBUG AND SCALE INSECTS

M.J.W. Copland

In general, biological control of glasshouse pests has concentrated on vegetable and some flower crops. For some years at Wye, we have been interested in extending this control to hot-house ornamental foliage plants which we define as those maintained above 15°C. While there is a wide diversity of plant families and species in cultivation, there are relatively few pests. These mainly comprise the familiar glasshouse whitefly, red spider mite, aphids, thrips and the slow-growing coccid species which are usually associated with woody subjects. We have concentrated on the control of the coccid group, in particular the mealybug Planococcus citri (Risso) and the soft scales Saissetia coffeae (Walker) and S. oleae (Bernard). The prospects for control seem promising for several reasons. Ornamental foliage plants have a long life and time is available to establish a balance between pest and parasite. The relatively high temperatures maintained throughout the year favour tropical control agents. There is a large number of predators and parasites known to attack these coccids, unlike the one parasite and one predator system used for whitefly and spider mite control. There is also a good deal of literature from many parts of the world on the control of these pests in the field.

Ornamental foliage plants could be a potentially large market for the producer of biological control agents, although we have found detailed figures hard to obtain. Van Lenteren et al. (1980) suggested 50% of the glasshouse area is devoted to ornamentals and a substantial amount of this must be allocated to high production cost, high value ornamental subjects. Pest control is needed throughout one plant's long life and there are three main groups of growers who might benefit. The first is the commercial grower who may be reluctant to use biological control because of residual pests. A pre-sale chemical clean-up of the plants could overcome this objection. In the case of chemical-sensitive subjects, such as ferns, biological control offers a good solution. The second group comprises the amenity and educational collections and the very large number of amateur plant growers. Here, the presence of many different plants alongside each other and access or use by the general public restrict the toxic chemicals normally used by commercial growers. An important benefit of biological control in plant collections

is that fish, butterflies and other livestock can cohabit the glasshouse. Thirdly, the majority of plants end up in the office and home. There should be considerable scope for biological control here where toxicity, smell and a general dislike of chemical control favour alternative methods and there is a willingness to try novel solutions.

Our approach has been to choose a range of beneficial species which could achieve control starting at any pest density and which will attack a range of pest stages. Our initial choice includes the following: Cryptolaemus montrouzieri Mulsant, the well known coccinellid beetle whose adult and larval stages consume mealybug and soft scale; the chalcid parasites Pauridea peregrina Timberlake and Leptomastidea abnormis (Girault) which attack young mealybug; Leptomastix dactylopii Howard and Anagyrus pseudococci (Girault) which attack older stages; Metaphycus helvolus Compere and Coccophagus lycimnia (Walker) which attack young soft scale; and Scutellista cyanea Motschulsky which attacks the mature stage.

We are particularly concerned with the relationship between temperature and biology. The high costs of fuel make it essential to use the minimum of glasshouse heating during the autumn, winter and spring period. Similarly in the office and home, comfortable working temperatures are rather low throughout the year. There is no shortage of studies on the relationship between biology and temperature in insects. Most of these examine the life cycle at constant temperatures then calculate the theoretical lower temperature threshold for the species and express the life cycle as a thermal constant requiring so many day/degrees. Whilst this is a useful concept, when used in practice to calculate life cycles under cyclical glasshouse temperatures, large errors are experienced especially at temperature extremes. This in turn has led to even more complex formulate which have not necessarily greatly improved the accuracy of predictions.

Our approach has been to recognise the complexity of the temperature relationship and to try to break it down into simpler component parts. We look at various aspects of biology over a range of temperatures in incubators and constant temperature rooms. We compare the results with those obtained under cyclical conditions within a glasshouse in which temperature is monitored continually using a microcomputer system. It is clear that the relationship with temperature is a complex interaction between growth and behavioural activities. For every species each process has its own unique relationship which we can calculate, although there are some overall trends. We find that the entire growth of pest

species, whose main activity is to sit and suck sap, shows a largely linear relationship with temperature but the rates of increase vary from stage to stage and between species. Overall egg production and longevity show an inverse relationship with temperature. Among predators and parasites the development of eggs and pupae and individual egg production shows a linear increase with temperature. Growth, which involves active search for food, and the activities of host searching and egg laying, have an optimal temperature relationship. In general, these behavioural activities require high temperatures but only for a few hours each day.

We do not view all this as a purely theoretical study, but as a practical method of applying biological control. For each pest species and its control agents, we are trying to produce a simple computer programme which can calculate the number of parasites or predators to be released to control a pest population of a certain size within a defined period. Under glasshouse conditions, in addition to the cyclical temperature regimes, there are the added complexities of pest density and host preference. Our solution is to monitor the hourly mean temperature for at least a twenty-four hour period and preferably longer, as simple daily maximum and minimum temperature data are not adequate. By this monitoring, we can predict, at hourly intervals, the accumulation of life cycle (without reference to day/degrees), the dispersal rate, the host encounter rate and the number of eggs that can be developed and laid. Temperatures may be adequate for growth but if they are below that required for specific activities, control will not be achieved. Although we are still developing this system, we are pleased with the results so far obtained as our predictions, based on monitored data, are accurate to within 10% of our glasshouse observations.

We see a second application in using this data in microcomputer glasshouse control systems. Here the heating system is programmed to provide the necessary mean temperature for parasite and predator development. Each day a relatively short period at a higher temperature meets the requirements for dispersal and egg laying. Provided these warmer periods coincide with maximum light, the plants also benefit from this cyclical temperature regime, whilst there is not necessarily any increase in the overall heating costs.

In the long term we need to gather a great deal of information to include all pest species and their biological control agents. We believe that the combination of biological control and microcomputers provides a unique solution for glasshouse pest control. The technique places a

powerful diagnostic tool in the hands of the advisor and supplier of biological control agents which can ensure a greater degree of success and therefore acceptance of the technique.

Acknowledgements

Credit must be given to Johanne Brown, Abdul Gahni Ibrahim and Colin Tingle who are engaged in this work, the Ministry of Agriculture and the University of London Central Research Fund for their support and to the many people who kindly sent parasite cultures for us to establish.

References

Van Lenteren, J.C., Ramakers, P.M.J. & Woets, J. (1980). World situation of biological control in greenhouses, with special attention to factors limiting application. Meded. Fac. Landbouww. Rijksuniv. Gent, 45, 537-544.

INTRODUCTION OF APHIDOLETES APHIDIMYZA (ROND.) (DIPTERA: CECIDOMYIIDAE) FROM AN OPEN REARING UNIT FOR THE CONTROL OF APHIDS IN GLASSHOUSES

Lise Stengard Hansen

Introduction

The aphid midge, Aphidoletes aphidimyza, has been the object of investigations concerning its possibilities as a control agent of aphids (El Titi, 1974; Markkula et al., 1977; Asjakin, 1977) and has been commercially available for growers in Finland since 1978. In Denmark work on the aphid midge started in 1979 and has been financed by the Danish Agricultural and Veterinary Research Council since 1981. This work consists partly of investigations on the biology of the midge and partly of practical control experiments on Danish glasshouse crops, mostly sweet pepper. In one glasshouse, control experiments have been carried out since the spring of 1980. Establishment was obtained by means of open rearing units. The results of these experiments are described below.

Method

In an unheated glasshouse (1000 m^2) with sweet pepper (Capsicum annuum) A. aphidimyza was introduced shortly after the peppers were planted (in the beginning of May). To ensure survival of the aphid midge from the time of introduction until aphids appeared, the introduction was made in "open rearing units". The principle of open rearing units is that the midge is provided with a food source, consisting of an aphid species which does not attack the glasshouse crop. Open rearing units are established early in the growing season, so that a large population is present by the time aphids appear. In this way control is ensured without the demand for time-consuming checks of the crop.

Establishment of open rearing units and population estimates

1980. On May 19, 8 boxes (30 x 70 x 30 cm), in which 100 Broad beans (Vicia faba, cv. Bonny Lad, height 15-30 cm) had been sown, were placed in the glasshouse. 100-200 Vetch aphids (Megoura viciae (Buckton)), specific to leguminous plants, were transferred to each box. Two weeks later (June 3) A. aphidimyza pupae in moist earth were distributed in the boxes. As peach potato aphid (Myzus persicae (Sulz.)) were observed on the peppers at the same time, suggesting that the rearing

units had been established too late, 8000 extra A. aphidimyza pupae were introduced into the glasshouse during the following month. When necessary, more M. viciae were transferred to the beans, so that a moderate population was constantly present during the first part of the growing season.

Twice a week from June 12 until September 1, approximately 460 pepper leaves were selected at random and the number of live aphids, A. aphidimyza larvae and eggs were counted. The data were then related to leaf area.

1981 and 1982. Boxes with bean plants (as described above) were placed in the glasshouse in the first week of May and infested with M. viciae. Introduction of A. aphidimyza proved to be superfluous, as a large population of eggs and larvae, deriving from overwintering pupae, was observed in the open rearing units 1 week later. The M. viciae population was supplemented when necessary. Exact population counts were not made. An evaluation of the experiment was based on the grower's opinion and the need for chemical control plus an inspection of the crop every 10-14 days.

Results

1980 (see Figure 1)

The dominant aphid species was Myzus persicae. The aphid population density increased rapidly during the first 4 weeks, followed by a slower increase until July 25. From this date on the density decreased until the beginning of September. The A. aphidimyza population showed the same pattern of increasing and decreasing densities, with a delay of approx. 7 days. At the end of the growing season the aphid population showed a slight increase without a corresponding increase in A. aphidimyza, due to the onset of diapause.

The aphid density never exceeded a level which necessitated a chemical treatment.

1981

The presence of M. viciae in the open rearing units in the first week of May was sufficient to ensure the survival of the midges emerging from diapause. They were able to control the aphids throughout the growing season. In the beginning of September, the aphids had been

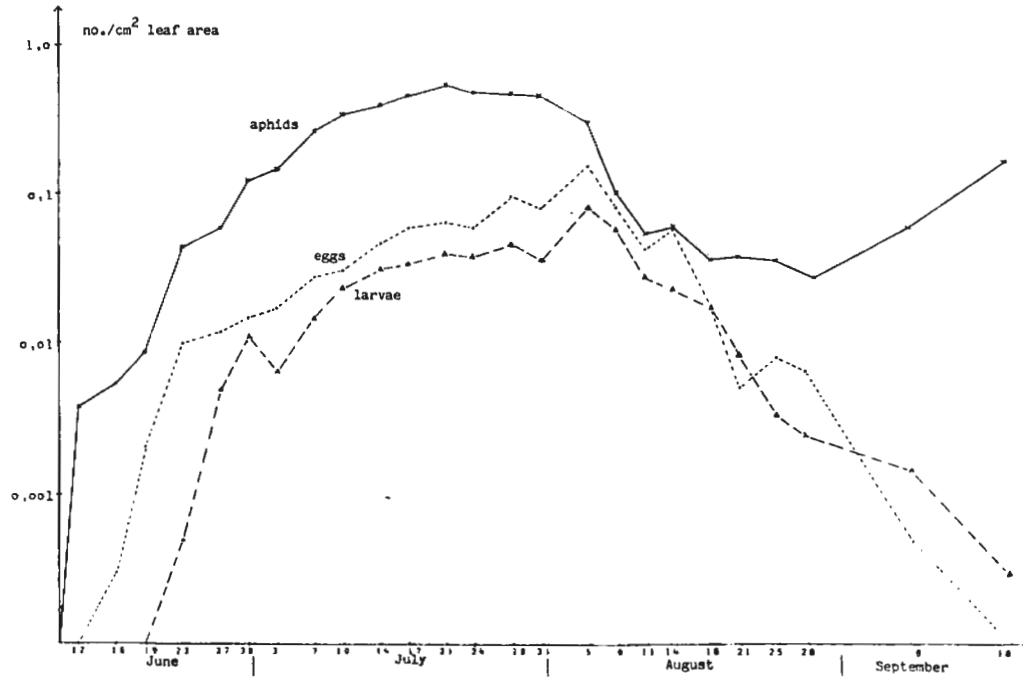


Figure 1: Population densities of aphids, A. aphidimyza eggs and larvae (no./cm^2) on sweet pepper
Aphids ×——×; A. aphidimyza eggs·····; A. aphidimyza larvae▲— — — —▲

eradicated, so that no population increase occurred after the midge entered diapause.

1982

The results up until the middle of July were parallel to 1981: Overwintering A. aphidimyza emerging from diapause invaded the open rearing units, so that additional introductions of the midge have been unnecessary. Colonies of Myzus persicae and A. aphidimyza have been detected on the pepper plants.

Discussion

In 1982 open rearing units were established in a number of glasshouses. From these experiments and the one mentioned above, the following conclusions can be made:

- A successful control of aphids can be obtained by means of open rearing units for A. aphidimyza.

- An overwintering population of A. aphidimyza can render annual introductions of natural enemies superfluous, if an alternative food source is provided in the beginning of May (in heated glasshouses in the middle of April (L:D = 14:1)).

- The survival of M. viciae on the bean plants is crucial to successful control. This means that the population of M. viciae must be kept at a density which is harmless to the bean plants. The safest way to ensure this is to introduce A. aphidimyza on the same day that M. viciae is transferred to the beans. The fact that the most successful establishment of open rearing units has been obtained in glasshouses with an overwintering population of A. aphidimyza confirms this.

- An extra supply of A. aphidimyza must be available in case the crop is already infested by aphids at the time of planting. In this case supplementary introductions of A. aphidimyza pupae must be made, until control is established.

References

Asjakin, B.P. (1977). Effectiveness of the cecidomyid Aphidoletes aphidimyza in the control of aphids on vegetable crops in greenhouses. (Russian) Zaschity Rastenii 53, 121-130.

El Titi, A. (1974). Auswirkung von der räuberischen Gallmücke Aphidoletes aphidimyza (Rond.) (Diptera: Itonididae) auf Blattlauspopulationen unter Glas. Z. ang. Ent. 76, 406-417.

Markkula, M. & Tiittanen, K. (1977). Use of the predatory midge Aphidoletes aphidimyza (Rond.) (Diptera: Cecidomyiidae) against aphids in glasshouse cultures. Proc. Symp. XV Int. Congr. Ent. Wash. D.C. USDA AS ARS-NE-85, 43-44.

PROGRESS IN APHID CONTROL IN PROTECTED CROPS

J.M. Rabasse, J.P. Lafont, I. Delpuech & P. Silvie

Resumé

PROGRES REALISES DANS LA LUTTE BIOLOGIQUE CONTRE LES PUCERONS EN SERRE

Des essais de lutte biologique sur aubergine ont porté sur deux types d'organismes aphidigphages: d'une part un parasite de Myzus persicae, Aphidius matricariae, qui commence a être bien connu sur le plan biologique et qui est souvent rencontré en serre; d'autre part, les mycoses à Entomophthoracées dont les possibilités dans ce type de culture n'ont pas encore été très étudiées.

A. matricariae s'est introduit spontanément, mais assez tard en 1978; en 1980 il a été lâché à une date plus précoce, mais le nombre de momies formées par les individus lâchés était faible. Le multiplication des parasites est plus rapide que celle des pucerons (Fig. 1) et, les deux années, les populations ont été contrôlées 3 semaines après que l'on ait observé 0.1 momie par plante. A partir de 5 momies par plante, on peut considérer que la population aphidienne est condamnée (Fig. 2). L'action des parasites est bien répartie sur les différentes plantes, quelle que soit leur situation et la population de pucerons qu'elles portent. Les momies constituent une image plus ou moins décalée dans le temps de l'action du parasite; une méthode est proposée pour mieux exprimer la parasitisme (formule 2, tableau 1).

Dans les essais de mycoses, nous n'avons pas encore réussi de contamination primaire massive. Le renforcement de l'humidité nocturne par l'utilisation d'un mist conduit à des épizooties mixtes de l'espèce épandue (sans qu'on ait vérifié l'identité de la souche) et d'autres espèces, qui sont assez semblables à celles que l'on peut observer en plein champ dans d'autres régions (Fig. 3).

Dans les deux cas, nos essais constituent donc des lâchers inoculatifs d'aphidiphages efficaces qui, après s'être installés en petite quantité, détruisent leur hôte plus vite que celui-ci ne se multiplie.

The resistance of Myzus persicae to insecticides is increasing (Sawicki et al., 1980) but, as yet, few aphidophagous organisms are used in glasshouses. We consider that the time is coming for a change in control methods, and discuss here ways in which natural enemies may be employed as control agents. We have taken as examples Aphidius matricariae and several fungal pathogens.

Firstly, Wyatt (1970) and Tremblay (1973) drew attention to the part that Aphidius matricariae Hal. could play against this pest. It became obvious later that this parasite was common and abundant in glasshouses where the principles of integrated pest management were applied (Scopes & Ledieu, 1979; van Lenterent et al., 1979). At the same time, several papers appeared dealing with laboratory results of some importance for the prospect of its practical use. These included rate of development (Scopes & Biggerstaff, 1977; Rabasse & Shalaby, 1980), host selection (T'Hart et al., 1978; Lafont, 1982) and fecundity (Rabasse & Shalaby, 1979). We first described the way this parasite settles on aubergine in experimental glasshouses (Rabasse, 1980), and in the present paper try to estimate its efficiency in the same ecological conditions, after release or natural invasion (Expt. 1978 & 1980).

Experiments on fungal epizootics on aphids under glass (Expt. 1982) were encouraged by the good results obtained by Hall (1980) using Verticillium lecanii, and also by the new methods for processing Entomophthoraceae developed at the Institut Pasteur (Latge et al., 1978).

Methods

Tests have been carried out in experimental glasshouses of 100 m^2, located at Valbonne and surrounded by a sparse Mediterranean vegetation, dotted with oaks. The aubergines cv. Bonica, grafted on K.N.V.F. tomato, were planted at a density of 2/m^2 and observed at weekly intervals. Up until 12.4.78, 9.4.80 and 27.4.82 insects were counted on all the plants but afterwards samples were used: 1/8 (48 half-plants) in 1978, 1/16 (24 half-plants) in 1980 and 1982.

Efficiency of A. matricarize against M. persicae

In 1978, A. matricariae entered naturally but late into the glasshouse: the first mummies being observed on 2 May, i.e. 7 weeks after the aphids (alates M. persicae were released 10 days after planting). Other aphid species were note numerous: equivalent to only 2% of the population of M. persicae on 23 May, when this species reached its maximum. In

1980, alates M. persicae were released 9 days after planting and Macrosiphum euphorbiae also formed numerous colonies which continued growing after M. persicae had been limited (Fig. 1). We released 258 A. matricariae males and 285 females on two occasions: 1 April and 10-11 April, i.e. 15 females per 100 aphids on the first occasion, and 9 per 100 on the second. On 22 April, it could be seen that the parasite was well established since there were 112 mummies on 33 plants. So on each occasion, about 0.5 mummies had been produced by each female released. In 1976, we obtained 1 or 2 mummies per female (Rabasse, 1980). These values are very low compared to the 400 mummies that a female parasite can produce in the best conditions (Shalaby & Rabasse, 1979; Lafont, 1982). As the initial efficiency of the individuals released is low, we have decided not to pay as much attention to the parasitoid/host ratio as do other authors (Hofsvang & Hagvar, 1980).

Fig.1 shows that plants grow at an even rate. The populations of M. persicae double every 2.5 days during the first period (which is very near the value obtained in laboratory experiments). Temperature was more than 1°C higher in 1980 than in 1978, but aphid multiplication was slightly slower that year, probably because of a breakdown in the heating system from 21 to 24 April. Fig. 2 shows that A. matricariae developed more slowly in 1980. The percentage of mummies clearly increases only when there are more than 1,000 green peach aphids per plant. In both years, control was achieved 3 weeks after 0.1 mummies had been observed per plant. In our environmental conditions, it is clear that once the parasite population reaches 5 mummies per 100 aphids, the aphid population crashes. Aphid densities, when the populations reached their peaks, were 94/dm^2 on 23 May 1978 and 87 on 12 May 1980.

Detailed studies, not reported here (Lafont, 1982), showed that:

- On the scale of our small glasshouses, the dissemination of this active wasp is rapid.

- At different heights, the plant is colonized first by aphids, then by parasites, inducing differences in the percentage of mummies (double on the middle leaves, than on the others) and care must be taken to take account of this when sampling.

- The parasite does not discriminate between plants with low or heavy aphid populations.

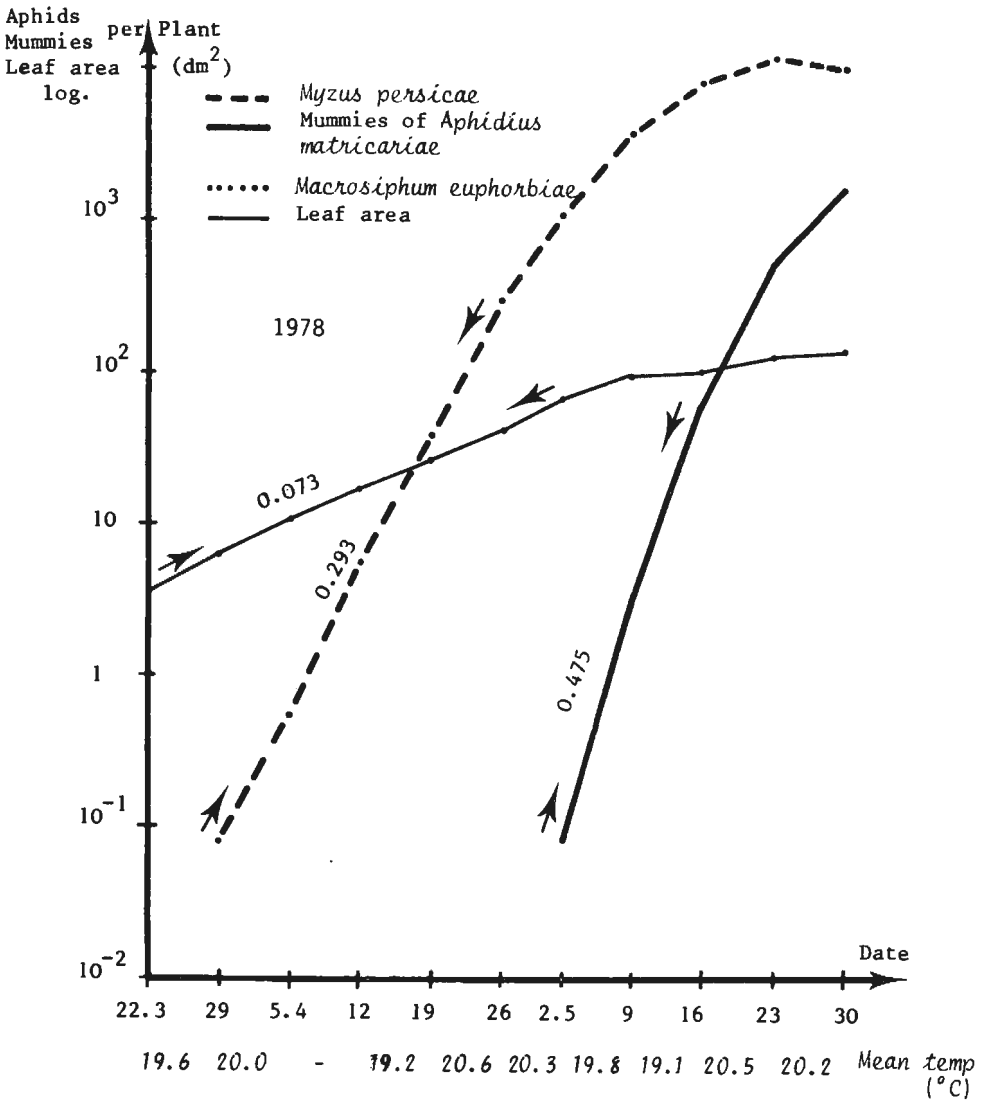


Figure 1: Population trends of Aphidius matricariae (mummies), Myzus persicae and Macrosiphum euphorbiae on aubergine in 1978 and 1980. (When the growth is more or less exponential, i.e. between arrows, the increase rate r is mentioned.)

/Continued ...

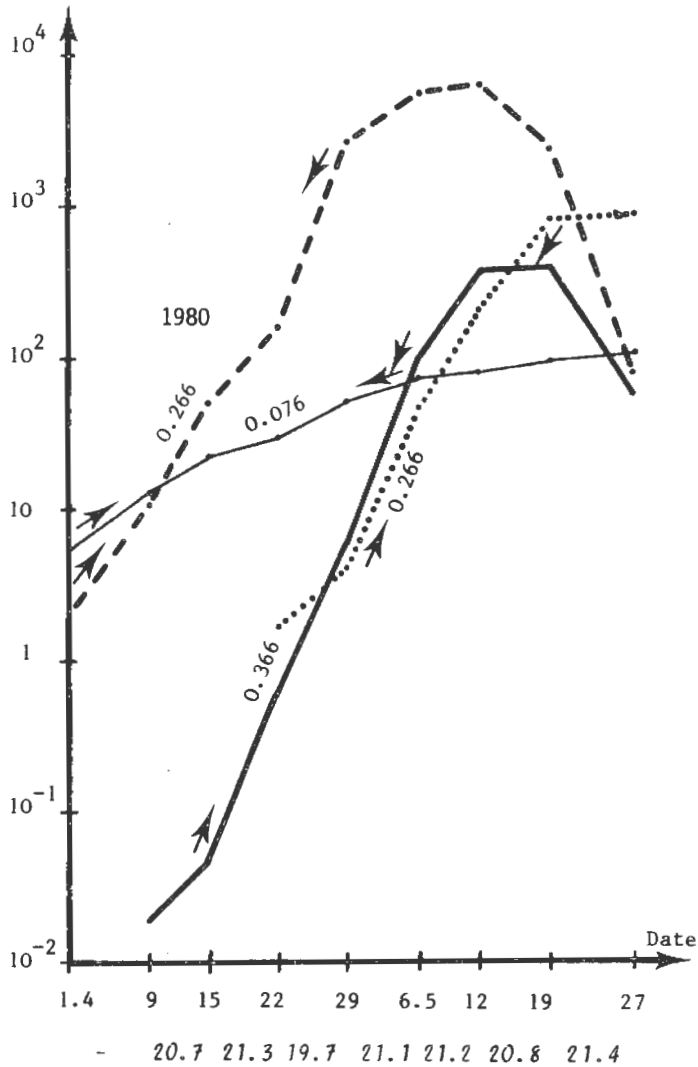


Figure 1: (Continued) - see previous page for caption

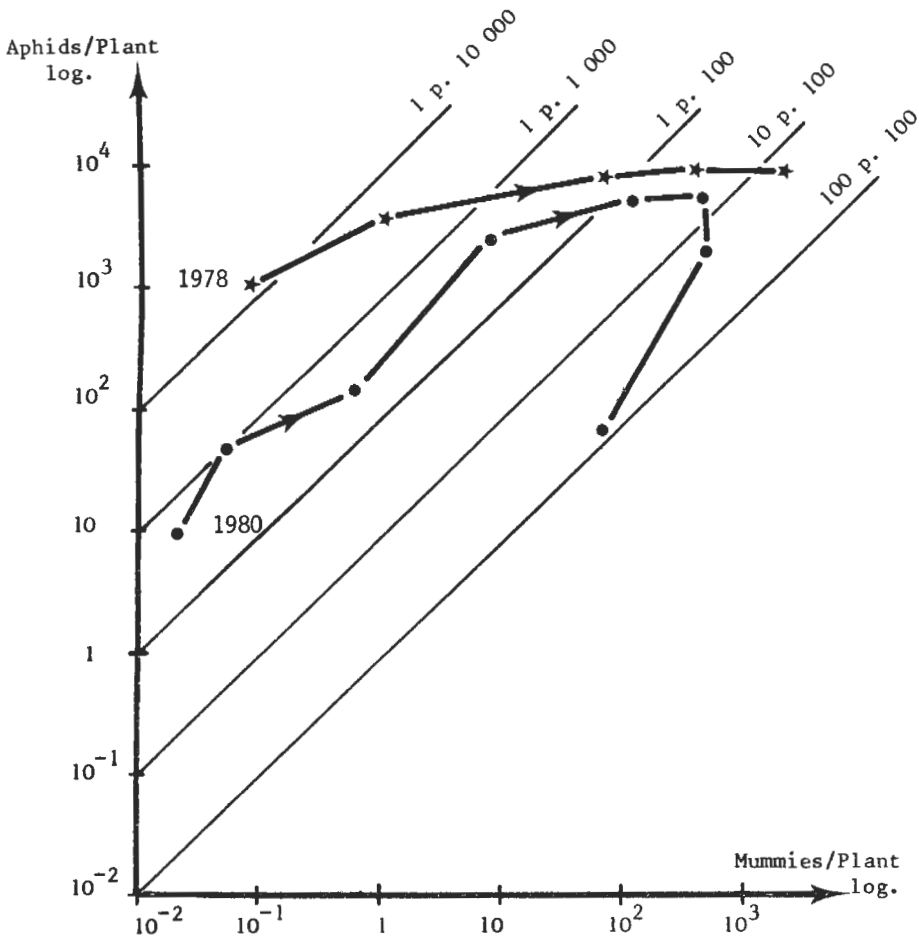


Figure 2: Development in time of the relationship between the mean number of living Myzus persicae and of mummies of Aphidius matricariae per plant (weekly observations)

In this kind of field trial, even when the action of the parasite is as strong as in Figure 2 and when other kinds of mortality and immigration of winged forms are negligible, it is better to compare natality to mortality caused by the biological control agent involved. In the large samples, necessary in aphid population studies, two kinds of data are easy to collect: the number of living aphids and the number of full mummies. At 20°C, mummies are formed 8.5 days after parasitization, and 5 days elapse before hatching. So, the number of mummies on d day M_d is the sum of the numbers of parasitized aphids P at different dates:

$$M_d = P_{d-0} + P_{d-10} + P_{d-11} + P_{d-12} + P_{d-13} \qquad (1)$$

If P changes about d-11 in the same way that M changes about d (we approximate this variation by an exponential growth in the intervals on each side of d):

$$M_d = P_{d-11} \left(e^{-2r'} + e^{-r'} + 1 + e^{r''} + e^{2r''}\right) \qquad (2)$$

So P_{d-11} is calculated from M_d. Then we calculate the increase of the aphid population A_{d-11} by linear interpolation after logarithmic transformation between two sampling occasions.

In this way, Table 1 gives a picture of the action of the parasite from the start of parasitism. Comparison with Fig. 1 shows that aphid increase is stopped precisely when its daily increase is balanced by parasitism. Nevertheless, this expression underestimates the action of the parasite, because only the parasitized aphids that transform into mummies on the plant are taken into account, and not the disturbed or parasitized aphids that go away.

Table 1: Daily increase of the aphid population A compared to the number of aphids parasitized P during the same day in the glasshouse (see text for calculation of A and B)

Date	Aphid population increase A	Parasitism P	$\frac{P}{A} \times 100$
28.4.78	22,657	107	0.5
5.5.78	77,524	2,523	3.3
12.5.78	121,907	10,639	8.7
19.5.78	104,869	71,641	68.3
11.4.80	1,146	20	1.8
18.4.80	3.021	196	6.5
25.4.80	57,772	3,989	6.9
1.5.80	76,394	15,845	20.7
8.5.80	19,871	15,993	80.5

Epizootics of Entomophthoraceae on aubergine

Several biological control trials with Entomophthoraceae have been carried out on aubergine and lettuce in 1981 and 1982 at Valbonne with the collaboration of the Institut Pasteur. We summarize below and in Figure 3 the results of only one of these on aubergine.

Climatic conditions. The minimum humidity (percentage and duration) required by the fungi to spread through aphid populations is not precisely known. In this experiment, we operated the mist system 6 sec. every 12 min. during the night and 6 sec. every 2 min. during the day. This resulted in a 2 mm spray for the night period and 12 mm for the day. It was therefore possible to maintain saturated conditions and free water when the glasshouse was closed, i.e. during 12 h, but, on sunny days, the spray barely affected the relative humidity, which remained under 50%.

Inoculum. Humidity was increased after each treatment, and after a relatively long period, a few aphids were found killed by the applied fungus as well as some killed by other species. Nevertheless, we could not precisely compare the strains released to the strains collected in the glasshouse. In this experiment, mycelium of Erynia neaoaphidis Rem. and Henn. was sprayed on 13 May, and the first diseased aphids infected

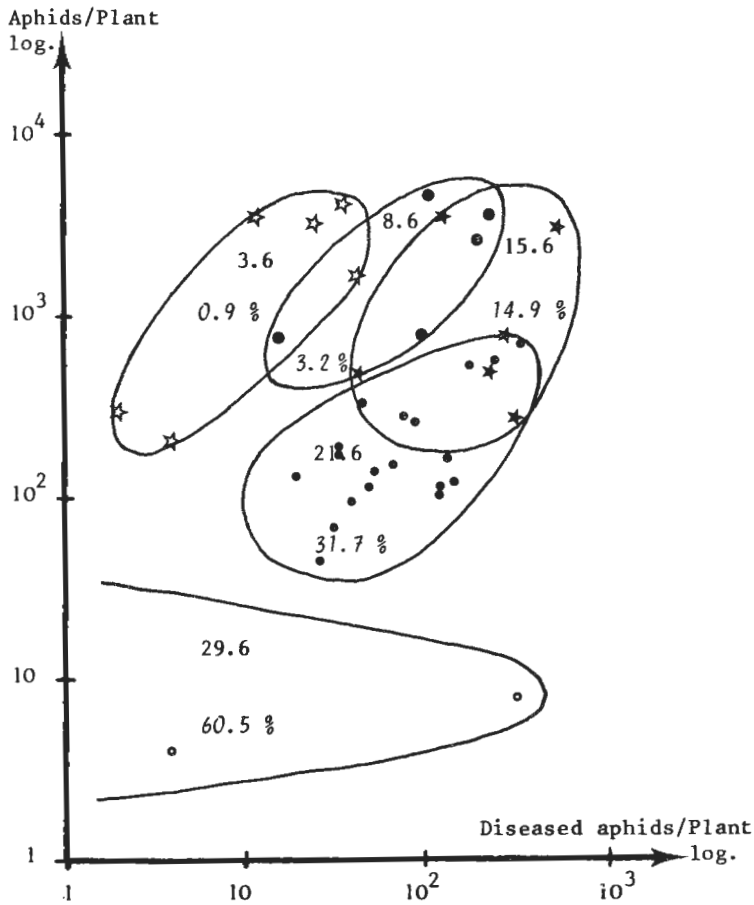


Figure 3: Relationship between the number of living and of diseased aphids per plant at different dates in 1982 (percentage of diseased aphids included). Aphids: Myzus persicae + Macrosiphum euphorbiae. Diseases: Erynia neoaphidis + Entomopthora planchoniana.

by E. neoaphidis and Entomophthora planchoniana Cornu were found on 27 May. We have to stress that this area is not known to be favourable to these fungi, and that they do not appear on crops on which humidity is not enhanced.

Epizootic. Figure 3 describes how an epizootic occurred in a mixed population of M. persicae and M. euphorbiae, whose composition changed slowly from a ratio of 3:1 M. persicae to M. euphorbiae on 27 May to one of 1:3 on 21 June (since M. persicae was also attacked by A. matricariae). The part played by each fungus also changed: the percentages of the aphids in which disease could be precisely identified were as follows:

8.6	E. neoaphidis	: 18% -	E. planchoniana	: 82% -	n = 68
15.6	"	60%	"	40% -	n = 158
21.6	"	68%	"	32% -	n = 148

When they are very numerous, diseased aphids spread the fungus among the aphids in neighbouring glasshouses. So the fungi do not act as biological insecticides, but develop an epizootic over several weeks similar to that occurring naturally in the fields of Brittany on the black bean aphid (Rabasse & Dedryver, 1982).

Discussion

These two types of biological control agents have some common features:

- They develop gradually so we do not use inundative release, the effect of which is expected within a short time, but cumulative release that requires several generations of the entomophagous organism to reach full efficiency.

- They are well fitted for natural survival and can appear spontaneously, at least in small glasshouses.

A. matricariae gave proof of its efficiency: it is specific and can therefore be used on only one of the important aphid species, but, on the other hand, it is more difficult to produce and store than other parasitoids used in integrated control under glass.

Up till now, the ways in which Entomophthoraceae could be used under glass have been little explored. Their scope for use may be limited by the difficulty in raising humidity sufficiently during hot days, as well as by risks of adverse effects on the crop plants under such conditions.

References

Hall, R.A. (1980). Control of aphids by the fungus Verticillium lecanii: effect of spore concentration. Ent. exp. & appl. 27, 1-5.

Hofsvang, T. & Hågvar, E.B. (1980). Use of mummies of Epherus cerasicola Stary to control Myzus persicae (Sulzer) in small glasshouses. Z. ang. Ent. 90, 220-226.

Lafont, J.P. (1982). Contribution à l'étude de la biologie d'Aphidius matricariae Hal. et de son efficacité contre Myzus persicae Sulz. (Hym., Aphidiidae; Hom., Aphididae). Mémoire de l'Ecole Pratique des Hautes Etudes, 116 pp.

Latge, J.P., Remaudiere, G. & Papierok, B. (1978). Un exemple de recherche en lutte biologique: les champignons Entomophthora pathogènes de pucerons. Bull. Sox. Pathol. Exotique 17, 196-203.

Lenteren, J.C. van, Ramakers, P.M.J. & Woets, J. (1979). The biological control situation in Dutch glasshouses: problems with Trialeurodes vaporariorum (Westwood), Liriomyza bryoniae Kalt. and Myzus persicae Sulz. Med. Fac. Landbouww. Rijksuniv. Gent 44, 117-125.

Rabasse, J.M. (1980). Implantation d'Aphidius matricariae dans les populations de Myzus persicae en culture d'aubergines sous serre. Bull. OILB/SROP, III/3, 175-185.

Rabasse, J.M. & Dedryver, C.A. (1982). Facteurs de limitation des populations d'Aphis fabae Scop. dans l'Ouest de la France. IV. Nouvelle données sur le déroulement des épizooties à Entomophthoracées sur féverole de printemps. Entomophaga 27 (in press).

Rabasse, J.M. & Shalaby, F.F. (1979). Incidence du parasite Aphidius matricariae Hal. (Hym., Aphidiidae) sur la fécondité de son hote Myzus persicae Sulz. (Hom., Aphididae) à différentes températures. Ann. Zool. Ecol. anim. 11, 359-369.

Rabasse, J.M. & Shalaby, F.F. (1980). Laboratory studies on the development of Myzus persicae Sulz. (Hom., Aphidiidae) and its primary parasite, Aphidius matricariae Hal. (Hym., Aphidiidae) at constant temperatures. Acta Oecologica, Oecol. Applic. 1, 21-28.

Sawicki, R.M., Devonshire, A.L., Payne, R.W. & Petzing, S.M. (1980). Stability of insecticide resistance in the peach-potato aphid, Myzus persicae (Sulzer). Pesticide Science 11, 33-42.

Scopes, N.E.A. & Biggerstaff, S.B. (1977). The use of a temperature integrator to predict the developmental period of the parasite Aphidius matricariae. J. appl. Ecol. 14, 799-802.

Scopes, N.E.A. & Ledieu, M.S. (1979). Integrated pest control on chrysanthemums and other flower crops. Scientif. Hortic. 31, 48-53.

Shalaby, F.F. & Rabasse, J.M. (1979). On the biology of Aphidius matricariae Hal. (Hymenoptera: Aphidiidae) parasite on Myzus persicae Sulz. (Homoptera: Aphididae). Ann. Agric. Sc. Moshtohor 11, 59-71.

T'Hart, J., De Jonge, J., Colle, G., Dicke, M., van Lenteren, J.C. & Ramakers, P. (1978). Host selection, host discrimination and functional response of Aphidius matricariae Haliday (Hymenoptera: Braconidae), a parasite of the green peach aphid, Myzus persicae (Sulz.). Med. Fac. Landbouww. Rijksuniv. Gent 43, 441-453.

Tremblay, E. (1973). Possibilità di empiego dell'Aphidius matricariae Hal. contro il Myzus persicae (Sulz.) in serra. Boll. Lab. Ent. Agr. F. Silvestri 30, 331-350.

Wyatt, I.J. (1970). The distribution of Myzus persicae (Sulz.) on year round chrysanthemums. II. Winter season: the effect of parasitism by Aphidius matricariae Hal. Ann. appl. Biol. 65, 31-41.

A GRANULOSIS DISEASE OF THE TOMATO MOTH LACANOBIA OLERACEA (L.)

G.N. Foster & N.E. Crook

Since 1977 the tomato moth (Lacanobia oleracea, also assigned to the genera Diataraxia, Hadena, Mamestra and Polia) has been second only to two-spotted spider mite (Tetranychus urticae) as a pest of tomato crops in the Clyde Valley, the main glasshouse area in Scotland. This change was due to the abandonment of steam sterilization, which killed over-wintering pupae. The moth's presence jeopardizes the acceptance of biological control methods for spider mite and glasshouse whitefly (Trialeurodes vaporariorum) because the persistent synthetic pyrethroids are more cost-effective than products containing Bacillus thuringiensis.

The appearance of a virus disease of L. oleracea caterpillars in the Clyde Valley in 1978 offered an alternative to B. thuringiensis in integrated control with the possible advantages of spread within the season and survival from one season to the next. Lloyd (1920) first noted a "flacherie" disease of L. oleracea in England and his description fits with the symptoms seen in Scotland. Although he reported the disease as "tolerably common", Speyer & Parr (1947), in continuing his work, noted only one affected caterpillar in over ten years of observation. Meynadier et al. (1969) described a granulosis disease from French L. oleracea. Dr J. Huber of the Institüt für Biologische Schadlings-bekämpfung kindly provided a sample of the French isolate collected in 1962. Electrophoresis of restriction enzyme digests of DNA from the French and Scottish isolates ($LoGV^F$, $LoGV^S$) revealed 20 fragments with three unique to each isolate, indicating that the isolates are distinct variants (Crook et al., 1982).

The disease is caused by a granulosis virus (subgroup B of the Baculoviridae). Each rod-like virus particle is enclosed in a protein capsule ca. 460 x 285 nm (Meynadier et al., 1969), just large enough to be resolved under the light microscope, so permitting an estimate of capsule concentration when preparing spray solutions.

The capsules dissolve when ingested by larvae and large numbers of capsules appear in the fat body, hypodermis and tracheal system a week after infection. Infected larvae are firstly pale and slightly bloated becoming blackish brown in death, when they normally hang down, clasping a leaf with the abdominal prolegs. In this position they drool a brown fluid with white granules.

Bench studies gave LD_{50} values ranging from $10^{4.3}$ capsules for 2nd instar larvae to $10^{6.6}$ capsules for 5th instar larvae. The LD_{50}s of $LoGV^F$ and $LoGV^S$ for 3rd instar larvae did not differ significantly.

Two experiments simulating commercial conditions showed the spraying strengths of 10^8-10^9 capsules ml^{-1} should be effective (Tables 1 and 2). Low survival of young larvae in nautral infestations on tomato is characteristic of tomato moth and explains the control value in Table 2.

Table 1: Survival of L. oleracea 4th instar larvae in sleeve cages on tomato plants sprayed with $LoGV^S$

Virus concentration (capsules ml^{-1})	Percent survival after 11 days		14 days	
0, 1.1×10^4, 1.1×10^5	100	-	100	-
1.1×10^6	98	1.8*	97	2.1*
1.1×10^7	72	5.6	48	6.2
1.1×10^8	25	5.4	12	4.1
1.1×10^9	22	5.2	8	3.4

Table 2: Survival of L. oleracea introduced at 100 eggs per tomato plant and sprayed with $LoGV^S$ when 3rd instar

Virus concentration (capsules ml^{-1})	Number of survivors per plant after 15 days	
0	9.0	1.7*
10^6	11.4	2.9
10^7	8.7	2.6
10^8	3.7	1.0
10^9	0.9	0.3

* Standard deviation

Clearance was obtained from the UK Government's Pesticides Safety Precautions Scheme to undertake commercial trials in 1981 using purified virus capsule suspensions at a high rate (10^9 capsules ml^{-1}) as a spot treatment or at a low rate (10^7 capsules ml^{-1}) to treat complete sections. Sites were chosen from holdings free from virus. Losses due to virus disease could not be separated from those due either to dislodgement and resultant starvation or to pupation. The low rate failed to establish granulosis (Site A, Table 3). At Site B, deaths due to virus disease, following treatment to the end plants of each row, were insufficient to control damage a fortnight after treatment. A further localized treatment apparently halted the attack. Damage was also minimized at Site C but the slight infestation in a plastic-clad tunnel at Site D probably died out because of an unusually severe deleafing programme.

Table 3: Trials data for Clyde Valley tomato crops treated with $LoGV^S$ for the control of L. oleracea

Site	A	B	C	D
Type	Glass	Glass	Glass	Plastic-clad
Number of plants	1800	2400	2000	2900
Virus concentration (capsules ml^{-1})	10^7	10^9	10^9	10^9
Area treated	Overall	Spot	Spot	Spot
Spray date	16 July	23 July*	13 August	24 June
Percent plants infested at spraying	0.8	5.8	3.0	0.6
Virus deaths seen	None	Many	Few	None
Larvae and damage on 25 August	224 healthy larvae on 2.1% of plants	No larvae but 9 plants with fresh damage	Minimal	None

* Second spray on 12 August

The glasshouse sites were searched for virus-infected larvae in 1982 but none could be found before it became necessary to treat each infestation. Virus-diseased caterpillars have, however, been detected each year on the three holdings where the virus was first detected in 1978. On these holdings the infection occurs in the first generation of

caterpillars and is initially very localized. It then appears to spread rapidly such that diseased caterpillars may be found in all parts of a moderately sized glasshouse (0.2 ha) within three weeks of the first dying caterpillars being seen. The epidemic continues in the second and third generations of larvae and provides good suppression of damage. Holdings neighbouring two of these sites have serious caterpillar attacks each year but no outbreaks of disease.

References

Crook, N.E., Brown, J.D. & Foster, G.N. (1982). Isolation and characterisation of a granulosis virus from the tomato moth, Lacanobia oleracea, and its potential as a control agent. J. Invertebr. Pathol. 40 (in press).

Lloyd, L. (1920). The habits of the glasshouse tomato moth, Hadena (Polia) oleracea, and its control. Ann. appl. Biol. 7, 66-102.

Meynadier, G., Poitout, S. & Kuhl, G. (1969). Une granulose, nouvelle affection de Mamestra oleracea L. (Lepidoptera, Noctuidae). Entomophaga 14, 421-427.

Speyer, E.R. & Parr, W.J. (1948). III. Animal Pests. I. The tomato moth (Diataraxia oleracea L.). Report of Exp. & Res. Stn., Cheshunt 1947, 41-63.

ASCHERSONIA ALEYRODIS, A SELECTIVE BIOLOGICAL INSECTICIDE

P.M.J. Ramakers

Introduction

Aschersonia spp. are highly specific insect pathogens; only Aleyrodids and Coccids are known to be hosts of these fungi. A. aleyrodis is an important factor in population dynamics of citrus whitefly, and manipulations of this fungus are already described by Fawcett (1908).

In more recent years, authors from Bulgaria and the USSR described attempts to use Aschersonia as a biological insecticides against greenhouse whitefly (Khristova, 1969; Spasova, 1974; Primak & Chizhik, 1975; Solovei & Koltsov, 1976; Kogan & Seryapin, 1978). Because of the characteristics of this fungus, mainly the lack of dispersal of its conidia under glasshouse conditions, it seems unlikely that it can compete with either chemicals or Encarsia formosa. Its specific nature, however, makes it worthwhile to investigate its potentials as an agent to restore the balance between whiteflies and their parasites in some critical situations. The availability of such an agent, either biological or chemical, would certainly increase the willingness of growers to use biological control methods at all.

Materials and Methods

Experiments were carried out on full-grown cucumber crops in heated glasshouses each containing about 100 plants. Minimum temperature was 18°C at night and 22°C at daytime. Some additional experiments were done on small potted plants (tobacco and egg plant).

In the first years (1979) and 1980) conidia of A. aleyrodis were produced on solid media in petri dishes or flat bottles, so only a very limited amount of conidia was available. In 1981, conidia were produced in a more efficient way on brown rice, resulting in a dry, storable powder containing $>10^8$ condia/gram (Rombach & Samson, in press). Before using this powder, viability of the conidia was checked, and only batches with >90% germination were used.

In 1979 and 1980, conidia were sprayed with a common pulverisator, and doses were varied by changing the titre of the suspension; the suspensions contained a wetting agent. In 1981, conidia were applied as

an ULV (spinning disk micronsprayer; 15,000 r.p.m.) to prevent loss of material by run off and to achieve a more regular spraying pattern on the leaves. In this case, suspensions (without detergent) of constant titre (5.10^6 con./ml) were used, and doses were varied by treating the plants longer or by repeating the treatment after some minutes, when the previous spray had dried up.

All experiments took place in the period April till June. In that part of the season, escapes of whitefly populations form control by Encarsia are likely to occur; furthermore, another fungus candidating for whitefly control, Verticillium lecanii (Kanagaratnam & Hall, 1982) will often fail in that period because of adverse weather conditions (Ekbom, 1981).

Results were valuated 2 weeks after spraying, by collecting leaves on which whitefly scales started to hatch. The numbers of "black scales" (Encarsia), "orange scales" (Aschersonia) and normal white scales were counted. A small percentage of dead scales could not be classified according to the cause of death. Mortality among young larvae (see van Alphen (1976) for host-feeding and Woets & van Lenteren (1976) for natural mortality) was not considered.

Results

First macroscopic symptoms of Aschersonia attack were observed 7 or 8 days after spraying. Mainly younger larvae instars were affected. Mortality rate was clearly determined by the amount of(viable) conidia applied, but in the experiments on full grown crops only slightly by the outdoor weather conditions, although the experiments passed through both rainy and sunny periods. It was difficult to obtain reliable results on small isolated plants; covering these plants or some leaves with transparent plastic during one day gave some improvement. However, prolongation of the covering gave no additional effect, and results were always inferior to those on a normal crop.

To obtain a high rate of mortality, between 10^{12} and 10^{13} conc./ha had to be applied; this is in accordance to the advice given by Osokima & Izhevskij (1976).

Spontaneous reinfection of untreated larvae was never observed, neither in neighbour glasshouses nor on control plants in the same glasshouse, not even on new leaves on a treated plant. This is in contradiction with Khristova (1971), but in agreement with the fact that most authors advise repeated treatments (Primak & Chizhik, 1975; Kogan &

Seryapin, 1978; Solovei, 1981).

Table 1 illustrates the effect of a weekly ULV application of Aschersonia conidia in two cucumber glasshouses, where a whitefly population was insufficiently parasitized (± 50%) by Encarsia formosa. The lower dose caused a significant but quantitatively unimportant mortality. Mortality caused by the medium and higher dose ($\geqslant 10^8$ con./plant) was high, fairly repeatable and quantitatively interesting in terms of plant protection.

Examinations of whitefly larvae and leaf epidermis strips under the microscope (meant to check the quality of the spraying technique) showed that the majority of the conidia did not germinate. This observation, together with the knowledge that Aschersonia conidia in laboratory germination tests need a chemical stimulus, indicates that the fungus material was probably used in a biologically suboptimal way.

Although Aschersonia is not pathogenic to Encarsia adults (unlike Verticillium lecanii; see Ekbom, 1979), an influence on the parasite population by elimination of hosts must be expected. Since, during the first half of the experiment, plot B served as a control of plot A, rates of parasitism, with and without, Aschersonia sprays could be compared. Table 1 shows that these rates were similar in both plots, so the sprays did not change the ratio between whiteflies and their parasites.

Table 1: Influence of sprays of Aschersonia conidia on the ratio between black scales (parasitized by Encarsia formosa) and white scales (affected neither by Encarsia nor by Aschersonia)

BLACK : WHITE

d.d.	10^8 conc./plant	water
May 14	1.8	1.5
21	0.8	1.1
27	1.3	1.1
June 4	1.0	1.2
11	0.9	1.7
17	2.4	0.8

Conclusions and Discussion

As a candidate biological control agent, A. aleyrodis showed some drawbacks, some advantages and some aspects that need further clarification.

Drawbacks are the absence of an epizootic process under glasshouse conditions, and the fact that this fungus does not affect the adult whiteflies. Therefore the treatment has to be repeated, and the application technique must be very precise (as for a contact insecticide).

A favourable aspect is the high specificity of this fungus, making it a suitable agent in integrated control programmes. Moreover, control was little affected by outdoor weather conditions, usually an important obstacle for using fungal pathogens otherwise than in soils. It is thought that this fungus, being a true insect pathogen, needs only a short period of high humidity for germination and penetration of the insect body. In a glasshouse crop with sufficient leaf mass, adequate conditions may exist during the night; therefore Kogan & Seryapin (1978) advise to apply the fungus in the evening. Abundance of sporulation on the dead insect may be stimulated by rainy weather, but this is without meaning for control because of what is asserted above.

Several aspects need more research work to allow an optimal handling of this pathogen. As was already stipulated by Pulev (1979), it is difficult to produce conidia of standard quality. Besides, more precise information should become available about the influence of storage conditions on this quality, the optimal chemical and physical conditions for the infection process, and the interaction between Aschersonia and Encarsia both on the level of the individual insect and in terms of population dynamics.

References

Alphen, J.J.M. van, Nell, H.W. & Sevenster, van der Lelie L.A. (1976). The parasite host relationship between Encarsia formosa Gahan (Hymenoptera:Aphelinidae) and Trialeurodes vaporariorum Westwood (Homoptera:Aleyrodidae). VII. The importance of host feeding as a mortality factor in greenhouse whitefly nymphs. Bull. OILB/SROP 1976/4: 165-169.

Ekbom, B.S. (1979). Investigations on the potential of a parasitic fungus (Verticillium lecanii) for the biological control of the greenhouse whitefly (Trialeurodes vaporariorum). Swedish J. agric. Res. 9, 129-138.

Ekbom, B.S. (1981). Humidity requirements and storage of the entomopathogenic fungus Verticillium lecanii for use in greenhouses. Ann. Ent. Fenn. 47 (2), 61-62.

Fawcett, H.S. (1908). Fungi parasitic upon Aleyrodis citri. Univ. Fla. Exp. Stud. 1, 1-41.

Kanagaratnam, P. & Hall, R.A. (1982). Control of glasshouse whitefly, Trialeurodes vaporariorum, by an aphid strain of the fungus Verticillium lecanii. Ann. appl. Biol. 100 (2), 213-219.

Khristova, E. (1969). The biological method for the control of the greenhouse whitefly. Rast. Zash. 17 (6), 17-19.

Khristova, E. (1971). Possibilities of using Encarsia formosa and Aschersonia aleyrodis in the control of Trialeurodes vaporariorum. Acta Hortic. 2 (17), 396-399.

Kogan, V. Sh & Seryapin, A.A. (1978). Against the greenhouse whitefly. Zash. Rast. (1978), no. 1, 29-31.

Osokina, G.A. & Izhevskij, S.S. (1976). A test on the control of the greenhouse whitefly. Zash. Rast. no. 2, 28-29.

Primak, T.A. & Chizhik, R.I. (1975). The possibilities of using the fungus Aschersonia for control of the greenhouse whitefly. Zakh. Roslin, no. 22, 53-56.

Pulev, V. (1979). The possibilities of using biological means and integrated plant protection in greenhouse cultivation. Rast. Zash. 27 (1), 22-25.

Rombach, M.C. & Samson, R.A. (1982). Small scale production of the entomopathogenic fungus Aschersonia aleyrodis. Proc. Int. Coll. Inv. Path. & Microb. Control, Brighton; Sept. 1982.

Solovei, E.F. & Koltsov, P.D. (1976). Effect of entomopathogenic fungi of the genus Aschersonia on the greenhouse whitefly, pest of vegetables in protected cultivation. Mikol. Fitopatol. 10 (5), 425-429.

Solovei, E.G. (1981). Aschersonia in greenhouses. Zash. Rast. no. 1, 30-31.

Spasova, P. (1974). Use of the entomopathogenic fungus Aschersonia against Trialeurodes vaporariorum. Gradinarstvo 16 (4), 13-16.

Woets, J. & Lenteren, van J.C. (1976). The parasite-host relationship between Encarsia formosa (Hymenoptera:Aphelimidae) and Trialeurodes vaporariorum (Homoptera:Aleyrodidae). VI. The influence of the host plant on the greenhouse whitefly and its parasite Encarsia formosa. Bull. OILB/SROP 1976/4, 151-164.

BREEDING FOR RESISTANCE TO WHITEFLIES IN TOMATOES - IN RELATION TO INTEGRATED PEST CONTROL IN GREENHOUSES

M.J. Berlinger, R. Dahan & Esther Shevach-Urkin

Cultivated plants have been selected by man for thousands of years. For most of the time, until the synthetic insecticides came into mass use, the selection was made under natural conditions; almost without protecting the plants against their insect and mite pests. Thus, the very susceptible hybrids which were heavily attacked and suffered excessive damage, died before fruit ripening occurred. Thus they were automatically selected out and not utilised in the evolutionary selection process. In this way man bred his plants, mainly unconsciously, for resistance to pests as well. On the other hand, one can imagine that by following this procedure man lost some very high yielding plants just because this character disappeared together with high susceptibility. Modern pesticides, which were brought into use after World War II, enabled the plant breeders to protect their breeding material by a "chemical umbrella". From that time onwards, the situation changed considerably, the breeder was able to preserve plants which were characterized by yields of high quality and quantity. The "green revolution" was one of the results of this new period of plant breeding. But, this method of breeding also resulted in a much higher degree of susceptibility to insect pests and mites.

Glasshouse vegetable production is the most extreme intensification in agriculture. From a commercial point of view, increasing output allows also an increasing input. At the same time the proportion of expenses on plant protection, among all expenses, becomes smaller. From this viewpoint, almost any pesticide input will be commercially acceptable. This process of evolution should slow down because: firstly, people are becoming more and more aware of the dangers of using pesticides; dangers both to the operator and to the consumer. Secondly, new pests become resistant to pesticides almost daily forcing the grower to increase the dosage applied, to use more toxic compounds and to apply them more often. This scenario will most likely result in a pesticide syndrome like that already described by Doutt & Smith (cited in Huffaker, 1971) in the case

history of cotton pests in the Canete Valley of Peru, and in the case of grapes in California (Huffaker, 1971). The most commonly accepted solution is to introduce an Integrated Pest Management (IPM) programme. This means to use all possible measures, which are known to suppress the pest populations, without disturbance between the measures applied. Next to chemical control the most common procedure in glasshouses is to use the natural enemies - Biological Control. These two control methods usually conflict and therefore cannot be applied together. Other control measures, e.g. mechanical methods, as mentioned earlier in this meeting (Berlinger, et al. - this volume) are almost useless in temperate zone glasshouses. Thus we come to a fourth measure, suggesting the use of resistant - or partially resistant - cultivars. This brings us back to the beginning where I tried to describe how plant resistance was originally lost in the favour of quantity and quality. It goes without saying that our present concept is not to return to old cultivars but to incorporate the resistant factor into the modern cultivars (de Ponti, 1978; Berlinger, 1980).

Breeding for resistance follows several steps:

1. Find a source of resistance. In this case cultivars, although old, non-commercial ones should be preferred. If no resistance can be found in such cultivars then wild types must be sought.

2. Development of methods for screening and determing resistant factor(s). If the resistance is a "yes" or "no" factor it is not difficult but if it is only a partial resistance, then the methods used are the key to the success, or failure, of the breeding programme. The methods should be revised continuously throughout the programme.

3. Study the mechanism of resistance. Will provide a better understanding of the pest/host plant interactions and allow us to improve our experimental methods.

Breeding for resistance to the greenhouse whitefly - Trialeurodes vaporariorum - has been carried out by de Ponti (de Ponti et al., 1975) and it is not my task to report on it. Breeding for resistance to the tobacco whitefly - Bemisia tabaci - was started about two years ago. As already mentioned above (Berlinger et al. - in this volume), B. tabaci is a notorious pest which, besides its direct damage, transmits the Tomato

Yellow Leaf Curl Virus (TYLCV) disease. Breeding for resistance to the TYLC virus is conducted by S. Cohen (virologist) and M. Pilovski (plant breeder) at our institute. Since this resistance is based on tolerance where the plants are in fact symptomless virus carriers and because the plants sources of TYLCV resistance are highly susceptible to B. tabaci it was of great importance to start a breeding programme for resistance to the whitefly. It must also be mentioned that the sources for whitefly resistance are susceptible to the virus. So, our aim is to incorporate both virus and whitefly resistance into one cultivar.

In a field test we screened about 30 accessions belonging to 8 species of the genera Lycopersicon and Solanum. The most promising a accessions were tested also in the laboratory, in choice and non-choice situations.

Partial resistance was found in some Lycopersicon spp: in one accession of L. hirsutum, in three of L. hirsutum faglabratum, in one of L. chilense and in two accessions of S. pennellii. Another S. pennellii accession was highly resistant in the field in summer but very susceptible in a laboratory test, conducted in winter.

For the continuation of the breeding programme, two resistant accessions of L. hirsutum f. glabratum and two of S. pennellii were chosen and transferred to the plant breeder (M. Pilovski) who has already started crossings.

The mechanism of resistance of L. hirsutum f. glabratum is not yet clear. Some accessions contain 2-tridecanone which was found in the glandular leaf hairs (Williams et al., 1980). This compound, which is commercially available, killed adult whiteflies in the gaseous phase. While testing various accessions, a good correlation was found between 2-tridecanone content and resistance (Esther Shevach-Urkin - unpublished data). The same was found by de Ponti and Kennedy (personal communication) for T. vaporariorum. In both cases we are not sure whether this is the sole mechanism. Some other chemicals, like un-decanone, are now being examined.

The resistance of S. pennellii accessions seemed to be based on the sticky exudate of the glandular leaf hairs (Gentile et al., 1968). We found that environmental conditions may influence the amoung of exudation so that the same plant may change from one extreme to the other. This knowledge is of the utmost importance if our experimental conditions are to be standardized and may explain the failure to prove resistance, by laboratory experiments, in a hybrid (glasshouse) found to be resistant

in the field (Berlinger & de Ponti, 1980).

Another background study, offering solutions to the adult B. tabaci via a parafilm membrane showed that this insect reacts to rather small differences of pH and that it prefers the neutral region (pH 6.0-7.25) (Berlinger et al.).

Concluding remarks

Lycopersicon and Solanum accessions differ markedly in their resistance to whiteflies. The resistance seemed to be polygenic and comprises various mechanisms like differences in pH, content of secondary plant substance, sticky exudations which are most likely to be toxic, etc. It seems that breeding for resistance to whiteflies in tomato is possible but complicated and still needs much research.

References

Berlinger, M.J. (1980). Resistance in tomato to the greenhouse whitefly in relation to integrated control in glasshouses. OILB/SROP Bull. 1980 III/3, 17-24.

Berlinger, M.J. & de Ponti, O.M.B. (1981). Methods for testing resistance to whiteflies in tomato and related species. OILB/WPRS Bull. 1981 IV/1, 115-118.

Berlinger, M.J., Dahan, R. & Cohen, S. (1982). Greenhouse tomato pests and their control in Israel. This volume.

Berlinger, M.J., Magal, Z. & Aliza Benzioni. The importance of pH in food selection by the tobacco whitefly, Bemisia tabaci. In preparation.

Doutt, R.L. & Smith, R.F. (1971). The pesticide syndrome-diagnosis and suggested prophylaxis. In Huffaker (Ed.) "Biological Control". pp. 3-15. Plenum Press, New York & London.

Gentile, A., Webb, R. & Stoner, A.K. (1968). Resistance in Lycopersicon and Solanum to greenhouse whiteflies. J. econ. Ent. 61, 1355-1357.

de Ponti, O.M.B. (1978). Status of resistance breeding in relation to integrated pest control. II. Arthropods. Working paper presented at the 8th session of the FAO Panel of Experts on Integrated Pest Control, September 1978, Rome.

de Ponti, O.M.B., Pet, G. & Hogenboom, N.G. (1975). Resistance to the glasshouse whitefly (Trialeurodes vaporariorum Westw.) in tomato (Lycopersicon esculentum Mill.) and related species. Euphytica 24, 645-649.

Williams, W.G., Kennedy, G.G., Yamamoto, R.T., Thacker, J.D. & Bordner, J. (1980). 2-Tridecanone: A naturally occurring insecticide from the wild tomato Lycopersicon hirsutum f. glabratum. Science 207, 888-889.

A SELECTIVE METHOD OF THRIP CONTROL OF CUCUMBERS

R.J.J. Pickford

At Humber Growers' Marketing Organisation Ltd. cucumbers are traditionally grown on steam sterilised soil and are trained and trimmed to the umbrella system which involves stopping the main leader at the supporting wire and allowing the laterals to hang down. As fuel costs continue to rise soil-less cultures were introduced thus eliminating the need to steam sterilise the soil. As these new techniques for growing cucumbers i.e. Growbags and Rockwool, came into use Thrips became a serious problem. The standard soil treatment with HCH for control of Thrips tabaci in an integrated programme for pests of cucumbers adversely affected the natural enemies, Phytoseiulus persimilis and Encarsia formosa through its fumigant action. Numerous alternative chemicals were evaluated but all failed to produce satisfactory control. An alternative method was investigated. It was believed that ensuring exposure of Thrips prepupae to a suitable insecticide when they descend to pupate on the soil was the key factor rather than insecticides being ineffective.

Trials with mixtures of polybutenes and insecticides sprayed onto sheets of plastic on the ground below were successful in controlling Thrips by killing the larvae prepupae when they descend to pupate. This method leaves the natural enemies Phytoseiulus and Encarsia unaffected on the aerial parts of the plant as the mixture does not vaporise. The results of trials are as follows:-

Trial I: Polybutene and Deltamethrin

Four plots, each containing seven plants, were selected:

Plot (a) Average Thrip damage - equal parts by volume of Polybutene 5 and water to which was added 4.16 cc Deltamethrin per litre of the above mixture and sprayed onto plastic beneath the crop at the rate of 0.87 cc Deltamethrin in 210 cc of the mixture (46.2 cc a.i. per ha, 444 litres of mixture per ha).

Plot (b) Severe Thrip damage - as (a).

Plot (c) Control - average Thrip damage - clean plastic laid beneath the crop.

Plot (d) Control - average Thrip damage - clean plastic laid beneath the crop.

During this trial leaves were removed from the lower, middle and upper parts of the plants and the Thrips population counted. Counts were also made on the plastic in areas A and B.

The results of Trial I after 14 days showed that control of Thrips was possible using Polybutene 5 plus Deltamethrin which has a lower viscosity thus rendering the product suitable for commercial application.

A further trial was, therefore, carried out to test the product on a larger scale and to provide more conclusive evidence of its suitability.

Trial II: Polybutene + Deltamethrin

Four plots, each containing 13 plants in Growbags, were treated as follows:

Plot A Polybutene 5 and Deltamethrin sprayed onto sheets of plastic beneath the crop.

Plot B Polybutene 5 and Deltamethrin sprayed onto sheets of plastic beneath the crop.

Plot C Control - clean sheets of plastic beneath the crop.

Plot D Control - clean sheets of plastic beneath the crop.

Thrip damage was severe in all areas. Individual plants were assessed for damage every 3-4 days which was expressed as a percentage of the leaves damaged. Sections of plastic sheets were removed at the same time and replaced by freshly sprayed sheets. A count of Thrips was made on the sections removed.

Results

Trial I

This trial produced highly satisfactory results. Control of Thrips in Plots A and B with correspondingly high numbers trapped on the plastic sheets was excellent, Table 1. In Plots C and D large numbers of Thrips were found on the leaves and none on the floor.

Trial II

Table 2 shows the declining damage as the plants in treatments A and B recover and the diminishing number of thrips trapped on the plastic sheets. The totals for each column are the average of ten 2.5 cm^2 taken from one 30.5 cm^2 at four day intervals, the control D was taken on the final days and shows an increase in the Thrip population. (Thrip counts in areas A and D are cumulative over 4 days.)

From the evidence of trials the mixture of Polybutene and Deltamethrin used to control Thrips was extended to a total of 70 acres of cucumbers in the 1981 season.

Some areas did not achieve as good a control as was expected. It was through that the reason for this failure was due to too little plastic on the floor and starting when the Thrips had become well established, rather than the volume of Polybutene and Deltamethrin being applied. Tests were carried out to establish how long the mixture is lethal to Thrips once applied, as there was little evidence that the volume applied affected the degree of control in the range 120 litres per acre to 240 litres per acre of the mixture (30.8 cc a.i. per ha, 296.5 litres of mixture per ha; 61.7 cc a.i. per ha, 593.0 litres of mixture per ha).

The mixture was applied to petri dishes and Thrips introduced and observations made after two hours. This shows that Polybutene + Deltamethrin is lethal to Thrips in covered dishes in excess of twenty weeks. Dishes with pesticide alone proved ineffective, Polybutene alone was also ineffective. Trials in the field indicate the mixture is lethal for at least ten weeks.

The results indicated that the sites in 1981 (seven acres) which failed to give a satisfactory Thrip control was most likely due to insufficient plastic or applying the mixture too late as the mixture is lethal for a considerable length of time.

During the winter of 1981/82 the product was further developed being granted a trade name 'Thripstick' and given provisional clearance in the UK. Thripstick is now supplied in 25 kilogram drums with the pesticide added and is ready to apply. Following experience gained in 1981 the following programme for control was initiated for the 1982 season:

1. The polythene sheeting is laid either to completely cover the glasshouse floor or to partially cover the floor and folded back until required.

2. A wide spectrum insecticide is applied to the floor (Parathion) 2-3 weeks after planting (to ensure a clean start).

3. Thripstick is applied as soon as the pest is seen on the crop.

This treatment was followed this season with highly satisfactory results on ninety-two acres. This represents 100% of cucumber grown in Growbags and Rockwool using Humber Growers' Biological Pest Control Unit.

Table 1: Thrips Trial I - sample counts per leaf (2 leaves x 7 plants each treatment) and floor trap 21 days after treatment

Treatment	Infestation	Thrips population per 14 leaves: Lower	Middle	Upper	Thrips mean 10 samples	Trapped Per 1 ft^2 = 924 cm^2
Polybutene 5 + Deltamethrin (a)	Average	2	2	8	6.3	907
Polybutene 5 + Deltamethrin (b)	Severe	2	1	2	9.0	1296
Control (c)	Average	115	102	106	-	-
Control (d)	Average	614	105	114	-	-

Table 2: Trial 2 - Decline in damage and numbers of thrips trapped after treatment of severe infestation

Treatment	Days after treatment	% infested foliage	No. thrips per 2.5 cm^2 of trap (mean of 10)
Polybutene + Deltamethrin (A, B)	4	100	55
"	12	82	30
"	20	60	5
	28	58	2
Control	28	100	115

INTEGRATED CONTROL OF CHRYSANTHEMUM PESTS

J.V. Cross, L.R. Wardlow, R. Hall, M. Saynor & P. Bassett

Observation studies, experiments and trials to develop an integrated control programme for pests of AYR cyrsanthemums have been carried out in experimental and commercial glasshouses in southern England since 1977. Four integrated control programmes have been developed, each offering an alternative approach to pest control, to suit the circumstances, needs and abilities of individual growers. Each programme combines routine introductions of one or more biological control agents with carefully timed routine applications of selective pesticides throughout the summer. The four programmes are now being tested by growers on a commercial scale to assess their effectiveness and reliability. Here the main observations and broad conclusions of the work are given, dealing firstly with the main pests and then with the four integrated pest control programmes derived.

Red spider mite

Red spider mite (Tetranychus urticae) is the most frequent, widespread and damaging pest of chrysanthemums in the UK. It has become resistant to all of the systemic and most of the contact acting pesticides available. Only cyhexatin and dienchlor remain generally effective. The mites live and breed mainly on the undersides of chrysanthemum leaves where it is very difficult to obtain good spray cover with contact acting pesticides on mature chrysanthemum beds. In the four integrated control programmes we have formulated, the predator mite Phytoseiulus persimilis is used for red spider mite control. The work has shown that control of red spider mite can be achieved most effectively and reliably when the predator is introduced approximately 4 weeks after planting. Earlier introductions may be unsuccessful when the incidence of red spider mite is too low, and are sometimes impractical because non-selective and persistent insecticides may be necessary to control other pests before predator introductions are made. Control may take over 5 weeks in cool weather or if red spider mite numbers are large, and later introductions may not allow sufficient time for control to be achieved before harvest. The rate of introduction of predators is limited by economic considerations but the work has shown that rates of one predator per 10 plants are

usually effective. Where aldicarb has been applied shortly after planting, a three week interval must elapse between application and introduction of predators. Furthermore, higher rates of introduction (up to one predator per plant) may be required. A strain of P. persimilis with useful levels of resistance to diazinon has been selected and is used in one programme where all other pests are controlled chemically.

Aphids

Several species of aphid have been recorded as pests of chrysanthemums but the most common and troublesome are Myzus persicae and Aphis gossypii which are resistant to a wide range of insecticides. Resistance of these two species to systemic insecticides such as demeton-s-methyl and aldicarb has reached very high levels and these chemicals are completely ineffective. However, both species remain at least partially susceptible to certain contact acting insecticides. Fortunately, initial infestations of these aphids are found mainly in the growing point of chrysanthemum plants where they are a relatively easy spray target, but large numbers may be found underneath the leaves when infestations are established.

Aphis gossypii, which is very resistant to pirimicarb and other carbamates, may still be controlled by direct contact with nicotine or diazinon sprays. Myzus persicae may be controlled by direct contact with nicotine or pirimicarb sprays. Toxicity to predators may be avoided by using selective chemicals such as nicotine or pirimicarb, or by selecting a resistant strain of predator.

In three of the integrated control programmes the entomopathogenic fungus, Verticillium lecanii, is used for aphid control. The trials have shown the best time to apply the fungus is two weeks after planting. If the application is made later when infestations have become established, the upper foliage of mature plants may be disfigures by 'white fluffy' diseased aphid bodies. High humidity is essential for the initial germination of spores and aphid parasitism, and for the subsequent development of disease epizootics. Humidities under blackout or thermal screens in glasshouses are usually high, but not sufficiently high for efficient biological control of aphids during periods of dry weather, when humidity outside the glasshouse is low.

Low humidity in the glasshouse during dry weather results in some failures to obtain adequate control in 1981. During these periods of dry weather when humidities are low, a special effort must be made to increase

humidity by closing vents and damping down. Such changes in cultural practice to benefit pest control may not be acceptable to some growers and may encourage plant diseases. Temperatures can also be critical but normal growing temperatures are usually adequate during the summer.

Thrips

In all the integrated control programmes thrips are controlled chemically. A single application of an insecticide such as carbaryl or diazinon one or two weeks after planting usually gives adequate control of thrips on the foliage. Occasionally, an additional spray may be applied just before the buds open to prevent damage to petals when thrips infest the buds and flowers, especially in summer.

Caterpillars

At least one spray is usually necessary in each crop round to prevent caterpillar damage. Bacillus thuringiensis or diflubenzuron is used when predators or parasites are present. Otherwise, sprays of diazinon or carbaryl may be used.

Leaf miner

Leaf miner, Phytomyza syngenesiae, can be readily controlled with insecticides. Diazinon or aldicarb are favoured chemicals but many others are effective. Resistance to chemicals has not been a problem as long as infestations are not allowed to persist, as infestation usually originates from susceptible wild strains on weeds out-of-doors. In one integrated control programme leaf miners are controlled biologically using hymenopterous larval parasites, Diglyphus iseae and Dacnusa sibirica. Introductions of adult D. sibirica at a rate of 3 per 1000 plants are made a few days after planting, followed by an introduction of D. iseae 5 weeks later. The wasps rapidly seek out and parasitise leaf miner larvae. High levels of parasitism occur providing that initial leaf miner infestations are low.

Programme 1

In this programme as many as possible of the major pests of chrysanthemums are controlled biologically. Growers must have some biological skill and knowledge to run the programme efficiently. Low humidity conditions can lead to problems with aphid control and leaf miner parasites do not work efficiently in cool weather. This programme has been used

successfully at a nursery at Margate, Kent, for 2½ years.

Days after planting	Action
5	Introduce 3 Dacnusa parasites/1000 plants
10	Spray carbaryl for thrips control
14	Spray V. lecanii for aphid control
28	Introduce P. persimilis at a rate of 1/10 plants
28-42	Spray B. thuringiensis
42	Introduce 3 Diglyphus parasites/1000 plants

Programme 2

A costly programme unless the grower is producing his own predators. Aphid control can be a problem during periods of dry weather. The programme has been used successfully at Efford Experimental Horticulture Station, Hants., for 1½ years.

Days after planting	Action
8-10	Apply aldicarb for leaf miner and thrips control
14	Spray V. lecanii for aphid control
28	Introduce P. persimilis at a rate of 1 per plant for red spider mite control
31-70	Apply sprays of B. thuringiensis if caterpillar damage is seen

Programme 3

This is the least expensive and simplest programme to operate provided aphid control can be achieved with the chemicals listed. Resistant predators are not available commercially. This programme is being tried in a 1 ha commercial glasshouse in Hants.

Days after planting	Action
10	Spray diazinon + pirimicarb for aphid, leaf miner and thrips control
20	Spray diazinon + nicotine for aphid, leaf miner and thrips control
28	Introduce diazinon-resistant predators at a rate of 1 per 10 plants for red spider mite control

42-70	Apply nicotine, diazinon, *B. thuringiensis*, pirimicarb or cyhexatin sprays as necessary

Programme 4

This has many of the attractive features of Programmes 1 and 3. It is currently being tested in a 0.5 ha glasshouse in Hants.

Days after planting	Action
10	Spray diazinon for thrip and leaf miner control
14	Apply *V. lecanii* for aphid control
20	Spray diazinon for thrips and leaf miner control if necessary
28	Introduce diazinon resistant *P. persimilis* at a rate of 1 per 10 plants for red spider mite control
42-70	Apply nicotine, diazinon, *B. thuringiensis*, pirimicarb or cyhexatin sprays as necessary

These four programmes were designed to suit AYR spray chrysanthemum production during the summer months. They can be modified for AYR pot chrysanthemum programmes.

A PRACTICAL METHOD TO MONITOR PESTS AND NATURAL ENEMIES IN INTEGRATED CONTROL EXPERIMENTS UNDER GLASS

Sherif A. Hassan

Summary

A simple method to monitor the abundance of pests and natural enemies in glasshouse biocontrol experiments was tried. Without counting individual arthropods, plants were examined for the presence or absence of insects and mites. This time saving method was used to monitor the whitefly Trialeurodes vaporariorum, its parasite Encarsia formosa, the two-spotted spider mite Tetranychus urticae, its predator Phytoseiulus persimilis as well as Thrips tabaci on cucumber plants between 1977 and 1980. The reliability of this method was shown by the results obtained in these experiments.

Zusammenfassung

Ein praktisches Verfahren zur Überwachung von Schädlingen und Nützlingen in Versuchen zur integrierten Schädlingsbekämpfung unter Glas

Eine einfache Methode zur Überwachung von Schädlingen und Nützlingen wurde bei der Anwendung von biologischen Bekämpfungsverfahren in Unterglaskulturen erprobt. Dabei wurden nicht die Individuenzahlen von Arthropoden festgestellt, sondern Pflanzen auf das Vorhandensein oder Nicht-Vorhandensein bestimmter Insekten bzw. Milben untersucht. Dieses zeitsparende Verfahren wurde zwischen 1977 und 1980 zur Überwachung von Weisser Fliege Trialeurodes vaporariorum, deren Parasit Encarsia formosa, Gemeiner Spinnmilbe Tetranychus urticae, deren Prädator Phytoseiulus persimilis sowie Thrips tabaci an Gurken unter Glas erprobt. Die Zuverlässigkeit diser Methode wird anhand der erzielten Ergebnisse belegt.

Introduction

To indicate the degree of control obtained by the introduction of natural enemies such as Encarsia formosa and Phytoseiulus persimilis to control the whitefly Trialeurodes vaporariorum and the two-spotted spider mite Tetranychus urticae as well as to monitor the abundance of secondary pests such as aphids and Thrips tabaci in glasshouse experiments, a practical method is needed. The counting of individual insects and mites on random sample plants is time consuming and sometimes provides unsatisfactory results. An experiment carried out by Mansveld et al. (1978) on a glasshouse tomato crop showed that weekly examination of a random sample of 0.6% of the total plants for parasitized and unparasitized whitefly pupae did not satisfactorily reflect their actual abundance compared to absolute counts on all the plants. To facilitate monitoring damage caused by T. urticae on cucumber plants without having to count the individual mites on sample plants, a damage index defining the intensity of damage to leaves, in 5 different categories, was developed by Hussey & Parr (1963). This rational method is commonly used to monitor damage by the red spider mite in integrated control experiments on cucumber. By using a quick method to examine plants, the number that can be examined by a given effort can be increased.

The method recommended at the present work involves the weekly examination of plants selected at random for the presence or absence of pests and natural enemies. Reducing the time required to examine each sample plant allowed an increase in the size of sample and the monitoring of several pests at the same time. Curves showing the proportion of plants including each species to be monitored are plotted. On the occurrence of plants showing visual damage due to a particular pest, the proportion of these plants affected is separately estimated. The method was frequently used between 1977 and 1980 but the present work reports only on data obtained in 1978 when T. vaporariorum, T. urticae and T. tabaci were generally abundant.

Materials and Methods

The glasshouses

Experiments 1 and 2 were conducted in two neighbouring glasshouses in Dossenheim near Heidelberg with 550 m^2, 1150 m^2 and 640, 1400 cucumber plants respectively, variety "Amazone lang", planted on May 3 and

harvested on August 17 = 106 days. Experiment 3 was carried out in a glasshouse in Heidelberg-Handschuhsheim with 200 m^2 and about 200 cucumber plants of the variety "Pipinex", planted on May 26 and harvested on October 18 = 133 days.

Introductions of natural enemies

Three releases of E. formosa at the rate of 1 to 2 parasites per plant were made in each of the three glasshouses. The time of the introductions can be seen in Figs. 1 and 2. A portion of tobacco leaf bearing 10 to 20 parasitized whitefly scales was placed on every 10th cucumber plant. A small number of whiteflies were present in all of the three glasshouses on the day of the first introduction.

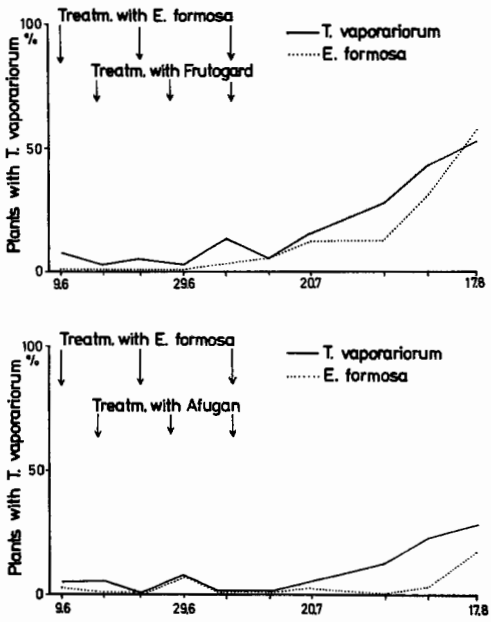


Fig. 1: Proportion of cucumber plants including Trialeurodes vaporariorum and Encarsia formosa in Experiments 1 and 2, 1978

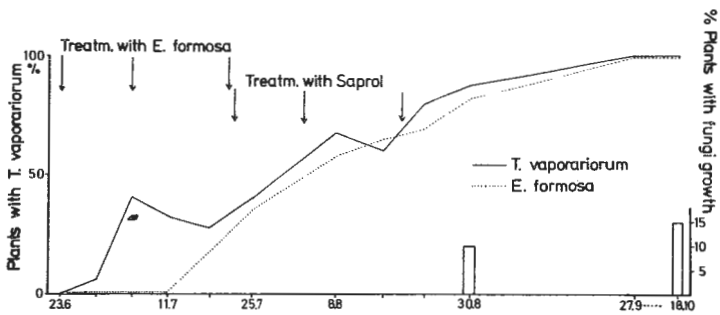


Fig. 2: Proportion of cucumber plants including Trialeurodes vaporariorum, Encarsia formosa or showing study mildew growth in Experiment 3, 1978

In Experiments 1 and 2, 10 to 20 T. urticae on a portion of bean leaf/plant were introduced and about 5 P. persimilis also on a portion of bean leaf were released 10 to 14 days later on alternate plants (Growers' Bulletin, 1978). A natural infestation of T. urticae was observed in experiments on June 23 and P. persimilis was introduced on June 29 (Figs. 3 and 4).

Monitoring

40 plants in each glasshouse, selected at random, were examined weekly. The selected plants were evenly distributed throughout each glasshouse and represented about 3, 6 and 20% of the total plant populations in the Experiments 1, 2 and 3, respectively. The sample plants were examined for the presence or absence of any stage of T. vaporariorum, E. formosa, T. urticae, P. persimilis and T. tabaci. On the appearance of obvious fungal growth (study mildew) on honeydew excreted by the whitefly adults and scales or plants with several yellow leaves due to T. urticae infestation, the number of plants showing damage was estimated by a quick estimate of all the plants in the glasshouse.

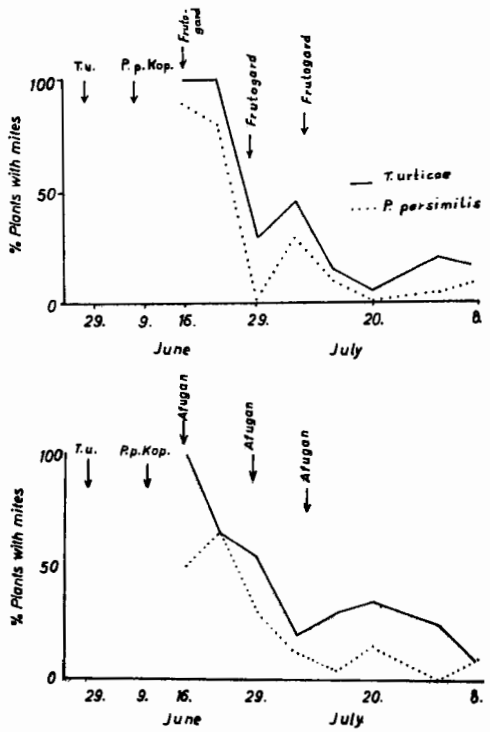


Fig. 3: Proportion of cucumber plants including Tetranychus urticae (T.u.) and Phytoseiulus persimilis (P.p.) in Experiments 1 and 2, 1978. Kop. = the company Koppert BV, The Netherlands.

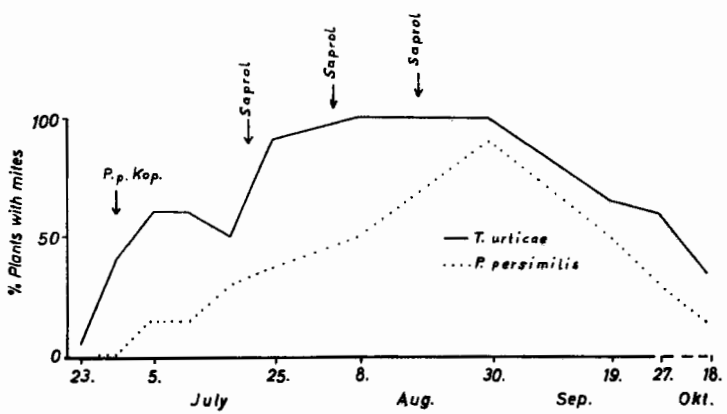


Fig. 4: Proportion of cucumber plants including Tetranychus urticae and Phytoseiulus persimilis in Experiment 3, 1978

Fungicide treatment

In each experiment a different fungicide was used to control the cucumber powdery mildew. Afugan WP 30 (pyrazophos) at 4.8 g/a, Frutogard (ditalimfos) at 6 g/a and Saprol (triforine) at 9 ml/a were used in Experiments 1, 2 and 3 respectively. In laboratory tests, these three fungicides were found to be harmless to P. persimilis (Hassan, 1979, 1982). Triforine but not pyrazophos was shown by Ledieu (1979) to be harmless to E. formosa.

Results and Discussion

Whitefly

The data showing the number of plants including whitefly or E. formosa stages are given in Fig. 1 (Experiments 1 and 2) and Fig. 2 (Experiment 3). With a low whitefly infestation in the Experiments 1, 2 and a culture duration of about 15 weeks (Fig. 1), the number of plants with whitefly and E. formosa stages increased slowly and reached 52.5, 27.5% (whiteflies), 57.5 and 17.5% (E. formosa) respectively. No plants showed any fungal growth and no economic damage was therefore observed. In Experiment 3 (Fig. 2) with a duration of 19 weeks, the number of plants with whitefly infestation reached 40% on July 5 and increased to 100% in September and October. The number of plants including E. formosa increased rapidly, closely following the increase in the number of whitefly infested plants, but about 15% of the plants suffered from fungal growth on the honeydew. More experiments are needed to estimate the threshold for economic damage.

Two-spotted spider mite

Figs. 3 and 4 show the number of plants with spider mites and P. persimilis. Due to the releases of T. urticae and P. persimilis as used in the "pest-in-first" method, an even distribution of the pest and the predator in Experiments 1 and 2 (Fig. 3) was achieved, nearly all the plants included both mites. The number of plants including mites decreased slowly but there were always some P. persimilis to act as protection against T. urticae. Due to a continuous invasion of T. urticae from a neighbouring bean crop in Experiment 3 (Fig. 4), the number of plants with T. urticae increased and reached 100% in August. The increase in the number of plants showing T. urticae was followed by an increase in the number of plants including P. persimilis. There was

no obvious damage to the plants due to T. urticae infestation and biological control was successful.

Cucumber plants in the two neighbouring glasshouses (Experiments 1 and 2) were attacked by Thrips tabaci in early June. Fig. 5 shows the number of plants with T. tabaci in these experiments. In Experiment 1 where the fungicide Frutogard was used, the number of plants with T. tabaci increased rapidly. In Experiment 2 where the fungicide Afugan was used three times to control powdery mildew, the number of plants with T. tabaci decreased after each treatment. The data show an obvious side effect of Afugan to T. tabaci.

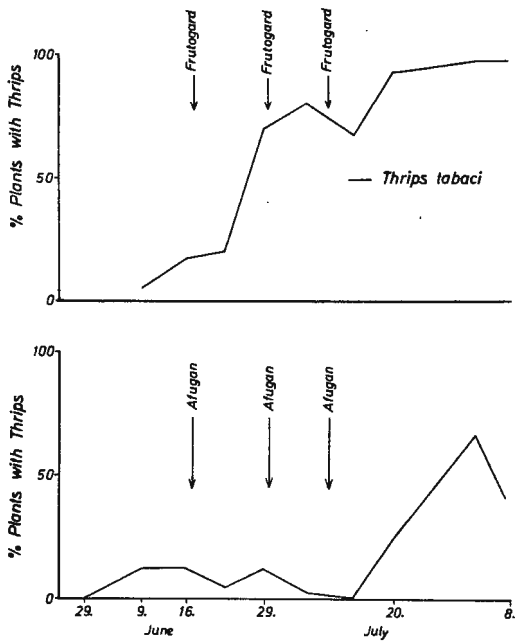


Fig. 5: Proportion of cucumber plants including Thrips tabaci in Experiments 1 and 2, 1978

The method used in this work to monitor T. urticae, P. persimilis, T. vaporariorum, E. formosa and T. tabaci was shown to be practical and provide useful information when used to develop integrated control programmes for crops under glass. The method is time saving and permitted the monitoring of several pests at the same time.

References

Eggenkamp-Rotteveel Mansveld, M.H., Ellenbroek, F.J.M., Lenteren, J.C. van & Woets, J. (1978). The parasite-host relationship between Encarsia formosa Gah. (Hym., Aphelinidae) and Trialeurodes vaporariorum (Westw.) (Homoptera, Aleyrodidae). VIII. Comparison and evaluation of an absolute count and a stratified random sampling programme. Z. ang. Ent. 85, 133-140.

Growers' Bulletin No. 1 (1978). The Biological Control of Cucumber Pests. Glasshouse Crops Research Institute, Littlehampton, Sussex, England, 18 pp.

Hassan, S.A. (1979). Biologische Schädlingsbekämpfung an Gurken und Tomaten im Gewächshaus. Rheinische Monatsschrift für Gemüse Obst Schnittblumen 67, 191-192.

Hassan, S.A. (1982). Relative tolerance of three different strains of the predatory mite Phytoseiulus persimilis A.-H. (Acari, Phytoseiidae) to 11 pesticides used on glasshouse crops. Z. ang. Ent. 93, 55-63.

Hussey, N.W., Parr, W.J. (1963). The effect of glasshouse red spider mite (Tetranychus urticae Koch) on the yield of cucumbers. Rep. Glasshouse Crops Res. Inst., 255-263.

Ledieu, M.S. (1979). Laboratory and glasshouse screening of pesticides for adverse effects on the parasite Encarsia formosa Gahan. Pestic. Sci. 10, 123-132.

DEVELOPMENT OF A MANAGEMENT PROGRAMME TO ENSURE WHITEFLY-FREE EARLY-SOWN TOMATOES ON GUERNSEY

N.W. Hussey

When commercial rearing companies attempted to control whitefly on Guernsey, using methods developed for nurseries in England, serious failures occurred. Several potential causes were eliminated, i.e. concentrations of salt on the foliage, high ethylene concentrations and differences between leaf and 'card' material for introduction. HCH vapours from use of that insecticide below plastic sheets to control leafminer pupae were found to be harmful. However, the problem was exacerbated by the severe contamination of young plants caused by early sowings, mild autumn climate and the presence of infested older crops in nearby houses.

Experiments were therefore made to produce clean seedlings as a prelude to release of Encarsia. Use of systemics applied to the pots so as to take advantage of root restriction was an obvious approach.

Phytotoxicity is a major problem but to establish the maximum tolerable rates, plants at the 5-6 leaf-stage were treated in the summer with dimethoate (Rogor), methomyl (Lannate), aldicarb (Temik), oxamyl (Vydate) and carbofuran (Yaltox). The first two chemicals were applied at 0.01, 0.03 and 0.05% a.i. using drenches of 50 or 100 cm^3/plant. The other three chemicals were "pepper-potted" as granules at 0.8 and 0.4 g/plant - again with two rates of water. 15 plants were used in each treatment. No damage was observed with dimethoate (0.1%) or carbofuran (0.4 g/plant); scarcely perceptible marginal scorch was caused by oxamyl (0.4 g/plant); methomyl and aldicarb caused obvious marginal scorch even at the lowest rates.

In order to assess the effect of these insecticides on whitefly populations 400 tomatoes cv. Dawn were sown on October 16 and maintained at 18°C (day) and 16.5°C (night) from pricking-off until the first flowers became visible when night temperature was reduced to 12°C. Twelve days after sowing, plants were spaced on four parallel 10 m benches and protected by different whitefly traps:- (1) six adhesive yellow traps were evenly spaced 12 in. above the seedlings; (2) the yellow traps were interspersed with 2-leaf cucumbers treated with aldicarb; (3) treated cucumbers only; (4) no treatment. Adult whiteflies were released near each bench 17, 24 and 42 days after sowing.

Whiteflies were assessed by destructive random sampling on each bench during the week beginning December 7 (52 days after sowing). The yellow traps reduced mean numbers of eggs and nymphs:- control 49.8 ± 14.0; trap cucumbers 21.9 ± 10.2; yellow and cucumber traps 11.4 ± 6.1; yellow traps alone 12.5 ± 3.6. The traps reduced the number of heavily infested plants. On the assumption that, at 18°C, eggs take 33 days to develop into pupae, plants were treated with systemics on December 8; 36 days after the first whiteflies were introduced on November 11 (when seedlings were only 2 in. high).

25 plants were used to evaluate each systemic which was applied at the non-phytotoxic rates established above:- aldicarb 0.2 g/plant, carbofuran 0.4 g/plant, oxamyl 0.4 g/plant, methomyl 0.01% and dimethoate 0.02%. On January 5 (28 days after treatment), examination of 25 plants in each treatment revealed the following proportion of infested plants:- control 62%; methomyl 46%; dimethoate 31%; carbofuran 28%; oxamyl 8% and aldicarb 0%. These levels occurred, despite the large numbers of whiteflies trapped on the yellow cards (mean 84/trap or 5 per plant).

Aldicarb would guarantee clean plants but is impractical in Guernsey due to contamination of soil water. Therefore, the programme proposed to protect early-sown tomatoes with adhesive yellow traps (1 per 5 ft. of bench) and to treat for whiteflies during the first week of December when the plants are stood-out on the bolsters. This would permit planting in early January without hazard and ensure that any whiteflies invading the crop later would not produce scales ready for parasitism before the middle of February when 'dribbles' of Encarsia could commence.

EXPERIENCES WITH PHEROMONAL TRAPPING OF LEPIDOPTERA IN GREENHOUSES

J. van den Bos

Air movements in greenhouses differ greatly from those outdoors. In greenhouses no horizontal air currents occur, but only air circulations with warm air rising and cold air falling. The wind speed is very low, usually varying between 5 and 20 cm/sec^{-1} when the ventilators are closed, and between 5 and 40 cm/sec^{-1} when open (G. Bot, Ir G.A. van den Berg, pers. comm.). These factors may affect pheromone-mediated communication among insects occurring in greenhouses. Experiments with pheromonal trapping of different Lepidoptera in greenhouses confirm this. Unpublished results of different Dutch research workers are summarized.

CLEPSIS SPECTRANA TR. (FAM. TORTRICIDAE)

(J. van den Bos, to be published in greater detail in: Agricultural Research Reports, Pudoc, Wageningen, The Netherlands)

Release-recapture trials were carried out in a Gerbera house (area 80 m^2, ridge height 5 m), and in an outdoor cage (area 42 m^2, height 2.5 m) of polyamide gauze (mesh width 1.25 mm, thread diameter 0.315 mm), planted with rows of Prunus triloba (L.). Air currents in the cage resembled those in a natural situation.

Laboratory reared male moths (greenhouse biotype) were released within 16 hours after emergence. Sticky traps (delta shape) were used throughout the experiments, and were baited with two virgin females of the field biotype, or with two virgin females of the greenhouse biotype (these females attract males of both biotypes in equal proportions). Other traps were unbaited. All the traps were placed at a height of 0.5 m.

In the outdoor cage two traps of each kind were used. They were placed 1 m from the walls of the cage. The distance between adjacent traps was 2.5-4 m. A total number of 715 moths was released, from June until October 1980.

In the greenhouse, the trap density was about the same (0.15 traps/m^{-2}). Two traps of each kind were placed between the plant beds, as well as along the walls inside the greenhouse. The distance between

adjacent traps was 3-4 m. The greenhouse trial was done twice. A total number of 1010 moths was released during three weeks in January 1981, and 726 moths during three weeks in June 1981. The ventilators were screened with gauze to prevent moth escape.

Recaptures in the outdoor cage and in the greenhouse were compared (Table 1).

Table 1: Comparison between recaptures of C. spectrana males in a greenhouse and in an outdoor cage (release-recapture trials using female-baited and unbaited traps)

	Greenhouse (January)	Greenhouse (June)	Outdoor cage (summer)
Number of males released	1010	726	715
% males recaptured:			
Along the walls	4.4%	5.9%	
Between the plant beds	1.2%	1.9%	
Total recapture	5.6%	7.8%	13.6%
% males recaptured after correction for the catches in unbaited traps	2.0%	4.5%	11.9%

Differences in these trials were evaluated by the chi-square method (1-sided test).

Pheromonal attraction by virgin females in the greenhouse appeared to be less effective than in the outdoor cages. In the greenhouse a significantly lower proportion of males was recaptured, both before and after correction for the catches in the unbaited traps ($P < 0.005$).

Recapture in the greenhouse were significantly higher along the walls than between the plant beds ($P < 0.005$). This was the case for both female-baited and unbaited traps ($P < 0.05$) (Table 1).

SUMMERFRUIT TORTRIX MOTH, ADOXOPHYES ORANA F.V.R. (FAM. TORTRICIDAE)

(in collaboration with Drs C. van der Kraan and P. van Deventer, Institute for Pesticide Research, Wageningen)

Different types of sticky traps, baited with synthetic pheromone (load 1 mg in polyethylene caps), or with two virgin females, were tested in a 180 m^2 greenhouse. Six traps were placed inside the greenhouse, 0-1 m from the walls. The distance between adjacent traps was 5-10 m. Two traps, baited with synthetic pheromone, were placed outdoors. Male pupae were allowed to eclose in the greenhouse at 10 m from the nearest traps. A total number of 3765 moths emerged during a period of 45 days (between 40 and 150 per day).

Only 33 moths (0.9%) were recaptured. Inside the greenhouse, mean catch was 2.0 per unbaited trap, and 4.8 per pheromone-baited trap. Outside the greenhouse, mean catch per trap was 5.5. These were escaped animals, as the experiment was done before the first flight of A. orana in the field had started.

BEET ARMY WORM, SPODOPTERA EXIGUA HB. (FAM. NOCTUIDAE)

(in collaboration with Drs C. van der Kraan and M. van de Vrie, Research Institute for Plant Protection, Wageningen, seconded to the Research Station for Floriculture, Aalsmeer)

Trapping of S. exigua with synthetic pheromone in infested commercial greenhouses seemed rather ineffective. Therefore a release-recapture trial was carried out in a 80 m^2 Gerbera house. Six traps, baited with synthetic pheromone (load 1 mg in polyethylene caps), were placed between the plant beds. Male pupae of a laboratory strain were allowed to eclose in the greenhouse. A total number of 395 moths emerged.

Only 2 specimens were recaptured. However, males of this strain readily responded to traps baited with synthetic pheromone which were located outdoors.

POTATO TUBERWORM MOTH, PHTHORIMAEA OPERCULELLA ZELL. (FAM. GELECHIIDAE)

(in collaboration with Drs C. van der Kraan and P. van Deventer)

Release-recapture trials, using traps baited with synthetic pheromone (load 1 mg in polyethylene caps), were performed in a 1000 m^2 greenhouse. In the centre of the greenhouse, 635 laboratory reared male moths of less than 1 day old were released. A total number of 505 moths dispersed. Twelve traps were placed inside the greenhouse, divided over three concentric circles around the release point. Three traps were placed outside the greenhouse.

The number of moths recapture was 62 (12.3%). Inside the greenhouse, 47 moths were recaptured in 8 traps within 7 m from the release point (5.9 per trap), and 8 moths at 11 m from the release point (2.0 per trap). Outside, 7 moths were recaptured. They had obviously escaped, although the ventilators remained constantly closed, as wild populations of this species do not exist in the Netherlands. Mean catch per trap was 4.6 inside, and 2.3 outside the greenhouse.

TOMATO LOOPER, CHRYSODEIXIS CHALCITES ESPER (FAM. NOCTUIDAE)

(in collaboration with Dr Ir C.J. Persoons,
Division of Technology for Society TNO, Dept. of Chemistry, Delft)

Pheromone-baited traps (load 1 mg in polyethylene caps) were tested in commercial greenhouses that were infested with C. chalcites.

Eight traps were placed inside a 4500 m^2 greenhouse, and one trap outside at a distance of ± 15 m. In the greenhouse, 27 males were caught (3.4 per trap), and outdoors 21 males (21.0/trap), between 18 September and 4 November.

Six traps were placed inside a 10,000 m^2 greenhouse, one trap inside an adjacent small greenhouse, and one trap outside at a distance of ± 15 m from these two greenhouses. In the 10,000 m^2 greenhouse 27 males were caught (4.5 per trap), in the small greenhouse 13 males (13.0 per trap), and outdoors 13 males (13.0 per trap) between 24 September and 4 November.

Catch per trap outdoors was always equal to or greater than catch per trap inside greenhouses, although the population density outdoors was supposed to be much lower.

COTTON LEAF WORM, SPODOPTERA LITTORALIS BOIDS. (FAM. NOCTUIDAE)
(in collaboration with M. van de Vrie and Dr Ir C.J. Persoons)

Four traps, baited with synthetic pheromone of the Egyptian form of S. littoralis (load 1 mg in polyethylene caps), were tested in a commercial Croton greenhouse of ± 1,000 m^2, that was infested with S. littoralis from Western Africa. In one week no moths were caught. However, in an ultraviolet electrocution lamp 64 moths were caught within this period.

Discussion

All presented evidence points in the same direction: pheromone-mediated communication is less effective in greenhouses than in the open air.

This may have different cuases. Basic male flight activitiy (not elicited by pheromone) may be lower in greenhouses, and females may call less frequently. A more likely explanation is that pheromone-mediated long-range behaviour of the males is disturbed. In the field, males react by flying up wind when they encounter pheromone molecules (Kennedy & Marsh, 1974). The specific nature of the air movements in greenhouses may disturb this anemotactic behaviour. Male behaviour in short-range orientation, however, may be unaffected.

As a result, the effectiveness of pheromone-baited traps for monitoring a pest in an early stage, or for mass trapping, is very low in greenhouse cultures. The question arises whether this can be applied in general to all insect species living in enclosed spaces. For example, Hoppe & Levinson (1979) and Levinson & Levinson (1980a, b) state that pheromone-baited traps can be used successfully for detection and mass trapping of storage moths (Phycitinae) and Trogoderma species in granaries, flour mills and food factories.

Disturbance of male anemotactic behaviour in greenhouses possible increases the effectiveness of application of pheromones for mating disruption.

In nocturnal moths, the male's response to female sex pheromone usually consists of a sequence of distinctive behavioural steps. There is evidence that each step requires a higher pheromone concentration. This has been demonstrated in laboratory essays by Schwinck (1955) in the Chinese silkworm moth, Bombyx mori (L.) and by Bartell & Shorey (1969) in

the light-brown apple moth, Epiphyas postvittana (Walker). It is also known to occur in male American cockroaches, Periplaneta americana L. (Rust, 1976; Silverman, 1977). In laboratory assays den Otter & Klijnstra (1980) pointed out that female sex pheromone is indispensible to evoke mating attempts in males of the summerfruit tortrix moth, Adoxophyes orana (F.v.R.). Shimizu & Tamaki (1980) studied the mating behaviour of the smaller tea tortrix (Adoxophyes sp.). They stated that the female sex pheromone is indispensible in releasing male behaviour in short-range orientation, even after initial contact with a female. Castrovillo & Carde (1980) stated that only female sex pheromone may release male short-range sexual behaviour, in the codling moth, Laspeyresia pomonella (L.).

Female sex pheromone may be indispensible in short-term orientation, both inside and outside greenhouses. Application of the mating disruption technique in greenhouses may only be effective if the concentration of synthetic pheromone in the air is made high enough to overflow the pheromone plumes produced by calling females, in order to disturb male short-range sexual behaviour. It may be easier to create high overall pheromone concentrations in greenhouses than in the field. Therefore, greenhouses seem to be well-suited for application of the mating disruption technique, as a control measure against noxious moth species, provided moth density is not too high to rule out the chance of random encounters and matings.

The author is indebted to Dr A.K. Minks for stimulating discussion and critical review of the manuscript.

References

Bartell, R.J. & Shorey, H.H. (1969). Pheromone concetrations required to elicit successive steps in the mating sequence of males of the light-brown apple moth, Epiphyas postvittana. Ann. ent. Soc. Am. 62, 1206-1207.

Castrovillo, P.J. & Carde, R.T. (1980). Male codling moth (Laspeyresia pomonella) orientation to visual cues in the presence of pheromone and sequence of courtship behaviours. Ann. ent. Soc. Am. 73, 100-105.

Hoppe, T. & Levinson, H.Z. (1979). Befallserkennung und Populations-Überwachung vorratsschädlicher Motten (Phycitinae) in einer Schokoladenfabrik mit Hilfe pheromonbeköderter Klebefallen. Anz. Schädlingskde., Pflanzenschutz, Umweltschutz 52 (12), 177-183.

Kennedy, J.S. & Marsh, D. (1974). Pheromone mediated anemotaxis in flying moths. Science (Wash. D.C.) 184, 999-1001.

Levinson, A.R. & Levinson, H.Z. (1980a). Trapping of storage moths by sex pheromone components as a tool of integrated control. Abstract 451 Max-Planck Institute of Behvarioual Physiology, Seewiesen near Starnberg, German Federal Republic.

Levinson, A.R. & Levinson, H.Z. (1980b). Monitoring and mass-trapping of Trogoderma species by traps providing pheromone, tactile and optical stimuli. Abstract 452 Max-Planck Institute of Behavioural Physiology, Seewiesen near Starnberg, German Federal Republic.

Otter, C.J. den & Klijnstra, J.W.(1980). Behaviour of male summerfruit tortrix moths, Adoxophyes orana (Lepidoptera: Tortricidae), to synthetic and natural sex pheromone. Ent. exp. & appl. 28, 15-21.

Rust, M.K. (1976). Quantiative analysis of male responses released by female sex pheromone in Periplaneta americana. Anim. Behaviour 24, 681-685.

Schwinck, I. (1955). Weitere Untersuchungen zur Frage der Geruchsorientierung der Nachtschmetterlinge: Partielle Fühleramputation bei Spinnermännchen, ins besondere am Seidernspinner Bombyx mori L. Z. vergl. Physiol. 37, 439-458.

Shimizu, K. & Tamaki, Y. (1980). Releasers of male copulatory attempt in the smaller tea tortrix moth (Lepidoptera: Tortricidae). Appl. Entomol. & Zool. 15 (2), 140-150.

Silverman, J.M. (1977). Patterns of response to sex pheromone by young and mature adult male cockroaches, Periplaneta americana. J. Insect Physiol. 23, 1015-1019.

MASS PRODUCTION AND INTRODUCTION OF AMBLYSIEUS MCKENZIEI AND A. CUCUMERIS

P.M.J. Ramakers

Rearing of Amblyseius spp.

Since the previous meeting of this group, the most important progress in the research on biological thrips control was the development of an efficient mass rearing method for Amblyseius spp. Using wheat bran as primary food source and Acarus farris as a substitute host, it was demonstrated that 3.10^4 (A. cucumeris) or 10^5 (A. mckenzieï) predatory mites (eggs excluded) can be produced per litre of rearing volume; food costs involved are only Dfl. 0.25. More details are described in Ramakers & van Lieburg (1982).

Introduction methods

Because the supply of predators was no longer limiting, it was possible to intensify this research and vary the numbers of introduced predators within a wide range. Table 1 lists the results of a number of field experiments, including the one described before (Ramakers, 1980), in steam disinfected glasshouses, each containing about 100 cucumber plants. All experiments resulted in a rather predictable final situation, with very few thrips (in the order of one larva per leaf) and a negligible amount of leaf damage left. Unlike Phytoseiulus persimilis, which tends to disappear after creating prey scarcity, the Amblyseius spp. we studied always maintained a rather low (<5 per colonized leaf) but well spread (100% of the plants and about 50% of the leaves colonized) and stable basic population. It is thought that the ability to prey on substitute hosts explains this phenomenon. It was demonstrated that A. cucumeris is able to survive on cucumbers or beans with only spider mites as a prey for at least 7 weeks, though it will not control this pest.

Before control is achieved, thrips numbers reach a peak, usually in June or July. Outdoor yellow traps indicate that migration of adults is important in that period. Biological control is most easily achieved by an inundative introduction of predators in spring after colonization of all plants by the pest insect, as was demonstrated in 1982 (Table 1). In these experiments as many as 1200 predators per plant were introduced, which resulted in immediate control.

Table 1: Maximum number (PEAK) of Thrips tabaci (larvae) and Phytoseiid predators (eggs + mites) per leaf, and number of thrips larvae per leaf after biological control was achieved (RESULT), as a result of inoculative introductions, inundative introductions and spontaneous occurrence of Amblyseius mckenziei or A. cucumeris in cucumber crops

Year	Predator sp.	Introduction		Peak Predator	Peak Thrips	Result Thrips
1978	A. mck.	May 30	Inoc.	10	16	1
1980	A. mck.	April 17	Inoc.	11	32	< 1
1980	A. mck.	April 17	Inoc.	10	40	< 1
1980	A. mck.	May	Spont.	12	171	1
1981	A. cuc.	March 26	Inoc.	33	23	5
1982	A. cuc.	May 14	Inund.	-	-	< 1
1982	A. mck.	May 7	Inund.	-	-	3

Inoculative introductions, at the first sign of thrips presence, as carried out in the years previous to 1982, would be more attractive to mass rearing companies, but control is less predictable. In young crops, the majority of plants can be free of any insects or mites, and introduced predators will decrease and become undetectable in two or three weeks. At such low population densities, the flying capacity of the thrips adults is a clear advantage. A repeated inoculative introduction of predators may be an answer to that problem, but this would be less convenient as long as they must be distributed by hand.

In further experiments we will therefore study the possibility of a pre-establishment of Amblyseius before thrips occurrence (Fig. 1). We are encouraged to do so, because in one commercial sweet pepper holding we succeeded, by accident, to establishe a large population of A. cucumeris long before any thrips symptoms were found. Only spider mites were present in sufficient numbers to account for the size, spread and stability of the predator population. Thrips appeared later in the season, but never reached considerable numbers.

Population dynamics

The field experiments of 1980 will be described in more detail. In that year, 3 neighbouring glasshouses were available. To prevent the use of chemicals, mildew resistant cucumbers were planted at the beginning of February. Encarsia formosa was introduced in that same month, and Phytoseiulus persimilis in March; aphids did not occur in this experiment. The first thrips symptoms were seen in mid April, and A. mckenziei was introduced inoculatively, in one house on every plant, in another on every 10th plant; no introductions were done in the third house (Fig. 2).

In the first two weeks after introduction, predators were hardly detectable. On May 12 and 28, a rough survey was made in order to demonstrate the spread of the predators. For this purpose, one leaf of each plant was checked with the naked eye in transmitted light. In this way, usually only the dark coloured adult predators are detected, so Fig. 2 is likely to underestimate the real spread. Little difference was found between both treated houses, and some predators managed to penetrate soon in the control plot. The latter may be transported accidentally by people during pruning, harvesting, etc.

Because predators in particular are easily overlooked in the field, numbers of both thrips and predators were established by careful microscopic inspection of sampled leaves as described in Ramakers (1980). In both houses with predator introduction, thrips populations reached a critical level at the end of May (Fig. 3), that was thought to be around the limit of acceptability for commercial growers. Predators then quickly reduced the pest and controlled it until the end of July, when the crop was removed. In the control house without predator introduction, the thrips population was higher and the crop suffered severe damage. Obviously the predators that penetrated into this house came too late; nevertheless, even this large thrips population was eliminated quite rapidly, so the experiment ended with similar thrips numbers in all plots.

The predator populations (Fig. 4) in the three plots were similar in terms of peak numbers. The superior pest control in the houses with artificial predator introduction is obviously due to the fact that all plants were colonized by predators much earlier. One should notice that after predator numbers decreased, the percentage of leaves colonized by predators remains fairly high, which is in striking contrast to population dynamics of a specialized predator like P. persimilis.

The maximum number of thrips larvae found on one cucumber leaf in field experiments was 795; the maximum number of predators was 27 eggs +

25 mites for A. mckenziei, 27 eggs + 31 mites for A. cucumeris.

Dosse (1958) reported that P. persimilis is cannibalistic to some extent. The same phenomenon was observed in A. mckenziei and A. cucumeris both in the field and in the laboratory, though it did not exclude the occurrence of such high densities as observed in the mass rearing units (up to 100 predators per cc). Victims are usually larvae, killed either by nymphs or adults. The three Phytoseiid spp. mentioned also prey on each other's larvae. In spite of that, populations of P. persimilis, A. mckenziei or A. cucumeris, can coexist on the same plants or even leaves. Their hunting behaviour differs so much, that they probably will seldom meet. However, if mixed populations of both Amblyseius spp. are introduced, one species will gradually displace the other. So far, such experiments were performed only on sweet pepper, on which A. cucumeris always dominated at the end. In this case, preying on each other's larvae is more likely to play a role, because of the similar niche preference of these species.

References

Dosse, G. (1958). Ueber die Entwicklung einiger Raubmilben bei verschiedenen Nahrungstieren (Acarina: Phytoseiidae). Pfl. sch. ber. 16, 122-136.

Ramakers, P.M.J. (1980). Biological control of Thrips tabaci (Thysanoptera: Thripidae) with Amblyseius spp. (Acari: Phytoseiidae). Bull. SROP/WPRS 1980 III/3, 203-208.

Ramakers, P.M.J. & Lieburg, M.J. van (1982). Start of commercial production and introduction of Amblyseius mckenziei (Acarina: Phytoseiidae) for the control of Thrips tabaci (Thysanoptera: Thripidae) in glasshouses. Med. Fac. Landbouww. Rijksuniv. Gent (in press).

EXPERIMENTAL VALIDATION OF A SIMULATION MODEL OF THE INTERACTION BETWEEN PHYTOSEIULUS PERSIMILIS & TETRANYCHUS URTICAE ON CUCUMBER

M.W. Sabelis, F. van Alebeek, A. Bal, J. van Bilsen,
T. van Heijningen, P. Kaizer, G. Kramer, H. Snellen,
R. Veenenbos & J. Vogelezang

Introduction

Many workers have demonstrated the efficiency of Phytoseiulus persimilis Athias-Henriot in controlling the two-spotted spider mite, Tetranychus urticae Koch, on greenhouse cucumbers (Bravenboer & Dosse, 1962; Bravenboer, 1963; Hussey et al., 1965; Addington, 1966; Legowski, 1966; Parr & Hussey, 1967; Begljarow, 1967; Gould, 1968; Hussey & Bravenboer, 1969; Gould et al., 1969; Gould, 1970, 1971; Markkula et al., 1972; Khristova, 1973; Markkula & Tiittanen, 1976; Pruszynski, 1976; Hussey & Scopes, 1977; Nachman, 1981). In practice insufficient control may arise from the effect of pesticides, low humidity or high temperature on the predators. This paper deals with another possible cause: the dose (timing) and the site of predator release.

The number of predators to be released should be large enough to prevent economic damage to the cucumber crop. According to Hussey & Parr (1963) the yield of cucumbers is unaffected until the damaged leaf area rises above 30% of the total leaf area. Since inundative releases of predators are presently not feasible, the strategy is to release a sufficient number of predators at an early stage of pest infestation. According to Hussey et al. (1965) two predators should be released on every second plant when the mean damaged area per leaf is equal to 5 cm^2 (incipient damage). In this way the spider mite population is not exterminated immediately, but it will keep increasing until the predator population is large enough to suppress the growth of the prey population. Hence the essential feature of the method is that it is not only based on the voracity of the predator, but also on its capacity of population increase. Usually the spider mite population is reduced to very low numbers, so that the predators die out in a few weeks as a consequence of food shortage and reintroduction of the predators is necessary whenever the spider mite pest resurges. The above prescription can only be successful in case of a uniform distribution of the pest over the crop since the dispersal power of phytoseiid predators is limited. Therefore, Hussey et al. proposed to infest the young crop uniformly with spider

mites and to introduce the predators later: the pest-in-first method. For some reason the method is not adopted by Dutch cucumber growers. Hence the distribution of the spider mites in their crop is far from being even. In January spider mites begin to emerge from hibernation in the glasshouse structure soon after the houses are heated. These mites descend onto young plants and give rise to patchy infestations of varying severity. Therefore, instead of prescribing a fixed dose of predators per plant, it is needed to adapt the dose in relation to the local degree of infestation.

'Realistic' simulation models of the predator-prey interaction may provide a useful tool in estimating the dose required for satisfactory control. Such a model has been developed for the case of greenhouse roses (Sabelis, 1981 and in prep.). In this culture the pest-in-first method is inappropriate because infection of harvested roses is not tolerated and because upward dispersal of the spider mites along the rose shoots is fast and, hence, hard to control with predatory mites. Therefore, timing and dose of predator release in the spider mite patches are of crucial importance in the greenhouse culture of ornamental roses in the Netherlands. Since the use of simulation models proved to be quite successful in solving this question, it may be used in other crops too. This paper describes the changes of the model that were necessary to simulate the predator-prey interaction on cucumbers. Moreover, experiments on biological control in greenhouse cucumbers are discussed and the results are compared with simulations to assess the validity of the model.

Simulation Model

The model simulates the number of mites in successive juvenile and adult age classes accounting for the rate of development, the rate of survival, the rate of reproduction and the sex ratio of the offspring. The residence times of the mites in each class are updated at each time interval in an 'hour-glass' integral. After the elapse of a development period the individuals are transferred to the next class. At each time interval of the simulation the number of male and female eggs produced by all adult females together are transferred to the male or female egg stage. In this way population growth of both predator and prey can be simulated starting from a specified distribution of mites over the age classes.

Development and reproduction depend on the amount of food acquired.

In the case of the predator the rate of prey consumption is computed on the basis of measured properties of the predator (searching behaviour, prey stage preference and the rate of food conversion) and the actual availability of the prey. Prey availability is defined as the number of mites divided by the leaf area occupied, i.e. the webbed leaf area of a spider mite patch. This webbed area is in fact a collection of webbed areas located on all the infested cucumber leaves constituting a patch. By simulation of the webbed area and the number of spider mites, prey density, and hence prey availability, can be quantified in the model. The predatory mites are assumed to stay and forage in the webbed area throughout the simulated interaction period. In this way food acquisition by the predator is modelled and the consequences for development and reproduction are accounted for by experimentally derived functions.

The consequences of food acquisition by the spider mites are not considered in the model. It is assumed that the spider mites have access to an unlimited source of plant food and consequently development and reproduction are unaffected by food scarcity. This assumption was thought to be reasonable since the cucumber plants frequently touch each other ensuring pathways for walk-over and since we only consider damaged leaf areas less than 30% of the total leaf area.

As mites are poikilothermic arthropods, the environmental temperature determines the rate of biochemical processes underlying development, reproduction, webbing and predation. Therefore, temperature is an important driving variable in the population model. The relations of the rate variables with temperature are measured at constant temperatures in the range of 10 to 33°C and are supplied to the model as functions. It is assumed that all temperature related rate variables react instantaneously to any change of temperature within the temperature range investigated. Effects of relative humidity are not accounted for, which is justified as long as relative humidity ranges between 50 and 90% (Sabelis, 1981).

Since the model was constructed for greenhouse roses, it is important to evaluate which inputs should be adapted when cucumber is the host plant under consideration. Table 1 shows that the life history of T. urticae on 'Sonia' rose leaves is hardly different from that on leaves of the varieties of cucumber used in this study. However, a female spider mite spreads its web cover 3.8 times faster over a cucumber leaf than over a rose leaf. It is assumed that the predatory behaviour of P. persimilis is not affected by the host plant.

Table 1: Life history traits of females of T. urticae and the daily increase of the area webbed by the adult female on rose and a mildew resistant variety of cucumber. (Temp. = 26°C; RH = 60-80%).

	Rose cv Sonia			Cucumber cv K1544 Pannevis		
	Mean	St. dev.	n	Mean	St. dev.	n
Development time from egg to adult female at first oviposition (hour)	252	14	30	254	11	30
Net reproduction	123	25	21	120	47	22
Rate of increase of the webbed area ($cm^2/♀/day$)*	0.195	-	20	0.687	-	20

* The relationship between the daily expansion of the webbed cucumber leaf area and the temperature is assumed to be proportional to the measured relation on rose leaves (Sabelis, 1981). Moreover, it is assumed that the expansion is not affected by the cucumber varieties used in this study.

The counting of individual mites is laborious on account of the small size of mites and their fast rate of multiplication. It is more convenient to estimate the size of the spider mite population from the leaf area occupied, i.e. the webbed area. Therefore, the dynamics of the webbed area after predator release in a spider mite patch was measured in greenhouse experiments on biological control on cucumber plants and these measurements were compared with computer simulations with the model outlined above.

Measurement of the webbed leaf area

The area covered by two-spotted spider mites was measured by estimating the webbed area of each cucumber leaf in the greenhouse. If the webbed part of the leaf was small or consisted of some small subareas, the webbed area was estimated directly in terms of square centimeters. However, if it was larger, the proportion of the total area per leaf side was estimated using a map showing the relative share of the areas between the main veins (Figure 1). The proportion per leaf ranges between 0 and 200% as the leaf can be colonized at both sides, the

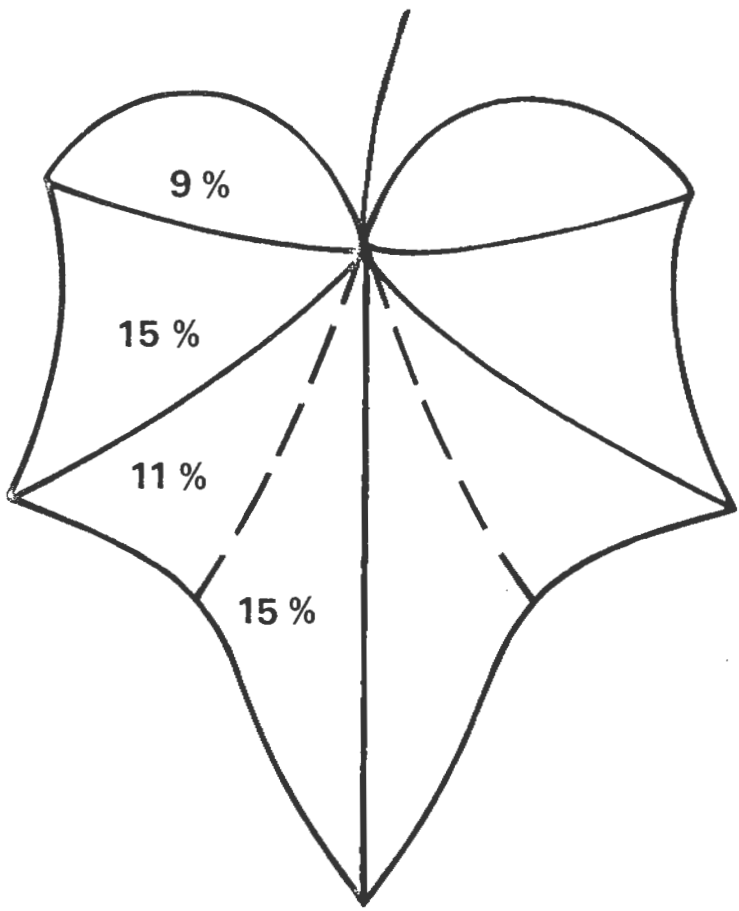


Figure 1: The share of the main interveinal leaf areas proportional to the total area of a cucumber leaf. The dashed 'veins' indicate imaginary dividing lines.

underside being highly preferred to the upperside. To enable computation of the area webbed by the spider mites, the area of one side of each leaf was estimated too. This was done by measuring the length of the middle rib of the leaf with the aid of a ruler and by computing the leaf area from one of the following regression equations:

$\ln y = 2.4 \ln x - 1.38$ (cv K1544 Pannevis; $r = 0.964$ and $n = 49$)
$\ln y = 1.79 \ln x + 0.61$ (cv Profito; $r = 0.972$ and $n = 45$)
y = leaf area
x = length of the mid-rib
r = correlation coefficient
n = number of replicates

The accuracy of the webbed area estimates was determined experimentally by comparing estimates of the webbed leaf area with accurate measurements obtained by cutting out the webbed parts of the leaf and measuring the leaf area using a leaf area meter. The estimates were maximally 12% higher and minimally 8% lower than the accurate measurements of the webbed leaf area ($n = 50$). The mean deviation was +2.5%. However, this test was only done once for one observer (the standard observer) under optimal conditions. Despite several measures to standardize the estimation procedure, systematic differences between the observers were revealed by comparing estimates of the webbed area of the same leaves ($n = 100$). This is demonstrated in Figure 2 in the form of a worst case display relative to the estimate of the standard observer.

Experiment on biological control in September 1981

The cucumber crop (K1544 Pannevis, a mildew resistant variety) used for the experiment, consisted of four rows of 23-24 plants growing vertically toward a wire stretched horizontally at some distance from the top of the greenhouse (Horticultural Station, Naaldwijk). After reaching the wire the plants were led downwards with only two side branches. Within each row the leaves of neighbouring plants frequently touched each other. The plants of row 2 and row 3 were also in contact with each other. However, the side rows 1 and 4 were separated from the middle rows by paths of 1 meter width.

The crop was planted in July after soil treatment with oxamyl. At the end of July a small spider mite infestation was suppressed by spraying dienochlor. Aphids were controlled with a pirimicarb treatment, thrips by

Amblyseius sp. and whitefly by Encarsia formosa. Temperature and humidity were continuously recorded by thermohygrographs. Temperature fluctuations are presented in Table 2 and relative humidity did not attain values critical for phytoseiid development.

Table 2: Daily minimum and maximum temperatures at 1 m height in the cucumber crop. The temperatures were measured with a thermohygrograph in September 1981.

Day-month	Maximum temp. °C	Minimum temp. °C	Day-month	Maximum temp. °C	Minimum temp. °C
3-9	29.5	15.5	17-9	30.0	22.0
4-9	29.5	15.0	18-9	30.0	21.5
5-9	32.0	18.0	19-9	22.0	18.0
6-9	32.5	19.0	20-9	28.0	20.5
7-9	29.5	22.0	21-9	23.0	19.0
8-9	29.0	20.5	22-9	30.0	20.0
9-9	32.0	22.0	23-9	23.0	19.5
10-9	23.0	20.0	24-9	32.0	17.5
11-9	23.5	22.0	25-9	27.5	17.5
12-9	23.5	18.5	26-9	24.5	18.0
13-9	28.0	21.0	27-9	27.0	20.0
14-9	25.0	21.0	28-9	25.0	19.0
15-9	32.0	20.5	29-9	23.0	19.0
16-9	27.5	20.0	30-9	31.0	15.0
			1-10	27.0	16.0

On 24 August each of four cucumber plants situated in the centre of row 2 and 3 were infested by attaching one bean leaf with a young spider mite colony (ca. 50 young adult females, 15 adult males and ca. 400 eggs) to the upperside of a cucumber leaf at body height. This infestation formed the main source of the spider mite patch, the size of which was measured on the dates indicated on the x-axis of Figure 3. The solid points in the Figure represent the estimates of the webbed area in rows 2 and 3. At 3 September predatory mites were released by sprinkling a leaf of every second plant with the contents of one of Koppert's predator jars.

Following the prescriptions used in practice only 1/3 of the content was used on the 70 m^2 crop area. The next day all leaves were inspected for the presence of predatory mites. In rows 2 and 3 197 female predators were counted. Their number in the side rows was low. The measurements presented in Figure 3 show that the webbed area in rows 2 and 3 initially increased and ultimately stabilized within a month since the introduction of the predators. The ultimate area webbed by the two-spotted spider mites amounted to ca. 250,000 cm^2, which was equal to approximately 15% of the total leaf area of the cucumber crop. The spider mite population in rows 2 and 3 was close to extermination at the end of the experimental period. However in rows 1 and 4, which had a low level of infestation and a low number of predators at 3 September, the webbed area was still increasing. These infestations would have been suppressed in a few weeks because these were heavily colonized by predators which had possibly migrated from the middle rows. In the last weeks of the experiment the state of the plants gradually worsened as a consequence of a nematode pest infesting the roots of the cucumber plants (Meloidogyne sp.). The experiment was stopped on 8 October. The nematode pest may have influenced the level at which the webbed area ultimately stabilized. However, we think that the effect was not of great importance since the webbed area was increasing steadily on the plants in the side rows although the turgor decrease in thes plants was not different from that in the middle rows.

Experiments on biological control in Spring 1982

A similar experimental procedure was followed in a subsequent series of two simultaneous experiments in neighbouring compartments of a greenhouse at the horticultural station in Naaldwijk. The soil was steam sterilized in November 1981. The cucumber crop (Profito, a mildew resistant variety) was planted at 28 January 1982. The plants were led slopingly upwards towards one of the two parallel wires stretched horizontally in the top of the greenhouse. Alternatingly, the plants were led towards the wire at the left and at the right hand side of the row. This V-planting system caused the leaves of neighbouring plants to make fewer contacts than in the crop of the previously discussed experiment. Mutual contact between the plants increased during April as a consequence of the plants branching downward from the wires. The cucumber crop consisted of 20 rows of 24 plants divided over four compartments (40 + 154 + 154 + 40 m^2 area) of the glasshouse. In two

compartments (40 + 154 m^2) six plants were selected that were distant from each other and from the side walls of the glasshouse. Each was infested by one bean leaf with a young spider mite colony (ca. 70 young females, 20 adult males and 500 eggs). On 10 March the content of one and a half predator-jar of Koppert was distributed uniformly on every second plant including the infested plants. The next day an average number of 60 predators was found per patch. As shown in Figure 4 the webbed area initially increased until it stabilized after a month following the introduction of the predators. After spider mite elimination less than 2% of the total leaf area was occupied by webbing.

Simultaneously, another experiment was carried out in two other compartments. Six distant plants were selected and each was infested with three bean leaves instead of one. The day after uniform predator release an average number of 43 predators per patch was found. As shown in Figure 5, the mean webbed area per patch continued to increase within the period of web assessments indicated in the Figure. After 8 April precise assessments were hampered because part of the leaves were picked by the grower as a measure to improve light penetration in the crop. The webbed area probably stabilized after 1.5 months since predator release at a level below 100,000 cm^2.

The damage caused by other pests was minor in all greenhouse compartments. Thrips was controlled by Amblyseius sp. and whitefly by Encarsia formosa. Leaf temperature was measured continuously by the aid of a Heiman infrared thermometer. The temperature fluctuations are given in Table 3. Relative humidity measured by thermohygrographs did not attain critical values for the development of the predatory mites.

Validation of the simulation model

To validate the model, simulations should be compared with the actual measurements presented above. These simulations can be carried out after supply of the following input data:

1. Life history of both T. urticae and P. persimilis in relation to temperature (Sabelis, 1981; Table 1).

2. Expansion of the webbed area per time unit and per female spider mite in relation to temperature (Table 1).

Table 3: Daily minimum and maximum temperatures of the upper side of a cucumber leaf at 1 m height. The temperatures were measured with a Heyman's infrared thermometer in March and April 1981. Temperature is at its minimum from 19.00 h until 7.00 h the next day.

Day-month	Minimum temp. °C	Maximum temp. °C	Day-month	Minimum temp. °C	Maximum temp. °C
10-3	16.0	19.0	1-4	18.0	22.0
11-3	17.0	19.0	2-4	18.0	23.0
12-3	19.0	21.0	3-4	18.0	23.0
13-3	19.0	23.0	4-4	18.0	23.0
14-3	20.0	22.0	5-4	18.0	23.0
15-3	19.0	23.0	6-4	19.5	24.0
16-3	19.0	23.0	7-4	19.0	23.0
17-3	20.0	23.0	8-4	19.0	23.0
18-3	20.0	24.0	9-4	18.0	24.0
19-3	19.0	23.0	10-4	18.0	25.0
20-3	19.0	24.0	11-4	18.0	23.0
21-3	19.0	22.0	12-4	18.0	25.0
22-3	19.0	22.0	13-4	18.0	24.0
23-3	19.0	23.0	14-4	18.0	25.0
24-3	19.0	24.0	15-4	19.0	24.0
25-3	18.5	22.0	16-4	18.0	25.0
26-3	18.5	24.0	17-4	19.0	24.0
27-3	19.0	24.0	18-4	18.0	25.0
28-3	18.5	22.0	19-4	18.0	24.0
29-3	18.5	22.0	20-4	18.0	23.0
30-3	18.5	22.0	21-4	18.0	23.0
31-3	18.0	22.0	22-4	18.0	24.0

3. Components of predatory behaviour and the conversion of ingested food by the female predator in relation to temperature (Sabelis, 1981).

4. Temperature fluctuations in the greenhouse during the experiments (Tables 2 and 3).

5. Initial number and age distribution of spider mites.

6. Initial number of phytoseiid predators, their age distribution, their feeding state and their oviposition history (= the number of eggs produced before release).

All input data are available, but some discussion should be added to the latter two. Firstly, the age distribution of the spider mites is only approximately known by using recently colonized bean leaves for infestation of the cucumber plants. Moreover, the number of mites was estimated from counts in a sample of bean leaves. Precise counting would have been laborious and superfluous, because the fraction of successful colonizations on the cucumber is not precisely known. Therefore, the initial number of spider mites supplied to start the simulations was modified so as to simulate a value of the webbed area at the date of predator release that is equal to the webbed area measured at this particular date.

Secondly, although the initial number of female predators is known from direct counts at the day after the predator release, the feeding stage, the age and more importantly the oviposition history, is not known since the predators in Koppert's jars are not selected for these characteristics. This problem was solved step by step. At first, simulations were carried out assuming the released female predators were satiated and did not deposit any eggs before their release. These simulations are presented in Figures 3, 4 and 5. Subsequently, the model was tested for its sensitivity for modifications of the assumptions. This sensitivity analysis is presented in the next section.

The simulated course of the webbed area corresponds with the measured values in Figures 3 and 4. This suggests that the model reacts to changes in the predator-prey ratio in a realistic way. Figure 5 shows that the measured webbed area stabilizes at a level that is approximately 30 times lower than simulated. The predator-prey ratio in this particular experiment was lower, but still close to that in the experiment presented

in Figure 3. Hence, the difference between measurement and simulation shown in Figure 5, points to a fundamental gap in the model structure.

A possible explanation for these contrasting results is found when considering the differences in crop structure between the 1981 and 1982 experiments and the related possibilities for plant-to-plant dispersal for the spider mites. In the 1981 experiment adjacent cucumber plants growing vertically contacted each other frequently and it may be supposed that this promotes plant-to-plant dispersal at all height levels in the crop. In contrast, plant-to-plant dispersal may have been hindered in the V-crop structure of the 1982 experiment due to less leaf contact between plants. Consequently, the iron wires used for conducting the growing plant may become relatively more important as a pathway from plant to plant. However, if these pathways are not found by the spider mite and the host plant is exhausted as a food source, the spider mite will die from starvation. Indeed, the plants selected for the introduction of the spider mites in the 1982 experiment presented in Figure 5 became over-exploited and chlorotic. Silken ropes with thousands of spider mites hung down from the tips of the leaves of these plants without getting contact with adjacent plants. The expansion of the webbed area from the infestation centres proceeded only over a few adjacent plants in contrast to the large expansion found in the 1981 experiment. This suggests that the spider mites were left stranded in already overexploited leaves and consequently mortality due to food shortage took over the key role of the predators in suppressing the spider mite population growth. This type of mortality was probably unimportant in the parallel experiment in which the amount of spider mites introduced in the crop was 3 times less (Figure 4). Here the plants selected for spider mite introduction were not overexploited as spider mite control by the predators was achieved earlier. The above theory fits to the phenomena observed but, of course, it is hypothetical as long as the mortality due to local food shortage is not measured directly. Its value is that it is a testable theory and that it may have an important bearing on our insight in the practice of biological control.

Sensitivity analysis

In the simulations presented in Figures 3, 4 and 5, it is assumed that the counts of the initial number of female predators were exact, that the released predators were initially satiated with food and that these predators did not lay eggs before their release. Most likely these

assumptions are not valid. Therefore, the model was tested for its sensitivity to modifications of these assumptions, as shown in Table 4.

Table 4: Sensitivity analysis of the simulation model: The change of the ultimate level of the webbed leaf area as a consequence of the change of one input parameter in the population model. The change in the webbed area is expressed relative to a simulation with standard inputs (equal to the simulation in Figure 4), i.e. 60 young female predators released at day 12 since the introduction of the spider mites in the cucumber crop, the predators were satiated at release and did not deposit any egg before, temperature fluctuates according to the measured course during the 1982 experiments.

	Relative change of the ultimate webbed area
Number of adult female predators released	
100	0.41
80	0.61
60	1.0
40	2.05
20	9.40
Gut filling of released predators	
100%	1.0
0%	0.95
Number of eggs deposited by predators before release	
0	1.0
20	1.002
40	1.12
50	1.56
60	4.03
Change of daily maximum temperature	
-2°C	0.77
-1°C	0.87
0°C	1.0
+1°C	1.17
+2°C	1.43

The sensitivity analysis shows that the initial food content of the gut is of little importance to the outcome of the simulations. However, it should be realized that the simulations were not done for the case of prolonged starvation of the predators which may affect the predator adversely. The model is rather sensitive to the oviposition history of the female predators. Therefore, it was estimated, though only in the 1982 experiments. This was done by measurement of the number of eggs that were produced at ample supply of prey by 30 female predators sampled randomly from the predator-jars. The females deposited an average number of 45 eggs per female (net reproduction). Because an average number of 70 eggs would have been expected if the females sampled were all in the pre-oviposition phase, the predator females probably deposited an average of 25 eggs before their release. Therefore, we can conclude that, like the food content of the gut, the oviposition history of the female predators released in the greenhouse experiments discussed above is of minor importance to the particular outcome of the simulations.

The model was most sensitive to the initial number of predators released in the crop. However, the accuracy of the predator counts on the day after predator release has not been determined. Nevertheless, it is unlikely that the difference between simulation and measurement in Figure 5 is caused by erroneous assessment of the initial numbers, since to enforce correspondence of the simulation with the measurements five times more predators were needed to initialize the model calculations, than actually counted in the greenhouse.

Another variable that is subject to inevitable deviations is the temperature. It is not uniform in the greenhouse, e.g. it may increase with height during sunny days. However, the variation of the temperature in the greenhouse has not been measured.

The conclusions drawn in the previous section can be affected by deviations in the temperature and in the number of predators released in the spider mite patches. Therefore, the analytic view set out in the previous section, is only valid if deviations in the number of predators released and in the temperature have been sufficiently small.

Discussion

The validation experiments carried out in the V-structured cucumber crop in 1982, have shown a phenomenon that cannot be explained by the model as it was constructed. The measured relative increase of the webbed area since the movement of predator release was the same whether one predator was released per 20 cm^2 (Figure 4) or per 100 cm^2 webbed area (Figure 5). According to the simulation model, a decrease of the number of predators released per unit webbed area, should result in an increasing proportion of the ultimate webbed area relative to its size at predator release. This contrast between experiment and model may be explained by assuming that high spider mite mortality occurs on heavily exploited plants whenever possibilities for plant-to-plant dispersal are reduced. Because crop structure has an important bearing on these possibilities, it may be relevant to investigate which crop structures can counteract adverse effects of unfavourable predator-prey ratios. We suggest this to be the case in the V-structured cucumber crop.

Are there also practical circumstances that promote the prey to escape from predation? As yet, we do not have any indication for prey escape. Spider mites can reach neighbouring host plants by walking, but also by spinning along silken ropes that are moved pendulum-wise by air currents and become attached to fresh host plants. The iron wires in the top of the greenhouse facilitated plant-to-plant movements, but these pathways are equally accessible for both spider mites and predatory mites. The silken ropes, however, provide a dispersal mode only to the spider mites. This strategy had low success in the V-structured crop, probably due to the distance between adjacent plants and to the very weak air currents in the greenhouse, which are not capable of moving the silken ropes sufficiently. Moreover, there was no indication that the predatory mites were unable to detect spider mite infestations on adjacent plants. Therefore, prey escape is considered to be irrelevant under the circumstances investigated in this study.

The model produced realistic values of the leaf area occupied after elimination of the spider mite pest (Figures 3 and 4). Here, the major component of the spider mite mortality was probably caused by predation. Since additional mortality, e.g. due to local food scarcity, merely ameliorates the spider mite control, the model can be used to make general prescriptions for the dose of predators to be released in a spider mite patch of a certain size. The prescriptions will be published in STING, a newsletter on biological control in greenhouses. The model may also be

used to optimise the dose in case the pest-in-first method is applied or in case both predator and prey are released simultaneously to create a buffer for forthcoming spider mite infestations. Moreover, it may help to define criteria for the quality of the predatory mites that are distributed among the growers, e.g. in terms of the number of eggs the female predators should produce after their release.

Acknowledgements

We gratefully acknowledge P. Ramakers for support and discussions and H. Klomp for comments on the manuscript.

References

Addington, J. (1966). Satisfactory control of red spider mite on cucumbers. Grower 66 (19), 726-727.

Begljarow, G.A. (1967). Ergebnisse der Untersuchungen und der Anwendung von Phytoseiulus persimilis Athias-Henriot als biologisches BekÄmpfungsmittel gegen Spinnmilben in den Sowjetunion. Nachrichtenblatt des Pflanzenschutzdienstes 21 (47), 197-200.

Bravenboer, L. (1963). Experiments with the predator Phytoseiulus riegeli Dosse on glasshouse cucumbers. Mitteilungen schweizerisches entomologisches Gesellschaft 36, 53.

Bravenboer, L. & Dosse, G. (1962). Phytoseiulus riegeli Dossé as a predator of red spider mite of the Tetranychus urticae group. Entomologia experimentalis et applicata 5, 291-304.

Gould, H.J. (1968). Observations of the use of a predator to control red spider mites on commercial cucumber nurseries. Plant Path. 17, 108-112.

Gould, H.J. (1970). Preliminary stidies of an integrated control programme for cucumber pests and an evaluation of methods of introducing Phytoseiulus persimilis A.-H. for the control of Tetranychus urticae Koch. Ann. appl. Biol. 66, 505-513.

Gould, H.J. (1971). Large scale trials of an integrated control programme for cucumber pests on commercial nurseries. Plant Path. 20, 149-156.

Gould, H.J., Hussey, N.W. & Parr, W.J. (1969). Large-scale commercial control of Tetranychus urticae Koch on cucumbers by the predator Phytoseiulus persimilis A.-H. Proc. 2nd Int. Congress of Acarology, 383-388.

Hussey, N.W. & Parr, W.J. (1963). The effect of glasshouse red spider mite Tetranychus urticae Koch on the yield of cucumbers. J. hort. Sci. 38, 255-263.

Hussey, N.W., Parr, W.J. & Gould, H.J. (1965). Observations on the control of Tetranychus urticae Koch on cucumbers by the predatory mite Phytoseiulus riegeli Dosse. Ent. exp. et appl. 8, 271-281.

Hussey, N.W. & Bravenboer, L. (1969). Control of pests in glasshouse culture by the introduction of natural enemies. "Biological control" (B. Huffaker, ed.), pp. 195-216. Plenum Press, New York.

Hussey, N.W. & Scopes, N.E.A. (1981). The introduction of natural enemies for pest control in glasshouses: ecological considerations. In: "Biological control by augmentation of natural enemies" (R.L. Ridgeway and S.B. Vinson, eds.), pp. 349-378. Plenum Press, New York.

Khristova, E. (1973). Dynamics of the distribution and ratio between mixed populations of T. atlanticus and T. urticae and P. persimilis. Gradinarska i Lozarska Nanka 10 (4), 83-87.

Legowski, T.J. (1966). Experiments on predator control of the glasshouse red spider mite on cucumbers. Plant Path. 15, 34-41.

Lewontin, R.C. (1965). Selection for colonizing ability. In: "The genetics of colonizing species" (H.G. Baker and G.L. Stebbins, eds.), pp. 79-94. Academic Press, New York.

Markkula, M., Tiittanen, K. & Nieminen, M. (1972). Experiences of cucumber growers on control of the two-spotted spider mite Tetranychus telarius (L.) with the phytoseiid mite Phytoseiulus persimilis A.-H. Annales Agricultur Fenniae 11, 74-78.

Markkula, M. & Tiittanen, K. (1976). 'Pest in first' and 'natural infestations' methods in the control of T. urticae Koch with Phytoseiulus persimilis Athias-Henriot on glasshouse cucumbers. Annales Agricultur Fenniae 15, 81-85.

Nachman, G. (1981). Temporal and spatial dynamics of an acarine predator-prey system. J. Animal Ecol. 50, 435-451.

Parr, W.J. & Hussey, N.W. (1967). Biological control of red spider mite on cucumbers: Effects of different predator densities at introduction. Rep. Glasshouse Crops Res. Inst., 135-139.

Pruszynski, S. (1976). From the researches upon the predacious mite Phytoseiulus persimilis Athias-Henriot. IV Some aspects of practical use of P. persimilis for biological control of spider mites (Tetranychidae). Roczniki nauk Rolniczych 7 (2), 193-208.

Sabelis, M.W. (1981). Biological control of two-spotted spider mites using phytoseiid predators. Part 1. Modelling the predator-prey interaction at the individual level. Agric. Res. Reports, No. 910, 242 pp.

Sabelis, M.W. (In prep.). Biological control of two-spotted spider mites using phytoseiid predators. Part 2. Modelling the predatory-prey interaction at the population level. Agric. Res. Reports.

Figure Legends

Figure 2: The maximum and minimum estimates registered in a group of four observers estimating the relative webbed area (%) of the same cucumber leaves. The estimates are classified according to the estimates of one of the observers (the standard observer). The maxima and minima are selected from 16-28 observations per class (class width = 5%).

Figure 3: Experiment on greenhouse cucumbers in the autumn of 1981 (one predator released per 80 cm^2 webbed leaf area): Simulated and measured increase of the webbed leaf area after introduction of T. urticae at 24.8.81 and the release of P. persimilis at 3.9.81. The measured webbed area at 3.9.81 amounts to 15538 cm^2. The number of predator females counted in the webbed area at 4.9.81 is equal to 197. Temperature fluctuations are given in Table 2.

Figure 4: Experiments on greenhouse cucumbers in the spring of 1982 (one predator released per 20 cm^2 webbed leaf area): Simulated and measured increase of the webbed leaf area after introduction of T. urticae at 26.2.82 and the release of P. persimilis at 10.3.82. The average webbed area is computed from the webbed areas in six separate infestation focusses. At predator introduction the webbed area amounts to 1233 cm^2. The mean number of predator females per infestation focus counted at 11.3.82 is equal to 60. Temperature fluctuations are given in Table 3.

Figure 5: Experiments on greenhouse cucumbers in the spring of 1982 (one predator released per 101 cm^2 webbed leaf area): Simulated and measured increase of the webbed leaf area after introduction of T. urticae at 26.2.82 and the release of P. persimilis at 10.3.82. The average webbed area is computed from the webbed areas measured in six separate infestation focusses. At predator introduction the webbed area amounts to 4337 cm^2. The mean number of predator females per infestation focus counted at 11.3.82 is equal to 43. Temperature fluctuations are given in Table 3.

Figure 2

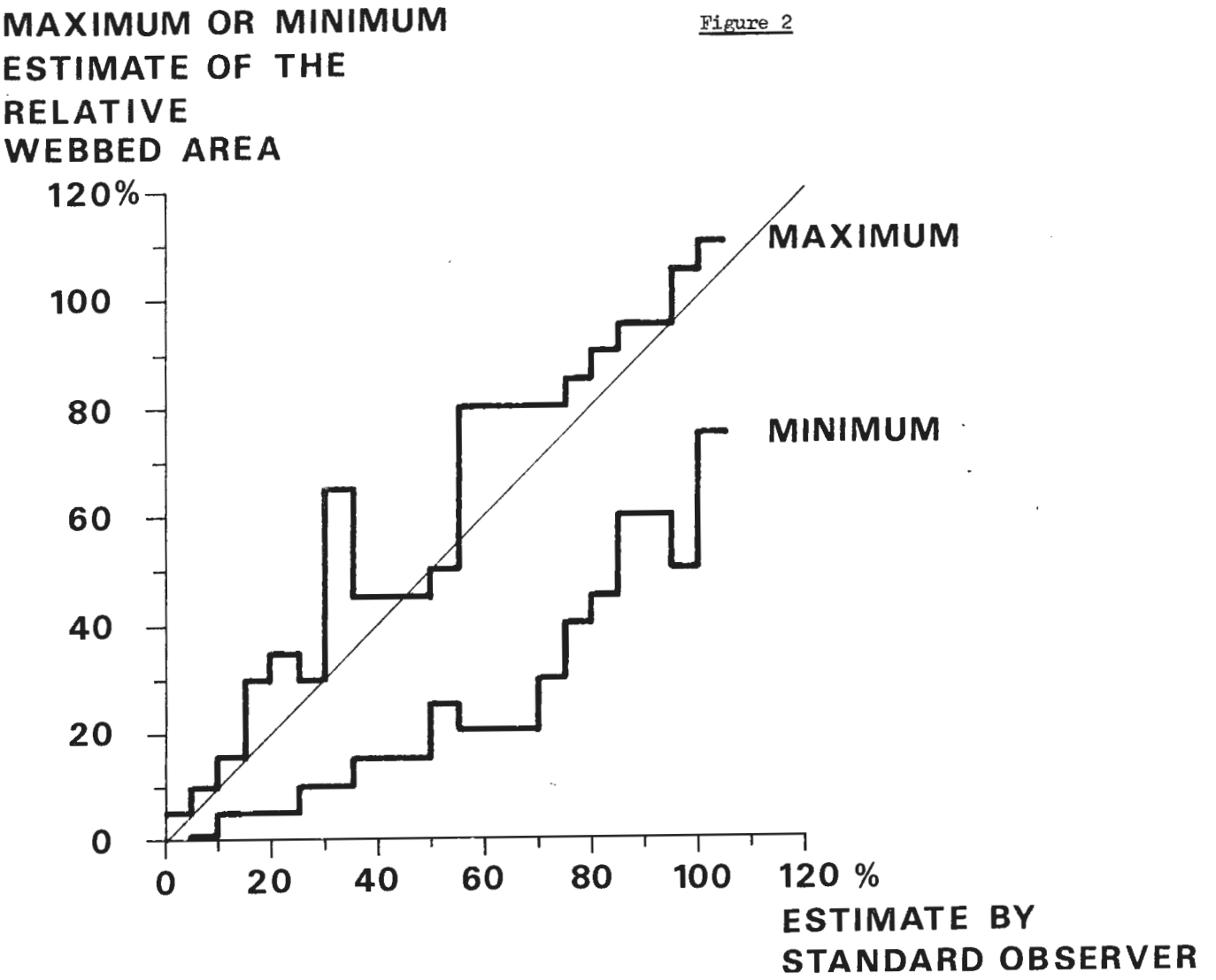

MAXIMUM OR MINIMUM
ESTIMATE OF THE
RELATIVE
WEBBED AREA
120%
100
80
60
40
20
0
0
20
40
60
80
100
120 %
MAXIMUM
MINIMUM
ESTIMATE BY
STANDARD OBSERVER

Figure 3

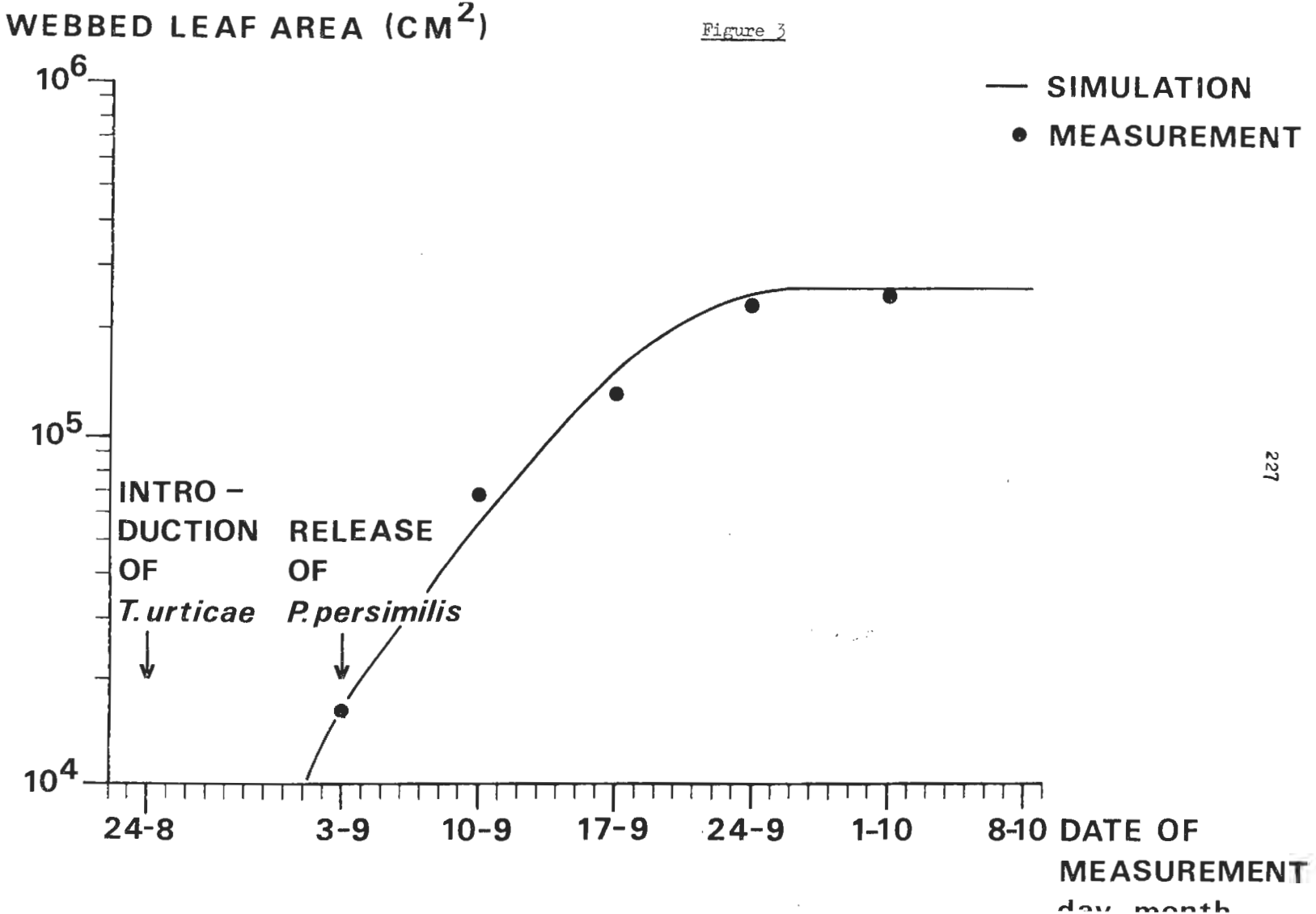
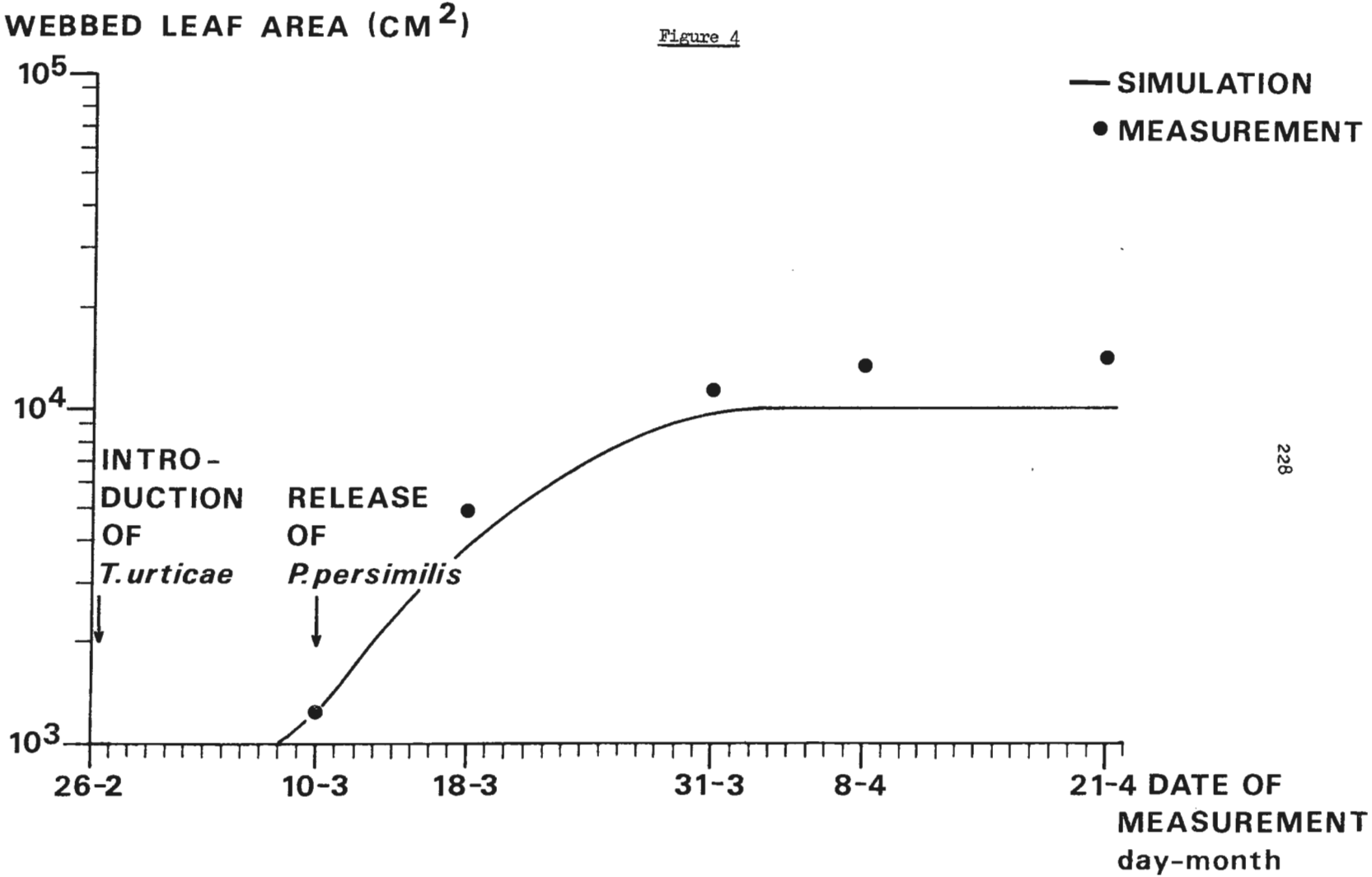

WEBBED LEAF AREA (CM^2)
10^6
10^5
10^4
— SIMULATION
• MEASUREMENT
INTRO – DUCTION OF *T. urticae*
RELEASE OF *P. persimilis*
24-8
3-9
10-9
17-9
24-9
1-10
8-10
DATE OF MEASUREMENT
day month

Figure 4


WEBBED LEAF AREA (CM 2)
10 5
10 4
10 3
SIMULATION
MEASUREMENT
INTRO-
DUCTION
OF
T. urticae
RELEASE
OF
P. persimilis
26-2
10-3
18-3
31-3
8-4
21-4
DATE OF
MEASUREMENT
day-month

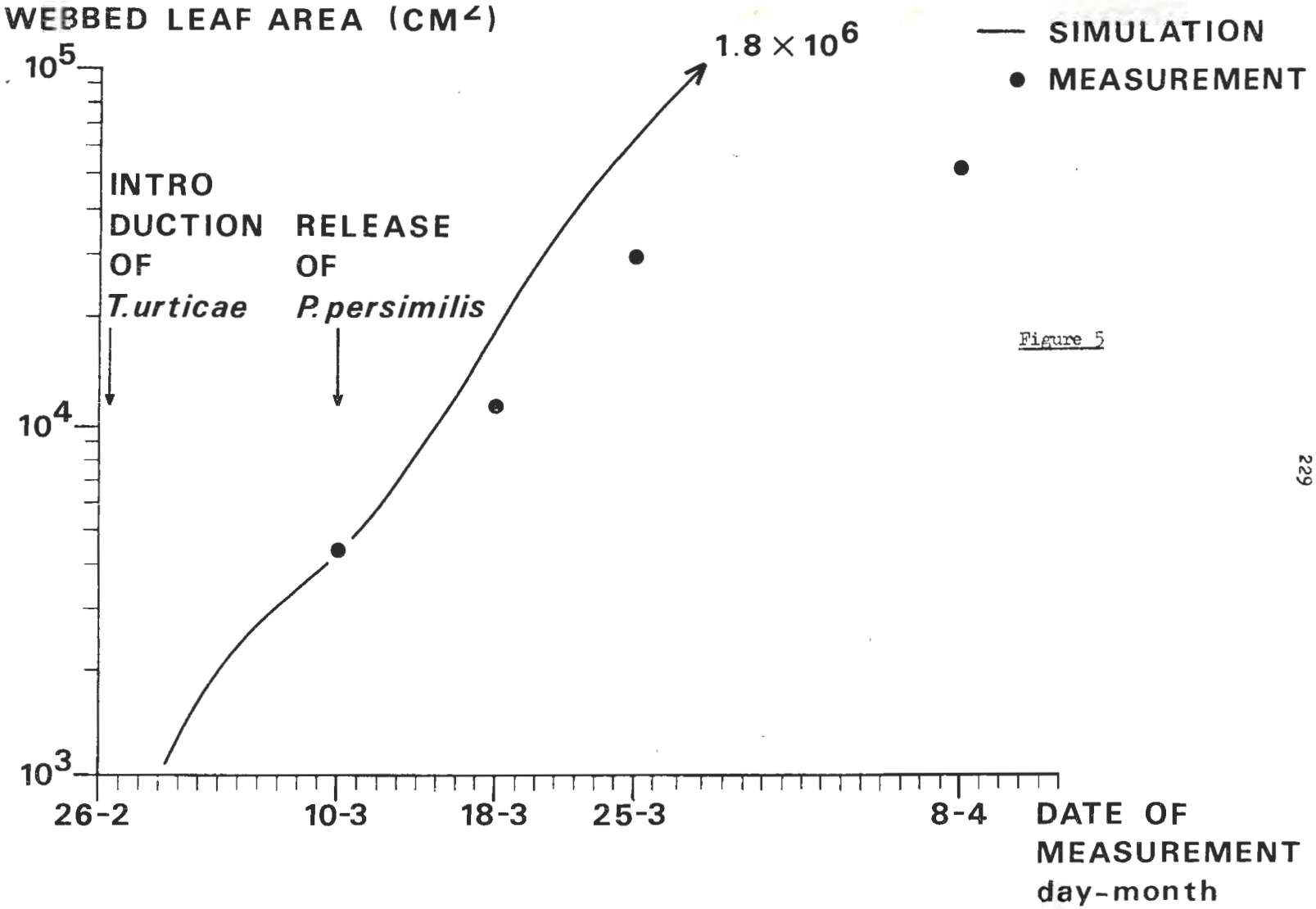

WEBBED LEAF AREA (CM²)
10⁵
10⁴
10³
1.8 × 10⁶
SIMULATION
MEASUREMENT
INTRO DUCTION OF T.urticae
RELEASE OF P.persimilis
26-2
10-3
18-3
25-3
8-4
DATE OF MEASUREMENT
day-month

Figure 5